GEOLOGICAL SURVEY OF PAPUA NEW GUINEA

MEMOIR 18

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Cover Photo: *Epimayaites* sp.aff. *palmarum* (Boehm) is an ammonite that characterises the Early to Middle Oxfordian (early Late Jurassic) of the Telefomin area (see also Pl.1, Fig. 1a). The original has a maximum diameter of 125 mm.

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ABSTRACT

Problems in Late Jurassic biochronology concerning the correlation between the European stratotypes and Papua New Guinea (PNG) and other parts of the Himalayan Province continue, because ammonite-rich sequences are scarce. Significant progress has recently been made, however, in Late Oxfordian-Kimmeridgian ammonite taxonomy in the Himalaya, Indonesia, PNG, and New Zealand. Time-correlations based on ammonites are therefore supplemented by those based on dinoflagellates, but major disagreements persist. Problems also exist with the correlation of the Middle and Late Callovian, which throughout most of the Indo-Pacific is lacking in ammonites.

In PNG, abundant Late Jurassic ammonites are known only from float collections made to the north of Telefomin. In 1991 Westermann and Francis attempted to collect *in situ* latest Middle Jurassic and Late Jurassic ammonite associations in this area, with little success. Oxfordian to Early Tithonian ammonites were found to occur almost entirely as float derived from thin, recessive, moderately ammonitiferous horizons within a belemnite-byssate bivalve biofacies. Bathonian to Early Callovian ammonites were found in situ, but the Middle to Late Callovian appears to be barren of ammonites. Despite these problems, some significant ammonite faunas with associated belemnites and bivalves were found.

The ammonites include Late Oxfordian – Early Kimmeridgian *Sulaites* Oloriz and Westermann, formerly known as "*Perisphinctes sularus/moluccanus* group", "*Pseudoparaboliceras", Idoceras,* and sometimes *Kossmatia.* Two or three species are distinguished: *S. sularus,* essentially Late Oxfordian, and the *S. gerthi-heteriensis* group, essentially Early Kimmeridgian. *Paraboliceras* branched from *Sulaites* in Early Kimmeridgian times and *Kossmatia* from *Paraboliceras* in the Late Kimmeridgian to Early Tithonian. The associated bivalves include various *Retroceramus* species which allow further correlation with sequences in eastern Indonesia and New Zealand. The belemnites are mainly members of the *Belemnopsis moluccana-galoi-stolleyi* clade as well as *Hibolithes taylori* Challinor, a ?Tithonian to Berriasian species endemic to New Guinea and originally considered Aptian/Albian.

The restriction of ammonites to thin, recessive horizons means that macrofossil dating for the Late Jurassic will have to rely heavily on the relative ages of the belemnites and bivalves, interpolated between ammonite faunas, which are widely separated in time. We report results from studies of the Crouch Collection, which include first PNG records of the bivalves *Palaeonucula* cf. *cuneiformis, Trigonopis, Thracia, Homomya* cf. *gibbosa* and *Goniomya.*

The lack of preserved, age-diagnostic dinoflagellates at Telefomin means that dinoflagellate-ammonite correlations will have to be established in less deformed sequences.

1. INTRODUCTION

Between 6th and 18th November, 1991, Francis and Westermann collected Jurassic ammonites and associated macrofauna consisting almost entirely of bivalves and belemnites from the northern part of the Telefomin area, in the Ok Tedi (formerly Blücher Range) 1:250 000 sheet area (Figures 1 & 2). This district is located in the Sepik headwaters region of Sandaun Province. The principal objective of this work was to study the Late Jurassic ammonite succession, which was believed to be one of the richest in the Indo-southwest Pacific, a region in which ammonites of this age are poorly known. Such a study might provide data crucial for the resolution of existing problems in biostratigraphic correlation from Papua New Guinea (PNG) to Europe that involve also problems in palaeobiogeography (Westermann, 2000). Other important objectives were to study the Middle Bathonian to Early Oxfordian macrofossil succession and to gain additional data on associations between ammonites and other fossil groups, both macrofossils and microfossils.

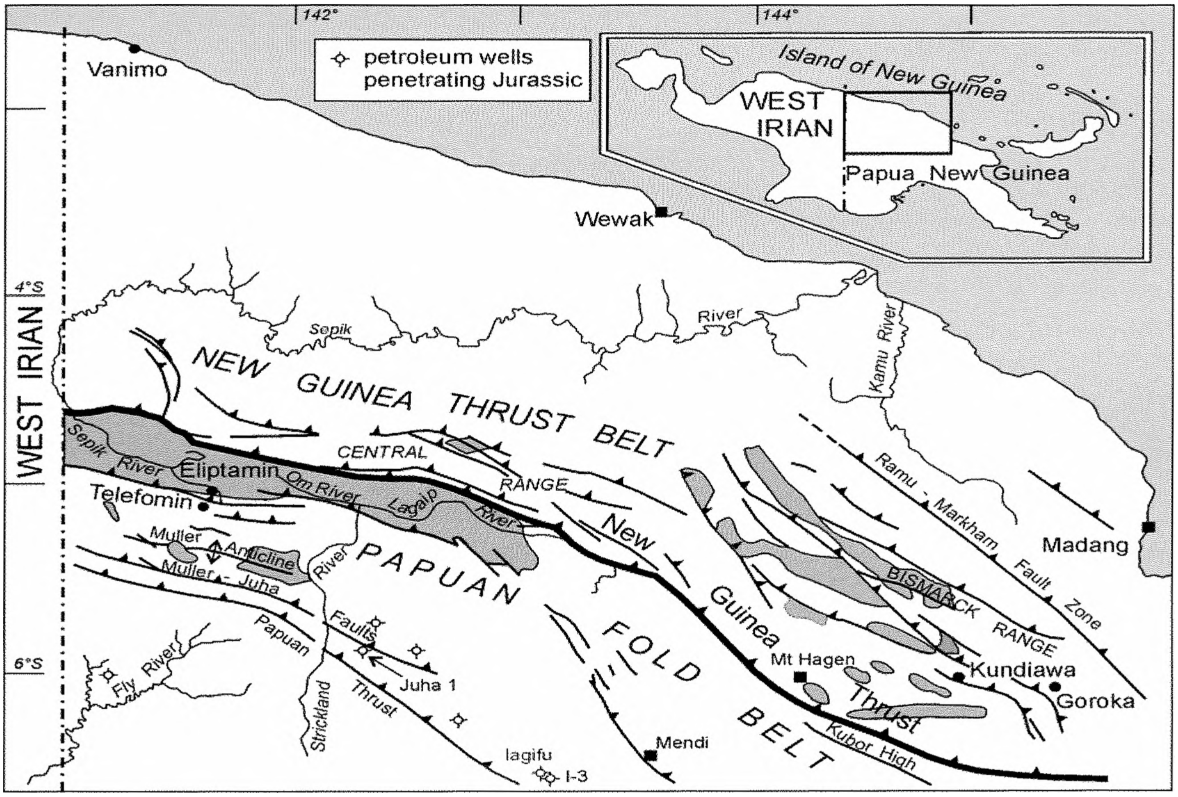


Figure 1. Distribution of the main areas of Jurassic strata in northwestern Papua New Guinea (after Sukamto and Westermann, 1992).

The northern part of the Telefomin area was believed to be the best area in PNG to conduct such a study, because of the apparently rich Late Jurassic ammonite fauna collected there in the 1970s, and the previous records of Bathonian/?Callovian ammonites and belemnites in the Elip Valley.

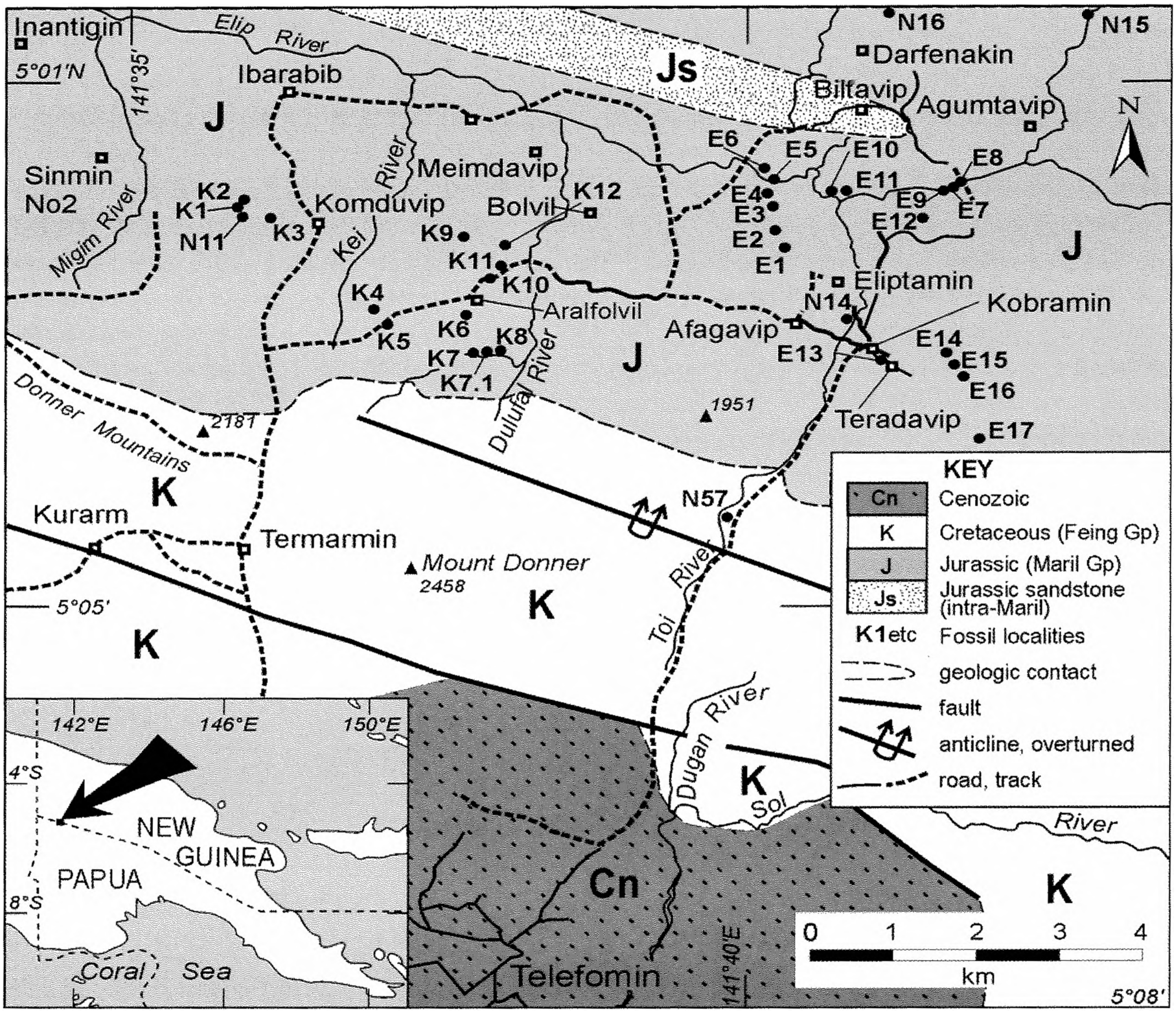


Figure 2. Telefomin sample locality data, Sepik River headwaters (geographic detail from the Telefomin 1:100,000 sheet 7287, Series T601; geology and localities N11, N15, N16 after Norvick (1973) with additional photogeological interpretation by GF for this work).

1.1 PREVIOUS GEOLOGICAL WORK

A pioneering geological reconnaissance of the Telefomin area was made by Australasian Petroleum Company (Sykes, 1954), a subsidiary of BP Petroleum Development Pty Ltd. Ammonites and other fossils collected on this reconnaissance were identified by palaeontologists of the BP Sunbury (UK) Research Centre (Banner, in Sykes, 1954). Sykes (1954) commented specifically on the scarcity of *in situ* ammonites, in comparison with their greater abundance in float. Another reconnaissance of the area was subsequently carried out by Smit (1968) of the Australian Bureau of Mineral Resources, now Geoscience Australia. From 1969-1973, BP Petroleum Development made geological surveys of areas to the south and southeast of Telefomin, and collected macrofossil samples, including ammonites (Jenkins and White, 1970; White et al., 1973). These studies were also among the first to use dinoflagellate palynology for dating the Jurassic and Cretaceous sequences of this region.

In 1971-72, a major 1:250 000 Blücher Range mapping project by the AGSO included the Telefomin area. The general geological results of this work were presented in Davies and Norvick (1974). The macrofaunal analyses were carried out by Westermann, S.K. Skwarko and J. Jeletsky. Age determinations based on these identifications were reported by Norvick (1973) and Arnold et al. (1979), but lists of most taxa identified remain in unpublished data files. The AGSO Palaeontological Collection includes about 30 ammonites from one of the landslips near Komduvip (macrofossil locality 11 of Davies and Norvick, 1974). Definitions of new and revised lithostratigraphic names for the Ok Tedi sheet area SB/54-7 were subsequently presented by Davies and Norvick (1977).

Large numbers of well preserved macrofossils, mainly from the Komduvip Landslips (see Figure 2), were brought to the Telefomin Baptist Mission by local villagers in the early 1970's, and collected by an Australian nurse, Betty Crouch. The Crouch Collection consisted of about 1000 molluscan fossils, mainly ammonites together with *c.* 20% bivalves (including *Retroceramus* and *Malayomaorica* – see Appendix 1) and *c.* 6% belemnites (largely *Belemnopsis* phragmacones – see Appendix 2) (Sukamto and Westermann, 1992).

In 1972, Westermann, during his visit to the area with S. K. Swarko, then of the Australian Geological Survey Organisation, inspected the Crouch Collection, removed about 50 ammonoids to McMaster University, and arranged for the Royal Ontario Museum (Toronto) to purchase most of the remainder. Thus most (*c.* 500) of the ammonoids from the Crouch Collection are now held at the Royal Ontario Museum (Francis and Westermann, 1993). Only about 35 ammonites and a similar number of other macrofossils from the Crouch Collection remain in the display room at the Telefomin Baptist Mission, but this room is required for other purposes. An attempt was made to donate the macrofossils to Telefomin High School, but lack of a suitable room at the high school to house the collection has prevented this (M. Yemis, pers. comm., 1991).

The Crouch Collection contains the common Early to Middle Oxfordian sphaeroceratid *Epimayaites* (for some, a subgenus of *Mayaites;* and including the microconch "*Paryphoceras"*), together with the Late Oxfordian to Early Kimmeridgian perisphinctid *Sulaites* (Oloriz & Westermann, 1998), the Late Kimmeridgian to Early Tithonian (in a two-fold division of the latter stage) ?berriasellines *Paraboliceras* and *Kossmatia,* and the Early Tithonian streblitines *Gymnodiscoceras* and *Uhligites.* A very few Late Kimmeridgian to Early Tithonian ?virgatosphinctines *Katroliceras/Pachysphinctes* and *Aulacosphinctoides/Virgatosphinctes* are also present.

The Mayaitidae and Perisphinctidae (Plate 1,2) closely resemble Oxfordian species of the Sula Islands and of West Irian. The Kimmeridgian-Tithonian Perisphinctidae (Plate 3,4), Oppeliidae and Ataxioceratidae (Plate 5,6) include many morphospecies described from the Lower Tithonian (two-fold division) of the Himalayan Spiti Shale (cf. Uhlig, 1903-10; Krishna et al., 1982; Krishna and Pathak, 1993). The Crouch Collection contains by far the most abundant and diverse Late Jurassic ammonite fauna in PNG, including taxa not known from elsewhere in PNG. Unfortunately, it consists almost entirely of float material and specific locality details for individual specimens are not available.

In 1972, Westermann and S.K. Skwarko made an unsuccessful attempt to reach the escarpment at the head of the Komduvip Landslips by helicopter, but were able to land at

Bathonian and Oxfordian ammonite localities on the Elip River to the north of Komduvip (Westermann and Callomon, 1988).

More detailed 1:100 000 scale mapping of the region to the north of Telefomin was carried out by Rogerson et al. (1987) with revisions to the lithostratigraphic nomenclature. Local names for the distal Mesozoic sequence were abandoned in favour of nomenclature originally defined in the Central Highlands, several hundred kilometres to the southeast of the Ok Tedi sheet area.

A study of *in situ* Bathonian and Early Callovian ammonites from the head of the Strickland River, 75 km east of Telefomin, and from the Sula Islands, has identified six stratigraphically controlled ammonite associations (Westermann and Callomon, 1988) of Late Bajocian/Early Bathonian to Early Callovian age. Several zones and subzones were soon established (Hillebrandt et al., 1992). In the Westermann & Callomon (1988) study, most macrocephalitine ammonites formerly regarded as Early Callovian, were found to be Middle and Late Bathonian.

Challinor (1990) has re-analysed belemnite samples in the AGSO and BP collections from the Ok Tedi sheet area, revising the taxonomy and establishing a detailed biozonation. One of his principal conclusions was that most, if not all, Jurassic and earliest Cretaceous belemnites were misidentified in earlier studies. This work by Challinor (1990) shows that belemnites are very useful for relative biostratigraphic correlation within Papua New Guinea and eastern Indonesia.

In addition to these macrofossil studies samples were submitted for foraminiferal, coccolith, and palynological analyses, and reports on these, or abridged versions, are appended (Appendices 3 – 5).

1.2 MESOZOIC LITHOSTRATIGRAPHY

Telefomin lies within a Mesozoic facies transition zone of the Papuan Basin, a margin-sag basin developed on Australian continental crust. To the south lies a proximal Jurassic/ Cretaceous sequence of interbedded sandy units (Koi-Iange Formation, intra-Imburu Formation sands, Toro Sandstone and intra-Ieru Formation sands) and fine clastics (Barikewa Mudstone, Imburu Formation and Ieru Formation fine clastics) (Figure 2). The fine clastics were deposited mainly in mid to outer neritic environments, whereas the sandy units were deposited mainly in inner neritic to marginal marine environments, during regressive phases (Home et al., 1990).

In the Telefomin area there is a northward transition to a more distal Wahgi Group (Rogerson et al., 1987), consisting mainly of bathyal fine clastics, with subordinate open marine sands, at least some of which are turbidites. The Jurassic macrofauna collected in the present study came from the ?Bajocian to ?Aptian Maril Formation (formerly known as Om Beds) of the Wahgi Group (Figure 2). The Maril Formation is ?structurally overlain by glauconitic quartz sandstones which are resistant, cliff-forming features. The 2100-2500 m crest of the Donner Mountains, between Telefomin and Eliptamin (Figure 1), is developed on these rocks, which were included in the Feing Group of Davies and Norvick (1974).

The Maril Formation consists mainly of grey to grey-black mudstone and silty mudstone, locally carbonaceous and pyritic, with subordinate siltstone, volcaniclastic sandstone and laminites, and rare quartz sandstone.

1.3 REGIONAL STRUCTURE

The structure of the Sepik headwaters region is dominated by gentle, northerly dipping master thrusts (Figure 1), separating major thrust plates which are internally imbricated (Rogerson et al., 1987). In the area to the north of Komduvip and Eliptamin, the principal structure is the New Guinea Thrust, which separates subthrust, uncleaved Wahgi Group from overthrust slate-grade Wahgi Group. The ammonite localities visited in the present study lie within the subthrust plate.

1.4 BIOSTRATIGRAPHIC AND CHRONOSTRATIGRAPHIC CORRELATION PROBLEMS

1.4.1 Ammonites, belemnites, and bivalves

The standard biostratigraphic and chronostratigraphic scale of the Jurassic is based on the Ammonitina (Plate 1 - 6). For inter-regional studies, regional biostratigraphic scales, such as those based on dinoflagellates, have to be correlated with it (Figure 3). There has been confusion resulting from alternative bifold and trifold subdivisions of the Tithonian. Workers such as Harland et al. (1989) have used a bifold scheme, whereas Krishna et al. (1982) and Francis and Westermann (1993) have used a trifold subdivision into Early, Middle and Late Tithonian. Recent data from the Himalayas suggest that even in these rich Tithonian ammonite sequences, the "Middle" Tithonian cannot be reliably distinguished from the Early Tithonian (see below). In the present study we have adopted the bifold subdivision now used by the majority of workers; the "Middle Tithonian" of the trifold division becomes the later part of the Early Tithonian.

Extensive areas of Upper Jurassic Papuan Basin rocks are present in PNG, but in most of these areas ammonites are rare. By far the most ammonitiferous known area of these rocks in PNG is Komduvip (macrofossil locality 13, Blücher Range Sheet SB54-7) (Davies and Norvick, 1974). This area lies about 10 km north of Telefomin and 7 km west of Eliptamin (Figure 2). Fossils come from large landslips derived from a northerly facing scarp developed in fine clastics of the distal Maril Formation and occurred about 1964.

All previous Upper Jurassic ammonite collections with abundant and diverse fauna, including the above mentioned Crouch Collection, were collected mainly *ex situ*, from slope deposits or stream beds. Stratigraphic collecting of *in situ* Maril Formation would have been extremely valuable, to establish species variability and the biostratigraphic succession, but proved unsuccessful.

Ammonite zonation for the Upper Jurassic of most of the Indo- Pacific Realm/Subrealm (formerly as Indo-southwest Pacific, Westermann, 1992; 2000) (Figure 4) has been hampered by serious taxonomic problems and is poorly known. This includes the Himalayan Province to which our faunas belong, that stretched from the central Himalaya to New Zealand, or even Antarctica. Major errors in the correlations with the standard west Tethyan stages concerned particularly the Kimmeridgian Stage. Most of the data existing a decade ago and their deficiencies were reviewed by Francis & Westermann (1993). Fortunately, much progress has been made in the last decade on ammonite taxonomy to alleviate this problem, especially in the central Himalaya and New Zealand (see chapter on ammonite taxonomy, below).

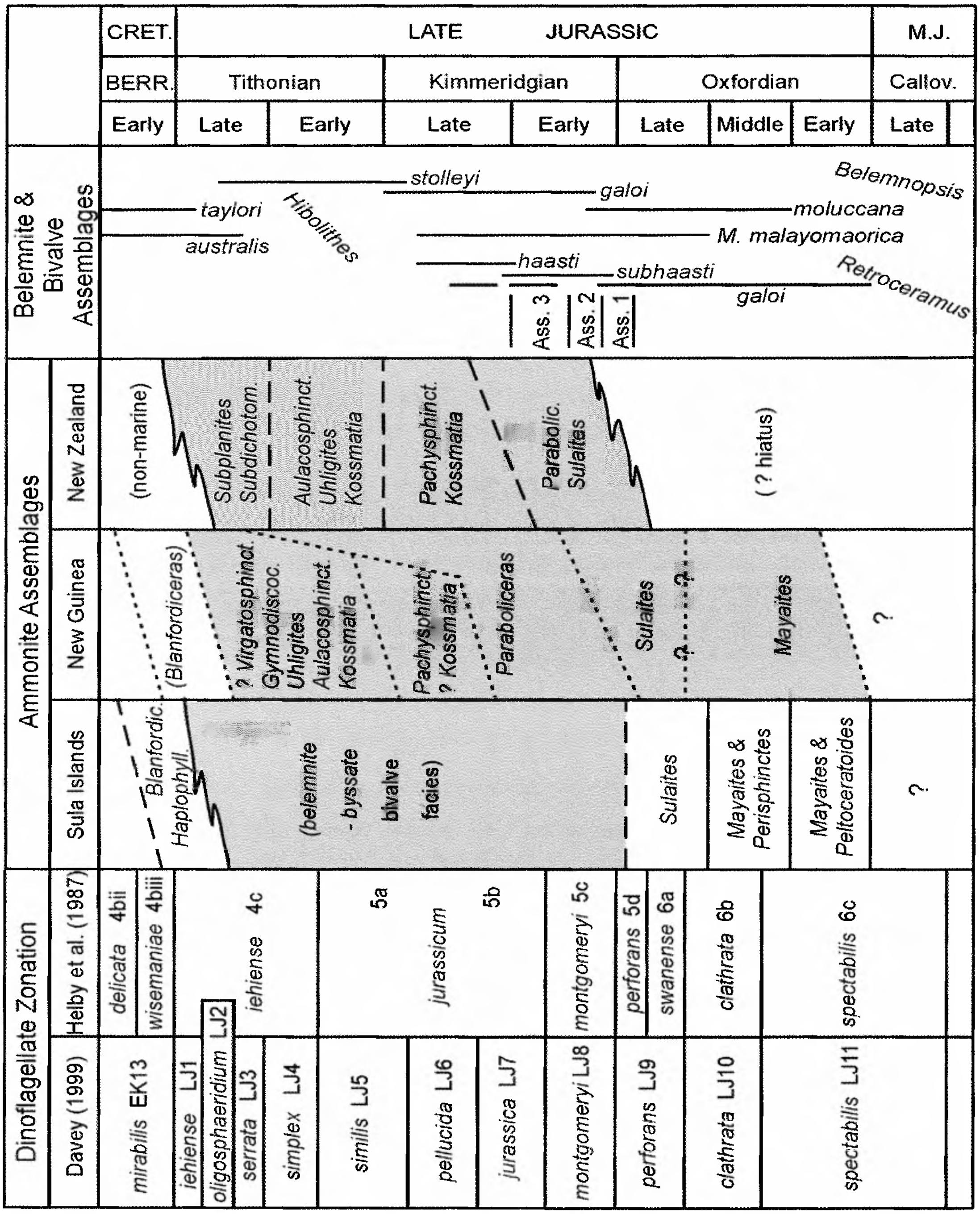
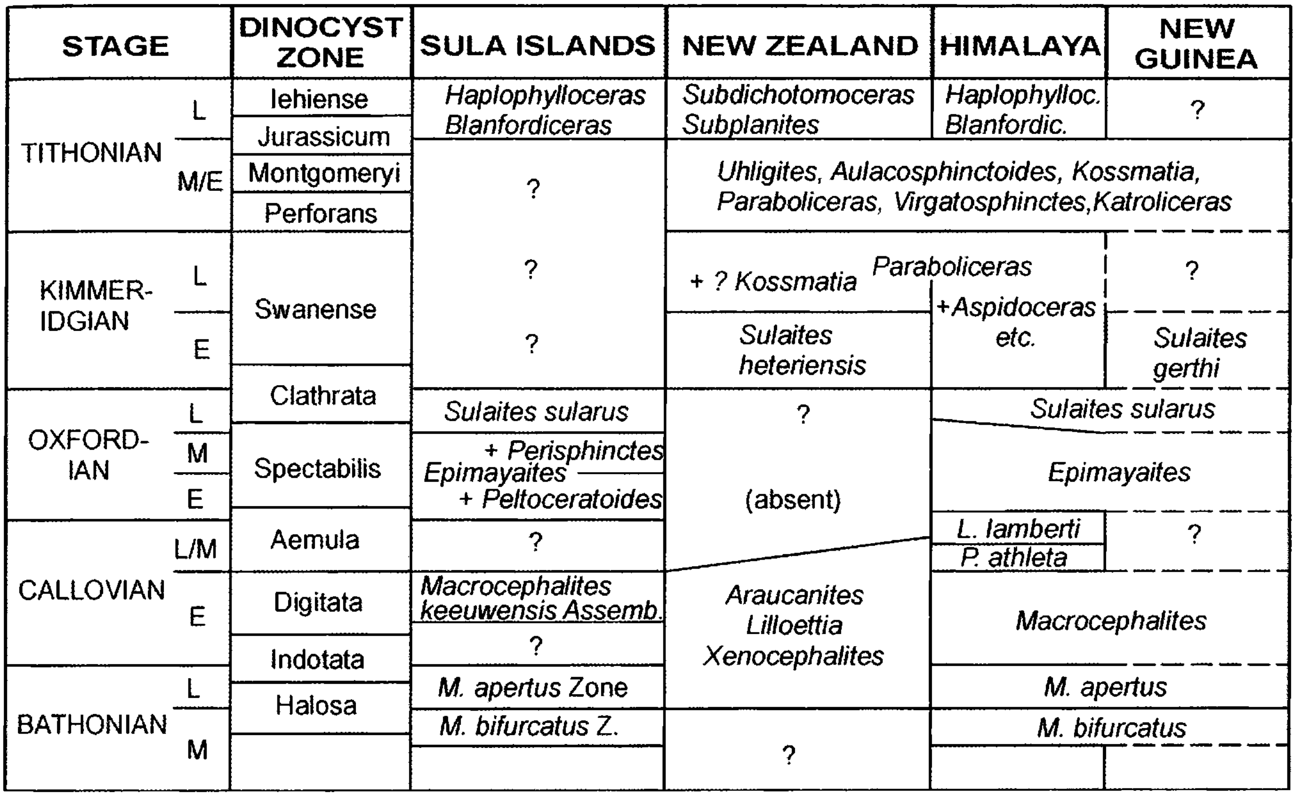


Figure 3. Correlation of Late Jurassic dinoflagellate zones, standard stages, and molluscan assemblages. The Helby et al. (1987) scheme is from Davey (1999), adjusted therein to correspond more closely with the correlations of Davey (1987), an adjustment not followed here. Ammonite data from Sato et al. (1978), Sukamto and Westermann (1992), Stevens (1997), Westermann et al. (2002), and this work, with oblique lines reflecting uncertainty resulting from rarity of fossils or their *ex situ* occurrence. Berr. = Berriasian,

Callov. = Callovian, Cret. = Cretaceous; the belemnite sequence refers only to Sula Islands and Papua New Guinea. In New Zealand *R. galoi* appears earlier than shown here.



STAGE		DINOCYST ZONE	SULA ISLANDS	NEW ZEALAND	HIMALAYA	NEW GUINEA
TITHONIAN	L	Iehiense	*Haplophylloceras* *Blanfordiceras*	*Subdichotomoceras* *Subplanites*	*Haplophylloc.* *Blanfordic.*	?
		Jurassicum				
	M/E	Montgomeryi	?	*Uhligites, Aulacosphinctoides, Kossmatia, Paraboliceras, Virgatosphinctes,Katroliceras*		
		Perforans				
KIMMERIDGIAN	L	Swanense	?	+ ? *Kossmatia*	*Paraboliceras* +*Aspidoceras* *etc.*	?
	E		?	*Sulaites heteriensis*		*Sulaites gerthi*
OXFORDIAN	L	Clathrata	*Sulaites sularus*	?	*Sulaites sularus*	
	M	Spectabilis	+ *Perisphinctes* *Epimayaites* + *Peltoceratoides*	(absent)	*Epimayaites*	
	E					
CALLOVIAN	L/M	Aemula	?		*L. lamberti* *P. athleta*	?
	E	Digitata	*Macrocephalites keeuwensis Assemb.*	*Araucanites* *Lilloettia* *Xenocephalites*	*Macrocephalites*	
		Indotata	?			
BATHONIAN	L	Halosa	*M. apertus Zone*		*M. apertus*	
	M		*M. bifurcatus Z.*	?	*M. bifurcatus*	

Figure 4. Correlation of Late Jurassic ammonites and dinoflagellate ('dinocyst') zones, Himalaya-Indonesia-PNG-New Zealand. Dinoflagellate data from Helby et al. 1987); ammonite data from Sato et al. (1978), Krishna et al. (1982), Westermann and Wang (1988), Sukamto and Westermann (1992), Stevens (1997), Westermann et al. (2000, 2002), and this work.

(1) *Sulaites* (Plate 2) (for "*Perisphinctes*" *sularus-moluccanus* group of Francis & Westermann, 1993, and "*Pseudoparaboliceras aramaraii*" Gerth, 1965) occurred throughout the Himalayan Bioprovince (for a review see Westermann et al., 2002). In the Himalaya, it appeared together with the youngest *Epimayaites* faunas in the Late Oxfordian and probably was restricted there to that substage. In the Moluccas (Sula Islands), *S. sularis* (Boehm) occurs above mid-Oxfordian *Epimayaites*, mainly or entirely in the Late Oxfordian. In New Zealand, *S. heteriensis* (Stevens), a probable subspecies of *S. gerthi* Oloriz & Westermann, is associated in its upper range with *Paraboliceras macnaughti* (Stevens); its age is very probably Early Kimmeridgian, especially because the Oxfordian appears to be represented largely by an hiatus. It therefore stands to reason to date *S. sularus* as Late Oxfordian and *S. gerthi/heteriensis* as Early Kimmeridgian.

(2) *Paraboliceras* (Plate 3, Figure 2; Plate 4) appears already in the Kimmeridgian in the Himalaya and even in the Early Kimmeridgian of New Zealand (see above).

As elsewhere in Indonesia and Papua New Guinea, the *ex situ* collections from the Komduvip landslips contain no age-diagnostic Kimmeridgian ammonites. This regional non-documentation of an entire stage is a unique current problem in Himalayan Province biostratigraphy east of the Ethiopian Province (includes western Himalaya) (Hudson et al., 1987; Francis and Westermann, 1994), although now documented for New Zealand (Stevens, 1997). Westermann and Wang (1988) and Gradstein et al. (1989) have previously proposed that in the central and eastern Himalaya and Indonesia, at least, the Kimmeridgian and parts of the adjacent stages are developed in a belemnite-byssate bivalve biofacies, virtually without ammonites.

Challinor (1990) has described a succession of New Guinea (PNG-West Irian) Late Jurassic and Early Cretaceous belemnites, some with associated retroceramid and buchiid bivalves. The Late Jurassic *Belemnopsis moluccana-galoi-stolleyi* lineage is very useful for correlation in New Guinea and Indonesia. Unfortunately in pre-1980s PNG work, members of this lineage were usually wrongly referred to the Indo-East African *Belemnopsis gerardi* group, or to the New Zealand *Belemnopsis aucklandica* group (Challinor, 1990). During the Middle Oxfordian to Tithonian, New Guinea and Indonesia formed part of a Himalayan Belemnite Province (Challinor et al., 1992) (= Indo-Tethyan Province/Subprovince, Challinor, 1991a, b). This also included the Himalaya and Western Australia, but not New Zealand which belonged to a South Pacific Belemnite Province (Challinor, 1991a). All belemnite species occurring in the eastern part of the Himalayan Province appear to be endemic, and most of the genera are long ranging (Challinor et al., 1992).

Because of this extreme provincialism among Late Jurassic belemnites, direct belemnite correlations with Europe (West Tethyan Province/Subrealm) are not possible. Thus Challinor (1989a; 1990; Challinor et al.1992) could only estimate ages and stage correlations for members of the *Belemnopsis moluccana* lineage and other index taxa from ammonite-belemnite associations on Sula and Misool Islands. Challinor's belemnite ages have been revised in the light of the new ammonite data presented here.

Byssate bivalves, particularly the *Retroceramus galoi-subhaasti-haasti* lineage and *Malayomaorica malayomaorica* (Krumbeck), are also useful for correlation throughout much of the Indo-southwest Pacific, but limits to the accuracy of correlations based on the former lineage have sometimes arisen through different macropalaeontologists having slightly different species concepts for different members of this lineage (Damborenea and Manceñido, 1992; Damborenea et al., 1992).

Retroceramus and *Malayomaorica* are more widely distributed than the Indo-Tethyan belemnites, but do not range into the West Tethyan Subrealm. The *Retroceramus-Malayomaorica* sequence in New Zealand has recently been revised by Damborenea and Manceñido (1992) and Hudson (2003), who have recognised retroceramids previously recorded from South America in the New Zealand material (see also Damborenea, 1996). The ages usually assigned to the *Retroceramus* and *Malayomaorica* bivalves are based mainly on their association with ammonites in New Zealand (Helby et al., 1988; Stevens, 1997) and Antarctica (Thomson and Wiley, 1972).

One distinctive bivalve-belemnite fauna occurs consistently throughout the PNG Maril Formation (Francis et al., 1990) and its more proximal equivalent, the Imburu Formation. This fauna consists of *Malayomaorica malayomaorica, Retroceramus* spp. and early forms of *Belemnopsis galoi* (Boehm), with *R. galoi* (Boehm) and *R.* cf. *galoi* in the lower part, and *R.*

haasti (Hochstetter) in the upper part. It typically forms a zone 15-25m thick, with the bivalves being particularly abundant, and is usually associated with dinoflagellates of the uppermost *Wanaea clathrata* and *Dingodinium swanense* Zones of Helby et al. (1987), where the latter zone is recognisable. This macrofauna is particularly useful for correlation within the Late Jurassic of New Guinea and Indonesia (Francis and Westermann, 1993).

Li and Grant-Mackie (1988) have recognised two Late Jurassic *Buchia* assemblages in Tibet. The long-ranging *Buchia* Assemblage I consists of *"B. concentrica"* and *Australobuchia spitiensis*, with Oxfordian *Praebuchia kirgisensis* in the lower part. It ranges from later Oxfordian to earliest Tithonian, and its highest occurrences are associated with possibly earliest Tithonian ammonites (see below). Assemblage I is separated from Assemblage II by an Early Tithonian facies-controlled *Grammatodon-Entolium* bivalve assemblage, which is less useful for international correlation. *Buchia* Assemblage II consists of *B. rugosa, B. piochii, B. pallasi* and about 10 other taxa (Li and Grant-Mackie, 1988). It is of late Early (Middle of three-fold division) to Late Tithonian age. These *Buchia* Assemblages can be broadly correlated through eastern Indonesia, but there are only a few records of them in PNG.

Matsumoto and Skwarko (1993) re-examined Cretaceous ammonites from regions to the east and southeast of the Ok Tedi 1:250 000 sheet area. They described a specimen of Berriasian *Fauriella boissieri* (Pictet) from the upper Maril Formation ("Tubu Shale") of the Kereru Range. There were earlier records of latest Tithonian or Berriasian *Haplophylloceras strigile* (Blanford) and *?Parandiceras* sp. (Glaessner, in O'Brien et al., 1961) from the same area, but the specimens were not described or figured.

1.4.2 Dinoflagellates

The principal biostratigraphic dating method for the Late Jurassic of the Papuan Basin is dinoflagellate palynology. Two of the alternative dinoflagellate zonations in current use for PNG and West Irian are those of Helby et al. (1987) and Davey (1987, 1999) (Figure 3). The zone and stage correlations of these workers differ radically over the Middle Oxfordian to Mid-Tithonian interval with assemblages assigned much younger ages by Helby et al. (1987) than those assigned by Davey (1987) and Welsh (1990). Serious problems of provincialism exist in dinoflagellates, and difficulties also arise over diachronous ranges for cosmopolitan Jurassic dinoflagellate indices such as *Rigaudella aemula* and *Nannoceratopsis pellucida* (Davey, 1987, his figure 13). The magnitude of the correlation problems can be seen most clearly in the case of the *Cribroperidinium perforans* Zone of Helby et al. (1987), which is placed in the Early Tithonian by these workers, but is assigned to the Late Oxfordian by Davey (1987). This clash would appear to have been essentially eliminated by the Davey (1999) scheme which, however, has not found universal favour in Australasia; Geoscience Australia, for instance, continues to prefer the Helby et al. (1987) correlations.

Since many of the Telefomin palynology samples came from the matrix of ammonites, one could expect some new information on these correlations to be gained from this study. Unfortunately, most microfloras are too poorly preserved, with low yield and low diversity, so very few fine zonal correlations could be made (see Appendix 5). Filatoff and Price (Appendix 5) correlate 91E4.2, E5, and E9 tentatively with spore/pollen zone APJ4 (latest Bajocian to earliest Callovian), equivalent to the Halosa and Indotata dinoflagellate Zones of Helby et al.(1987), and these collections have yielded ammonites of Early Callovian (91E4.2, E5) and

Middle to Late Bathonian (91E9) ages. Collections J1974ml and J1974o tentatively correlate with APJ5 (Early Callovian to Middle Oxfordian in Appendix 5) covering the Digitata to Swanense Zones of Helby et al. (1987), which those latter authors correlate with Early Callovian to Kimmeridgian; the ammonites in these two collections give Early to Middle Oxfordian ages. Thus the ammonites in these cases, although providing finer correlations, do not help in judging between the Davey (1999) and Helby et al. (1987) dinoflagellate schemes. Tithonian ammonite ages are given to 91E17 and 91E17.1, but unfortunately the matrix in each provided only tentative Late Jurassic palynological ages.

Two samples do have palynological ages that differ clearly from those given by the associated ammonites. 91E3.1 returned a Middle Jurassic age from the palynomorphs, but Early to Middle Oxfordian for the ammonite, and 91E6.2, with a Middle to Late Bathonian ammonite, was dated as Callovian to Middle Oxfordian (APJ5) by its palynoflora. The ammonite ages for these collections are accepted as being more likely to be correct than those from palynology.

Despite marked differences of opinion between palynologists over stage correlations, most palynologists who have worked on Papuan Basin sequences consider that the Late Jurassic is relatively complete, with no regional hiatus spanning an entire stage. The sole exception is Morgan (1989), who has noted that age-diagnostic dinoflagellates of the *Dingodinium swanense* Zone are rare in the northern and northwestern parts of the Papuan Basin. He attributed this to a regional hiatus, but the *Retroceramus-Malayomaorica* bivalve fauna (described above) which seems to occupy much the same stratigraphic interval (Kimmeridgian by Helby et al., 1987), is consistently present throughout these northerly and northwesterly areas. On this basis, it seems more likely that there is simply an absence of index dinoflagellates for the Swanense Zone, rather than a genuine hiatus.

We consider that the local Late Jurassic hiatuses delineated by palynology in the Fly Delta region (R. Morgan, pers. comm., 1989) are basin margin features on the flanks of the basement Oriomo High.

The large uncertainties that have existed in the correlations between dinoflagellate assemblages and stages have hampered reliable reconstruction of the geological history of the region over this interval, which is particularly important for petroleum exploration. It contains potential source rocks (Imburu and Maril Formations) and proven reservoir rocks (Digimu, Hedinia and Iagifu Members of Imburu Formation). Full resolution of the uncertainties involved in dinoflagellate assemblage-stage correlations will permit more reliable geohistory modelling.

2. RESULTS

2.1 1991 FIELDWORK (by Francis and Westermann)

Francis and Westermann collected a total of 33 ammonites, ranging in age from Bathonian to Tithonian from 19 localities, mostly *ex situ* (Figure 2, Table 1). It was found that the large rock faces exposed by the 1964 landslips around Komduvip, and seen from a helicopter by Westermann and Skwarko in 1972, were covered with younger colluvium and secondary regrowth. The limited Late Jurassic outcrop seen was devoid of ammonites, although much ammonitiferous float was found and 17 Late Jurassic ammonites were collected, all of which were taxa present in the Crouch Collection. It seems likely that the ammonites are confined to thin zones in recessive, concretionary mudstones. Even within these zones, only a few of the concretions contain ammonites.

Better outcrop, with some *in situ* specimens of Middle Bathonian to Early Callovian *Macrocephalites*, was found along the Elip River, but the Middle Jurassic ammonite faunas were much less abundant and diverse than those collected by S. Skwarko and Westermann (Westermann and Callomon, 1988) at the Strickland headwaters, 75km east of Telefomin. It seems likely that these rich ammonite zones, making up a high proportion of the stratigraphic sequence, are atypical of the Maril Formation in the northern Ok Tedi sheet. Belemnite rostra are the only macrofossils consistently present throughout most of the Late Jurassic sequence, and are locally abundant, with bivalves, in some sandy horizons.

It has become evident that the large size and diverse ammonite fauna of the Crouch Collection resulted from the diligence of the local villagers, who collected during a period of several years after major landslides. These provided large quantities of talus and much greater than usual exposure of bedrock. Despite the poor outcrop and scarcity of *in situ* ammonites found in the present study, we managed to collect significant Late Jurassic macrofossil assemblages at several localities.

2.1.1 Description of Macrofossil Samples and Localities (prefixed 91)

Six-figure grid references and generalised locality names are given in Table 1 and are based on the 1979 Telefomin 1:100,000 topographic sheet no. 7287, Series T601, first edition. All localities are shown on Figure 2.

K1: A belemnite with some grey calcareous mudstone matrix, occurring as float in the bed of Mulum Creek. The belemnite is latest Kimmeridgian *Belemnopsis galoi* (Boehm) or Tithonian *B. stolleyi* Stevens. It is associated with common float concretions containing ?Late Kimmeridgian to Early Tithonian *Kossmatia* sp., which were not collected.

K2: Grey-black mudstone containing a belemnite, which is a late form of *Belemnopsis galoi/stolleyi*, as float derived from a small outcrop of mudstone with moderate SW dip. Age: Late Kimmeridgian or Tithonian.

K3: Dark grey calcareous muddy siltstone containing a belemnite, late *Belemnopsis galoi* (Boehm) or *B. stolleyi*. Similar rocks with an attitude of 330°/35°SW crop out 50m to the south (upstream). Age: Late Kimmeridgian or Tithonian.

Table 1. List of samples and macrofauna collected during the 1991 field work (all prefixed with 91)

Sample No.	Locality	GR	In Situ?	Selected Macrofauna	Age
K1	Mulum Ck	678438	no	*Belemnopsis galoi/stolleyi*	latest Oxfordian/Tithonian
K2	Kasol Ck	679439	no	late *Belemnopsis galoi/stolleyi*	Kimmeridgian/Tithonian
K3	Kasol Ck	682436	no	latest *Belemnopsis galoi* or *B. stolleyi*	Oxfordian/Kimmeridgian
K4	Komduvip rd	694423	no	*Kossmatia tenuistriata*	Late Kimmer.?/Early Tithonian
K5	Aralfolvil tr.	696421	close to	*Belemnopsis* cf. *galoi*, *Retroceramus* sp.	?latest Oxfordian-Early Tithonian
K6	near Inum Ck	705422	close to	?*Sulaites* gr. *gerthi*, *R.* cf. *haasti*, *Belemnopsis* cf. *stolleyi*	?(Early) Kimmeridgian
K7	Dulufal R	706417	yes	*Belemnopsis galoi*	latest Oxfordian/Kimmeridgian
K7.1	Dulufal R	707417	no	*Sulaites* gr. *gerthi*	latest Oxf./Early Kimmeridgian
K8	Dulufal R	707417	no	*Retroceramus galoi*	Late Oxfordian/?earliest Kimmeridgian
K8.1	Dulufal R	707417	no	*Sulaites moluccanus*	
K8.2	Dulufal R	707417	no	*Belemnopsis moluccana*	
K8.3	Dulufal R	707417	no	?*Sulaites* sp.	
K8.4	Dulufal R	707417	no	"*Kossmatia*" cf. *indica*	
K9	Aralfolvil tr.	705433	close to	*Thracia (Thracia)* sp.	(Late) Oxfordian
K9.1	Aralfolvil tr.	705433	close to	*Retroceramus* aff. *galoi*	
K9.2	Aralfolvil tr.	705433	close to	*Belemnopsis* cf. *moluccana*,. Perisphinctidae indet.	
K9.3	Aralfolvil tr.	705433	close to	*Belemnopsis* sp., *Sulaites moluccanus*	
K9.4	Aralfolvil tr.	705433	close to		
K10	Aralfolvil	708428	no	*Belemnopsis* cf. *stolleyi* *Sulaites* gr. *gerthi*	?Early Kimmeridgian
K11	Inum Ck	709429	no	?*Virgatosphinctes* sp.	?Early Tithonian
K12	Inum Ck	710432	no	*Retroceramus* aff. *galoi* *Belemnopsis moluccana*	Oxfordian
K12.1	Inum Ck	710432	no	*Belemnopsis galoi*	latest Oxfordian/Kimmeridgian
E1	Abi Ck	743431	no	?*Paraboliceras* sp., *Hibolithes taylori*	Tithonian/Berriasian
E2	Abi Ck	742434	no		
E3	Abi Ck	742437	yes		
E3.1	Abi Ck	742437	no	*Epimayaites alfuricus*	Early/Middle Oxfordian
E3.2	Abi Ck	742437	no	*Macrocephalites* sp	Middle Bathonian/Early Callovian
E4	Abi Ck	741439	no	*Hibolithes taylori*	Tithonian/Berriasian
E4.1	Abi Ck	741439	no	*Virgatosphinctes* cf. *densiplicatus*	Early Tithonian
E4.2	Abi Ck	741439	no	*Macrocephalites* cf. *keeuwensis*	?Early Callovian
E5	Abi Ck	742441	close to	*Dicoelites* cf. sp. B	(?late) Early Callovian
E6	Elip R	741442	yes	*Conodicoelites kalepuensis*	Middle/Late Bathonian
E6.1	Elip R	741442	yes	*Macrocephalites bifurcatus*	
E6.2	Elip R	741442	yes	*Macrocephalites bifurcatus*	
E7	Abun R	763440	yes	*Macrocephalites* sp.	Middle Bathonian/Early Callovian
E8	Abun R	763441	no	*Macrocephalites* sp	Middle Bathonian/Early Callovian

(cont.)

Table 1 (continued)

------ E9	Abun R	762440	no	*Macrocephalites bifurcatus*	Middle/Late Bathonian
E10	Elip R	749439	no		
E11	Elip R	751439	close to		
E11.1	Elip R	751439	close to	*Macrocephalites* sp	Middle/Late Bathonian
E11.2	Elip R	751439	close to	*Macrocephalites bifurcatus*	Middle/Late Bathonian
E12	Elip R	760435	yes		
E13	Dingdang	55416	no	*Retroceramus subhaasti*	Late Early to early Late Kimmeridgian
E14	Elip R	763417	?yes		
E15	Elip R	764415	no	*Oxytoma (Oxytoma)* cf. *decemcostata*	?Bajocian
E16	Elip R	765414	no	*Macrocephalites bifurcatus intermedius*	Middle Bathonian
E16.1	Elip R	765414	no	*Trigonia (Trigonia)* aff. *moorei*	?Bajocian/Bathonian
E17	Kwambila Ck	766407	no	*Paraboliceras* gr. *spitiense*	(?Late)Kimmeridgian/Early Tithonian
E17.1	Kwambila Ck	766407	no	*Kossmatia* cf. *densistriata*	(?Late)Kimmeridgian/Early Tithonian

K4: Three dark grey, slightly calcareous mudstone float concretions, containing ammonites of the ?Late Kimmeridgian to Early Tithonian *Kossmatia tenuistriata* (Gray) group; occur alongside spur road on heights above Komduvip and may have been transported some distance as roadbase material.

K5: Belemnites and poorly preserved retroceramids in a slumped block of dark grey calcareous siltstone and mudstone close to subcropping source; Kimmeridgian or Tithonian *Belemnopsis galoi* or *B. stolleyi* and *Retroceramus* sp.

K6: Dark grey calcareous mudstone boulders and cobbles, occurring in the lower and middle parts of a small landslide derived from about 10 m of stratigraphic section. The fauna consists of *Belemnopsis stolleyi*, *Retroceramus* cf. *haasti* and *Sulaites* cf. *gerthi* Oloriz and Westermann. This fauna probably belongs to the Early Kimmeridgian *Belemnopsis galoi-R.* cf. *haasti* Assemblage, although the belemnite suggests a Tithonian age.

K7: Dark grey calcareous mudstone, grading locally to siltstone, with common latest Oxfordian to Kimmeridgian *Belemnopsis galoi* (Boehm); an outcrop on the Dulufal River with extensive mesoscale faulting and blocks dipping moderately to the southeast and steeply to the northwest.

K7.1: Dark grey, sandy concretionary limestone (float) containing a specimen of Early Kimmeridgian *Sulaites* cf.*gerthi*, found in the bed of the Dulufal River about 50 m downstream from K7.

K8: A large stream boulder in the Dulufal River which yielded probably Late Oxfordian ammonites, belemnites and bivalves. The fauna consists of: *Sulaites* cf. *sularus* (Boehm) (8.1),*S.?* cf. *indicus* (Kruizinga) (8.4), *Retroceramus galoi* (Boehm)(8) and *Belemnopsis moluccana* (Boehm) (8.2). Late Oxfordian (or Early Kimmeridgian).

K9: A collection of boulders very close to source on the crest of a small knoll yielded the following probably Late Oxfordian ammonites, belemnites and bivalves from a subcropping 1-2 m stratigraphic interval: *Sulaites sularus* (Boehm)(K9.3), Perisphinctidae sp. indet. (K9.2), *Retroceramus* aff. *galoi* (Boehm)(K9.1), *Thracia (Thracia)* sp. (K9) and *Belemnopsis* cf. *moluccana* (K9.2).

K10: A single float boulder at Aralfolvil village, which contained an ammonite and belemnites. A Kimmeridgian or Early Tithonian fauna was identified: *?Sulaites gerthi* and *Belemnopsis stolleyi* or *B. galoi*.

K11: Dark grey mudstone boulder in Inum Creek, downstream from Aralfolvil; contains possibly Tithonian *?Virgatosphinctes* sp.

K12: Two float boulders of dark grey, calcareous mudstone in the bed of Inum Creek; one (K12) contains an Oxfordian *Retroceramus* aff. *galoi-Belemnopsis moluccana* association, and the other (K12.1) contains latest Oxfordian to Kimmeridgian *Belemnopsis galoi* (Boehm).

E1: A float boulder in the bed of Abi Creek, containing *?Paraboliceras* and *Hibolithes taylori* Chall. The latter was formerly considered to be Apto-Albian (Challinor (1990), but its occurrence with a pre-Hauterivian berriasellid ammonite in this sample prompted a review of data on other occurrences, and it is now considered to be Tithonian to Berriasian (see Belemnites section, below).

E3.1: A concretion in a grey siltstone/mudstone boulder from the bed of Abi Creek, containing Early to Middle Oxfordian *Epimayaites alfuricus* (Boehm).

E3.2: Another boulder from the same locality containing Middle Bathonian to Early Callovian *Macrocephalites* sp.

E4: A boulder of mudstone/silty fine sandstone containing *Hibolithes taylori* similar to those in E1.

E4.1: Dark grey mudstone concretion (float in Abi Creek), containing Early Tithonian *Virgatosphinctes* cf. *densiplicatus* (Waagen) (Plate 6, Figure 1a,b).

E4.2: Dark grey siltstone/mudstone boulder in Abi Creek yielded the Early Callovian *Macrocephalites keeuwensis* Boehm.

E5: Belemnite in dark grey mudstone boulder, debris from small landslide about 5 m high; *Dicoelites* cf. sp. B Challinor and Skwarko (1982), of (?late) Early Callovian age.

E6, E6.1, E6.2: A collection from much the same horizon in beds oriented 303°/45°NE, along about 40m of the Elip River (south bank), just downstream from confluence with Abi Creek. It consists of Middle Bathonian *Macrocephalites bifurcatus* Boehm (E6.1, E6.2) and *Conodicoelites kalepuensis* Challinor (E6).

E7: Fragmentary Middle Bathonian to Early Callovian *Macrocephalites* sp. in outcrop of dark grey sandy mudstone on Abun River; ammonites are transported.

E8: Float specimen of Middle Bathonian to Early Callovian *Macrocephalites* sp. in the bed of Abun River.

E9: Float specimen of Middle Bathonian *Macrocephalites bifurcatus* from near E8.

E11.1, E11.2: A 5 m diameter float boulder of grey siltstone/mudstone close to source on north bank of Elip River, contains the Middle Bathonian *Macrocephalites bifurcatus* (E11.2) and *Macrocephalites* sp. indet (E11.1). The ammonites are fragmentary and were transported.

E13: A float cobble of grey mudstone from Dingdang, east of Eliptamin, which contains 'middle' (i. e., late Early to early Late) Kimmeridgian *Retroceramus subhaasti* (Wandel).

E15: Float boulder of micaceous, carbonaceous mudstone and muddy sandstone with bivalve, in bed of upper Elip River; *Oxytoma* cf. *decemcostata* Whitehouse of probable Bajocian age.

E16: A float concretion of dark grey mudstone containing Middle Bathonian *Macrocephalites bifurcatus intermedius* West. & Call., in bed of upper Elip River.

E16.1: A float boulder of grey siltstone with an incomplete specimen of ?Bajocian to Bathonian *Trigonia (Trigonia)* aff. *moorei* Lycett, found in the bed of the upper Elip River. The associated pollen and spores are of Late Bajocian to Tithonian age (AJP4-AJP6 Zones) (see Filatoff and Price, Appendix 5).

E17, E17.1: Two float concretions of dark grey mudstone from a locality on Kwambila Creek, a small left bank tributary of the upper Elip River. These contain (?Late Kimmeridgian/)Early Tithonian *Paraboliceras* gr. *spitiense* Uhlig and Tithonian *Kossmatia* cf. *densistriata* (Gray), and are probably within 200 m of source.

2.1.2 Lithostratigraphy and Sedimentology

Maril Formation, Wahgi Group

The Maril Formation in the Telefomin area appears to be mainly, if not entirely, of Middle to Late Jurassic age. The Berriasian to ?Aptian upper Maril Formation, which is well developed in the Wabag (Davies, 1980) and Karimui (Francis et al., 1990) 1:250 000 sheet areas has not been found near Telefomin. The only definite indication of Early Cretaceous in the Maril Formation of the Telefomin area is at locality 29 of Arnold et al. (1979) in the Digiam Valley, 30km northeast of Telefomin. Here Berriasian to Valanginian *Belemnopsis jonkeri* occurs in a float sample (P5003) which is associated with other float of Tithonian/?Berriasian age (Challinor, 1990).

In the Telefomin area, the Maril Formation consists dominantly of fine clastics, with sands up to 5 m thick being locally prominent in the Bathonian and Callovian. The fine clastics have occasional *Chondrites* burrows. At some localities turbidite structures such as graded bedding, load casts, convolute lamination and larger scale disrupted, lenticular bedding are present. These were recorded on the Kei River to the east of K12, along Abi Creek (at E1, E2, E4.2, and near E5), and on the Elip River (E10, near E11, and at E12). Most, if not all, of these localities are in Middle Jurassic strata.

The turbidites are distal, with Bouma CDE sequences being most common. However, a basal

B subdivision is present at E12. Turbidite structures have previously been reported from these sequences by Davies and Norvick (1974) and Rogerson et al. (1987). Much of the Late Jurassic has insufficient grain size variation to show clear evidence of turbidites. Where sandstone/fine clastic laminites occur in it, they only show more subtle features possibly of turbiditic origin. The Late Jurassic fine clastics are dominantly massive to crudely bedded, whereas those of the Middle Jurassic are often rhythmically bedded with 0.1-0.25 m beds.

The sandstones and fine clastics are mainly quartzo-feldspathic, with clear, subhedral to anhedral quartz with straight extinction and fresh, subhedral plagioclase. The latter is probably derived from penecontemporaneous distal volcanism. Subhedral biotite or white mica are present in some samples, and most samples are micropyritic, with pyrite aggregates often encrusting microfossils or detrital grains. A chloritic clay matrix is usually present, although in some samples there is highly birefringent clay (?illite/sericite) and in others variable amounts of calcite microspar is present. Nannofossil slides from K2, E3-3.2 and E4.2 contain devitrified glass with spherulitic textures (H.K. Hekel, Appendix 3). Some samples have zeolite microveins possibly formed by burial metamorphism.

In addition to the common quartzofeldspathic rocks, there are subordinate quartz sandstones and grey-brown volcanolithic-feldspathic sandstones and laminites. The clean, coarse to medium quartz sandstones are greyish white to light grey rocks, locally glauconitic, with subrounded to well rounded detrital grains. They are dense and compact, with overgrowths in optical continuity with the detrital grains, superficially resembling metamorphic quartzites of the type which occur in metamorphosed Maril Formation to the north of the Elip River.

The quartz sandstones occur as interbeds up to 0.6 m thick in turbiditic mudstones on the Elip River, upstream from its confluence with the Tol River. There is a possible outcrop of a thicker bed, or a large slumped boulder, on the Elip River to the west of Kobramin (91E14, GR 764415). Boulders of quartz sandstone, some with impressions of coarsely ribbed ammonites (?macrocephalids or ?mayaitids), are frequently found as float.

Late Jurassic volcanolithic-feldspathic sandstones crop out along Mulum Creek, downstream from 91K1, and are also found commonly as float in the Elip River downstream from the Tol confluence. Their detrital grains consist mainly of ?andesitic rock fragments, often chloritised.

The fine clastics of the Maril Formation contain numerous concretions and concretionary bands. Macrofauna are most commonly found in these concretions, although belemnites also occur frequently as free specimens in mud to sandy mud matrix. Microfossil assemblages are usually sparse, and lacking in age-diagnostic forms (Appendices 3 and 4). This is typical of much of the Maril Formation. Poorly preserved radiolaria (Spumellaria) occur as rare specimens in some samples, and are sufficiently frequent in 91E17 to indicate an outermost neritic or bathyal environment. Despite the general evidence for open marine sedimentation, and the specific evidence for bathyal turbiditic deposition at some localities, the palynomorph assemblages are frequently dominated by transported land plant taxa (Appendix 5). This is not uncommon in Mesozoic and Neogene turbidites of PNG, where palynomorph assemblages are often more indicative of provenance than of depositional environment.

The general depositional environment appears to have been a continental slope, which was receiving quartz-rich terrigenous detritus from land areas to the south and west, and distal pyroclastic detritus from volcanism within the basin.

Feing Group

The Maril Formation is structurally overlain by a sequence of massive, cliff-forming quartz sandstones, with overlying volcaniclastic sandstones and fine clastics, which cap the Donner Mountains to the south of Komduvip and Eliptamin. The lowest exposed part of this sequence was formerly considered to be Aptian-Albian, based on the belemnite *Hibolithes taylori* identified by Challinor (1990) from Geoscience Australia locality 57 of Norvick (1973) to the southwest of Eliptamin. However, the age of this taxon has now been revised to Tithonian/Berriasian (Challinor, Appendix 2). Norvick (1973) reported Cenomanian (locality 56) and Turonian (localities 64 and 65) planktic foraminifera in samples from higher in the sequence.

Francis and Westermann did not traverse these rocks, but examined large boulders of sandstone derived from them in the bed of the Bon River upstream from Misinmin No.1 (GR 693360 to 698369). They are lithologically similar to the glauconitic quartz sandstones and volcanolithic-feldspathic sandstones occurring as minor lithologies in the Maril Formation. Some of them contain abundant, poorly preserved belemnites.

Davies and Norvick (1974) mapped this sequence as undivided Feing Group, which consists of latest Tithonian/Berriasian Toro Sandstone and Berriasian/Campanian Ieru Formation. Because there were several quartz sandstone units in the lower part of the sequence, none of which could be specifically identified as Toro Sandstone, these two formations could not be differentiated. General problems have arisen in defining the base of the Toro Sandstone, as innermost neritic sands similar to the Toro were subsequently found to occur within the underlying Imburu Formation in a number of areas (Iagifu, Hedinia and Digimu Members of Denison and Anthony, 1990). Because these problems restrict the suitability of the base Toro Sandstone as a group boundary, Francis and Deibert (1988, table 4.1) abandoned the term Feing Group and extended the underlying Kuabgen Group upwards to include the Toro Sandstone.

Kimmeridgian and Tithonian rocks occur consistently as outcrop or as float in small catchments mapped as Feing Group, and there is an apparent overlap in age with the distal fine clastics of the Maril Formation (Arnold et al., 1979; A. Welsh, pers. comm., 1990). The specific ages for Feing Group rocks fall into two main Tithonian/Valanginian and Albian/Turonian concentrations. The Kimmeridgian/Barremian lower part of the Feing Group, with prominent quartz sandstones, includes equivalents of the upper Imburu Formation, as well as the Toro Sandstone and lower Ieru Formation.

Detailed sedimentological data like those on the Toro Sandstone provided by Nicholson et al. (1975) and Varney and Brayshaw (1993) are not available for Feing Group sands. Although the quartz sandstones in the lower Feing Group resemble parts of the innermost neritic Toro Sandstone in gross lithology, it is uncertain whether they are innermost neritic sands, or open marine sands like the thin Bathonian-Callovian quartz sandstones of the Maril Formation. Outer neritic intra-Ieru sandstones are known to occur in the Aptian-Albian Omati unit (Francis, 1988) of the Purari Delta region, which extends into the zone of facies transition to the Wahgi Group, and locally progrades over the Maril Formation. The quartz sandstones of the Feing Group could have similar palaeogeographic relationships.

If the Feing Group does prograde over the Maril Formation in the Telefomin area, then the Tithonian/Berriasian boundary probably lies within it, rather than in the Maril Formation. Further work on the biostratigraphy and sedimentology of the Feing Group is required.

2.1.3 Structure

The Maril Formation is structurally overlain by a tightly folded thrust sheet of Feing Group, which we interpret as an overturned anticline-syncline pair. The mesoscale structure of the subthrust Maril Formation proved to be complex, with dips usually exceeding 25° and common mesoscale faulting. The fine clastics often display a reticulate close jointing, which is usually associated with late mature to overmature rocks passing into the zeolite facies of burial metamorphism.

The following are examples of structural complications noted in our fieldwork. Note, however, that these are isolated observations and can not by themselves be used for detailed structural structural analysis.

Head of main landslip west of Komduvip (GR 683425): A cold H_2S spring at the head of Mulum Creek has deposited a greyish-white siliceous sinter coating the ground and fallen tree branches. The water is seeping from a plane of weakness which dips at *c.* 20° to the northeast and is possibly a thrust. A fault with a stratigraphic separation of several hundred metres, might account for the occurrence of ammonite float ranging from Early/Middle Oxfordian to Lower Tithonian in the main landslip.

91E3, Abi Creek: Beds of dark grey mudstone with a mesoscale thrust oriented 285°/34°S, subparallel to bedding.

91E4, Abi Creek: About 40 m downstream from 91E3, the dip steepens to 65°S and there is a mesoscale anticlinal rollover. This could be a partially exposed isoclinal fold, or drag associated with an unexposed northerly-dipping reverse fault.

Elip River upstream from 91E11.1 at GR 754440: There is mesoscale faulting of an outcrop with a moderate northeasterly dip. Subvertical conjugate shears trend 057° (dominant) and 095°. Striae along these shears are mainly subhorizontal, indicating strike-slip, but are locally overprinted with nearly vertical striae associated with dip-slip.

Elip River, upstream from footbridge (GR 760437): Fine clastics oriented 320°/55°NE are cut by a set of 065°/30°SE mesoscale faults, with striae plunging at 22° to 215°. The striae are offset by subvertical 090°-100° shears. About 200 m to the east at 91E12, graded sandstone/mudstone laminites oriented 305°/75°N are overturned.

The poor outcrop, lack of marker horizons and the structural complications usually preclude reliable lithostratigraphic correlations between faunal localities only a few hundred metres apart. The only exception to this is the Elip Gorge upstream from the confluence with Abi Creek, where Bathonian strata can be traced along strike for at least 400 m. Generally, the sequence has to be reconstructed from palaeontological evidence and it is not possible to make reliable estimates of its thickness. In this respect, the Maril Formation of the Telefomin area is less suitable for establishing a macrofossil zonation than the Jurassic sequences on Sula and Misool.

Despite the mesoscale structural complications, the Maril Formation seems to young fairly consistently to the south and the macroscale structure might be less complex. The mesoscale evidence for thrusting and oblique-slip faulting is consistent with the macroscale thrust stacking mapped by Rogerson et al. (1987).

2.2 MACROFOSSIL DATA FROM OTHER COLLECTIONS

The scarcity of good *in situ* ammonite assemblages in our 1991 collection means that work on the Late Jurassic ammonite assemblages and their faunal associations must also be based on the earlier Crouch, Geoscience Australia, and BP Collections. Although almost entirely *ex situ*, these much larger collections serve as an important taxonomic data set. Most ammonoids had been removed from the concretions, but some have remained attached to other macrofauna, especially bivalves. It is only in the AGSO and BP collections from areas to the south and east of Telefomin, that ammonites are likely to be found in association with age-diagnostic dinoflagellates.

2.2.1 Crouch Collection

Although the Crouch Collection provides the most abundant and diverse Late Jurassic ammonite fauna, it consists mainly, if not entirely, of float specimens with no supporting site data for individual samples. Information provided by Komduvip and Aralfolvil villagers who were involved in the collection of these samples, suggests that most of the fauna came from the main landslip to the west of Komduvip (Figure 2), and the remainder came from other localities in the Komduvip area.

The Crouch Collection consists mainly of *c.* 550 ammonoids belonging to the following taxa:

- 3% Phylloceratina (almost entirely *Ptychophylloceras*)
- 97% Ammonitina, of which
    - 40% Sphaeroceratidae: almost exclusively *Epimayaites,* including the microconch "*Paryphoceras*"
    - 23% Perisphinctidae: *Sulaites*
    - 23% Berriasellinae: *Paraboliceras* and *Kossmatia* in similar numbers
    - 9% Streblitinae: *Gymnodiscoceras* and a few *Uhligites*
    - 2% Ataxioceratidae:*Aulacosphinctoides, Virgatosphinctes* (?partly a dimorphic pair), *Katroliceras/Pachysphinctes*

Table 2 presents a list of selected samples from the Crouch Collection (ROM prefix refers to registration numbers of the Royal Ontario Museum), which contain age-diagnostic macrofossil associations, or which were used for geochemical or palynological studies of associated matrix materials.

2.2.2 Geoscience Australia Collection

Locality 71 of Norvick (1973) is on Anemen Creek, 15 km northeast of Telefomin (Figure 2).

Table 2. Selected macrofauna from the Crouch collection.

Sample	Macrofauna	Age
ROM J1974g	*Paraboliceras* cf. *sabineanum*	(Late Kimmeridgian?)/Early Tithonian
ROM J1974k1	*Sulaites? indicus*	late Oxfordian/Early Tithonian
ROM J1974k2	*Sulaites sularus*	Late Oxfordian
ROM J1974m1	*Epimayaites* cf. *alfuricus*	Early/Middle Oxfordian
ROM J1974n	*Sulaites gerthi* with *Retroceramus* aff. *galoi*	Early Kimmeridgian
ROM J1974o	*Epimayaites palmarus/sinuatus*	Early/Middle Oxfordian
ROM J1974r	*Retroceramus* aff. *galoi*	Late Oxfordian/Early Kimmeridgian
ROM J1974rn	*Retroceramus* aff. *galoi*	Late Oxfordian/Early Kimmeridgian
ROM J1974s7	*Sulaites gerthi*	Early Kimmeridgian
ROM 0574	*Virgatosphinctes* cf. *raja*	Early Tithonian
ROM 56675	*Paraboliceras* cf. *mutilis*	Kimmeridgian/Tithonian
ROM 49311-2, 49316	*R.* aff. *galoi*	Oxfordian/Early Kimmeridgian
ROM 49313	*Sulaites gerthi* with *?Malayomaorica malayomaorica*	Early Kimmeridgian
ROM 49314-5	*Retroceramus* aff. *galoi* with *M. malayomaorica*	Oxfordian/Early Kimmeridgian
ROM 49324-6, 49328-32	*R. galoi*	Oxfordian/Early Kimmeridgian
ROM 49327, 49333	*R.* aff. *galoi*	Oxfordian/Early Kimmeridgian
ROM 49334-5	*R.* cf. *galoi*, juv.	? Oxfordian/Early Kimmeridgian
ROM 49336	*Homomya* cf. *gibbosa*	Middle/early Late Jurassic
ROM 49337	*Goniomya (G.)* aff. *intersectans*	Jurassic-Eocene
ROM 49341-2	*Malayomaorica malayomaorica*	Oxfordian/Kimmeridgian
ROM 49343	*Trigonopis* sp.	Jurassic/Early Cretaceous
ROM 49344-51, 49353-4	*Palaeonucula* cf. *cuneiformis*	(?)Callovian/Oxfordian

Here Maril Formation outcrop and float close to outcrop (samples 0906, 0908-0914, 0917-0918) and stream float (samples 0919, 0921-22, 2076-2082) have yielded an abundant and diverse fauna of ammonites, bivalves and belemnites, only the latter of which have been studied in detail. Challinor (1990) identified *Belemnopsis* cf. *stolleyi* Stevens and *Hibolithes australis* Chall. in outcrop and near source samples (912, 914 and 918), and these taxa plus *B.* cf. *mangolensis* Chall. and *Parahibolites feraminensis* Chall. in streamfloat (919 and 2078).

Although Challinor (1990) believed that *Parahibolites feraminensis* was of Albian age, its occurrence with Tithonian *Hibolithes* cf. *australis* in 919, and with Tithonian/Berriasian *H. taylori* at localities 26 and 29 of Arnold et al. (1979), suggests that it is Tithonian/?Berriasian. All of the other belemnite taxa at locality 71 indicate a Tithonian age. The ammonites and bivalves at this locality require detailed study, as the unusually diverse fauna provides good opportunities for correlations between different macrofossil groups.

A float boulder of Maril Formation argillite in the Digiam River, 30 km northwest of Telefomin (locality 24 of Arnold et al., 1979), yielded *?Sulaites, Retroceramus* cf. *galoi* and *Belemnopsis moluccana*. The belemnite-bivalve assemblage is probably Oxfordian.

2.2.3 BP Collection

This collection contains a number of Late Jurassic bivalves, belemnites and a few Late Jurassic ammonites from the Strickland Gorge (MND series of Jenkins and White, 1970) and other valleys to the south and west (JKA series of White et al., 1973). Specific locality details and other supporting data are available in the above open file reports and in the archives of BP Developments of Australia Ltd. However, Jenkins and White (1970) miscorrelated several of the individual sections in the composite stratotype for the Koi-Iange, Imburu and Toro Formations (Davey, 1987) and underestimated the distances that float had been transported. These errors meant that much of their Late Jurassic fauna, which comes almost entirely from the Imburu Formation, was wrongly assigned to the Toro and Koi-Iange Formations.

A number of the MND and JKA macrofossil samples have been analysed for dinoflagellates by Collett et al. (1974), Davey (1987) and A. Welsh (pers. comm., 1988), and yielded good age-diagnostic assemblages. These are particularly important for correlation of macrofossil and palynological datums, as the late mature/overmature Maril Formation of the Telefomin area did not yield age-diagnostic dinoflagellates. Some of the JKA samples have been analysed for belemnites by Challinor (1990) and for ammonites and bivalves by Grant-Mackie.

The original identifications of macrofauna in the MND samples were made by Clarke (in Jenkins and White, 1970, their Appendix A). In the following summary, his taxonomic nomenclature for these faunas has been revised in the light of more recent work, and names here considered to be suspect are placed in quotation marks.

MND Series, Strickland Gorge

MND 19M (lower Imburu Formation) and MND 135M (float from Imburu Formation) contain an ammonite identified by Clarke (in Jenkins and White, 1970, Appendix A) as perisphinctid "aff. *Idoceras*". In MND 135M this ammonite is associated with *Retroceramus galoi* and is therefore very probably the Early Kimmeridgian *Sulaites* cf. *gerthi.*

The perisphinctid "aff. *Dichotomoceras*" in MND 150M, from float on the floor of the Strickland Gorge, could also be *Sulaites.*

MND 147M from the middle Imburu Formation contains *“Buchia concentrica”, Australobuchia spitiensis*, *Grammatodon (Indogrammatodon) "virgatus"* and *Hibolithes* sp. (Jenkins and White, 1970, their Appendix A). The *Buchia* association belongs to the middle or upper Assemblage I of Li and Grant-Mackie (1988) and is Kimmeridgian or Early Tithonian. Associated dinoflagellates identified by Collett et al. (1974) belong to the *Dingodinium jurassicum* or lower *Pseudoceratium iehiense* Zones of Helby et al. (1987).

JKA Series, Fly-Palmer Survey

JKA 963M from the middle Imburu Formation of the Wok Narin, some 40 km south of Telefomin, contains *Belemnopsis galoi* (Boehm) (Challinor, 1990), and an ammonite initially identified as "cf. *Aulacosphinctes*" by Grant-Mackie, which is probably an older homeomorph, such as the mainly Kimmeridgian *Torquatisphinctes.* The fauna is probably Kimmeridgian.

3. PALAEONTOLOGY, BIOSTRATIGRAPHY, BIOFACIES

3.1 RECENT PROGRESS IN AMMONITE TAXONOMY

In the decade since publication of our last report (Francis & Westermann, 1993) significant progress has been made on the taxonomy, age, and biogeography of Late Jurassic ammonites in the Himalayan Bioprovince that stretched from the central Himalaya at least to New Zealand. This concerns especially the identification of Late Oxfordian and Kimmeridgian ammonites, which had essentially been unknown in this entire province.

Recent work on the famous Himalayan section of the Upper Jurassic Spiti Shale (Pathak, 1993; Cariou et al., 1994; Enay & Cariou, 1996, 1997) identified our "*Perisphinctes sularus-moluccanus* group" in a similar stratigraphic situation, above the Early to Middle Oxfordian *Mayaites* fauna, i. e., Late Oxfordian, as in the superior sections of the Moluccas, or together with the latest, Late Oxfordian, mayaitids. They also identified for the first time indubitable Kimmeridgian taxa, and, significantly, together with them, early representatives of true *Paraboliceras*. *Kossmatia* is restricted here to the Tithonian.

In his recent monograph on Late Jurassic ammonites of New Zealand, Stevens (1997) described several new species (see discussion in Westermann et al., 2002). In the Early Kimmeridgian, or Late Heterian regional stage, "*Idoceras*" *heteriense* is associated, at least in the upper parts, with "*Kossmatia*" *macnaughti*. Whereas the former is a close affiliate of, and probably conspecific with, the New Guinean *Sulaites gerthi,* the latter is clearly a *Paraboliceras* according to its weakly projecting ribs with broad ventral interruption. Stevens, however, based his distinction of *Paraboliceras* from *Kossmatia* on the presence versus absence of parabolae (missing from *macnaughti*) a character of proven specific instability. Parabolic ribs are often restricted to the more inflated morphospecies of coeval pairs in the Oxfordian-Kimmeridgian of southern Europe, possibly representing mere variants (non-sexual polymorphism) in a morphic continuum (Atrops and Melendez, 1993). This problem of classification, however, demonstrates the close affinity between *Paraboliceras* and *Kossmatia* (should be placed in a single genus? cf. Westermann et al., 2002). *Paraboliceras macnaughti* is the earliest known representative of this clade and ranges here throughout most of the Kimmeridgian and Tithonian. *Kossmatia* branched off *Paraboliceras* in the later Kimmeridgian or Early Tithonian, with its early transitional representatives again known from New Zealand.

Oloriz and Westermann (1998) revised the taxonomy of the diverse "*Perisphinctes sularus-moluccanus* group", best developed and known from the Sula Islands of eastern Indonesia (Sato et al., 1978; Sukamto & Westermann, 1992), placing it in the new genus *Sulaites* (type species "*Perisphinctes*"*sularus* Boehm, with neotype designated - Plate 2). *S. sularus* includes "*P.*" *moluccanus* Boehm. Other probable *Sulaites* from the Moluccas are "*P*" *boehmi* and "*Kossmatia*" *indica,* both of Kruizinga (1926), but both are based on single float specimens. The New Guinea *Sulaites* were long ago described by Gerth (1965) under "*Pseudoparaboliceras aramaraii*" and "*Perisphinctes (Pachyplanulites) novaguinensis*". The former was renamed *S. gerthi* Oloriz & West. (1998) because Gerth's names are *nomina nuda,* with no type species or holotypes designated, and the latter needs additional research before renaming.

S. gerthi is the dominant form in New Guinea and differs from *S. sularus,* the dominant form in the Moluccas, in the more compressed whorls with denser costae and, probably, the somewhat younger age, i. e., Early Kimmeridgian versus Late Oxfordian (Francis & Westermann, 1993; Westermann , 1996). This is a significant departure from the earlier and even recent identification of these forms with either Kimmeridgian *Idoceras* or Tithonian *Kossmatia/Paraboliceras.* The *Retroceramus galoi-Malayomaorica malayomaorica* bivalves that are associated with *Sulaites gerthi* in ROM 49313 are probably latest Oxfordian or Early Kimmeridgian. *S. gerthi* is also associated with *R.* aff. *galoi* in ROM J1974n and probably with *Belemnopsis* cf. *stolleyi* in 91K6 and 91K10. In the former sample *Retroceramus* cf. *haasti* is also present. The limited evidence from associated bivalves and belemnites suggests that *S. gerthi* is slightly younger than *S. sularus,* i. e., Early Kimmeridgian versus Late Oxfordian.

3.2 NOTES ON BIVALVE TAXONOMY

The Telefomin bivalves include a number of forms recorded here for the first time from the PNG Jurassic (*Palaeonucula* cf. *cuneiformis* (Sowerby), *Retroceramus subhaasti* (Wandel), *Trigonopis, Thracia, Homomya* cf. *gibbosa* (Sowerby), and *Goniomya*), but the fauna is dominated by various *Retroceramus* morphotypes. Specific identification of the latter is hampered by the known morphological variability of retroceramid species, and by the lack of data on the range of form represented in single populations, especially from the type localities of species cited here. Identifications are also hampered by the general absence of evidence for stratigraphic relations among the Telefomin specimens.

Middle and Late Jurassic retroceramids in Indonesia, Australasia, Antartica, and southern South America show a similar, but apparently not identical sequence of forms (Crame, 1982; Damborenea, 1990; 1996). The material from Telefomin indicates that the New Guinea specimens fit into this sequence. Although there has been tacit acceptance by workers such as Crame (1982) that the upwards replacement of *Retroceramus galoi* (Boehm) by *R. subhaasti* (Wandel) and then *R. haasti* (Hochstetter) seen in parts of this area represents an evolutionary lineage, the morphologic limits of each species have not been established in collections from the type localities of each. This creates difficulties in the identification of isolated specimens with uncertain stratigraphic relationships. Furthermore, the stratigraphic range of each species has not been clearly documented, and this hinders confident dating of samples, even where identification is more certain.

R. galoi and *R. subhaasti* were described from eastern Indonesia (Boehm, 1907; Wandel, 1936), whereas the type locality of *R. haasti* is in the North Island of New Zealand (Zittel, 1864). F. Hasibuan and Grant-Mackie have studied collections of Indonesian species from Misool (in part, Hasibuan, 1990) and Grant-Mackie received collections from Sula (type locality of *R. galoi*), made during the expedition lead by Westermann (Sato et al., 1978).

New Zealand members of this retroceramid 'lineage' have recently been studied by Boyd (2003) using a statistical approach (Fourier outline shape analysis, with principal components and canonical variates analyses and multivariate analysis of variance) in an attempt to separate clearly the morphologic segments (species) involved. The study readily differentiated *R. galoi* and *R. haasti,* and showed that the stratigraphically intervening form is morphologically closer to the former than to the latter, and would thus be most appropriately named *R.* cf. *galoi,* pending the erection of a formally defined taxon to accommodate it. It is this terminology that is used herein, where relevant.

These studies, together with valuable comments on the Sula and Telefomin retroceramids by S. Damborenea, have been of considerable assistance in analysing the Telefomin fauna, but problems of identification have not been eliminated. Thus most retroceramid determinations remain in open nomenclature.

The Telefomin faunas include the following retroceramids:
Retroceramus galoi (Boehm) (Plate 7, Figure 3 - 7, 10) in 91K8, ROM 49324-26, ROM 49328-32; two juvenile shells that are probably this species in ROM 49334-5. This species occurs in New Zealand with the ammonites *Sulaites heteriensis* and *Paraboliceras macnaughti* (Stevens 1997) and is now given a latest Bathonian to Early Kimmeridgian age (Westermann et al., 2002).

Retroceramus* aff. *galoi (Plate 7, Figure 8, 9; Plate 8, Figure 1 - 7) in 91K9.1, 91K12, ROM J1974r, ROM J1974n, ROM 49311-12, ROM 49314-6, ROM 49327, ROM 49333-5. In New Zealand this taxon, once thought more closely similar to *R. subhaasti* (Wandel), occurs with *R. galoi* in the upper part of the range of the latter and extends above it for a short distance into the range of *R. haasti.* It occurs only below the range of *Kossmatia,* and thus does not extend into the Tithonian. It has a range of late Early to early Late Kimmeridgian.

Retroceramus subhaasti (Wandel) (Plate 8, Figure 8) is recorded only in 91E13. It occurs with *R. galoi* in its type area, Misool Island, and on the adjacent Sula Islands (Hasibuan, 1990; Sato et al., 1978); in both areas it lies below strata with *R. haasti* and has been regarded at least tentatively as Late Oxfordian to Early Kimmeridgian. In the PNG context it is more likely to have a range similar to that of *R.* cf. *galoi,* i. e., late Early to early Late Kimmeridgian. This raises the question of its stratigraphic relation to *R.* cf. *galoi,* but this is not able to be elucidated without *in situ* faunas here or more detailed sampling overseas.

Retroceramus* cf. *haasti (Hochstetter) (Plate 7, Figure 1, 2) in 91K6. Specimens are unfortunately incomplete but ammonite and belemnite associates support a likely range of Late Kimmeridgian to early Early Tithonian for this taxon.

3.3 NOTES ON BELEMNITE TAXONOMY AND AGE

3.3.1 The *Belemnopsis moluccana* lineage in Indonesia and Papua New Guinea.

The *Belemnopsis moluccana* lineage is named from its first appearing species, *B. moluccana* (Boehm). It includes five described species, *B. moluccana, B. galoi* (Boehm), *B. stolleyi* Stevens, *B. alfurica* (Boehm), and *B. mangolensis* Challinor & Skwarko, together with transitional forms. *B. moluccana, B. galoi,* and *B. stolleyi* have significant stratigraphic ranges and form a well-defined evolutionary lineage. *B. alfurica* and *B. mangolensis* appear briefly, and are apparently divergent side branches that left no descendants. The group has been recorded widely throughout eastern Indonesia and is present at many localities in the Maril Formation of PNG. Individual species within the *moluccana* lineage are recognised by differences in cross sectional shape, outline (dorsal or ventral views), profile (lateral view), position of maximum transverse diameter, and degree of hastation. A full discussion of the lineage is contained in Challinor (1989a), and only the main points are discussed here. Taxon ages stated in Challinor (1989a), however, are incorrect and are amended herein.

Belemnopsis moluccana (Oxfordian to Early Kimmeridgian) (Plate 9, Figure 1 - 3, 11 - 15) is strongly depressed in posterior cross section (mean posterior A value *c.* 117; for A values see Challinor, 1989a), throughout its stratigraphic range. The cross section of *B. galoi* (Plate 9, Figure 4 - 8, 17, 18) is moderately depressed in the lower part of its range (early *B. galoi,* Early Kimmeridgian, mean A value *c.* 107), but less depressed at higher stratigraphic levels (late *B. galoi,* Late Kimmeridgian to Early Tithonian, mean A value *c.* 102). *Belemnopsis stolleyi* (Early to Late Tithonian) (Plate 9, Figure 9, 10, 19 - 21) is approximately equidimensional in posterior cross section (mean A value *c.* 100) throughout its known range in Sula and Misool Islands.

The point of maximum transverse diameter in *B. moluccana* is located near the mid-point of the guard, except at the top of its stratigraphic range (8B, 2D, Sula – Sato et al., 1978), where it is located nearer the protoconch in some large specimens. Some late *B. moluccana* cannot be separated from *B. galoi* by the position of maximum diameter, and occur with the latter taxon at locality 2D on Sula. In the earliest *B. galoi* the point of maximum diameter may be located near mid-guard, but is usually slightly behind the level of the protoconch (i. e., nearer the apex), and remains relatively unchanged throughout most of its stratigraphic range. The point of maximum diameter in *B. stolleyi* is located at the anterior of the alveolar region and the guard is weakly conical in outline, particularly in large specimens.

All three taxa are less hastate in profile. *B. moluccana* is usually slightly or moderately hastate, but a few late appearing specimens may be almost cylindrical, while *galoi* and *stolleyi* are usually subcylindrical or slightly conical in profile. The degree of hastation depends largely on the position of maximum transverse diameter, and the more posteriorly this occurs the more hastate is the guard.

Both the position of maximum transverse diameter and the degree of hastation are influenced by ontogenetic factors, and in all species of the *moluccana* lineage the position of maximum transverse diameter in pre-adult specimens lies nearer the apex than in adults, and frequently near mid-guard. Most juvenile and many near adult specimens of all species are therefore hastate to some degree. They can be difficult to identify on hastation characters alone, and the misidentification of later members of the lineage is possible.

The mean posterior A value for populations of *Belemnopsis stolleyi* in Sula Islands is close to 100 (Figure 5), and *B. galoi* has not been identified within these populations. But at CP01-03, east of Cape Bogal on Misool, populati at about the same stratigraphic level (to judge from associated buchiids and other macrofossi and with similar A values, apparently include late *B. galoi* (Challinor 1991b). This illustrates the difficulty of placing taxonomic boundaries within an evolving lineage. In this instance the situation is further complicated by the likely presence of pre-adult specimens, which mimic the morphology of *B. galoi,* within populations of *B. stolleyi* at CP01-03.

While guard outline, profile, and hastation are all useful in the identification of fully adult specimens, complete or almost complete guards are necessary. Cross section data are more reliable (although there is much overlap between taxa) (Figure 5), and are only slightly affected by ontogenetic factors (the cross section becomes slightly more depressed with growth in *B. moluccana* and *B. galoi*). But such data should be derived from complete specimens that can be identified with confidence. Ideally, data should be obtained from as many specimens as possible from one locality, so that the effects of evolutionary change within the lineage are minimised, and some indication of non-evolutionary variation within the taxon is available. These constraints place limitations on the use of cross section data alone, particularly for late members of the lineage.

The A values of members of the *moluccana* lineage have been reinvestigated using extensive data derived from earlier studies (Challinor and Skwarko, 1982; Challinor, 1989a), but it has not been practical to re-examine the specimens, now held at the Geological Research and Development Centre, Bandung, Indonesia. The A values quoted above are means derived from numerous specimens, and each is associated with a range of values. The value ranges are usually symmetrically placed with regard to the mean, and appear to be normally distributed.

Identification of *B. moluccana* based on the cross section of single specimens will usually be reliable, but some early *B. galoi* (those most depressed in cross section) fall within the range of *B. moluccana*. With *B. alfurica* (mean A = 102; not included in Figure 5), late *B. galoi* (mean A = 102), and *B. stolleyi* (mean A = 100), there is extensive overlap in values, and early and late *B.*

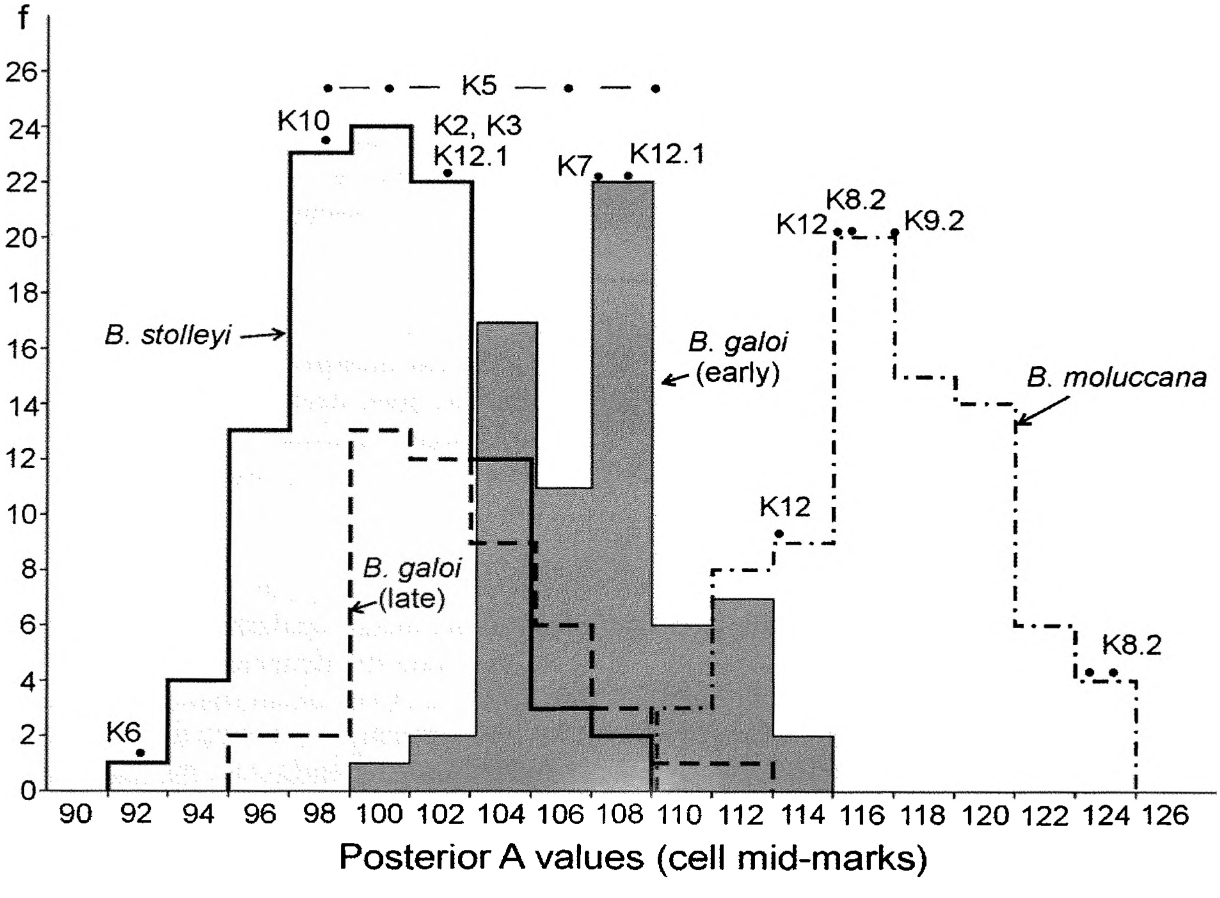


Figure 5. Frequency distributions of posterior A values (measured at a point *c.* 50% of the distance from protoconch to apex) in *Belemnopsis moluccana*, early and late *B. galoi*, and *B. stolleyi*, based on collections from Sula Islands and Misool Archipelago (see text). The A values of the Telefomin specimens are indicated above the cells in which they would

occur.

galoi are not well separated. Misidentification is also very possible between *B. mangolensis* (A = 105; not included in Figure 5) and early *B. galoi* (A = 107), particularly if few specimens are available.

Frequency distributions for *B. moluccana, B. galoi* (early and late), and *B. stolleyi,* based on posterior cross section have been prepared using data from the best preserved samples available (Figure 5). Data for *B. stolleyi* are derived from specimens from localities 8G, 8H, 8H2, 8I, and R76M. Those for late *B. galoi* are from 2A, 1C, CP93, CP106, and CP107, for early *B. galoi* from 8K, 2D, and CP91A, and for *B. moluccana* from 2D, 8B, CP60, CP64, CP67, CP 9, and CP101 (alphanumerics 8G etc. are for localities in Sula Islands - Sato et al., 1978; Challinor and Skwarko, 1982; CP and R prefixes denote Misool localities - Challinor, 1991b). Relative stratigraphic positions are thought to be approximately correct within the Sula and Misool sequences, but are less certainly so between the island groups.

The cross sections are stable (apart from variation about the mean) in *B. moluccana* and *B. stolleyi,* but decrease throughout the stratigraphic range of *B. galoi,* leading to the concept of an early population (mean A = *c.* 107) and a late population (mean A = *c.* 102) for that taxon (Challinor, 1989a). Occassional specimens of *B. moluccana* (e. g., Plate 9, Figure 13) are more depressed in cross section than those included in Figure 5. Very strongly depressed cross sections appear to be confined to some of the earliest members of the taxon.

Errors in relative stratigraphic placing may affect the validity of the data in Figure 5 and there is some evidence that this has occurred with *B. galoi.* The distributions are unimodal and approximately symmetrical in *B. stolleyi,* late *B. galoi,* and *B. moluccana.* But with early *B. galoi* the distribution is bimodal and skewed towards the higher values (Figure 5).

Sample sizes for early *Belemnopsis galoi* from localities 8K and CP91A differ (*n* = 48 and 13), and to simplify comparison, the total in each frequency distribution cell for locality CP91A has been multiplied by 3.7 (i. e., 48/13). Provided the 13 specimens collected from CP 91A are an accurate indication of the posterior A value in that population, this proceedure should not distort the results.

A comparison of the distributions for 8K and CP91A (modified as described for CP91A) provides the following A value data (values for 8K stated first).

Mean, 107.5, 105.5; mode 108, 104; number of observations above cell 108, 13, 4; number of observations below cell 108, 20, 34. These data suggest that the specimens from locality CP 91A were derived from a higher stratigraphic level than those from 8K. Locality 2D (*n* = 6, mean A = 107.3) may be from approximately the same stratigraphic level as 8K.

Belemnopsis stolleyi and *B. moluccana* together span the total range of A values included in Figure 5. The highest values for *B. stolleyi* (those from specimens with the most depressed cross sections), and the lowest from *B. moluccana* (from the least depressed guards) are close to 109.

Early *B. galoi* has a mean A value of *c.* 107 and a modal value of *c.* 108, and the negative and positive tails of its distribution extend almost as far as the mean values for *B. stolleyi* and *B. moluccana.* In terms of posterior cross section, early *B. galoi* is clearly a distinct taxon intermediate between *stolleyi* and *moluccana.*

Late *Belemnopsis galoi* and *B. stolleyi* are poorly separated by the data. The mean value for late *B. galoi* in Figure 5 is *c.* 102 and the modal value is *c.* 100. Both mean and modal values for *B. stolleyi* are *c.* 100. Because the data do not well separate the two, fragmentary specimens will be difficult to identify. This is probably why it has been difficult to firmly identify *B. stolleyi* from New Guinea in the past. Most are recognised as *B.* cf. *stolleyi* (Challinor, 1990).

The positions of the Telefomin specimens, based on their A values, are indicated in Figure 5, and are an important (but not the only) basis of the identifications. The determinations are discussed below.

3.3.2 Ages of members of the *moluccana* lineage

The *Malayomaorica malayomaorica/Retroceramus galoi/R. subhaasti (*cf. *galoi)/R. haasti* assemblages occur widely with belemnites of the *moluccana* lineage in Indonesia and PNG. It is also present in New Zealand, where its chronostratigraphic distribution is fairly well established.

Retroceramus galoi appears early in New Zealand compared with most other regions (Callovian – Westermann et al., 2002), and becomes more abundant in Late Oxfordian to Early Kimmeridgian exposures. *M. malayomaorica* appears in Late Oxfordian to Early Kimmeridgian beds and persists until the Late Kimmeridgian. *R. galoi* is replaced in New Zealand by *R.* cf. *galoi (R. subhaasti* has not yet been identified in this sequence) at about the middle of the Early Kimmeridgian, and *R. haasti* appears at about the Early/Late Kimmeridgian boundary. *R. haasti* and *M. malayomaorica* disappear towards the top of the Late Kimmeridgian. Appearances/disappearances are from Meesook and Grant-Mackie (1995); international correlations of the New Zealand sequence from Stevens (1997) and Westermann et al. (2002). The (Late Oxfordian/)Early Kimmeridgian *Sulaites heteriensis* (Stevens), formerly *"Idoceras" heteriense*, appears in New Zealand at about the same time as *M. malayomaorica.*

The *Retroceramus galoi/subhaasti/haasti* assemblage, with *M. malayomaorica,* is present in Sula Islands (Sato et al., 1978), where *R. galoi* and *M. malayomaorica* occur with the stratigraphically highest *Belemnopsis moluccana* and lowest early *B. galoi* at locality 2D. This suggests that the *B. moluccana-B. galoi* transition occurs in the Late Oxfordian or Early Kimmeridgian. The lowest *B. moluccana* known from Sula Islands are present at locality 9B (*Belemnopsis* sp. *B* of Challinor and Skwarko, 1982) with *Retroceramus galoi, R. subhaasti,* and *Sulaites sularus,* thought to be slightly older than *Sulaites heteriensis* in New Zealand, suggesting a Late Oxfordian age for this horizon.

The highest *Belemnopsis moluccana* in Misool occurs with *Retroceramus* cf. *galoi* at CP104 (field observation), just below CP91A, with early *B. galoi, M. malayomaorica,* and *R.* cf. *haasti* (Hasibuan, 1990), suggesting a Late Oxfordian or Early Kimmeridgian age. The lowest *B. moluccana* in Misool that are associated with *R.* cf. *galoi* occur at CP94. Beneath CP94 (from CP101 down to CP60 - Challinor 1991b), *B. moluccana* occurs with three moderately abundant *Hibolithes (H. boloides, H. longiscissus, H. quadratus),* and with *Demubelus weberi.* At the base of its range (CP58, 60, 62, 67, 68), *B. moluccana* is associated with abundant *Belemnopsis wanneri* Stolley, and at CP58, 60, and 67 with *Conodicoelites abadi* (Challinor, 1991b). None of the *Hibolithes, Demubelus, Belemnopsis, or Conodicoelites* associated with *B. moluccana* throughout much of the middle and lower parts of its range in Misool are known in Sula or PNG, suggesting that the early members of *B. moluccana* (and the *Hibolithes, Demubelus,* etc.) are either missing from those regions or have not yet been discovered.

Praebuchia kirghisensis, an Oxfordian indicator (Li and Grant-Mackie, 1988), occurs below CP100 and above CP97 (Hasibuan, 1990). There is no firm dating for *Belemnopsis moluccana* below CP97 in Misool. The presence of *Conodicoelites* (and of *Dicoelites rotundus* below, at CP66) suggests that some *B. moluccana* (those at and below CP67 and 68) could be as old as Bajocian (with a few exceptions, *Dicoelites* and *Conodicoelites* are Bajocian-Oxfordian on the world scene). An Oxfordian age is more likely, as belemnite species rarely persist through more than a single stage. Thus an Oxfordian to Early Kimmeridgian age is suggested for *Belemnopsis moluccana.*

Early *Belemnopsis galoi* is associated with *Retroceramus* cf. *galoi* and *M. malayomaorica* at CP105 and CP91A in Misool (field observations), at 2D in Sula with *R. galoi* and *M. malayomaorica,* and at 8K with *R. haasti* and a new buchiid (Sato et al., 1978). Early *B. galoi* is approximately Early Kimmeridgian in age. Late *B. galoi* occurs at CP106, 107, and 108 in Misool, apparently without members of the *Retroceramus/Malayomaorica* assemblage, and in Sula at 1C1 with *Retroceramus* sp. and at 2A with a new buchiid (Sato et al., 1978). Thus the occurrence of late *B. galoi* apparently occurs above horizons of the typical *Retroceramus/Malayomaorica* assemblage, although the retroceramid and buchiid at 1C1 and 2A may indicate the assemblage is stratigraphically nearby. Late *B. galoi* is considered here to have evolved near the Early/Late Kimmeridgian boundary, and is approximately Late Kimmeridgian and Early Tithonian in age.

Belemnopsis stolleyi at CP02-03 is associated with *Australobuchia subpallasi* and *A. subspitiensis* (Hasibuan, 1990), those at 8I to 8L with *A.* cf. *plicata* and a number of ammonites (*Haplophylloceras* cf. *strigile, ?Virgatosphinctes, ?Uhligites, ?Aulacosphinctoides),* and those at 8G and 8I with *Hibolithes australis,* all of which suggest a late Early or Late Tithonian age. Thus *B. stolleyi* apparently persisted to near the end of the Tithonian, but its earliest members could be of early Early Tithonian age.

No precise age data are available for the latest *B. stolleyi.* Challinor (1991b) placed the Jurassic/Cretaceous boundary in Misool at the first appearance of *Duvalia robusta, D. ceramensis,* and *B. jonkeri,* and these occurrences lie above the latest *B. stolleyi* and at about the same level as the latest *Hibolithes austr* However, the relationship of this boundary to the international Jurassic/Cretaceous bounc is not known. *Hibolithes australis* is probably confined to the Late Tithonian and the earliest Cretaceous.

3.3.3 *Hibolithes taylori*

Hibolithes taylori (Plate 11, Figure 1-7) is apparently endemic to PNG, and when first recognised (Challinor, 1990), it was assigned an Aptian-Albian age, mostly on its association with a new species of *Parahibolites, P. feraminensis* (Plate 11, Fig. 8-11), but also on its apparent absence from Tithonian beds in Sula Islands (Challinor and Skwarko, 1982), from Tithonian-?Hauterivian beds in the central Bird's Head of West Irian (Challinor, 1989b), and Tithonian and Early Cretaceous beds in Misool archipelago (Challinor, 1991b).

The collection localities of *H. taylori* in PNG were originally recorded as being located in the Late Tithonian-Berriasian Toro Sandstone, or the stratigraphically equivalent basal part of the more distal Tubu Unit. On the above evidence the collection localities were re-assigned to the Aptian-Albian Omati Unit and Chim Formation (Challinor, 1990).

The original Tithonian-Berriasian age and Toro Sandstone/Tubu Unit allocations are now thought to be correct. A detailed re-examination of faunal associations at the *H. taylori* localities and nearby has shown that *H. taylori* (and *Parahibolites feraminensis* where present) occurs consistently with Kimmeridgian to Berriasian taxa in float collections, and has not been found with mid-Cretaceous macrofossils, palynomorphs, or microfauna (observations by Francis).

It is possible that *Parahibolites feraminensis* (Plate 11, Figure 8 - 11) has been incorrectly assigned to *Parahibolites (*although it is similar in all characters except size - Challinor, 1990), as that genus is of Aptian-Albian age on the world scene (Stevens, 1973). A small specimen similar in size to *Parahibolites* elsewhere, collected from the Aptian Bawia unit (sheet SB/54-7, Ok Tedi), and assigned to *P. blanfordi* by Glaessner (1945), is, however, associated with a mid-Cretaceous fauna (observation by Francis). Either *Parahibolites* occurs earlier in PNG than elsewhere, and its stratigraphic range is disjunct, or *P. feraminensis* has been wrongly classified.

As *Hibolithes taylori* is not associated with Kimmeridgian taxa elsewhere in eastern Indonesia or PNG, and occurs in PNG associated with *Hibolithes australis* (Plate 11, Figure 12 - 15) (confined to strata no older than (?latest) Tithonian in Indonesia), it is apparently of latest Tithonian and/or Berriasian age. The Toro Sandstone has been firmly dated as latest Tithonian-Berriasian by palynology (Davey, 1987). *"Parahibolites" feraminensis* is apparently of approximately the same age.

3.3.4 Other latest Tithonian-Early Cretacous PNG belemnites.

Several other latest Tithonian to Early Cretaceous belemnite taxa that occur in eastern Indonesia have not been found in the immediate Telefomin area, but do occur elsewhere in PNG (Challinor, 1990).

Hibolithes australis (Plate 11, Figure 12-15) is known from Sula Islands (localities 8G, 8H1, 1D), and from R76M in Misool. In each instance it is associated with *Belemnopsis stolleyi.* It also occurs at CP93 (Misool) associated with what is possibly a late *B. galoi/B stolleyi* transitional population, and at CP91D with *Belemnopsis jonkeri.* It is present in PNG in the Maril Formation at locality 71, Ok Tedi map sheet SB/54-7, on a north-flowing tributary to Elip River *c.* 15 km ENE of Telefomin village (Challinor, 1990). It is also associated with *B. stolleyi* and *B.* cf. *mangolensis* at locality 69 (Tubu Unit, Tikori saheet, SB/55-13). In all known instances it is present with Late Tithonian or Early Cretaceous fossils (except possibly at CP93 in Misool). It is never abundant but is a useful Late Tithonian-Early Cretaceous indicator.

Belemnopsis jonkeri (Plate 10, Figure 10 - 13) occurs at many localities in Misool (Challinor, 1991b) and with *Hibolithes gamtaensis* at CP201 on the Ainim River, central Bird's Head, West Irian (Challinor, 1989b). *B. jonkeri* is present in PNG at locality 187 (Ieru Formation, Ok Tedi sheet SB/54-7), *c.* 85 km SE of Telefomin village, where it is associated with ammonites and bivalves of Early Cretaceous age (Norvick, 1973), and at locality 453 (Toro Sandstone) within Sheet SB/54-7-2. It occurs with *H. gamtaensis* at both localities. *B. jonkeri* and *H. gamtaensis* are present in the basal Toro Sandstone at locality JKA453 and are latest Tithonian or Berriasian at that locality (Challinor, 1990).

Hibolithes gamtaensis (Plate 11, Figure 16 - 18) is associated with *B. jonkeri, Hibolithes miosensis,* and with the rare diplobelinid belemnite *Chalalabelus* (Barremian age elsewhere), and with ?Hauterivian ammonites at CP201 in West Irian (Challinor, 1989b). *H. gamtaensis* is present in the Feing Group of PNG at locality 5, Digiam River, *c.* 20 km WNW of Telefomin village, and at locality 187 (see above).

3.4 MOLLUSCAN BIOSTRATIGRAPHY

3.4.1 Bajocian

Bajocian faunas of PNG are poorly known. They include two isolated records of *Oxytoma* cf. *decemcostata* Whitehouse. One of these was in 91E15 collected by Francis and Westermann, and the other in a sample from a locality in the Maril Formation of the Wahgi Gorge, *c.* 300 km southeast of Telefomin (D.W. Haig, pers. comm., 1992). Both PNG occurrences are likely to be Bajocian, although a greater range for the species is possible. *Trigonia* aff. *moorei* Lycett in 91E16.1 is probably of Bajocian or Bathonian age. There is a single record of the Bajocian/Bathonian ammonite *?Irianites* from the Maril Formation in the Wabag 1:250 000 Sheet area to the east of Telefomin (Davies, 1980).

Bajocian stephanoceratid ammonites have been recorded from the Maril Formation in pioneering pre-1960s work (O'Brien et al., 1961), but these identifications need to be confirmed by modern taxonomic studies.

3.4.2 Bathonian-Callovian

Although age-diagnostic Middle Bathonian to Early Callovian ammonites and belemnites occur consistently in the Eliptamin area, the ammonites are less abundant and diverse than those in the Strickland headwaters (Geoscience Australia localities 105 and 106 of Norvick, 1973). 91E16 contains *Macrocephalites bifurcatus intermedius* Boehm, an index for the Middle Bathonian assemblage of this name defined by Westermann and Callomon (1988) and later raised to *M. b. intermedius* Assemblage Subzone within the lower *M. bifurcatus* Assemblage Zone (Westermann in Hillebrandt et al., 1992) (Figure 4).

Samples 91E6, 91E6.1 and 91E6.2 come from the same bed. The fauna consists of *M. bifurcatus* and the belemnite *Conodicoelites kalepuensis*. *M. bifurcatus* occurs through the *M. bifurcatus* Zone. *Conodicoelites kalepuensis* has previously been found with the *M. b. intermedius* Assemblage of Geoscience Australia locality 106, and on the Sula Islands (Challinor, 1990).

Dicoelites sp. B Challinor and Skwarko (1982) occurs in association with the late Early Callovian *M. keeuwensis* Assemblage of the Sula Islands (Westermann and Callomon, 1988), and *Dicoelites* cf. sp. B in 91E5 is probably of similar age.

No age-diagnostic fauna of Middle or Late Callovian age has been found. Middle and Late

Callovian sequences dated by dinoflagellates occur in the Koi-Iange Formation of the Strickland Gorge (Davey, 1987) and in the Maril Formation of the Kikori-Purari Delta and Gulf of Papua. Although strata of this age appear to be usually present, the only possible PNG record is a ?Middle Callovian/earliest Oxfordian *?Hibolithes ingens* (Geoscience Australia sample 20NG2635) from the Maril Formation of the Kerowagi District, about 270km southeast of Telefomin (Challinor, 1990).

3.4.3 Oxfordian

The Early to Middle Oxfordian of Telefomin is characterised by the corresponding dimorphic pair *Epimayaites* gr. *palmarus* (Boehm) ♀ (M)/*Paryphoceras* gr. *alfuricus* (Boehm) ♂ (m). They occur in 91E3.1, ROM J1974m1 and ROM J1974o, and make up about 40% of the Crouch Collection. Despite the abundance of *Epimayaites* (with *Paryphoceras* being a junior synonym), other age-diagnostic taxa such as the Early Oxfordian *Parawedekindia-Peltomorphites/ ?Peltoceratoides* dimorphic pair and Middle Oxfordian *Perisphinctes (Kranaosphinctes),* present in the Sula Islands, are rare or absent in PNG. Thus it is not usually possible to distinguish Early and Middle Oxfordian on ammonite evidence. The *Epimayaites* Assemblage is associated, however, with the bivalve *Retroceramus galoi* (Boehm) and the belemnite *Belemnopsis moluccana* (Boehm), suggesting Middle Oxfordian.

In the Sula Islands, the Lower Oxfordian occurrences of these *Epimayaites* are associated with dinoflagellates of the lower *Wanaea spectabilis* Zone of Helby et al. (1987), and the Middle Oxfordian occurrences with dinoflagellates of the upper *W. spectabilis* Zone (Sukamto and Westermann, 1992; Francis and Westermann, 1993) (Figure 6).

The *Sulaites* assemblage, first known from the Late Oxfordian of Indonesia, is diversely developed in the Telefomin area. The 91K8, 91K9, ROM J1974k1 and ROM J1974k2 faunas all belong to this assemblage, and are similar to those occurring in localities 8B and 9B of the Sula Islands. This *Sulaites* assemblage is associated with *Retroceramus galoi, R.* aff. *galoi, Belemnopsis moluccana* and forms transitional between *B. moluccana* and *B. galoi*. In the Sula Islands, this transient occurs with dinoflagellates of the *Wanaea clathrata* Zone of Helby et al. (1987), whereas *Sulaites sularus* occurs below the first *Malayomaorica* (Sukamto and Westermann, 1992). This suggests that *S. sularus* is slightly older than *S. gerthi* (Oloriz & Westermann, 1998). The first New Zealand occurrence of *Sulaites,* i. e., *S.* cf. *gerthi,* was identified by Francis & Westermann (1993) and named *Idoceras heteriense* by Stevens (1997).

3.4.4 (?Latest Oxfordian-)Kimmeridgian

On Sula and in PNG, the main *Sulaites* assemblage is overlain by a facies dominated by belemnites together with *Retroceramus* and *Malayomaorica,* both the latter being epibyssate bivalves. There are only sporadic occurrences of poorly known ammonites, the only ones probably belonging to *Sulaites* gr. *gerthi,* i. e., resembling "*Pseudoparaboliceras aramaraii*" and "*P. novaguinense*" originally described from West Irian (Gerth, 1965; both *nomina nuda*). The exact stratigraphic levels at which these ammonites occur, however, are uncertain. The most probable age is Early Kimmeridgian (see below).

This "belemnite-byssate bivalve facies", depleted in ammonoids, is common throughout the Indo-southwest Pacific (Westermann and Wang, 1988; Francis and Westermann, 1993; Meesook and Grant-Mackie, 1995), and its palaeoecology is discussed below. In PNG, three successive assemblages can be recognised within it (ascending order):

1. A basal *Retroceramus galoi-Malayomaorica* Assemblage

2. An overlying *Retroceramus haasti-Malayomaorica* Assemblage

3. A *Belemnopsis galoi-Retroceramus* cf. *haasti* Assemblage.

Assemblages 1 and 2 are not very common in the Telefomin area, but are well developed elsewhere in the Maril Formation and in the Imburu Formation (see below).

Assemblage 1. This includes early forms of *Belemnopsis galoi* (Boehm) and transients to *B. moluccana*. It is of latest Oxfordian/ earliest Kimmeridgian ageg. The initial appearance of *Malayomaorica malayomaorica* in the Sula sections (Sato et al., 1978) is slightly younger than the youngest recorded occurrences of the Late Oxfordian *Sulaites* (see Figure 5). More limited data from PNG are consistent with a similar stratigraphic relationship between these taxa. However, in New Zealand, the initial appearance of *M. malayomaorica* precedes that of *Sulaites* (Helby et al., 1988), and could still be Middle Oxfordian (Damborenea and Manceñido, 1992).

It has been suggested (Davey, 1987; D. Haig, pers. comm. to G. Francis, 1992) that there is a transgression recorded from innermost neritic in the basal Imburu Formation to mid-neritic in the middle Imburu in the Strickland and probably elsewhere in the region. This could explain the delayed appearance of *Malayomaorica* here compared with New Zealand, it not having arrived until water depths were great enough.

On Misool (locality 81CP91A) and in PNG (BP sample JKA 616), the oldest occurrences of *Belemnopsis galoi* (Boehm) are associated with dinoflagellates of the *Wanaea clathrata* Zone (Challinor, 1990).

ROM 49314, with *R.* aff. *galoi* and *M. malayomaorica* belongs to Assemblage 1. This assemblage also occurs in the lower Imburu Formation of the Strickland Gorge (BP samples MND 173M and 174M of Jenkins and White, 1970). In MND 174M the associated dinoflagellates belong to the *Cribroperidineum perforans* Zone of Davey (1987), equivalent to both the *perforans* and *Dingodinium swanense* Zones of Helby et al. (1987).

Assemblage 2. This consists of *Retroceramus haasti, Malayomaorica malayomaorica* and early forms of *Belemnopsis galoi*. In Muabu-1 well (2638.8 m), it is associated with dinoflagellates of the *swanense* Zone (Glaessner, in Australasian Petroleum Co. Pty Ltd, 1967; Helby and Partridge, 1977). On Sula (locality 8K), it is also associated with dinoflagellates of the *swanense* Zone (R. Helby, pers. comm., 1992). The *R. haasti-M. malayomaorica* bivalve assemblage (without *B. galoi*) is widely distributed throughout the Indo-southwest Pacific (Damborenea et al., 1992). At Kawhia, New Zealand, *R. haasti* and *M. malayomaorica* occur with dinoflagellates of the middle and upper *swanense* Zone and an ammonite identified by Stevens (1997) as *Kossmatia* (Helby et al., 1988), but which is probably an Early Kimmeridgian member of the Ataxioceratinae (Francis and Westermann, 1993).

No samples definitely referrable to Assemblage 2 have been found near Telefomin, but ROM

49313 with *Sulaites* cf. *gerthi* and *?M. malayomaorica* possibly belongs to it. Faunas from this Assemblage occur in the Maril Formation at Geoscience Australia localities 22, 28 and 29 of Arnold et al. (1979), 35-55km northwest of Telefomin.

Assemblage 3 consists of transitional and late forms of *Belemnopsis galoi* and a *Retroceramus* which is probably *R. haasti* or a closely related form. *B. stolleyi* appears near the top of this assemblage, although it is more common higher in the sequence. This assemblage is present in the middle Imburu Formation of the Strickland Gorge, where abundant *Retroceramus* sp. (Jenkins and White, 1970) occurs with dinoflagellates of the upper *Omatia montgomeryi* Zone in MND 178 (Davey, 1987). This is 31m stratigraphically above the highest recorded occurrences of *M. malayomaorica* (MND 174M).

Telefomin fauna 91K6, with *R.* cf. *haasti*, *Belemnopsis* cf. *stolleyi* and *?Kossmatia* or *Sulaites* cf. *gerthi,* probably belongs to the upper part of Assemblage 3. *R. haasti* is typically a Kimmeridgian form, but has sometimes been erroneously assigned to the Early Tithonian, based on misidentifications of associated ammonites (Francis and Westermann, 1993). However, the youngest PNG occurrences of retroceramids similar to *R. haasti* are slightly younger, and could be earliest Tithonian. The belemnite suggests a Tithonian age.

Assemblage 3 occurs at Sula Islands locality 1C1, where *Retroceramus* sp. is found with late *Belemnopsis galoi.* The faunas at Sula localities 1C2 and 2A possibly also belong here. In New Zealand *R. haasti* and closely comparable forms do not range above the highest occurrences of *M. malayomaorica*, and thus there is no equivalent of Assemblage 3.

Above the *B. galoi-R.* cf. *haasti assemblage* is a latest Kimmeridgian/earliest Tithonian interval, with consistent occurrences of long ranging *Belemnopsis stolleyi* or *B. cf. stolleyi*, and rare occurrences of index taxa with more restricted ranges. In the basal part of this interval on Misool (localities 81CP91B and 93), there are sporadic occurrences of late *B. galoi* with *B. stolleyi* (Challinor, 1991b), but this association has not been found in PNG. Slightly higher in the Misool sequence there are rare *Australobuchia misolica, A. subpallasi* and *A. subspitiensis* and an ammonite which has been identified by Grant-Mackie as *Uhligites.* However, poorly preserved specimens of Kimmeridgian *Streblites* can easily be mistaken for Early Tithonian *Uhligites* (Francis and Westermann, 1993). This fauna is associated with dinoflagellates of the lower *Dingodinium jurassicum* Zone (Helby and Hasibuan, 1988).

The "*Buchia concentrica*"*-Australobuchia spitiensis* assemblage from the middle Imburu Formation in the Strickland Gorge (MND 147M) could have come from this sequence, or from the overlying Tithonian. It belongs to the Kimmeridgian/Early Tithonian middle to upper *Buchia* Assemblage I of Li and Grant-Mackie (1988).

3.4.5 Tithonian

The large Telefomin collection, which includes all genera, and probably all species, known from PNG, contains *Aulacosphinctoides,* rare *Virgatosphinctes, Uhligites, Gymnodiscoceras, Kossmatia, Paraboliceras,* and *Paraboliceratoides,* as well as rare Kimmeridgian to basal Tithonian *Pachysphinctes* or *Katroliceras.* There is thus no good evidence for Late Tithonian in the Telefomin ammonite fauna, which appears to belong mainly to the Early (including Middle) Tithonian. Because significant *in situ* collections remain unknown from New Guinea, we will not attempt to compare these taxa with Himalayan assemblages.

The absence of age-diagnostic Late Tithonian macrofossils in the Telefomin area may be due to facies. Late Tithonian to Valanginian strata consist largely of a quartz sandstone facies (Feing Group), lacking ammonites and retroceramids. Late Tithonian ammonites have also not been found elsewhere in the Ok Tedi Sheet area and are rare in PNG. The only PNG records of Late Tithonian to earliest Berriasian, i. e., *Blandfordiceras,* come from the lower part of the upper Maril Formation in the Kikori-Purari Delta, where it is known locally as the Tubu Shales (O'Brien et al., 1961). The Tubu Shales have also yielded the belemnites *Hibolithes australis* Challinor (1990), *?Duvalia* sp., *H.* cf. *"obtusirostris"* and *Belemnopsis* cf. *"porrectus"* (probably *H. gamtaensis* Challinor and *B. jonkeri* Stolley).

A Late Tithonian to earliest Berriasian ammonite assemblage, consisting mainly of *Blandfordiceras* cf. *wallachi* (Gray) and *Haplophylloceras strigile* Blandford, occurs in the Sula Islands (Sato et al., 1978; Francis and Westermann, 1993). It is associated with *B. stolleyi* Stevens, *H. australis* Challinor, sporadic *B. mangolensis* Challinor, and with a *"Buchia" rumphii- Australobuchia* cf. *plicata* association from *Buchia* Assemblage II of Li and Grant-Mackie (1988). At locality 1A2 dinoflagellates of the lower *P. iehiense* Zone of Helby et al. (1987) occur with *B.* cf. *wallachi* and *Haplophylloceras strigile.*

The *Belemnopsis* cf. *stolleyi-Hibolithes australis-B.* cf. *mangolensis-Parahibolithes feraminensis* belemnite assemblage from Anemen Creek (locality 71 of Norvick, 1974) is of late Early or Late Tithonian age. The oldest occurrences of *Hibolithes taylori* are probably at a similar stratigraphic level. In the (?Late) Tithonian, there is a change from the *B. stolleyi-H. australis* assemblage to an overlying *Belemnopsis jonkeri-Duvalia* assemblage. This occurs at Misool localities 81CP01 and 81CP91D, the former lying stratigraphically below dinoflagellates (81CP111) of the Early Berriasian *Kalyptea wisemaniae* Zone of Helby et al. (1987) and the latter lying slightly above the *D. jurassicum* Zone (Helby and Hasibuan, 1988; Challinor, 1990). In PNG *Duvalia* is rare, but *B. jonkeri* occurs more consistently and is sometimes associated with *H. taylori.*

The Tithonian and Berriasian of PNG seem to have a greater diversity of belemnites than the Oxfordian and Kimmeridgian, but much additional work is required to correlate belemnite datums with those of ammonites and dinoflagellates.

3.5 THE BELEMNITE-BYSSATE BIVALVE FACIES

This fully marine biofacies (Westermann and Wang, 1988; Francis and Westermann, 1993) with only rare ammonoids is now known to be developed consistently throughout the latest Oxfordian and Kimmeridgian of the Tethyan Himalaya, Eastern Indonesia, Papua New Guinea, and New Zealand (Meesook and Grant-Mackie, 1995). In the Sula and Misool Islands of Indonesia and in New Zealand it extends into the Tithonian. The belemnite-byssate bivalve facies includes a fauna which consists typically of *Belemnopsis* and/or *Hibolithes* spp. and one or two taxa of *Retroceramus* and *Malayomaorica* or *Australobuchia.* The lithofacies is dark grey to grey-black mudstone or shale and often with calcareous nodules bearing the invertebrates, which are often pyritised.

Mytiliform or submytiliform bivalves related to *Retroceramus* are interpreted as having been endobyssate (Stanley, 1972), and this mode of life for the Telefomin forms is supported by the frequent occurrence of articulated individuals in the collections. Co-occurrence of multiple specimens in single concretions suggests a gregarious clustering habit, but this was by no means general, and many *Retroceramus* were found isolated. Specimens are sometimes found in shellbeds with a relatively high species diversity, such as the Captain Kings and McNaught Shellbeds of the New Zealand Kimmeridgian (Fleming and Kear, 1960), but more generally occur in less fossiliferous units of low species diversity, indicating deeper water sites.

The ecology of buchiids has recently been reviewed by Li and Grant-Mackie (1988). Species were epifaunal, byssally attached, sessile organisms living gregariously throughout most of their Jurassic range, but becoming more individually isolated (and thus having a more stable shell form) in the Late Tithonian and Early Cretaceous. They also occur occasionally in shallow water shellbeds with, for instance, astartids and trigoniids, but much more frequently are found in lower diversity, more offshore biotopes. Li and Grant-Mackie (1988; 1993) concluded that the dark *Buchia*-ammonite-lutite facies in southern Tibet was characteristic of outer neritic and bathyal environments. These sediments, however, generally lack *Retroceramus*. The abundant *Retroceramus* and the slightly greater diversity of the Telefomin faunas suggest that they came from the shallower end of this range.

From bivalve assemblages and sedimentological evidence, an outer shelf to uppermost slope environment, *c.* 100-200 m depth can be inferred, but the possibility that bivalves from these zones were transported into deeper water cannot be excluded. Retroceramids and buchiids were both filter feeders, so bottom sediments in the region were firm enough and conditions clean enough to avoid clogging of gills with mud particles. This suggests that in the localities where they lived, turbidite flows must have been infrequent.

A byssate bivalve-ammonoid facies is now well known from the Devonian, Carboniferous, and much of the Mesozoic. It is usually considered to be associated with dysaerobic lower water masses and exaerobic bottom conditions (Kauffman, 1988; Brett et al., 1991), which might have been unfavourable for demersal ("nekto-benthic" and "bentho-pelagic") ammonites. *Retroceramus* appears to have preferred cool water, as documented from associated boreal agglutinating foraminifera in Nepal (Gradstein et al., 1989). Kauffman (1988) suggested that large Cretaceous inoceramids might have had an unusual metabolism, with symbiotic bacteria tolerant of low oxygen conditions. However, some of the New Zealand occurrences are in sandy sediments with a diverse associated macrofauna, apparently deposited initially under well oxygenated conditions, and later transported into deeper waters to the byssate bivalve-belemnite facies (Grant-Mackie, pers. obs.).

Carbon isotope data on Kimmeridgian *Belemnopsis* from New Guinea also indicate cool water, similar to that in the Boreal Province in northern Russia (Stevens and Clayton, 1971). Since the oxygen requirements of the mobile belemnites were at least as high as of the sluggish ammonites, low oxygenation of the lower water masses could not have discriminated against all ammonoids, which in general were probably also less bottom-dependent (i. e., more pelagic) than belemnites (Westermann, unpublished). Another possible explanation is that during the Kimmeridgian most waters of the northeast Gondwanan shelf and ocean margin were too cold for the south Tethyan ammonoids, probably due to upwelling, whereas belemnites were less affected. North Tethyan and boreal ammonoid species were unable to cross the tropical broad eastern Tethys ocean.

In PNG the *Retroceramus-Malayomaorica malayomaorica* assemblages in the Maril Formation are consistently associated with low diversity assemblages of agglutinated foraminifera, including *Riyadhella, Glomospira,* and *Hyperammina* (Haig, 1978), which D.W. Haig (pers. comm., 1985) interpreted as an upper bathyal, dysaerobic facies. This fauna occurs in distinctive tuffaceous, carbonaceous mudstones, which weather to form purplish red, red-brown and yellow-brown mottled colours (Francis et al., 1990). However, the latest Oxfordian/Kimmeridgian *Retroceramus-Malayomaorica* faunas and associated lithofacies seem to be poorly developed in the Telefomin area, where retroceramids appear to be more common in the underlying Oxfordian sequence. The associated agglutinated foraminifera have not been found.

Lloyd (Appendix 3) found most samples to be barren of foraminifera, with only rare *Lenticulina* in 91E16 and 91E17.1. These very sparse assemblages do not permit detailed palaeoenvironmental interpretations. Finely disseminated pyrite in the fine clastics provides evidence for dysaerobic conditions, but these conditions occur commonly at depths of several centimetres below the seabed in relatively impermeable, fine clastics. Thus there is a lack of specific lithologic evidence for dysaerobic bottom water conditions in the Maril Formation of Telefomin.

In most of the Mesozoic of PNG, ammonites are rare. This scarcity of ammonites is not restricted to the Late Jurassic of the Maril Formation, but is characteristic of the entire Carnian to Aptian, and the Senonian of the Wahgi Group. The only known area in PNG with a significantly thick interval of Jurassic ammonite-rich facies is the Middle to Upper Bathonian of the Om-Lagaip confluence, but this is probably fairly localised, as the corresponding part of the Maril Formation at Eliptamin is much less rich in ammonites. In Papuan Basin sequences, the problem is not so much explaining the scarcity of ammonites in Mesozoic open marine facies, but explaining the small minority of occurrences where they are abundant.

Throughout the Indo-southwest Pacific region, thick ammonite-rich facies like the Bathonian-Early Callovian and Oxfordian of Sula, and the Tithonian-Berriasian of Malla Johar in the Himalaya (Krishna et al., 1982) seem to be exceptional, and this goes for most of the Mesozoic, not just the Middle and Late Jurassic. Thus the problem of the belemnite-byssate bivalve facies remains unresolved.

3.6 A SHALLOWER WATER BIVALVE FACIES

It is difficult to reconstruct detailed bivalve associations from collections which consist mainly of float material, but some inferences can be made. The sandstone matrix of *Oxytoma* cf. *decemcostata* (91E15) and *Homomya* cf. *gibbosa* (ROM 49336) is much coarser than the matrix of the other bivalve samples, and thus these taxa probably occupied a different habitat. Furthermore, the former species comes from much older strata than *Retroceramus* and the majority of the bivalves.

The remainder occur in dark siltstone/mudstone and their ranges all overlap with those of the Telefomin *Retroceramus*. *Thracia* was collected with *Retroceramus*, and is thus part of the same association. In New Zealand, Late Jurassic *Palaeonucula* (although not *P. cuneiformis*) and *Myophorella* (not *Trigonia*) are subsidiary elements of *Retroceramus-*

Malayomaorica/Australobuchia faunas, and *Goniomya* is a very rare member. *Opis, Tancredia* and *Homomya*, present in other New Zealand biotopes, are not known in this association. Hallam (1976) listed these taxa, together with *Parallelodon, Trigonia* and *Goniomya*, as members of a high diversity, nearshore marine association, which is dominated by bivalves, including *Oxytoma.*

From the above evidence, it is likely that the Telefomin bivalve faunas include representatives of two biotopes, an inner neritic Bajocian to ?Oxfordian *Oxytoma, Opis, Tancredia* and *Homomya* fauna and an Oxfordian to ?Kimmeridgian outer neritic or uppermost bathyal *Retroceramus-Malayomaorica*-cephalopod fauna, with subsidiary *Thracia. Palaeonucula, ?Parallelodon, Trigonia* and *Goniomya* could have been members of either fauna.

4. GEOCHEMISTRY AND PALYNOLOGY OF CONCRETIONS

The failure to obtain large, stratigraphically controlled ammonite collections, means that studies have to be based largely on existing collections dominated by float material. This problem is not restricted to the Telefomin area, as many of the more important collections from Indonesia consist largely of float samples. Such collections would be more useful if indirect evidence such as geochemistry or palynology allowed approximate estimates for the stratigraphic positions of these samples to be made.

Table 3, part 1: Geochemistry of fossiliferous concretions (Bathonian – Kimmeridgian)

|Age : **Bathonian** | **Early/Middle Oxfordian** | **?Oxfordian** | **(?Late) Oxfordian** | **?Kimmeridgian** |

Sample No.		**91E16**	**ROM J1974m1**	**ROM J1974o**	**ROM**	**91E3.1 J1974r1**	**ROM J1974r2**	**ROM J1974k1**	**ROM J1974k2**	**ROM J1974n**	**ROM J1974s7**
Major Elements (wgt %)											
SiO_2	21.3	52.2	59.1	58.8	53.7	74.4	35.5	45.7	56.9	35.5	
Al_2O_3		5.8	7.1	5.5	8.2	5.7	5.9	7.7	4.4	5.7	5.9
TiO_2	0.24	0.28	0.24	0.21	0.19	0.21	0.4	0.16	0.26	0.23	
Fe_2O_3	25.4	4.1	2.8	4.5	1.7	1.9	2.8	4.4	1.5	2.2	
MnO	0.8	0.36	0.19	0.24	0.39	0.05	0.97	0.2	0.43	0.8	
MgO		1.4	<0.05	0.38	0.64	0.53	0.27	0.12	<0.05	0.34	0.34
CaO	22.1	17.6	13.4	11.8	17.6	3.9	26.4	19.8	13.7	24.1	
Na_2O	0.62	0.35	0.38	0.46	1.1	0.6	1.1	<0.05	1.1	1.0	
K_2O	0.6	0.69	0.61	0.69	0.57	0.64	0.78	0.39	0.56	0.62	
P_2O_5	2.1	0.56	0.9	2.1	1.4	0.97	1.2	4.5	2.4	1.2	
SO_3	1.1	1.2	1.5	1.1	1.0	0.99	2.0	5.2	0.78	0.9	
Trace Elements (ppm)											
V_2O_5	22	-	-	8	-	-	-	-	-	7	
Cr_2O_3	30	-	-	-	-	-	-	-	-	13	
Co_3O_4	63	15	-	-	-	-	15	13	-	-	
NiO	17	13	-	-	-	-	10	-	-	-	
CuO	50	20	-	-	-	-	21	-	-	7	
As_2O_3	20	18	-	-	-	-	16	14	-	-	
Rb_2O		6	-	-	-	-	-	-	-	-	-
SrO	64	41	39	-	25	18	63	54	35	41	
Y_2O_3	15	-	-	-	-	-	-	-	10	-	
ZrO_2	21	10	-	-	-	-	15	-	-	-	
SnO_2	27	13	-	-	-	-	-	-	-	-	
Sb_2O_3	33	15	-	-	-	-	12	-	-	-	
TeO_2	31	16	-	-	-	-	12	-	-	-	
Cs_2O	27	36	-	-	-	-	25	-	-	-	
BaO	33	74	-	-	34	18	59	19	-	15	
La_2O_3	54	-	-	-	-	-	-	-	27	17	
Ce_2O_3	7	-	20	61	-	-	21	16	48	34	
Nd_2O_3	44	-	-	-	-	-	-	-	16	-	
Sm_2O_3	59	-	-	-	-	-	-	-	6	-	
Ta_2O_5	59	39	-	-	-	-	33	-	-	-	
WO_3	38	46	-	-	-	15	59	15	-	-	

Table 3, Part 2: Geochemistry of fossiliferous concretions (Tithonian)

| Age : ---------------------- **Early Tithonian** ----------------------..|

Sample.		**ROM**	**91E4.1**	**91E17**	**91E17.1**	**ROM**		**ROM**
No.	**0574**				**J1974g**	**Ji974w**		
Major Elements (wgt %)								
SiO_2	74.6	83.4	70.3	9.8	57.9	72.4		
Al_2O_3		8.0	4.9	5.0	3.5	8.4		5.9
TiO_2		0.26	0.18	0.17	0.89	0.29		0.17
Fe_2O_3		4.1	3.1	4.5	2.4	3.7		5.1
MnO		<0.05	0.02	<0.05	0.03	0.21		<0.05
MgO		0.05	0.33	0.41	0.75	0.12		0.59
CaO		5.0	2.5	3.9	39.8	14.5		4.4
Na_2O		0.57	0.6	0.35	0.51	0.29		0.36
K_2O		0.81	0.53	0.35	0.38	1.0		0.46
P_2O_5		4.5	0.55	3.8	2.2	1.5		4.0
SO_3		1.8	3.8	2.2	3.2	1.6		3.4
Trace Elements (ppm)								
V_2O_5		-	11	11	-	-	-	
Cr_2O_3		-	6	-	-	-	-	
Co_3O_4		13	14	12	-	18		13
NiO		-	-	-	-	12		-
CuO		-	-	-	-	21		-
As_2O_3		13	6	-	-	22		5
Rb_2O		-	-	-	-	-	-	
SrO		26	16	15	57	64		17
Y_2O_3		15	-	10	-	-	10	
ZrO_2		-	-	-	-	-	-	-
SnO_2		-	-	-	-	-	-	
Sb_2O_3		-	-	-	-	11	-	
TeO_2		10	-	-	-	12		-
Cs_2O		18	-	-	-	21	-	
BaO		40	-	21	-	54		8
La_2O_3		-	-	-	41	-	-	
Ce_2O_3		-	9	12	47	-	10	
Nd_2O_3		-	8	12	-	-	10	
Sm_2O_3		-	-	-	-	-	-	
Ta_2O_5		22	-	6	-	39		13
WO_3		44	15	-	-	56		-

Table 3 presents results from whole rock XRF analyses carried out at McMaster University on concretions and other matrix associated with 16 macrofossil samples from Telefomin. Because the detection limit for many trace elements was 50 ppm, only limited data were obtained on trace elements in these rocks. Some general trends in geochemistry are evident: the Tithonian concretions have relatively high silica contents, whereas those from Oxfordian rocks have high CaO contents. The one analysed Bathonian sample is sideritic, with a high FeO content.

Although general trends are evident, there are significant exceptions, even in a small data set like this. Thus Late Callovian to ?earliest Kimmeridgian ROM J1973k2 has a silica content of >70%, much greater than that of any other sample of similar age and comparable with those of the Tithonian samples. Because of such exceptions, it is unlikely that geochemical evidence could discriminate with certainty between concretions of different ages within the Late Jurassic.

Unfortunately, samples from both the recent collection and the older Crouch Collection proved to be overmature, with poor to non-existent preservation of dinoflagellates and only generalised ages could be assigned to some of them (Filatoff and Price, Appendix 4). The only preserved dinoflagellates of any stratigraphic value are Middle Callovian/Oxfordian *?Wanaea digitata* Cookson & Eisenach in 91K8.3 and the chorate cyst cf. *Hystrichosphaeridium pachydermum* Cookson & Eisenach, which occurs in 91K4, 91K6, 91K7.1, 91E17, 91E17.1, and J1974m1. All of the latter samples are known to be Late Jurassic on macrofossil evidence.

The overmaturity of the sequence and lack of preserved index dinoflagellates are due to the deformation in the Komduvip-Eliptamin area, which increases northwards toward the hinterland. However, the Imburu Formation in areas to the south of Telefomin is early to fully mature, and consistently yields age-diagnostic dinoflagellates (Collett et al., 1974; Davey, 1987; Lowe, 1987). Age-diagnostic Late Jurassic dinoflagellates have also been recovered from the Feing Group in the Kutik Valley, 50km southeast of Telefomin (A. Welsh, pers. comm., 1990). Future work on the correlation of PNG macrofossil and dinoflagellate successions will have to be based largely on material from the Imburu Formation and Feing Group, in areas along structural trends south of Komduvip.

5. CONCLUSIONS

1. The Middle and Late Jurassic ammonites of Telefomin come from thin horizons within recessive concretionary mudstones. The poor outcrop, barren interzones, and complex structure make it impossible to obtain stratigraphically controlled ammonite collections. The apparent richness of the earlier Crouch Collection was due to the efforts of local villagers, who collected extensively after a period of major landslides, which provided abundant ammonite-rich talus.

2. Because of the pervasive deformation, the rocks are late mature to overmature and age-diagnostic dinoflagellates have not been preserved. Dinoflagellate-ammonite correlations must be established from work on less deformed rocks along structural trends to the south of Komduvip, but these sequences are less rich in ammonites.

3. Thus the relative stratigraphic positions of Telefomin faunal localities have to be determined from the macrofauna present. This is a common problem in PNG and Indonesia. Much work is required on associations in these spot samples and float collections, even though it is inherently more difficult than studies of well exposed, stratigraphically controlled sections.

4. Despite the difficulties noted above, some age-diagnostic molluscan associations have been found. These include members of the almost certainly Late Oxfordian ammonite *Sulaites sularus* and probably Early Kimmeridgian *S. gerthi*, which have previously been mistaken for other Kimmeridgian and Tithonian taxa.

5. There is evidence from stratigraphic and dinoflagellate data in New Zealand that *Paraboliceras* and its slightly younger branch *Kossmatia* may have evolved in the southwestern Pacific from *Sulaites* gr. *gerthi* during the Early Kimmeridgian near the end of the *swanense* zone.

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APPENDIX 1

BIVALVES (J. A. Grant-Mackie)

NB. Some specimens and plaster copies of others are held in the Department of Geology, University of Auckland. Any of these that are figured in Plates 7 or 8 are registered in that Department's Catalogue of Type & Figured Specimens with alphanumerics prefixed by 'L'.

1991 Collection of Francis and Westermann

91K6: Two partial *Retroceramus* valves of relatively small size, one a right valve lacking the posteroventral half (L4463; Plate 7, Figure 1, 2), the other a right or left valve, lacking the umbo and bearing the cast and part body whorl of ?*Sulaites*. Ribs are broader on one bivalve and more pinched on the other; they are moderately spaced for the size of the shells and are slightly asymmetric, the ventral flank being a little steeper than the dorsal. Although too incomplete to identify with any certainty, these features, together with the mytiliform outline and moderate inflation, suggest *R. haasti* rather than older forms. This is consistent with the associated ammonite and belemnite (Appendix 2), the latter of which has not been found in certain association with *R. galoi*.

Retroceramus cf. *haasti* (Zittel); probably Late Kimmeridgian, possibly to earliest Tithonian.

91K8: Three *Retroceramus*-bearing siltstone concretions. These specimens are grossly similar to those in 91K6, although one right valve (L4464; Plate 7, Figure 4, 5) is much larger, 105 mm maximum oblique dimension (= length), 55 mm normal to that (=width), and 17 mm inflation. Ribs, however, are symmetrical in profile, much more crowded on the umbo, and a little more so on the rest of the disc. These features, together with an insignificant posterodorsal wing, indicate *R. galoi,* and thus a Late Oxfordian to Early Kimmeridgian age.

91K9: A slightly distorted, almost complete, thin-shelled right valve of moderate size (27 cm long, *c.* 9 mm high) in micaceous fine sandstone (L4465; Plate 8, Figure 10). The valve is elongate-oval and rounded in outline, with a broad, low umbo and inconspicuous beak located a little anterior of the midline. The posterior margin is narrowly truncated and the shell surface bears many low, rounded concentric, somewhat irregularly spaced folds, each ca 1mm wide. Shell inflation is *c.* 3 mm, but appears to have been exaggerated by lateral postmortem deformation, which has accentuated a single, low posteroventral ridge, and either produced or accentuated a shallow furrow on the anterior flank of the ridge. These features are all consistent with location in the Jurassic-Recent genus *Thracia*, and the valve is quite similar to an undescribed form in the Middle Jurassic of New Zealand.

91K9.1: Two *Retroceramus* specimens in siltstone, one a juvenile valve (length *c.* 20 mm, width 13 mm, inflation 6 mm) lacking the beak, the other bivalved and undistorted (length *c.* 55 mm, width 41 mm, inflation of one valve 15-16 mm) but incomplete (L4466; Plate 8, Figure 1, 4). The specimens are broadly mytiliform in outline, with subequal valves of moderate inflation and moderately strong, regularly-spaced concentric ribs of regular strength, 4-6 per 20 mm of shell length; the ribs are symmetrical in profile. The hingeline is *c.* 23 mm long and makes an angle of *c*. 55° with the line of maximum inflation on the best preserved valve; the posterodorsal shell margin meets the hingeline at *c*. 160°. The umbo is relatively narrow and the beak seems markedly prosogyral. These specimens are more closely similar to *R. galoi* than to *R. subhaasti* or *R. haasti* in outline, inflation and curvature of the umbo, but differ from *R. galoi* in ribbing density. Although juvenile stages of *R. galoi* often show the crowding of ribs seen in 91K9.1, adult shells more generally have ribs about twice as widely spaced as on the present specimen. Ribbing in *R. haasti* is even more widely spaced and is asymmetric, and the shell is broader. In *R. subhaasti* also, the shell is broader; ribbing is of rather irregular spacing and strength, but not as closely spaced as in this adult Telefomin specimen. Argentinian collections recently reviewed by Damborenea (1990) include the Late Bathonian *R. patagonicus*, which is closely comparable to the present material, but has ribs slightly more spaced and irregular, and has a shell with a smaller obliquity angle (32-38° vs. 55°). There are also Japanese Middle Jurassic species (e.g. *R. ogurai* and *utanoensis*, Hayami spp. (1960)) broadly similar in rib spacing, but in these the ribs are broader and more rounded, and the shell outline is different. Among all of the above species, the Telefomin shells are most closely related to *R. galoi*.

Retroceramus sp. aff. *galoi* (Boehm), of probable Late Oxfordian - Early Kimmeridgian age.

91K12: A grey-black siltstone concretion containing a gaping, articulated bivalved *Retroceramus*, lacking the posterior portion of each valve (L4467; Plate 8, Figure 2). The valves were slightly larger than the larger specimen in 91K9.1 (60-65 mm long, *c*. 43 mm wide, 20 mm in inflation), but the outline and ribbing characters are similar. Rib density is a little lower on 91K12, at 13-14 (vs. 18-19) in the first 40 mm of length and thus approaches *R. galoi* more closely. The specimen is presumably conspecific with that in 91K9.1 and of comparable age.

91E13: A dark grey to grey-black siltstone concretion containing the internal cast of a very well preserved, undistorted right valve of a *Retroceramus* 72 mm long, 48 mm wide and with an inflation of 19 mm (L4468; Plate 8, Figure 8, 11). The cast lacks only the central 15 mm of the umbo. The shell has essentially the same outline as those of 91K9.1 and 91K12, but markedly different ribbing. On the juvenile 27 mm of the shell, ribs are weak and narrow, and spaced *c*. 2 mm apart. The rest of the valve bears 6 strong, sharp-crested and narrow symmetrical ribs spaced 8-9 mm apart, with broad, rounded interspaces, in some of which 3-4 faint, low rounded secondary ribs can be seen. Sculpture weakens markedly on lateral flanks, especially posterodorsally. The hingeline is not completely preserved, but was 28 mm long, with the beak situated 9-10 mm from the anterior end; the hingeline makes an angle of 55° with the line of maximum shell inflation (shell "length") and of 155° with the posterodorsal margin. Ligament pits are narrow and widely spaced (3 mm apart) on the hinge plate; four are preserved but there are likely to have been two or three additional pits. Adult primary ribbing features are rather like those seen in many specimens of *R. galoi*, which often also shows the more crowded juvenile ribbing of the Telefomin valve, but the faint secondaries of the latter are not known in *R. galoi*. The hinge plate of E13 is essentially similar to that of *R. galoi* and *R. subhaasti*. Dr S. Damborenea (pers. comm., 1993) considers that the ribbing is similar to that in some forms intermediate between *R. galoi* and *R. haasti*, and that some specimens from the Sula Islands previously identified as *R. subhaasti* by Skwarko (in Sato et al., 1978) also have ribbing similar to that in 91E13. The Russian Bajocian-Bathonian *R. borealis* (Koshelkina, 1962) also has ribbing closely similar, but lacks the finer juvenile and adult secondary ribs. The Telefomin shell also shows some relationship with *R. stehni* from the Callovian of Argentina (Damborenea, 1990), especially in the adult ribbing form and its posterodorsal weakening, but that species lacks the secondary ornament and has a longer hinge plate, with broader and more numerous ligament pits. This shell is probably a member of the same lineage as those of 91K9.1 and 91K12. Given the general trend of increased rib spacing seen in the *R. galoi-subhaasti-haasti* series, as well as in the Argentinian Jurassic (Damborenea, 1990), 91E13 is probably a younger member.

Retroceramus subhaasti (Wandel), of late Early to early Late Kimmeridgian age.

91E15: An internal cast and a fragment of the external cast of the left valve of a large bivalve (length 51 mm, height *c.* 50 mm, inflation 11 mm), in mottled, medium grey micaceous and carbonaceous medium sandstone (L4469; Plate 8, Figure 9). The ventral margin of the internal cast is incomplete, but the shell was subcircular, with a continuously curved margin running ventrally from the anterodorsal margin to the ventral margin of a large, 29 mm long posterior ear, which has a broad, shallow sinus forming its posterior margin and meeting the dorsal margin in a right angle. The straight hingeline is *c.* 35 mm long; the beak is prosogyral and situated 18 mm from the anterior end of the overall shell length. No anterior ear is clearly visible, but one seems to be present. Ornament on the internal cast consists of 10 strong, spaced radial ribs, straight posteriorly, curving towards anteriorly, and produced as short digitations at the margins. The small external fragment shows no sign of any subsidiary ribbing, and interspaces between the primary radials, as well as the posterior ear, could have been smooth, apart from very late intercalated secondaries. However, the partial nature of the cast, its weathered condition and the grain size of the matrix all tend to mask the possible presence of any weak tertiary radials.

All of the above features clearly demonstrate similarity with the genus *Oxytoma*. The widespread, long-ranging Jurassic *O. inequivalvis* differs from the present specimen in its smaller size and the presence of fine subsidiary riblets. The Western Australian *O. decemcostata* Whitehouse reaches the same size as the Telefomin shell, possesses 10 primary ribs (as its name indicates) and rather weaker secondaries, but also possesses faint tertiaries and perhaps a deeper sinus to the posterior ear and larger marginal digitations of the ribs. Figures of the Australian material by Skwarko (1974) suggest that it is more distorted and of incomplete outline, so that these apparent differences may not be real and thus the Telefomin and Australian specimens might be conspecific. The Western Australian species occurs in the Newmarracarra Limestone, of well established Early Bajocian (Laeviuscula Zone) age (Skwarko, 1974; Westermann & Wang, 1988). In PNG *O.* cf. *decemcostata* has only previously been recorded from a single locality in the Maril Formation of the Wahgi Gorge, *c.* 300 km southeast of Telefomin (D.W. Haig, pers. comm., 1992). Both PNG occurrences are likely to be Bajocian, although a greater range for the species is possible.

Oxytoma (Oxytoma) cf. *decemcostata* Whitehouse; ?Bajocian.

91E16.1: Two valves of a single individual, slightly displaced one from the other, in dark grey siltstone. The shells lack their anteriors and the posterodorsal of the left valve. They are of moderate size (length *c.* 43 mm, height *c.* 36 mm, inflation 9 mm) and trigonal outline, with a low ridge bordered by a shallow groove, running from the beak to the posteroventral margin. The ornament is not well preserved, but anterior to the ridge are narrow concentric ribs spaced *c.* 2 mm apart. The posterior area has a series of fainter, more closely spaced radials, the median of which is gemmate and stronger than the rest. Hinge details are not seen, but the rather inconspicuous beak is located *c.* 30% of shell length from the anterior. Despite poor preservation, this specimen is clearly a trigoniid, and the combination of radially ornamented bipartite posterior area, a concentrically ribbed petal area and smooth radial space between shows it to be *Trigonia (Trigonia)*. However, most species of *Trigonia* s. s. are less elongate than the Telefomin specimen. It is similar to the Bajocian-Bathonian *T. moorei* of Western Australia (Skwarko, 1974) and Mt Everest (Wen et al., 1976) in its size, weak posterior sculpture and height/length ratio, but the concentrics are more closely spaced and the ventral margin seems less arched. Most other *Trigonia* sensu stricto are relatively shorter, and no comparable species is known to occur in the Jurassic of New Zealand or Southeast Asia.

Trigonia (Trigonia) sp. aff. *moorei* Lycett; Bajocian - Bathonian.

Crouch Collection

Held in the Royal Ontario Museum (prefix ROM)

ROM J1974r: Two *Retroceramus* with mytiliform outline, moderate inflation, hingeline *c.* 40% of overall length, a narrow, clearly prosogyrous beak and ribs that are sharp-crested, more or less symmetrical, narrower than their interspaces and spaced 10-11 over 40 mm of adult shell (measured along the line of maximum inflation, inclined at *c.* 50° to the hingeline). There is a distinct, much finer sculpture over the initial 10-15mm of the shell, with ribs spaced about 1 mm apart, comparable with 91E13, although the latter has a broader shell. These two specimens have a few more ribs than the *R.* aff. *galoi* in 91K9.1 and 91K12, but are otherwise very similar and are considered to be conspecific.

Retroceramus sp. aff. *galoi* (Boehm); Late Oxfordian to Early Kimmeridgian.

ROM J1974n: An ammonite and a *Retroceramus* right valve (Plate 7, Figure 8; Plate 8, Figure 3) in a concretion of grey-black siltstone. The bivalve is somewhat narrower than those in ROM J1974R (length *c.* 50 mm, width 30 mm, inflation 14 mm) and the adult ribs show a faint angulation posteroventrally, which is not present in other *R.* aff. *galoi.* In other respects, however, this specimen appears to be conspecific, and is so identified.

ROM 49311-12, 49316: Three concretions in grey-black, pyritic siltstone, each with 2-3 valves of *Retroceramus*. ROM 49312 (Plate 8, Figure 5, 6) contains an articulated pair of subadult valves. ROM 49316 (Plate 7, Figure 9) includes also a fragment of flanks and venter of *Epimayaites* sp. The retroceramids are essentially similar in all respects to those identified above as *R.* aff. *galoi.* None reaches the size of the larger specimens of *R. galoi sensu stricto*, and their beaks are somewhat less incurved than in that species. Most show differentiation between juvenile and adult ornament as in ROM J1974r.

Retroceramus sp. aff. *galoi* (Boehm); Late Oxfordian to Early Kimmeridgian.

ROM 49313: A poorly preserved, incompletely exposed single valve of crudely circular outline and low inflation, with many faint, closely spaced radials of irregular strength. *M. malayomaorica* is a common associate of *R. galoi, R. subhaasti* and *R. haasti* over much of their geographic range. In New Zealand, where their relative ranges are best known, it appears in the upper portion of the range of *R. galoi* co-occurs through the ranges of the other two species

(Helby et al, 1988), with a maximum age therefore of Oxfordian-?earliest Tithonian. The rarity of *R. haasti* in the Telefomin collections, and the association of *M. malayomaorica* with *R. galoi* in ROM 49314 and ROM 49315, suggest that the Telefomin *M. malayomaorica* specimens come from the lower portion of its range, that is Late Oxfordian-Early Kimmeridgian.

?Malayomaorica malayomaorica (Krumbeck); Late Oxfordian to (?Early) Kimmeridgian.

ROM 49314-5: Two portions of a single concretion in grey-black siltstone, containing two bivalve taxa. Some are isolated *Retroceramus* valves, as in ROM 49311-2, the largest being nearly 60 mm long. In addition, there are two left valves of an oval, posteroventrally produced form of moderate inflation, with numerous weak, rather irregular radials and a distinct posterior ear. These features indicate *Malayomaorica malayomaorica*, although the right valve is not represented here.

Retroceramus sp. aff. *galoi* (Boehm), *Malayomnaorica malayomaorica* (Krumbeck); Late Oxfordian to Early Kimmeridgian.

ROM 49324-26, 49328-32: Eight well preserved, moderate sized *Retroceramus*, with ribbing more widely spaced than that of the specimens identified as *R.* aff. *galoi* and equating in shape and ornament with New Zealand specimens of *R. galoi* (e. g., Plate 7, Figure 3, 6, 7, 10).

ROM 49327, 49333: Two *Retroceramus* valves with the concentric ornament more closely spaced than in *R. galoi*, resembling *R.* aff. *galoi* (e. g., Plate 8, Figure 7).

Retroceramus sp. aff. *galoi* (Boehm); Late Oxfordian to Early Kimmeridgian.

ROM 49334-5: Two juvenile *Retroceramus* valves with the form and ornament of *R. galoi*, but too small to be confidently assigned to that species.

Retroceramus cf.*galoi* (Boehm); Late Oxfordian to Early Kimmeridgian.

ROM 49336: A thin shelled, elongate-oval equivalved shell with moderate inflation, rounded lateral margins, broadly rounded low umbones, beak at about anterior third, and no evidence of ornament (Plate 8, Figure 17, 18). There is a posterior gape of the valves and the hinge plate was small, although the nature of the dentition cannot be seen. The shell is pholadomyoid in form, but lacks the radial ornament of *Pholadomya* and is readily accommodated in *Homomya*. It corresponds in nearly all respects with the English Bajocian-Oxfordian type species *H. gibbosa*, which is also known from Asia (see Tamura, 1960). It may be accommodated in that species, but it seems to have a less inflated ventral margin.

Homomya cf. *gibbosa* (Sowerby); Middle to early Late Jurassic.

ROM 49337: An eroded, elongate-oval articulated shell, in dark siltstone (Plate 8, Figure 12, 16). Although incomplete, lacking the ventral margin, the shell can be seen to have been equivalved, well inflated and thin shelled. It bears chevron ribbing on the broad, low umbones. Ribbing is of the V-shaped type, with pairs of straight oblique elements meeting at an acute angle in the sub-umbonal region, but apparently dying out early in ontogeny, as the adult portion lacks ribs. Valves are inequilateral, with the beaks situated at about the anterior third. These features indicate the Jurassic-Eocene genus *Goniomya*. The type species *G. (Goniomya) intersectans* (Smith), from the English Bathonian has also been recorded from Tibet (Wen, 1982). It has the same type of sculpture as the Telefomin shell, but with ribbing persisting into the adult ventral and lateral regions of the shell. In many other species the arms of the chevrons are separated, either by a subumbonal smooth zone, or by short horizontal ribs. This specimen, however, is too incomplete for closer determination.

The genus has a Jurassic-Eocene range. Although most species of *Goniomya* have ornament somewhat more complex than the type species, it cannot be assumed that there is a close genetic relationship, and therefore a close stratigraphic similarity, between this type species and the Telefomin specimen.

Goniomya (Goniomya) sp. aff. *intersectans* (Smith); Jurassic - Cretaceous.

ROM 49341-2: These two left valves in grey-black siltstone show the same oval outline, inflated umbo, small posterior auricle and fine, variable radial ornament of *M. malayomaorica*. Unfortunately, no byssate right valve is included.

Malayomaorica malayomaorica (Krumbeck); Late Oxfordian to Kimmeridgian.

ROM 49343: A small to medium sized, articulated bivalve in grey-black siltstone (Plate 8, Figure 13 - 15). It has a trigonal outline, with a high, prominent umbo, prominent posteroventral ridge, continuously rounded anterior and ventral margins, well defined lunule and, at least in the juvenile stage, regular narrow spaced concentrics. Despite the lack of visible dentition or marginal crenulations, this shell is clearly an astartid and has the characters of *Trigonopis,* a group recently afforded full generic status by Gardner and Campbell (2002). The lunule is too shallow, the ribbing is too spaced and the beak too rounded for location in *Opis s. s.*, and the shell lacks the median ridge and ventral elongation of *O. (Pachyopis)*. Its characters are very similar to those of the Oxfordian – Kimmeridgian *Trigonopis morgani* (Trechmann) from New Zealand (Marwick, 1953; Gardner and Campbell, 2002) and *T. stevensi* Quilty (1977) from the Kimmeridgian of Ellsworth Land, Antartica, but it is more dorsoventrally extended than either of these species and has a more curved posterodorsal margin than in *T. stevensi.*

Trigonopis sp.; Jurassic to Early Cretaceous.

ROM 49344-51, 49353-4: Ten medium sized articulated, equivalved specimens of rounded trigonal to trapezoidal outline. The broad, low umbo projects considerably above the hingeline, the beak is located about a quarter of the distance from one end (presumed posterior) and that end is obliquely truncate, the other (?anterior) being slightly narrower and rounded. These shells are readily identified as nuculids, and their features are very closely similar to those of Callovian-Oxfordian *Palaeonucula cuneiformis*, known from India, China and New Zealand. Without the internal features, however, it is not possible to be certain that they are conspecific, but external features, including the range of variability in outline and umbonal angle, suggest this.

Palaeonucula cf. *cuneiformis* (Sowerby); (?)Callovian to Oxfordian.

APPENDIX 2

BELEMNITES (A. B. Challinor)

The 1991 collections of Francis and Westermann.

The Telefomin belemnites are generally poorly preserved and many are juveniles. They are present in siltstones that have been subjected to reticulate close jointing associated with overmaturity and zeolite facies metamorphism. Micro-joints run through the specimens, and they tend to fracture on extraction. Many were received as fragments and most are abraded. Usually only small numbers of specimens, sometimes one, were received from each locality, and all specimens are float. Consequently some identifications listed in this appendix, many based on posterior cross sectional data alone, could be incorrect. This applies particularly to those of the later members of the *moluccana* lineage, but, given the nature of the available material, they are the best possible at this time. Establishing an accurate position within the *B. galoi-stolleyi* part of the lineage is a statistical process and requires many well-preserved specimens to give fully reliable results. The locations of the samples within the *moluccana* lineage and based on their cross sections are shown in Figure 5.

Sample 91K1. A complete but distorted and badly abraded pre-adult specimen *c.* 95 mm long and *c.* 11.5 mm in maximum diameter. Accurate diametral measurements cannot be obtained, and it is not included in Figure 5.
Late *Belemnopsis galoi (*Boehm) or *B. stolleyi.*
Age: Late Kimmeridgian or Tithonian.

91K2. An apical fragment *c.* 30 mm long and 13 mm in maximum diameter.
Late *Belemnopsis galoi* or *B. stolleyi.*
Age: Late Kimmeridgian or Tithonian.

91K3. A complete specimen *c.* 85 mm long and 12 mm in maximum diameter coated with adherent matrix. It is a transversely and sagittally hastate, almost adult guard, and the point of maximum transverse diameter is located behind the protoconch.
Late *Belemnopsis galoi* or *B. stolleyi.*
Age: Late Kimmeridgian or Tithonian.

91K5. Seven fragments, the largest 40 mm long and *c.* 11 mm in maximum diameter. All are abraded, jointed, and some have adherent matrix. External measurements were not possible, but the diameters of internal growth stages have been measured. Due to the diffuse nature of the growth rings these should be regarded as approximate. Posterior A values range from 98 to 109, within the ranges of *B. stolleyi* and early and late *B. galoi.* This is a large range of A values from one locality, and possibly indicates a mixed collection.
Belemnopsis galoi and/or *B. stolleyi.*
Age: Kimmeridgian and/or Tithonian.

91K6. A large robust fragment 50 mm long and *c.* 16 mm in maximum diameter. It is strongly

laterally compressed and resembles specimens of *B. stolleyi* from Sula Islands in shape, but is more compressed than most.
Belemnopsis stolleyi. Age: Tithonian.

91K7. A complete adult specimen 95 mm long and *c.* 15 mm in maximum diameter. The widest point is located just behind the protoconch. It is slightly hastate transversely, and cylindrical or very slightly hastate in profile. Fragments of four other specimens are included in the collection. The A value indicated in Figure 5 is from the complete specimen.
Belemnopsis galoi (?early) Age: (?Early) Kimmeridgian.

B. galoi is also present at locality N11, Kei River, west of Eliptamin (Figure 2) (Challinor, 1990).

91K8.2. Five anterior fragments of small specimens (up to 40 mm in length and 10 mm in diameter). Cross sections at mid-guard are all strongly depressed.
Belemnopsis moluccana (Boehm).
Age: Oxfordian or Early Kimmeridgian

91K9.2. A hastate anterior fragment 30 mm long and *c.* 11 mm in maximum diameter, abraded and with adherent matrix. Measurements were taken from internal growth stages at about midway along the guard.
Belemnopsis moluccana.
Age: Oxfordian or Early Kimmeridgian.

91K10. An almost complete slightly abraded pre-adult guard 75 mm in length and 10 mm in maximum diameter. It is slightly hastate in outline, and cylindrical in profile.
Belemnopsis stolleyi or late *B. galoi.*
Age: ?Tithonian

91K12. A large specimen 110 mm in length and *c.* 17 mm in maximum diameter (Plate 9, Figure 1). Widest point *c.* midway along the guard, hastate in outline and profile. It is strongly depressed in cross section. Three smaller fragments of pore-adult guards with depressed cross sections, one of which falls near the boundary between early *B. galoi* and *B. moluccana* (Figure 5).
Belemnopsis moluccana.
Age: Oxfordian and/or Early Kimmeridgian.

91K12.1. A complete specimen 80 mm long and 10.5 mm in mnaximum diameter. Slightly hastate both transversely and sagittally. It is a typical slender, symmetrical, pre-adult with an elongate apical region. Cross section moderately depressed. A second apical fragment is *c.* 30 mm long, with a less depressed cross section.
Belemnopsis galoi (?early) Age: Early Kimmeridgian.

91E1. A fragment of anterior stem and alveolar region, 60 mm long and *c.* 17 mm in maximum (sagittal) diameter. It has a *Hibolithes*-like ventral groove and a strongly compressed cross section. A second similar fragment is 50 mm long (Plate 11, Figure 4), and a number of other fragments are available.
Hibolithes taylori Challinor

Age: Late Tithonian and/or Berriasian.

91E4. A number of small fragments including part of a pre-adult belemnite with a compressed cross section and *Hibolithes* type ventral groove.
Hibolithes taylori. Age: Late Tithonian or Berriasian.

H. taylori is also present at locality 57, Telefomin area (Challinor, 1990).

91E5. A hastate specimen 80 mm long and *c.* 12 mm in maximum diameter, with *c.* 10 mm of the apex missing (Plate 10, Figure 7 - 9). The widest point is midway along a guard that is moderately transversely hastate and slightly sagittally hastate. It bears a short, shallow, narrow dorsal groove confined to the alveolar and anterior part of the postalveolar guard, and a wide and deep ventral groove running the full length of the fragment. The cross section is strongly depressed (anterior A value 121, posterior A value 128). It is compared with *Dicoelites* sp. B (A values 112, 122), a (?late) Early Callovian form described from Sula Islands (Challinor and Skwarko, 1982, age revised). It also resembles *Dicoelites* sp. C (A = 106, 111), an Early to mid Oxfordian taxon, also from the Sula Islands. It's A values are greater than either sp. B or sp. C, but it appears to be closest in form to *D.* sp. B.
Dicoelites cf. *D.* sp. B Challinor and Skwarko, 1982.
Age: Early Callovian.

91E6. A large, almost complete, fully conical specimen 110 mm in length, and with a maximum (sagittal) diameter of *c.* 28 mm. An estimated 15 mm of apex missing (Plate 10, Figure 1-2; see also Plate 10, Figure 3 - 6). It is strongly laterally compressed, and bears a shallow, moderately wide ventral groove extending to within 10 mm of the apical end, and a shallower dorsal groove extending almost as far down the specimen. A second smaller, less complete, pre-adult guard and an apical fragment are also available. These three are similar in all respects to *Conodicoelites kalepuensis* from Sula Islands, Indonesia (Challinor and Skwarko, 1982), and also to *C. keewensis* (Boehm), also from Sula. *C. keewensis* is apparently a more robust, less elongate taxon, but the type specimens are now missing. *C. kalepuensis* also occurs at localities N15 and N16 (north of Eliptamin, Figure 2), and at locality 106, Wai Oma (Strickland River), *c.* 80 km east of Eliptamin, in each instance in the Maril Formation (Challinor, 1990).
Conodicoelites kalepuensis Challinor and Skwarko.
Age: Middle Bathonian.

APPENDIX 3

FORAMINIFERA (Alan R. Lloyd)

1991 Collection of Francis and Westermann.

Samples 91K1, 91E1 and 91E17.1 were examined in thin section, while the remainder were examined as washed residues. Belemnites and ammonites have been recorded from other splits of most samples, but only four of the splits submitted for foraminiferal analysis contain ammonites.

Washed residues: 91E1 from Abi Creek yielded a single specimen of the agglutinating foraminifer *Ammobaculites*. It is not age-diagnostic, but has been observed in Jurassic and Cretaceous sediments elsewhere in Papua New Guinea. Sample 91K11 from Inum Creek did not yield any foraminifera from its washed residue, but yielded a small fragment of an ammonite. The environment of deposition can only be given as open marine.

Thin sections: the grey calcareous concretion (91E2) from Abi Creek is seen to be very rich in glauconite, and to contain some indeterminate benthic foraminifera, indeterminate microfossils and possible gastropods. The age of the sample, which was deposited under marine conditions, is indeterminate. In thin section sample 91E16 from Elip River contains the benthic *Lenticulina* sp. and some indeterminate fossils. None of the fossils is age-diagnostic, but the sample was deposited under open marine conditions. Tithonian sample 91E17.1, from Kwambila Creek, contains the benthic *Lenticulina* sp., possible planktonic foraminifera and some indeterminate fossils. Not age-diagnostic - deposited under open marine conditions.

Generally poor foraminiferal faunas, lacking age-diagnostic forms, have previously been found in samples of the Maril Formation from the Kundiawa region.

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APPENDIX 4

CALCAREOUS NANNOFOSSILS (H.K. Hekel)

1991 Collections of Francis and Westermann

A total of 35 outcrop samples from the Maril Formation was examined for calcareous nannofossils on standard nannofossil slides; visual kerogen and petrographic observations were also made on the fine fraction in the nannofossil slides. (The lithology of the samples has been outlined in the body of the text, so only specific details of the report not already mentioned are included below.)

Nannofossil ages: 91K6 Bajocian to ?Late Jurassic; 91K12 Bajocian to Late Jurassic; the remaining samples were barren.

Lithology and Visual Kerogen:

91K2 common pyrite and frequent kerogen, tuffaceous appearance with spherulitic devitrified glass
91K3, K5 high kerogen content
91K4, E1 common pyrite and kerogen
91K6 common kerogen
91K7 pyrite and common kerogen
91K7.1, E9, ROM J1974o pyrite
91K8, K9.4, K12, E6, E17, E17.1 pyrite and kerogen
91K10 pyrite and a fair amount of kerogen
91K11 pyrite and massive kerogen
91E3, E3.1 pyrite and kerogen; tuffaceous appearance with devitrified glass
91E3.2 kerogen and rare pyrite; tuffaceous appearance with devitrified glass
91E4 glauconite, some pyrite and some kerogen
91E4.1 high pyrite
91E4.2 high kerogen and some pyrite; tuffaceous appearance
91E5 colourless carbonate rhombohedra and common kerogen
91E6.1, 6.2 pyrite and some kerogen
91E7 pyrite and a fair amount of kerogen
91E13 some kerogen
91E15 glauconite, pyrite and some kerogen
91E16, 16.1 common colourless carbonate rhombohedra, pyrite, kerogen

In addition, samples 91K8.3, 91K9, and ROM J1974m were analysed but lacked any of the above content.

Ages and Comments:

91K6 contains rare, poorly to moderately well preserved nannofossils: *Zeugrhabdotus erectus* (rare), *Ellipsagelosphaera fossacincta* (rare), *Watznauria barnesae* (rare) and Coccolith indet. (rare). A Bajocian to ?Late Jurassic age is indicated by *E. fossacincta* (Bajocian to Cretaceous), in the absence of Cretaceous strata. The upper age limit is questionable, as the absence of Cretaceous taxa could be facies-related, in a poorly fossiliferous sample. Environment: A sparse nannofossil assemblage like this would normally indicate a nearshore marine environment.

91K12 contains frequent, poorly to moderately preserved nannofossils: *Ellipsagelosphaera fossacincta* (frequent), *E. communis* (rare), *E. britannica* (rare), *?Watznauria barnesae* (frequent), Coccosphaere (rare) and Coccolith indet. (rare).

Bajocian to Cretaceous is indicated by *E. fossacincta* in a reasonably diverse assemblage. Environment: As in 91K6, the nannofossils suggest a nearshore marine environment.

Only two of the 35 samples examined for nannofossils yielded positive results. This low nannofossil recovery rate is typical of Jurassic samples, and similar to earlier results from the Maril Formation in the Kundiawa region. The two Jurassic assemblages recovered are only long-ranging Bajocian to Late Jurassic forms.

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APPENDIX 5

PALYNOLOGY (J. Filatoff and P.L. Price)

1991 Collection of Francis and Westermann

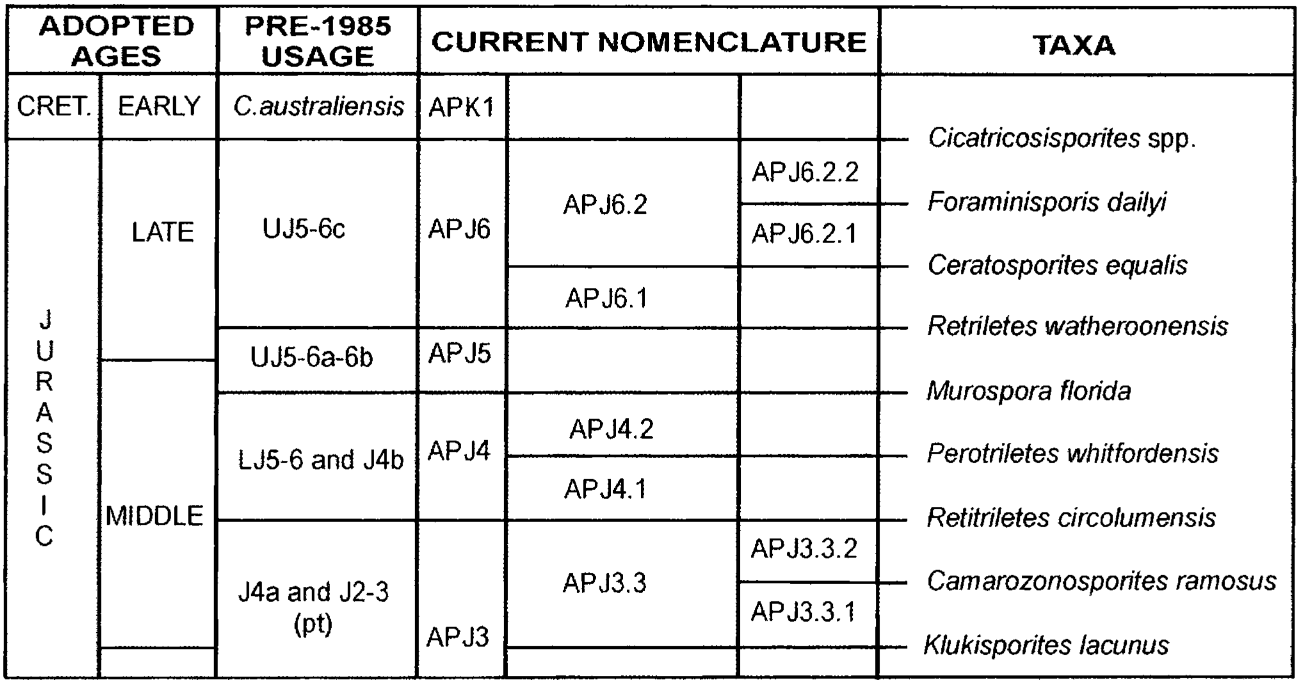
Thirty five samples were processed and examined palynologically for biostratigraphic purposes. The palynostratigraphic schemes used are depicted in Figures 6, 7. Results are summarised in Table 4. Distribution charts listing the species observed are presented in Tables 5 - 7. [**Note** that the correlation scheme used in Table 4 differs somewhat from that favoured in this Memoir.]

AGE	SPORE/ POLLEN UNITS	DINOCYST ZONES (Helby et al., 1987)	DINOCYST UNITS	INDEX TAXA
BERRIASIAN (pt)	APK1 (pt)			
		Kalyptea wisemaniae	ADJ3.5	*K. wisemaniae*
TITHONIAN		*Pseudoceratium iehiense*	ADJ3.4	*P. iehiense*
KIMMERIDGIAN	APJ6	*Dingodinium jurassicum*	ADJ3.2	*P. iehiense*
OXFORDIAN		*Omatia montgomeryi*	ADJ3.2	*O. montgomeryi*
		?Cribroperidineum perforans	ADJ3.1	*O. montgomeryi*
	APJ5	*Dingodinium swanense*	ADJ2.3	*D. swanense* (consistent)
		Wanaea clathrata	ADJ2.2	*W. clathrata*
		Wanaea spectabilis	ADJ2.1	*W. clathrata* (acme)
CALLOVIAN		*Rigaudella aemula*	ADJ1.5	*S. crystallinum*
		Wanaea digitata	ADJ1.4	*R. aemula*
BATHONIAN	APJ4	*Wanaea indotata*	ADJ1.3	*W. digitata*
		Caddasphaera halosa	ADJ1.2	*W. indotata*
			ADJ1.1	*C. halosa*

Figure 6. Pan-Australian dinocyst units, late Middle Jurassic to Early Neocomian (*Pyxidella* to *Fromea cylindrica* Superzones)

The organic residues recovered from all Telefomin samples comprised opaque to poorly translucent detritus typical of late mature to overmature rocks. Palynomorphs were identified in the majority of samples, but were dark brown to black in colour and corroded. This lack of translucency and exinal damage in most instances precluded identification to species level, thereby reducing the precision of the palynostratigraphic assignment. Nevertheless, moderately rich, moderately well preserved assemblages (with whole specimens) were recovered from a number of samples.

For the greater part, however, and commensurate with the maturity level, the palynomorphs were rather degraded, particularly in samples with the greater abundances of dinoflagellate cysts where the palynomorphs appear to have been subjected to the corrosive effects of pyrite attack. Additionally, palynomorphs seem more susceptible to the effects of thermal alteration if they have been partly oxidised during transport and deposition. Dinocysts were recovered from relatively few samples and these were almost entirely restricted to a few robust chorate taxa. It would seem that more delicate species had been degraded beyond recognition.



ADOPTED AGES		PRE-1985 USAGE	CURRENT NOMENCLATURE			TAXA
CRET.	EARLY	*C.australiensis*	APK1			*Cicatricosisporites* spp.
JURASSIC	LATE	UJ5-6c	APJ6	APJ6.2	APJ6.2.2	*Foraminisporis dailyi*
					APJ6.2.1	*Ceratosporites equalis*
				APJ6.1		*Retriletes watheroonensis*
	MIDDLE	UJ5-6a-6b	APJ5			*Murospora florida*
		LJ5-6 and J4b	APJ4	APJ4.2		*Perotriletes whitfordensis*
				APJ4.1		*Retitriletes circolumensis*
		J4a and J2-3 (pt)	APJ3	APJ3.3	APJ3.3.2	*Camarozonosporites ramosus*
					APJ3.3.1	*Klukisporites lacunus*

Figure 7. Middle and Late Jurassic spore/pollen units.

Six samples (91K8, K9.4, K11, E1, E4, E15) were devoid of recognisable palynomorphs and thus their age could not be assessed by the palynological method. Samples 91K8.3, K10, E13, and Crouch Collection samples ROM J1974m and ROM J1974o yielded the richest and best preserved assemblages and are possibly of early Late Jurassic age. They were characterised by an abundance of a proto-*Tsuga* pollen, *Callialasporites dampieri*, and abundance and diversity of lycopsid spores. The palynological evidence, considered in isolation, suggests a nearshore marine environment for these samples. In addition to the richness and "good" preservation of the land plant palynoflora, a markedly subordinate dinocyst flora was present. Rare microforaminiferal test linings were also a feature of these assemblages. Despite the palynological evidence for a nearshore environment, the macropalaeontological and sedimentological evidence (see above) indicate an open marine environment for these samples.

A robust spore *Murospora florida* (the index species defining the base of unit APJ5), was observed in nearly all of the above samples. Samples with the highest relative abundances of dinocysts included 91K4, K6, K7.1, E17, and E17.1. As indicated above, the palynomorphs here tended to be severely carbonised, corroded and limited in diversity. All were characterised by a prominence of robust chorate dinocyst taxa, particularly a form reminiscent of *Hystrichosphaeridium pachydermum*. This species is known to range through the Late Jurassic and early Neocomian, with an acme attained in the late Oxfordian-early Kimmeridgian *Cribroperidineum perforans* and *Omatia montgomery* Zones of Davey (1987, fig. 14). These samples probably represent a more distal marine environment, or at least one sheltered from the extremes of terrestrial influx and undergoing slower sedimentation.

The remaining productive assemblages were sparse, as well as being strongly carbonised and poorly preserved. Many lacked any indication of dinocysts or other aquatic indicators. Many, however, included a notable proportion of *C. dampieri* as well as marker species such as *Camarozonosporites ramosus, Retitriletes circolumenus* and *Contignisporites cooksoniae*, suggesting a late Middle Jurassic age assignment.

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[NOTE: Since this report was received Davey (1987) has been superseded by Davey (1999). This, however, makes no difference to the correlation above of the perforans *and* montgomeryi *zones – see also Figure 3.]*

Table 4: Summary of palynological data

SAMPLE No.	AGE	ENVIRONMENT	PRESERVATION	YIELD	DIVERSITY	REMARKS
----- 91K2	?Jurassic	indeterminate	very poor	very low	ext. low	Sparse assemblage of strongly carbonised, mostly unidentifiable spore/pollen remnants; no unequivocal phytoplankton evident.
91K3	?Jurassic	indeterminate	very poor	very low	ext. low	Sparse assemblage as above.
91K4	?Late Jurassic	marine, moderate terrestrial input	very poor	very low	very low	Sparse assemblage of highly carbonised, degraded, largely unidentifiable palynomorphs; mostly chorate cysts of *H. pachydermum*.
91K5	?Jurassic	indeterminate	very poor	ext. low	ext. low	Very sparse assemblage of highly carbonised, mostly unidentifiable palynomorphs.
91K6	?Late Jurassic	marine, moderate terrestrial input	very poor	ext. low	ext. low	Very sparse assemblage of highly carbonised, largely unidentifiable palynomorphs including chorate dinocysts cf. *H. pachydermum*.
91K7	?Jurassic	indeterminate	very poor	ext. low	ext. low	Extremely rare, highly carbonised and corroded spore/pollen; no unequivocal phytoplankton.
91K7.1	?Late Jurassic	marine, moderate terrestrial input	very poor	low-mod.	low	Sparse to moderate yield of strongly carbonised and degraded chorate dinocysts cf. *H. pachydermum*, microplankton and a moderate diversity of spore/pollen.
91K8.3	APJ5-APJ6	marine, high terrestrial input	poor	moderate	moderate	Moderately rich assemblage of carbonised and degraded spore/pollen, *C. dampieri* dominant; spores, especially lycopsid and sphagnoid forms, diverse; rare microforams and phytoplankton.
91K9	?Jurassic	indeterminate	ext. poor	ext. low	ext. low	Rare carbonised remnants of *Corollina* only.
91K10	APJ5-APJ6	marine, high terrestrial input	poor	moderate	moderate	Moderately rich assemblage of carbonised, degraded spore/pollen dominated by *C. dampieri* and lycopsid spores; rare microforams and phytoplankton, including chorate dinocysts.
91K12	?APJ4-APJ6	?marine	very poor	very low	very low	Sparse assemblage with few identifiable forms, mostly spore/pollen, but also probable phytoplankton.
91E3	?APJ4	?marine	very poor	very low	very low	Mostly unidentifiable, carbonised spore/pollen remnants and rare probable chorate dinocysts.
91E3.1	?mid-Jurassic	marine, moderate to high terrestrial	very poor	very low	very low	Mostly unidentifiable carbonised spore/pollen remnants, with rare microforams and phytoplankton.
91E3.2	AJP4-AJP5	no marine evidence	very poor	very low	very low	Sparse assemblage of largely unidentifiable carbonised, corroded spore/pollen; no unequivocal phytoplankton evident.

(cont.)

Table 4 (continued)

SAMPLE NO.	AGE	ENVIRONMENT	PRESERVATION	YIELD	DIVERSITY	REMARKS
91E4.1	Jurassic	no marine evidence	ext.-very poor	ext.-very poor	very low	Very sparse assemblage of strongly carbonised and corroded palynomorphs; no unequivocal phytoplankton evident.
91E4.2	?APJ4	no marine evidence	ext.-very poor	very low	very low	Very sparse assemblage similar to above
91E5	?APJ4	no marine evidence	ext.-very poor.	very low	very low	Very sparse assemblage as above .
91E6	APJ4-APJ5	no marine evidence	ext.-very poor	very low	very low	Very sparse assemblage as above.
91E6.1	APJ4-APJ5	no marine evidence	ext. poor	very low-low	moderate	Sparse assemblage of strongly carbonised corroded spore/pollen, with moderately common *C. dampieri*; phytoplankton not evident.
91E6.2	APJ5 *dampieri*	no marine evidence	very-ext	low	low poor	Assemblage similar to above with C. relatively common.
91E7	?Middle Jurassic	no marine evidence	very poor-poor	very low-low	low-moderate	Very sparse assemblage of strongly carbonised and degraded spore/pollen; no unequivocal phytoplankton.
91E9	?APJ4	?marine, high terrestrial input	very poor	low-moderate	low-moderate	Assemblage of highly carbonised and degraded spore/pollen; *Osmundacidites* and *C. dampieri* common, rare questionable dinocysts.
91E13	APJ4-APJ6	marine, high terrestrial input	poor	low-moderate	very low-moderate	Moderately carbonised spore/pollen assemblage with rare dinocysts; lycopsid spores common.
91E16	?Middle Jurassic	no marine evidence	very poor	low	low	Sparse assemblage of strongly carbonised and degraded spore/pollen (*C. dampieri* common); no unequivocal phytoplankton.
91E16.1	AJP4-AJP6	no marine evidence	very poor	very low	very low	Rare, strongly carbonised spore/pollen remnants, phytoplankton not evident.
91E17 carbonised	?Late Jurassic	marine, low terrestrial input	very-ext. poor, ?pyrite	moderate	low	Moderate yield of highly corroded, palynomorphs; chorate dinocysts (mostly cf. *H. pachydermum*) dominant.
91E17.1	?Late Jurassic	marine, low to moderate terrestrial input	ext.-very poor, ?pyrite	low-moderate	low	Highly corroded, carbonised assemblage of chorate dinocysts (incl. cf. *H. pachydermum)* and spore/pollen similar to above.
J1974ml	?AJP5	marine, high terrestrial input	ext.-very poor	low-moderate	moderate	Sparse to moderate assemblage of carbonised, degraded spore/pollen and rare dinocysts.
J1974o	?AJP5	marine, high terrestrial input	very poor	low-moderate	moderate	Common *C. dampieri* and lycopsid spores characterise assemblage similar to above; microforaminiferal test lining present, but phytoplankton not evident.

Table 5: Telefomin 91K samples: check list of the total flora

91K	1	2	4	5	6	7	7.1	8.3	9	10	12
Antuisporites saavus										?	
Camarozonosporites "neoclivosus" sp. nov.									+		
Camarozonosporites ramosus								+		+	
Camarozonosporites "reticulatus" sp. nov.								?		?	
Ceratosporites equalis										?	
Concavissimisporites spp.								+		+	
Contignisporites cooksoniae var. *"constrictus"*									+		+
Contignisporites cooksoniae var. *"parallelos"*									?		
Coronatispora perforata								?		?	?
Cyathidites spp.	+	+	+	+		+	+	+		+	+
Foveosporites moretonensis										+	
Foveosporites multifoveolatus										+	
Gleicheniidites senonicus								+		+	+
Granulatisporites minor										+	
Klukisporites scaberis										+	
Lycopodiacidites asperatus										?	
Murospora florida								+		+	
Neoralstrickia spp.								+		+	+
Neoralstrickia suratensis var. A										+	
Neoralstrickia suratensis var. B										+	
Neoralstrickia truncata								+		+	
Osmundacidites comaumensis								+		+	
Osmundacidites wellmanii								+		+	+
Polycingulatisporites cranulatus										+	
Retitriletes austroclavatidites								?		+	
Retitriletes circolumenus								+		+	
Retitriletes eminulus										cf.	
Retitriletes "microlumenus" sp. nov.										+	
Retitriletes nodosus										?	
Retitriletes "proxiradiatus" sp. nov.										+	
Retitriletes spp.							+	+		+	+
Rogalskalsporites canaliculus								?		+	
Sestrosporites "pseudoalveolatus" sp. nov.								?			
Staplinisporites caminus								+		+	
Staplinisporites manifestus								?			
Stereisporites antiquasporites										+	
Stereisporites spp.							+	+			
Kekryphalospora douglas										?	
Alisporites lowoodensis/similis								+		+	
Araucariacites australis								?		?	?
Callialasporites dampier								+		+	
Callialasporites triobatus								+		+	
Corollina torosa			+			+		+	+	+	+
Falcisporites australis								+		+	
Piceaepollentites parvisaccatus										+	
Podocarpidites allipticus/verrucosus										+	
Podosporites tripakshii										+	
"Saccate Pollen" "undifferentiated" gen. et sp. nov	+	+	+			+	+	+			+

(cont.)

Table 5 (Continued)

	1	2	4	5	6	7	7.1	8.3	9	10	12
Vitreisporites signatus								+			
Leiosphaeridia spp.										?	
Pterospermelia australiensis											?
Veryhachium valensii var. "*longispinus*"								?			
Cleistophaeridium spp.								+		+	
Escharisphaeridia spp.								?			
Hystrichosphaeridium pachydermum			cf.		cf.		cf.				
Prolixosphaeridium spp.										+	+
Wanaea digitata								?			
Planispiral microforaminifera							+			+	
Trachospiral microforaminifera								+			
Scolecodont								?			

Table 6: Telefomin 91E samples: check list of the total flora

91E	3	3.1	3.2	4.1	4.2	5	6	6.1	6.2	7	9	13	16	16.1	17	17.1
Anapiculatisporites dawsonensis												?				
Antuisporites "verrucosus" var. *"uniannulus"* sp. nov.					?											
Camarozonosporites ramosus	?						?			+						
Camarozonosporites "reticulatus" sp. nov.														+	+	
Ceratosporites equalis														?		
Contignisporites cooksoniae var. *"constrictus"*														+		
Contignisporites cooksoniae var. *"parallelos"*			+									+				
Contignisporites spp.					+											
Coronatispora perforata																?
Cyathidites spp.	+	+			+	+	+	+	+	+	+	+	+	+	+	
Foraminisporis "vicinilaesuratus" sp. nov.											?					
Gleicheniidites senonicus	+													?		
Ischyosporites punctatus	?		?													
Klukisporites spp.										?		?				
Murospora florida							?	?	+							
Neoraistrickia spp.	+	+		+	+	+		+		+	+	+	+	+	+	+
Osmundacidites comaunenis	+	+										+				
Osmundacidites spp.				+	+	+	+	+	+	+	+	+	+	+		?
Osmundacidites wellmanii	+	+	+													
Retitriletes austroclavatiditges			+					+				+		+		
Retitriletes circolumenus			?			?					?	+				
Retitriletes "microlumenus" sp. nov.						?		?								
Retitriletes spp.	+	+	+	+	+	+	+	+	+	+	+	+		+	+	?
Rogalskalsporites canaliculus	?	?	?	+								+			?	+
Rogalskaisporites "folliculosus" sp. nov.												+		?		
Stereisporites spp.											+	+			+	
Alisporites lowoodensis/similis								+	+				+			
Alisporites spp.										+						
Araucariacites australis		?	+		?	?	?		?	?		+				
Araucariacites fissus												+				
Callialasporites dampieri	+	+	+		+	+	+	+	+	+	+	+	+	+	+	+
Callialasporites trilobatus								+			+	+	+		+	
Callialasporites turbatus												+				
Corollina torosa	+	+	+		+	+	?	+	+	+	?	+	+	+		?
Falcisporites australis			?													
Piceaepollenites parvisaccatus								+			+					
Podocarpidites ellipticus/verrucosus			+					+								
"Saccate Pollen" "undifferentiated" gen. et sp. nov.	+	+	+		+	+	+	+	+	+	+	+		?	+	?
Micrhystridium spp.		+														
Cleistosphaeridium spp.	?														+	?
DINOCYSTS gen. et spp. indet.											+	+				
Hystrichosphaeridium pachydermum															cf	cf
Prolixosphaeridium spp.												+				
Planispiral microforaminifera		+														

Table 7. Telefomin ROM J1974 samples: check list of total flora

ROM J1974	m	o
Camarozonosporites "neoclivosus" sp. nov.	+	
Camarozonosporites ramosus	+	+
Camarozonosporites "reticulatus" sp. nov.		+
Concavissimisporites spp.	?	
Contignisporites cooksoniae var. *"constrictus"*		+
Contignisporites cooksoniae var. *"parallelos"*	+	
Coronatispora perforata		+
Cyathidites spp.	+	+
Gleicheniidites senonicus		?
Klukisporites spp.	+	
Lycopodiacidites asperatus		+
Matonisporites cooksoniae	?	
Murospora florida	+	
Neoralstrickia spp.	+	+
Neoralstrickia truncata	+	
Osmundacidites spp.	+	+
Retitriletes austroclavatidites	+	+
Retitriletes circolumenus		+
Retitriletes eminulus		?
Retitriletes spp.	+	+
Retitriletes "williamsii" sp. nov.	+	
Rogalskalsporites canaliculus	+	+
Sestrosporites "pseudoalveolatus" sp. nov.	+	
Stereisporites spp.	+	+
Alisporites lowoodensis/similis		+
Araucariacites australis	+	
Callialasporites dampieri	+	+
Callialasporites trilobatus	+	+
Corollina torosa	+	+
Piceaepollenites parvisaccatus		+
Podocarpidites ellipticus/verrucosus		+
"Saccate Pollen" "undifferentiated" gen. et sp. nov.	+	
DINOCYSTS gen. et spp. indet.	?	
Hystrichosphaeridium pachydermum5	cf	
Prolixosphaeridium spp.	+	
Planispiral microforaminifera		+

PLATES

GEOLOGICAL SURVEY OF PAPUA NEW GUINEA

MEMOIR 18

JURRASIC MOLLUSCAN PALAEONTOLOGY OF THE TELEFOMIN AREA, PAPUA NEW GUINEA

J. A. Grant - Mackie, G. Francis, G. E. G. Westermann
and A. B. Challinor

with contributions on the micropalaeontology by
J. A. Filatoff, H. K. Hekel, A. R. Lloyd and P. L. Prince

PLATE 1 Early to Middle Oxfordian Ammonitina of Telefomin (x0.9).

Fig. 1a, 1b. *Epimayaites* aff. *palmarum* (Boehm) ♀ (macroconch), almost complete (arrow indicates end of phragmacone) ROM (Royal Ontario Museum) 56669.

Fig. 2a, 2b. *Epimayaites ("Paryphoceras")* aff. *alfuricus* (Boehm) ♂ (microconch), complete, ROM 56670.

PLATE 1

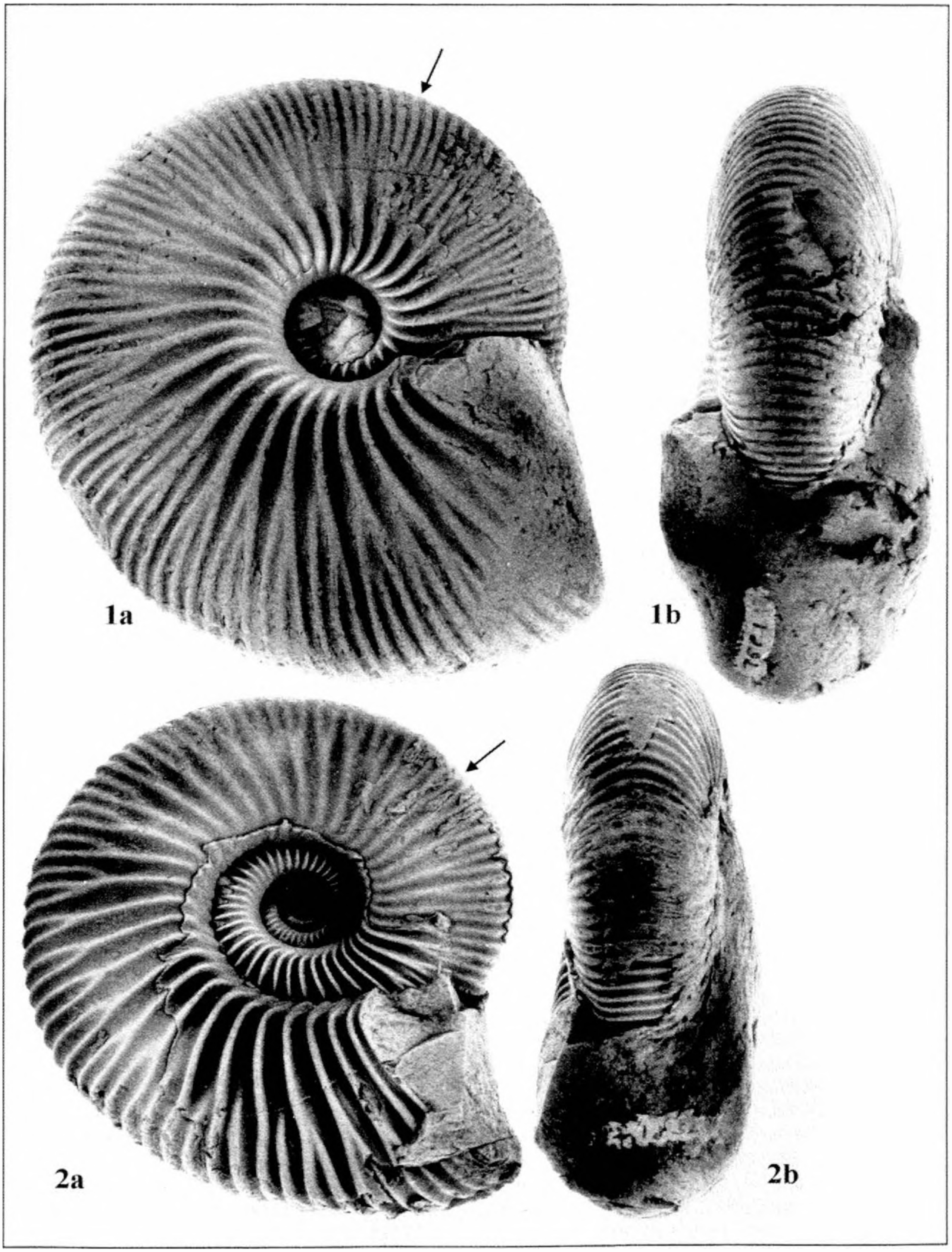


PLATE 2 Late Oxfordian to Early Kimmeridgian Ammonitina of Telefomin (x0.9).

Fig. 1a-1c. *Sulaites sularus* (Boehm), complete except for beginning of body-chamber, ROM 57215.
Fig. 2a, 2b. *Sulaites gerthi* Oloriz & Westermann (?♂), ROM 56671.
Fig. 3a, 3b. *Sulaites? indicus* (Kruizinga), ROM 56672.

PLATE 2

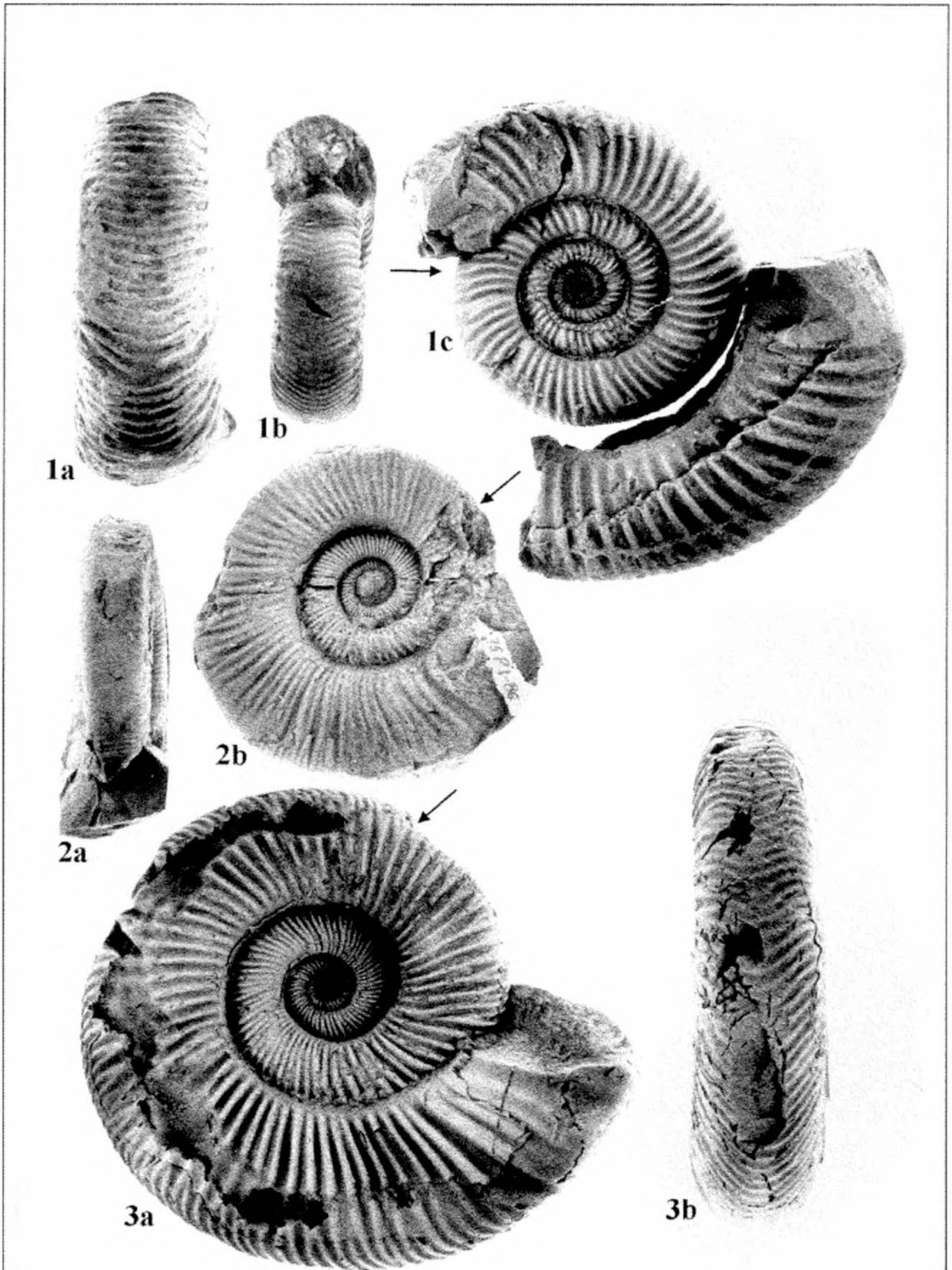


PLATE 3 Late Kimmeridgian and Early Tithonian Ammonitina of Telefomin and West Irian (x0.9).

Fig. 1a, 1b. *Pachysphinctes(?)* or *Katroliceras(?)* sp. indet., phragmacone, from unknown locality in West Irian, Tokyo University specimen.

Fig. 2a, 2b. *Aulacosphinctoides* sp. ♀, almost complete, from Telefomin, ROM 56676.

PLATE 3

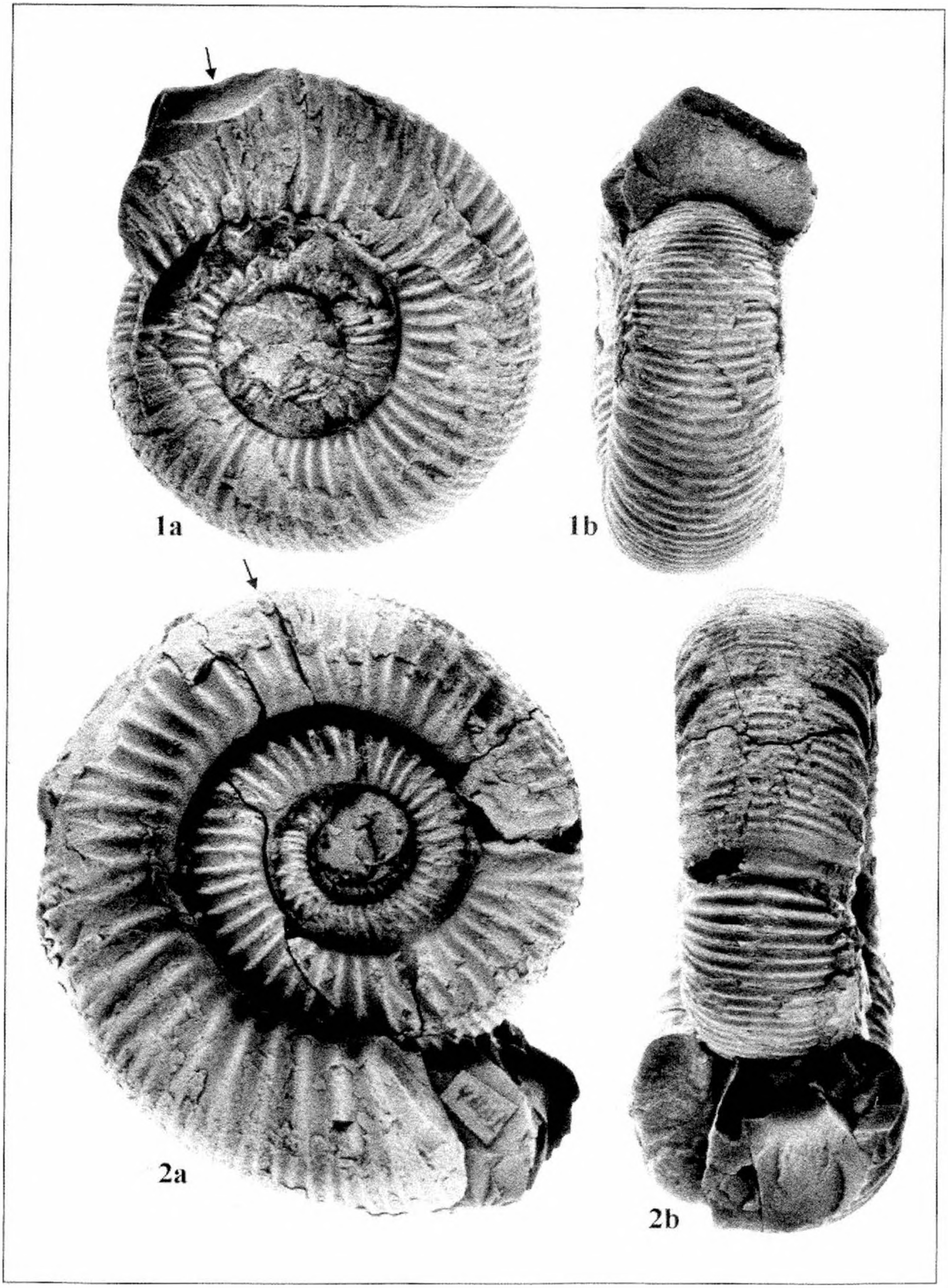


PLATE 4 Late Kimmeridgian? to Early Tithonian Ammonitina of Telefomin and West Irian (x0.9).

Fig. 1a, 1b. *Kossmatia tenuistriata* (Gray), almost complete, Loc. N1, West Irian, Tokyo University specimen.

Fig. 2a, 2b. *Paraboliceras subineanum* (Oppel), almost complete, Telefomin, 91K7.1, ROM 56673.

PLATE 4

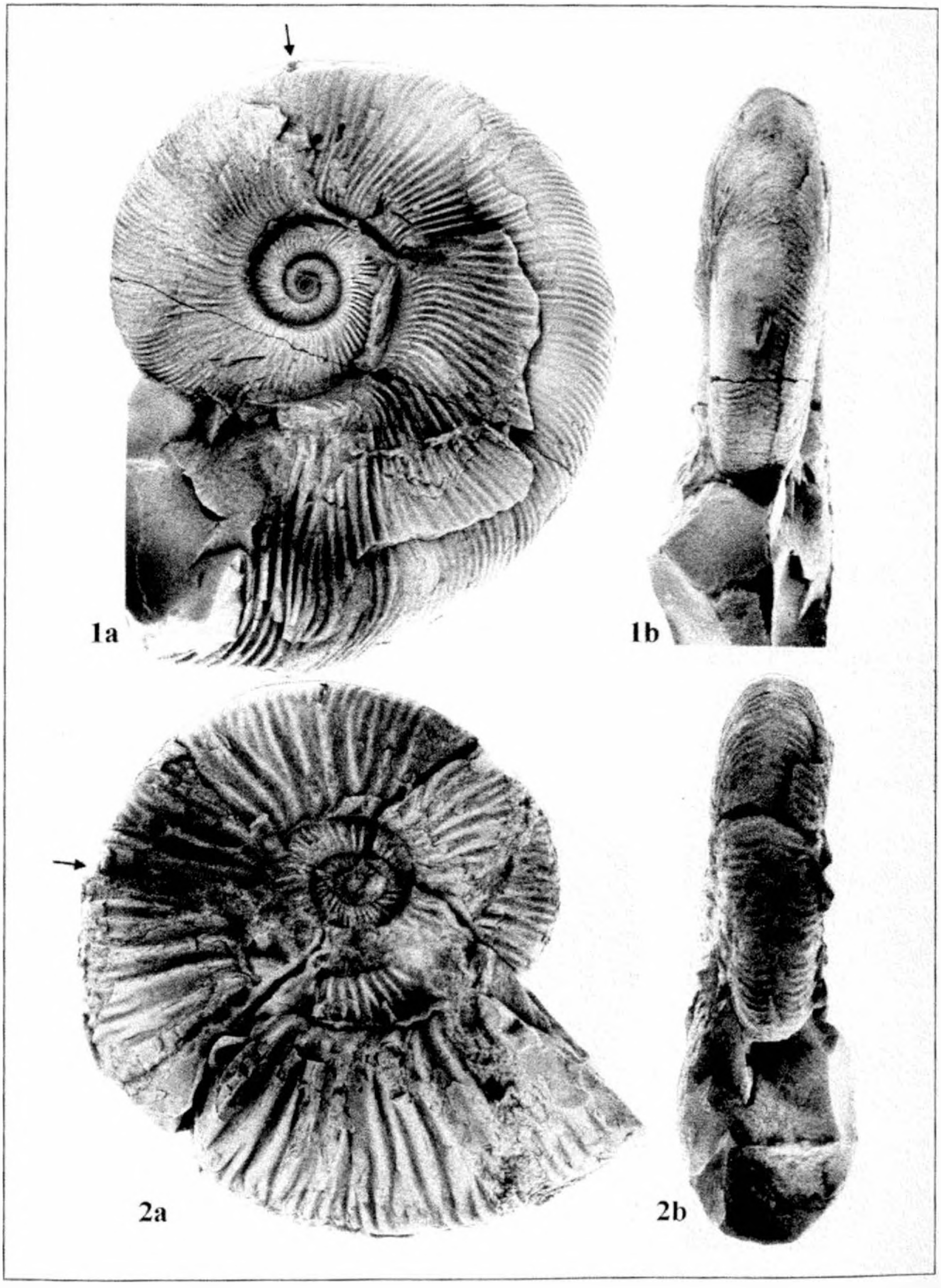
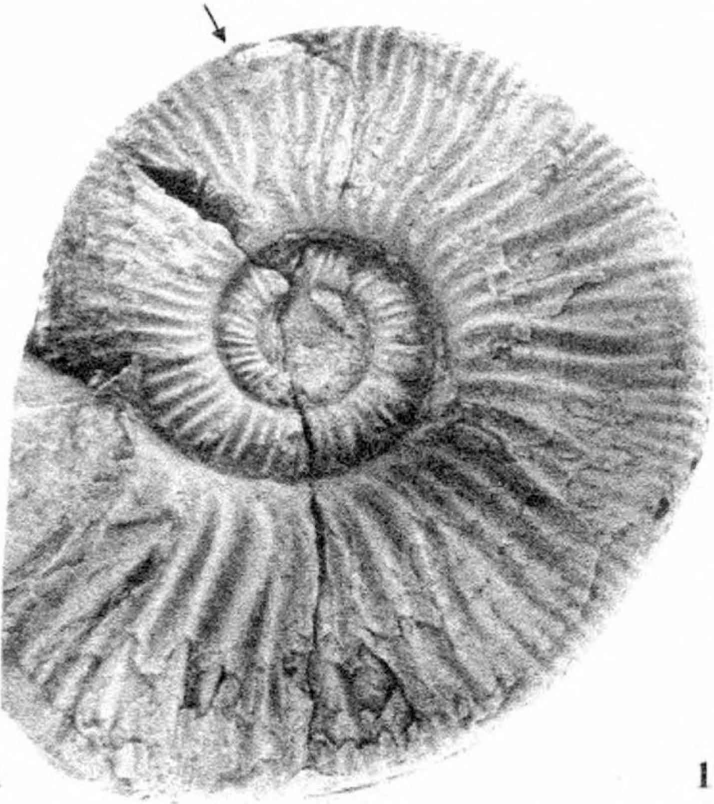


PLATE 5 Late Kimmeridgian? to Early Tithonian Ammonitina of Telefomin

Fig. 1a,1b. *Paraboliceras* cf. *spitiense* Uhlig, almost complete, Loc. E17, ROM 56674, x0.9.

Fig. 2a, 2b. *Paraboliceras (Paraboliceratoides)* cf. *mutilis* Uhlig ♀, with first half of body-chamber, ROM 56675, x0.72.

PLATE 5



1a

1b

2a

2b

PLATE 6 Tithonian Ammonitina of Telefomin and West Irian

Fig. 1a, 1b. *Virgatosphinctes* cf. *tenuiplicatus* (Waagen), incomplete phragmacone with body-chamber fragment, Telefomin, Loc. E4.1, ROM 56677, x0.9.

Fig. 2. *Virgatosphinctes* aff. *raja* Uhlig ♀, large body-chamber fragment, Telefomin, AGSO No. 0547, x0.63.

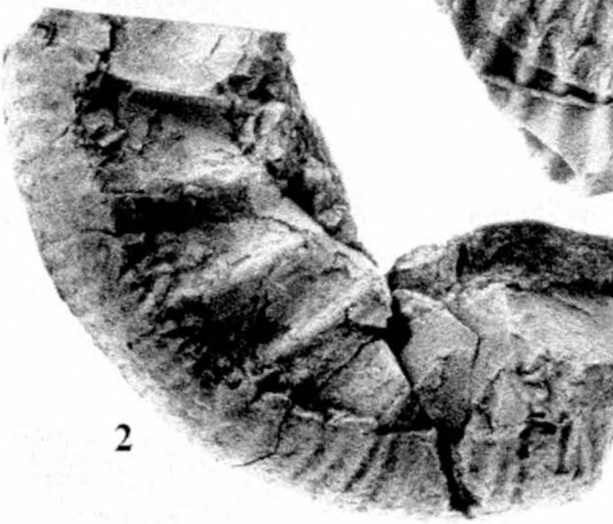
Fig. 3a, 3b. *Gymnodiscoceras* cf. *acucincta* (Blandford, in Uhlig), complete, West Irian (S15), Tokyo University specimen, x0.9.

Fig. 4. *Uhligites* cf. *indopictus* (Uhlig)♀, septate to end, Telefomin 1, ROM 56678, x0.75.

PLATE 6

1a

1b



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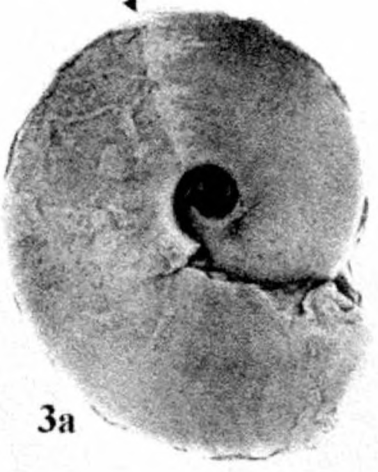

3a

3b

4

Plate 7. Telefomin Late Jurassic retroceramids; all x0.9. Numbers prefixed by 'L' are specimen numbers in the Catalogue of Type & Figured Specimens held in the collections of the Department of Geology, University of Auckland (see also Plate 8).

Fig. 1, 2. *Retroceramus* cf. *haasti* (Zittel), partial right valve (L4463) in external and anterior views, locality 91K6, near Inum Creek.

Fig. 3. *Retroceramus galoi* (Boehm), external view of incomplete right valve, specimen ROM 49328.

Fig. 4, 5. *Retroceramus galoi* (Boehm), almost complete right valve (L4464) in external and posterior views, locality 91K8, Dulufal River.

Fig. 6, 7. *Retroceramus galoi* (Boehm), steinkern in dorsal and external left valve views, specimen ROM 49325.

Fig. 8. *Retroceramus* aff. *galoi* (Boehm), subadult right valve in anterior view (with ventral view of *Sulaites gerthi* Oloriz and Westermann), specimen ROM J1974n.

Fig. 9. *Retroceramus* aff. *galoi* (Boehm), three partly exposed valves in external view, ROM 49316.

Fig. 10. *Retroceramus galoi* (Boehm), external view of nearly complete adult left valve, specimen ROM 49326.


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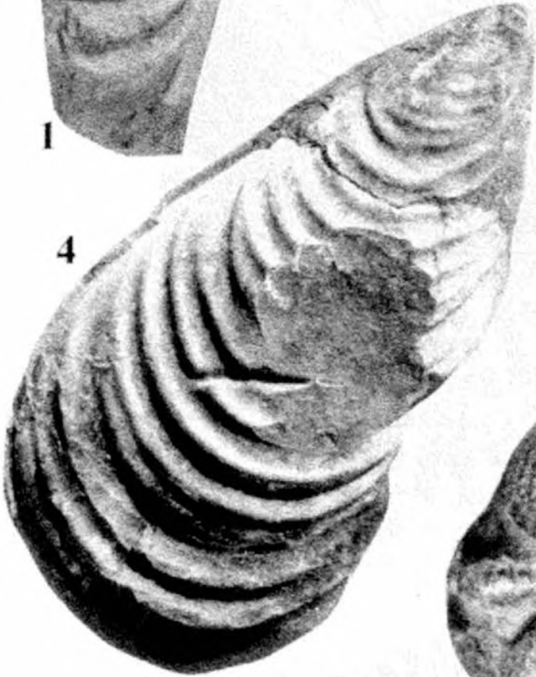
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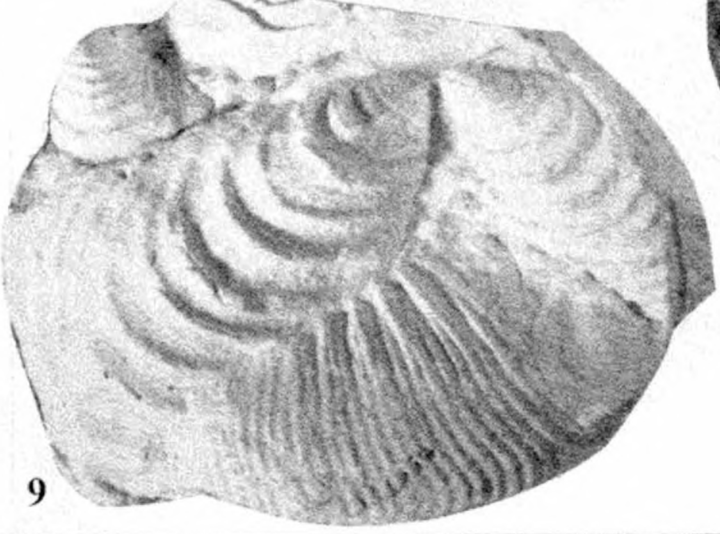
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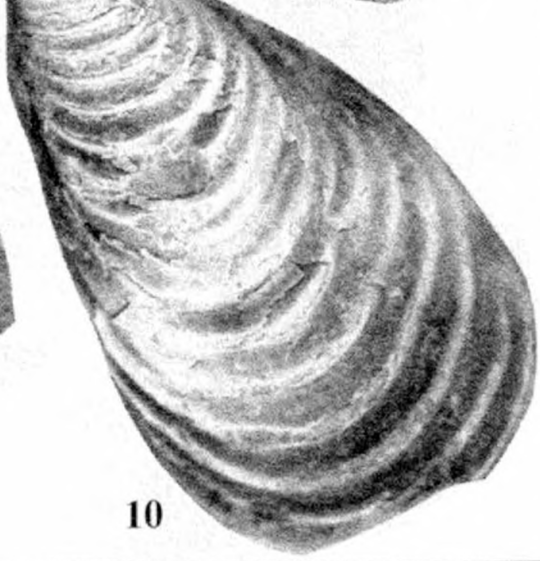
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Plate 8. Telefomin Middle and Late Jurassic bivalves; all x0.9.

Fig. 1, 4. *Retroceramus* aff. *galoi* (Boehm), partial steinkern (L4466), lacking left valve beak and ventral regions of both valves, in external right valve and posterodorsal views, locality 91K9.1, Aralfolvil track.

Fig. 2. *Retroceramus* aff. *galoi* (Boehm), incomplete right valve (L4467) in external view, locality 91 K12, Inum Creek.

Fig. 3. *Retroceramus* aff. *galoi* (Boehm), subadult right valve in external view, with associated *Sulaites gerthi* (see also Pl. 10, Fig. 8), specimen J1974n.

Fig. 5, 6. *Retroceramus* aff. *galoi* (Boehm), subadult steinkern in external left valve and posterodorsal views, specimen ROM 49312.

Fig. 7. *Retroceramus* aff. *galoi* (Boehm), right valve in external view, specimen ROM 49327.

Fig. 8, 11. *Retroceramus subhaasti* (Wandel), right valve (L4468) in external and posterodorsal views, locality 91E13, Dingdang.

Fig. 9. *Oxytoma (Oxytoma)* cf. *decemcostata* Whitehouse, left valve (L4469) in external view, locality 91E15, upper Elip River.

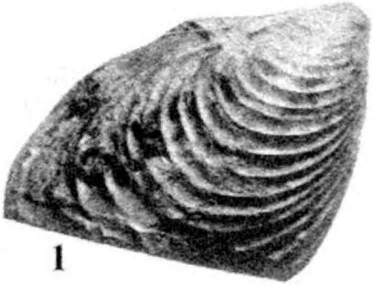
Fig. 10. *?Thracia* sp., right valve (L4465) in external view, locality 91K9, Aralfolvil track.

Fig. 12, 16. *Goniomya (Goniomya)* aff. *intersectans* (Smith), steinkern in external right valve and dorsal views, specimen ROM 49337.

Fig. 13 – 15. *Trigonopis* sp., articulated specimen in posterodorsal, dorsal, and external right valve views, specimen ROM 49343.

Fig. 17, 18. *Homomya* cf. *gibbosa* (Sowerby), steinkern in external left valve and dorsal views, specimen ROM 49336.

PLATE 8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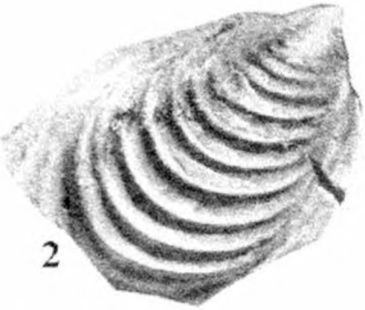
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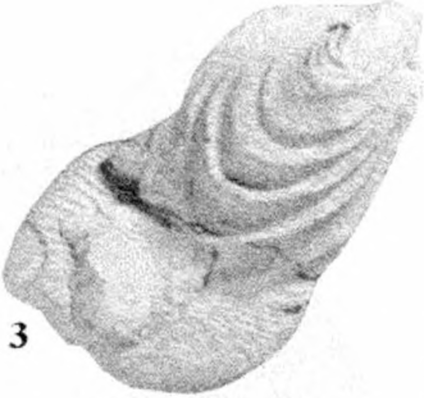
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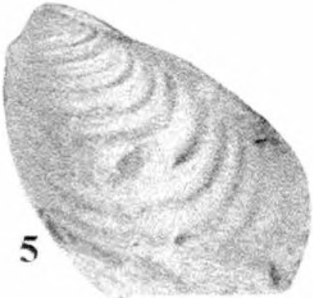
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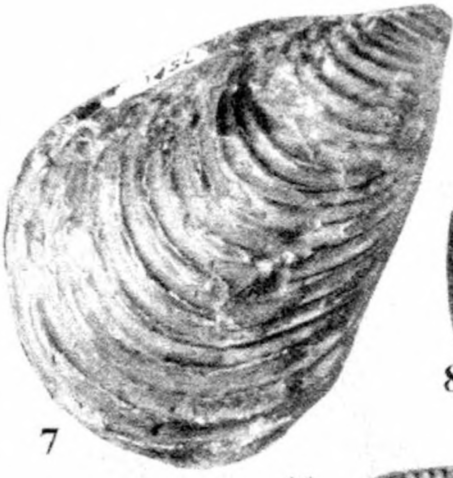
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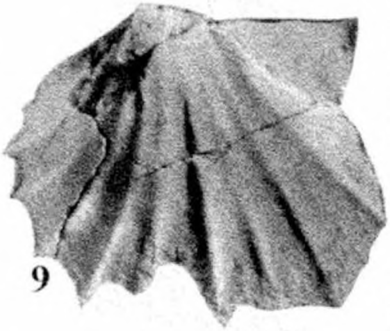
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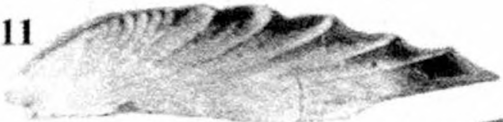
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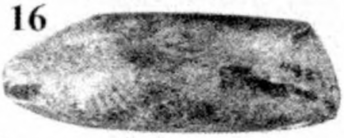
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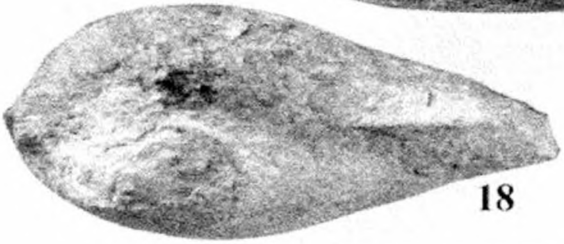
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PLATE 9. Species of the *Belemnopsis moluccana* lineage.

[Note: 1: In Plates 7 – 9 external views are of the ventral surface of the belemnite unless otherwise stated, and x0.9; cross sections are x1.8. C1934 = specimen number in the Catalogue of Type and Figured Specimens, Department of Geology, University of Auckland, New Zealand; IMC274 = specimen number in the Indonesian Macropaleontology Collection, Geological Research and Development Centre, Bandung, Indonesia; CPC 27699 = specimen number in the Commonwealth Palaeontological Collection, Geoscience Australia, Canberra, Australia.

2: These well-preserved specimens have been selected to illustrate the outline and cross sectional shape of typical examples of each taxon. Fig. 1 is a PNG specimen; the others are from Indonesia. Bracketed numbers beside the cross sections are A values (those below 100 indicate a compressed cross section, lower numbers = more compressed, 100 indicates an equidimensional section, those above 100 indicate a depressed section, higher numbers = more depressed).]

Fig. 1. *Belemnopsis moluccana* (adult), C1934, locality 91K12, Inum Creek, tributary to Abi River, Telefomin area.

Fig. 2. *B. moluccana* (pre-adult), IMC274, locality 8B, Sula Islands, Indonesia.

Fig. 3. *B. moluccana* (late pre-adult), IMC488, locality CP104, Misool, Indonesia.

Fig. 4. *Belemnopsis galoi* (adult, early form, transitional from *moluccana*), IMC281, 8K, Sula Islands.

Fig. 5. *B. galoi* (adult), IMC 293, 2A,m Sula Islands.

Fig. 6. *B. galoi* (pre-adult), IMC296, 2A, Sula Islands.

Fig. 7. *B. galoi* (adult), Imc500, CP91A, Misool.

Fig. 8. *B. galoi* (pre-adult), IMC517, 8K, Sula Islands.

Fig. 9. *Belemnopsis stolleyi* (adult), IMC309, 8G, Sula Islands.

Fig. 10. *B. stolleyi* (late pre-adult), IMC297, 8I, Sula Islands.

Fig. 11. *Belemnopsis moluccana,* IMC483, CP94, Misool.

Fig. 12. *B. moluccana,* IMC468, CP96, Misool.

Fig. 13. *B. moluccana* (apical view, x 2, of a very stron gly depressed specimen from low in the stratigraphic range of the taxon), IMC480, CP157, Misool.

Fig. 14. *B. moluccana,* uncatalogued specimen, CP99, Misool.

Fig. 15. *B. moluccana,* uncatalogued, 8B, Sula Islands.

Fig. 16. *Belemnopsis galoi,* uncatalogued, 2D, Sula Islands.

Fig. 17. *B. galoi,* uncatalogued, CP106, Misool.

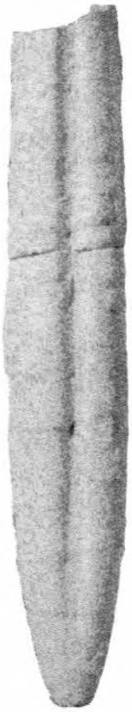
Fig. 18. *B. galoi,* IMC475, 8K, Sula Islands.

Fig. 19. *Belemnopsis stolleyi,* uncatalogued, 8I, Sula Islands.

Fig. 20. *B. stolleyi,* IMC538, 8G, Sula Islands.

Fig. 21. *B. stolleyi,* uncatalogued, 8H2, Sula Islands.

PLATE 9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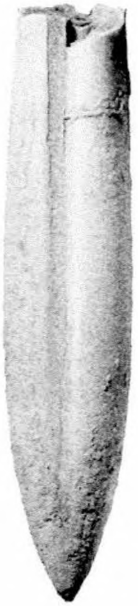
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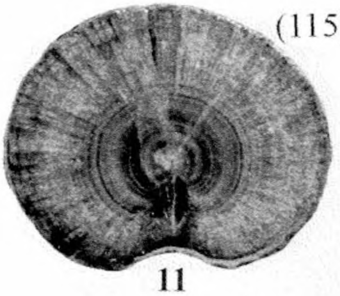

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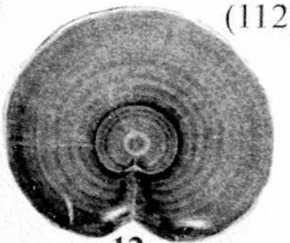

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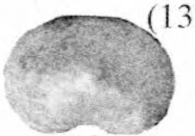

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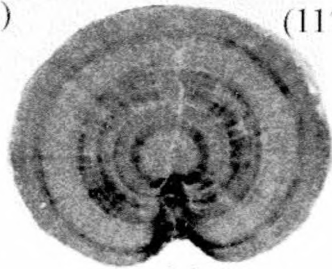

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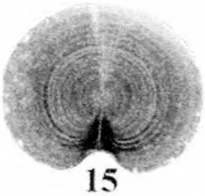

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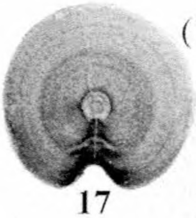

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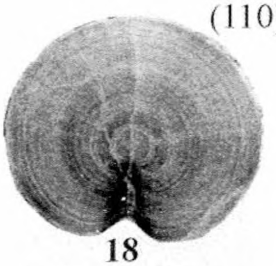

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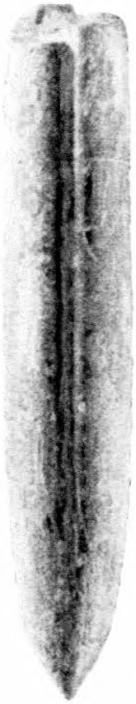
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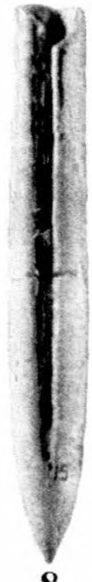
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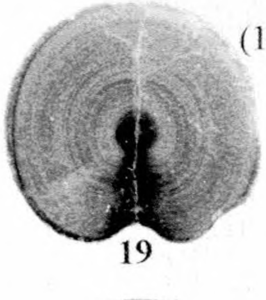

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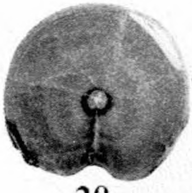

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Plate 10. **Fig. 1, 2.** *Conodicoelites kalepuensis,* C1933, locality 91E6, Elip River, Telefomin area. Dorsal and ventral views.

Fig. 3, 4. *C. kalepuensis,* CPC27688 (ventral and left lateral views), locality 106, Wai Lagaip-Ok Om confluence, Ok Tedi map sheet SB/54-7.

Fig. 5. *C. kalepuensis,* CPC27690, cross section 60 mm from apex, locality 16, Abum River, tributary to Elip River, Telefomin area.

Fig. 6. *C. kalepuensis,* CPC27691, cross section towards apex, locality N16, Telefomin area.

Fig. 7-9. *Dicoelites* cf. *D.* sp. B Challinor and Skwarko 1982, C1935, locality 91E5, Abi River, Telefomin area. Dorsal, ventral, and left lateral views.

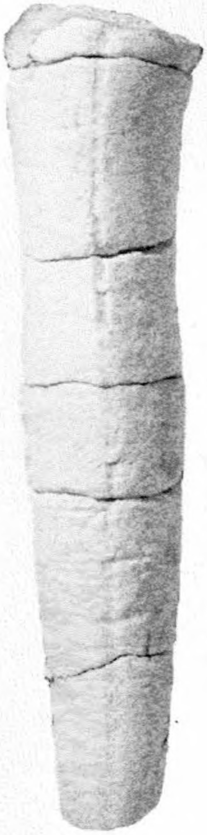
Fig. 10. *Belemnopsis jonkeri,* IMC394 (acetate peel, cross section near midguard; flask-shaped structures extending inwards from circumference are acrothoracican barnacle borings), locality CP201, Ainim River, West Irian, Taminabuan map sheet 1:250,000.

Fig. 11. *B. jonkeri,* IMC395 (acetate peel, cross section near midguard), locality CP200, Ainim River.

Fig. 12. *B. jonkeri,* IMC372, locality CP200, Ainim River.

Fig. 13. *B. jonkeri,* IMC371, locality CP200, Ainim River.

PLATE 10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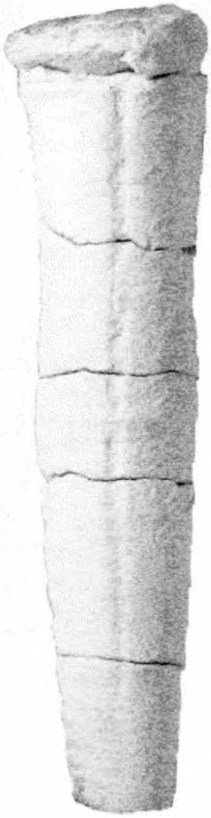
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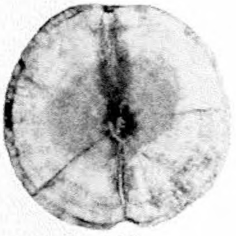
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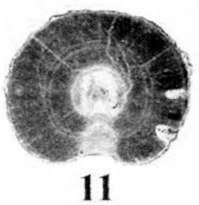
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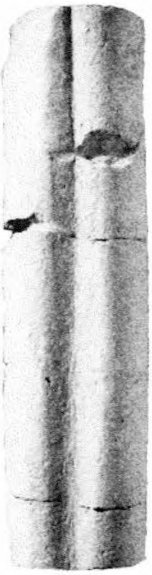
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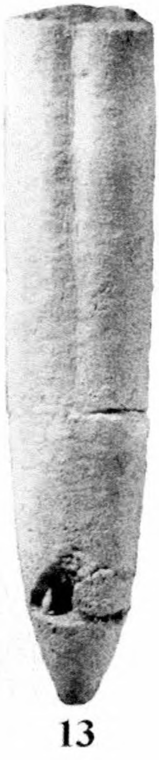
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Plate 11. Fig. 1. *Hibolithes taylori,* CPC27698, locality 29, Digiam River, Ok Tedi and southern Atbalmin map sheet 7187/7188 1:100,000.

Fig.2. *H. taylori,* CPC27699, locality 26, Digiam River.

Fig. 3. *H. taylori,* CPC27695, Locality 29, Digiam River.

Fig. 4. *H. taylori,* C1936, locality 91E1, northwest of Eliptamin, Telefomin area.

Fig. 5. *H. taylori,* CPC27701, abraded anterior cross section (growth lines indicate true cross section shape), locality 120, Hindenberg Wall, Ok Tedi map sheet SB/54-7.

Fig. 6. *H. taylori,* CPC27702, cross section in apical region (abraded), collection JKA 384, *c.* 3 km ESE of locality 130, Wok Feneng headwaters, Ok Tedi map sheet SB/54-7.

Fig. 7. *H. taylori,* CPC27700, cross section near apex of alveolus (abraded), locality 42, Ok Tedi headwaters, Ok Tedi map sheet SB/54-7.

Fig. 8. *Parahibolites feraminensis,* CPC27703, locality 29, Digiam River.

Fig. 9. *P. feraminensis,* CPC27706 (ventral view of postalveolar guard), collection 1057, unlocalised, but close to locality 137, southeast of Feramin village, Ok Tedi map sheet SB/54-7.

Fig. 10. *P. feraminensis,* CPC27707 (cross section in alveolar region), collection 919, locality 71, Anamen Stream, Ok Tedi map sheet SB/54-7.

Fig. 11. *P. feraminensis,* CPC 27706 (same specimen as in Fig. 9; cross section near protoconch).

Fig. 12. *Hibolithes australis,* IMC763, locality 1D, Sula Islands, Indonesia.

Fig. 13. *H. australis,* CPC27692, locality 69, Kereru Range, Kirori map sheet SB/55-13 1:250,000.

Fig. 14. *H. australis,* IMC764 (anterior cross section, near protoconch - abraded), locality CP74, Misool, Indonesia.

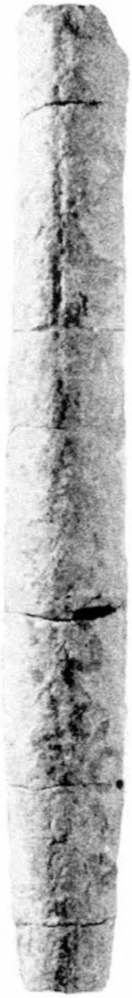
Fig. 15. *H. australis,* IMC766 (posterior cross section), locality CP74, Misool.

Fig. 16. *Hibolithes gamtaensis,* CPC27693, locality 187, Wai Oma, Ok Tedi map sheet SB/54-7.

Fig. 17. *H. gamtaensis,* CPC27709 (originally described as *H.* sp. I, Challinor 1990, but now regarded as a less hastate member of *gamtaensis*), locality 187, Wai Oma.

Fig. 18. *H. gamtaensis,* CPC27694 (posterior cross section), locality 187, Wai Oma.

PLATE 11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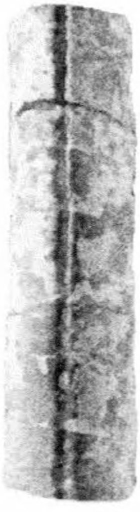
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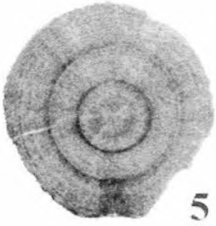
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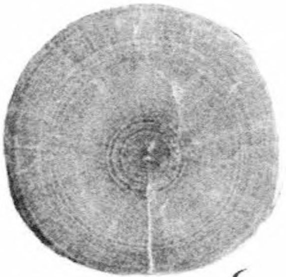
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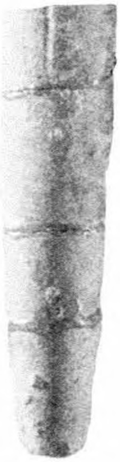
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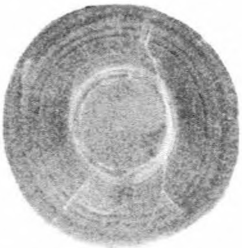
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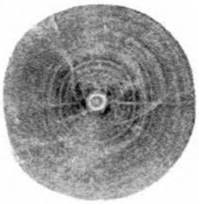
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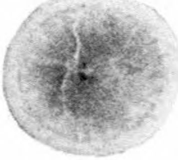
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