A belemnite biozonation for the Jurassic–Cretaceous of Papua New Guinea and a faunal comparison with eastern Indonesia

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Middle and Late Jurassic and some Early Cretaceous Belemnitida collected mostly within the region covered by the Ok Tedi and Mianmin 1:250 000 sheets in the central highlands of Papua New Guinea are identical with those of eastern Indonesia. *Conodicoelites kalepuensis* confirms that part of the Maril Formation is Bathonian in age. Members of the *Belemnopsis moluccana-B. galoi-B. stolleyi* lineage which spans the Late Jurassic of Indonesia confirm that the Imburu Mudstone and Upper Maril Formation are Oxfordian–Late Tithonian in age. *Hibolithes australis* n. sp. spans the Late Tithonian–earliest Berriasian interval; *Belemnopsis jonkeri* and *Hibolithes gamtaensis* n. sp. range from Berriasian to Valanginian confirming these ages for the Toro Sandstone, basal Ieru Formation and basal Tubu unit. *Hibolithes taylori* n. sp. (Aptian–Albian), *Parahibolites feraminensis* n. sp. (Albian) and *Dimitobelus macgregori* (Albian–Cenomanian) are present in the Upper Ieru Formation and Chim Formation. The presence of *Hibolithes taylori* in outcrops previously mapped as Toro Formation suggests that the Aptian–Albian Omati Unit has been wrongly identified as Toro Formation in some instances.

Introduction

This paper erects a belemnite biozonation for the Late Jurassic and Early Cretaceous of Papua New Guinea. It establishes the approximate stratigraphic ranges of nine belemnite species including two new taxa not known from other regions. It uses macrofossil and dinoflagellate data to provisionally correlate and date the taxa, and compares the Papua New Guinea belemnite succession with that of eastern Indonesia.

Figure 1. Geological sketch map (igneous and metamorphic rocks omitted) of Ok Tedi sheet and southern part of Mianmin sheet, illustrating location of material studied.
Approximate location of samples from outside map area shown on index diagrams.

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The region from which the fossils were collected is mountainous and mostly covered by rainforest, and its geology is complex (Davies & Norvick, 1974). A proximal to distal sedimentary sequence fining northwards with lateral facies changes and deformed by folding and numerous faults (normal, thrust, and possible strike slip) has led to many stratigraphic problems. The recognition of individual units in some instances is difficult and the position of fossil localities relative to formation boundaries is poorly known, particularly in the more distal beds of the northerly part of the region.

Most of the belemnites discussed were collected within the area covered by the Ok Tedi (formerly Blucher Range) and Mianmin 1:250 000 sheets (International index SB/54-7, SB/54-3) published by the Bureau of Mineral Resources, Australia (BMR) and Geological Survey of Papua New Guinea (GSPNG). Collections located on the Ok Tedi and Southern Atbalmin 1:100 000 sheet (sheet 7187/7188 published by the GSPNG) and from a number of measured sections in the Telefomin (SB/54-7/2), Palmer River (SB/

54-7/5) and Muller Range (SB/54-7/6) sheets plotted on British Petroleum 1:100 000 base maps were also studied. These localities lie within sheets SB/54-7 and SB/54-3 but not all are shown on them. Fossil localities are indicated in Figure 1 and the approximate positions of those outside the Ok Tedi and Mianmin sheets are shown on locality diagrams.

Most of the fossils studied are held at the Bureau of Mineral Resources, Canberra, Australia. Figured specimens with catalogue numbers preceded by CPC are held in the Commonwealth Palaeontological Collection housed at the BMR. Figured specimens with catalogue numbers preceded by IMC are held in the Indonesian Macropaleontology Collection housed at the Geological Research and Development Centre, Bandung, Indonesia.

Lithostratigraphy

The stratigraphy adopted here (Fig. 2) has been developed by G. Francis (GSPNG). Some nomenclature is provisional
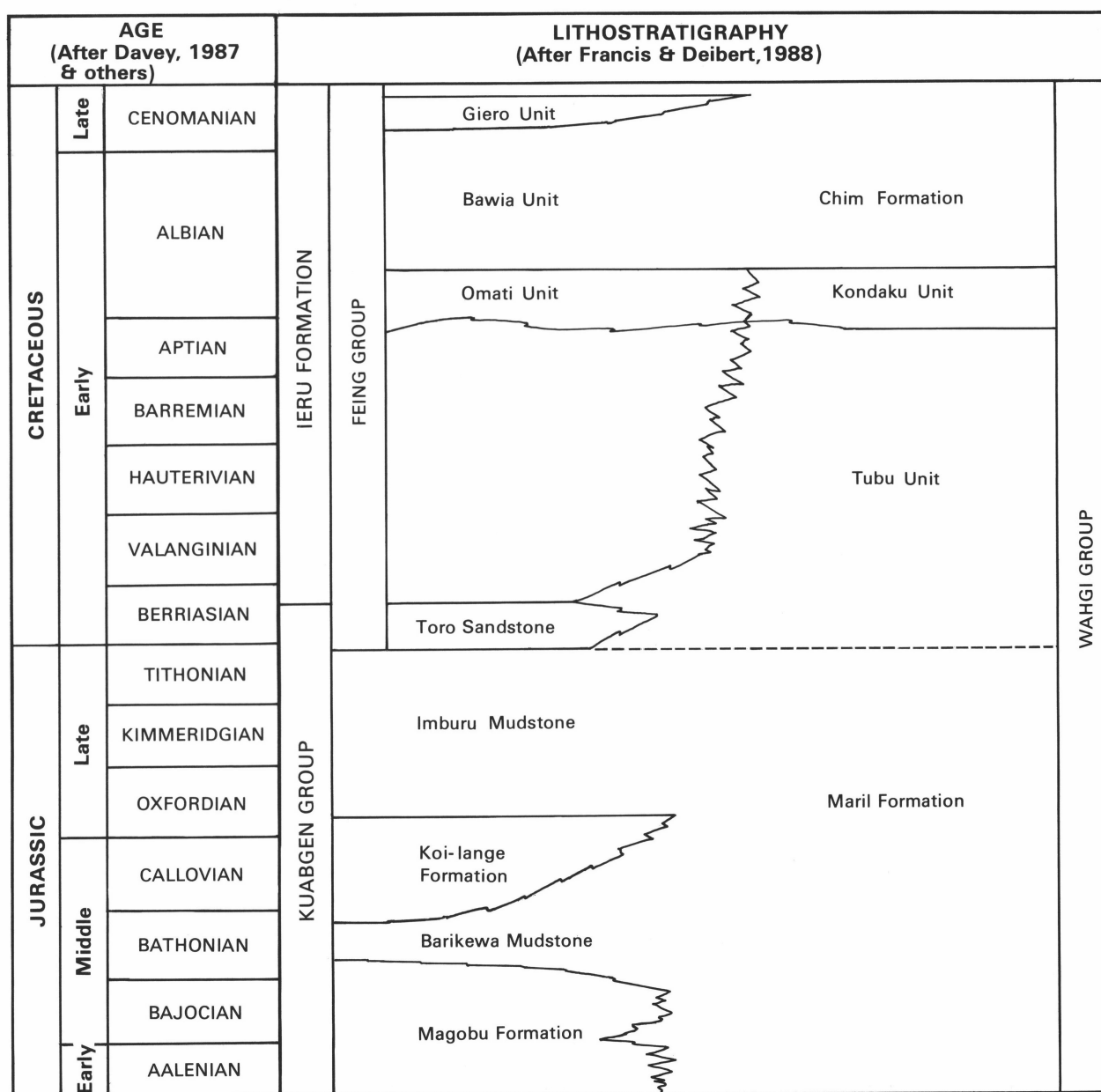
Figure 2. Provisional lithostratigraphy and age correlation of Jurassic-Cretaceous within Ok Tedi and Mianmin sheets (after Francis & Deibert, 1988, with addition of the Feing Group of authors).

with informal units used in subdivision of the Ieru Formation and upper Wahgi Group. Formation ages have been determined largely by palynology (Davey, 1987) and micropalaeontology, and there are some unresolved problems.

The original lithostratigraphic nomenclature (used in BMR fossil collection records) is based on White & others (1973) and Davies & Norvick (1977) but is undergoing revision on more recent data. These include remapping of part of the Mianmin 1:250 000 sheet by GSPNG (Rogerson & others, in press), a review by Francis (1986), a revision of the Wahgi Group in its type area (Haig & others, 1986), more precise dating of the Imburu Mudstone, Toro Sandstone and lower Ieru Formation (Davey, 1987) and a reassessment of correlations of the Toro Sandstone and lower Ieru Formation (Francis, 1988). Major problems are the lack of precision in definition and a proliferation of lithostratigraphic nomenclature with different names used for the same unit in adjacent regions. Synonyms relevant to this paper include:

Chim Formation	Maram Shales and Chimbu Tuffs (Edwards & Glaessner, 1953)
	Chim Formation and uppermost Kondaku Tuff (Bain & others, 1975)
	Chim Formation (Haig & others, 1986)
Kondaku Unit	Purari Greywackes, ?in part (Edwards, 1950)
	middle Kondaku Tuffs (Edwards & Glaessner, 1953)
	middle Kondaku Tuffs (Bain & others, 1975)
	Kondaku unit (Francis, 1986)
	Kondaku unit (Haig & others, 1986)
Wahgi Group	Wahgi Group and Jimi Greywacke (Bain & others, 1975)
Maril Formation	Maril Shale and lower Kondaku Tuff (Edwards & Glaessner, 1953)
	?Kompiai Formation, Maril Shale and lower Kondaku Tuff (Dow & Dekker, 1964)
	Maril Shale and Sitipa Shale (Dow & others, 1972)
	Maril Shale and lower Kondaku Tuff (Bain & others, 1975)
	lower Om beds (Davies & Norvick, 1977)
	Maril Formation (Haig & others, 1986).

Stratigraphic distribution of belemnites

Details of belemnite collections examined are tabled in Appendix 1. The following comments expand that list and present additional data. New taxa discussed here are described or discussed elsewhere, either in Appendix 2 or in Challinor (1989b, in press).

Conodicoelites kalepuensis is known from several localities, all within the Maril Formation. It is present in mid-Bathonian beds in Sula Islands (Challinor & Skwarko, 1982) but, in view of its occurrence at several localities in Papua New Guinea, an unrestricted Bathonian age is suggested here. Ages suggested for ammonites and bivalves associated with *C. kalepuensis* range from Bajocian to Oxfordian (Norvick, 1973).

Belemnopsis moluccana occurs at a number of localities in the Maril Formation and at one locality (sample JKA 600) in the lower Imburu Mudstone. In eastern Indonesia *B. moluccana* ranges through the Oxfordian to early Tithonian (Challinor, 1989b, in press). An Oxfordian–early Tithonian

age is suggested for the material studied here but the stratigraphic range of these collections is not known. Specimens in sample P 5014 may be early forms (Challinor, 1989b, in press); if so, they are probably early Oxfordian in age. Ages adopted for associated macrofossils in Papua New Guinea range from late Bajocian to Tithonian (Norvick, 1973; Arnold & others, 1979).

Belemnopsis galoi occurs in the Maril Formation and Imburu Mudstone. In eastern Indonesia the taxon is restricted to the early Tithonian (Challinor, in press). The stratigraphic positions of the Maril occurrences are not known, but on field evidence all occurrences in the Imburu Mudstone (samples JKA 583 (float), JKA 616 and JKA 1267) are close to the base of the formation. According to Francis (1986), the lower Imburu Mudstone is Oxfordian–Kimmeridgian in age and the stated stratigraphic position of the samples cannot be reconciled with the known age range of the taxon. Sample JKA 137 contains early forms of the species and samples JKA 712, JKA 616 and JKA 1267 late forms, so much of the stratigraphic range of the taxon is included within its collection localities. Ages for associated bivalves and ammonites range from late Bajocian to Tithonian (Norvick, 1973; Davies, 1982).

Belemnopsis stolleyi has not been certainly identified (all specimens are poorly preserved) but *B.* cf. *stolleyi* is present in the Maril Formation (locality 71 sheet SB/54-7) where it is associated with *Hibolithes australis, H.* cf. *australis* and *Belemnopsis* cf. *mangolensis. B. stolleyi, H. australis* and *B. mangolensis* are known from the Late Tithonian in eastern Indonesia (Challinor & Skwarko, 1982) and the association of specimens comparable with or identical to each of the three species points to a Late Tithonian age. Associated bivalves at locality 71 have been assigned a Callovian–Tithonian age (Norvick, 1973).

Hibolithes australis or *H.* cf. *australis* occurs in the Maril Formation and Imburu Mudstone and in the Tubu unit of the Wahgi Group (sample KAB 69). It ranges from Late Tithonian to early Berriasian in eastern Indonesia (Challinor, in press) and Papua New Guinea. Ammonites and bivalves associated with *H. australis* at locality 71 suggest a Late Jurassic age (Norvick, 1973).

Hibolithes gamtaensis and *Belemnopsis jonkeri* are present in the basal Toro Sandstone (sample JKA 453 sheet SB/54-7/2) and Ieru Formation (locality 187, sheet SB/54-7). *H. gamtaensis* is probably identical with *Hibolithes* sp. cf. *obtusirostris* of authors, and in Papua New Guinea this species has been recorded throughout the Berriasian and Valanginian. It occurs within the latest Berriasian to earliest Valanginian *Egmontodinium torynum* dinoflagellate zone of Davey (1987) in the Strickland Gorge type section of the lower Ieru Formation (G. Francis, GSPNG, personal communication, 1986). Ammonites and bivalves of Early Cretaceous age are associated with *B. jonkeri* at locality 187 (Norvick, 1973) and the Toro Sandstone has been firmly dated at Latest Tithonian–Berriasian by palynology (Davey, 1987). Both *H. gamtaensis* and *B. jonkeri* occur in the Neocomian of Indonesia (Challinor, in press).

Hibolithes taylori is present at a number of localities originally mapped as Toro Sandstone (samples JKA 146, JKA 384, sheets SB/54-7/2, 7/5; localities 42, 136, sheet SB/54-7) and Maril Formation (localities 26, 29, sheet 7187/7188). These units are apparently misidentified because:

(1) *Hibolithes gamtaensis* and *Belemnopsis jonkeri* are known from the Toro Sandstone and basal Ieru

Formation and in age equivalent strata in Irian Jaya and Misool (Challinor, 1989a, in press) but are nowhere associated with *H. taylori*;

(2) *H. taylori* and *Parahibolites* are associated at two localities (26 and 29, sheet 7187/7188), and *Parahibolites* is restricted to post-Neocomian strata worldwide (Stevens, 1965, 1973).

G. Francis (GSPNG, personal communication, 1986) suggests that the 'Toro Sandstone' at localities JKA 146, JKA 384, 42, 136 is in fact Omati unit, and 'Maril Formation' at localities 26 and 29 is Chim Formation. Microfossil evidence from localities 42 and 136 suggests Late Jurassic–Late Cretaceous ages and 'probably Callovian' bivalves are present (Norvick, 1973). A Kimmeridgian–Tithonian age for localities 26 and 29 was suggested in Arnold & others (1979) but this was based on the belemnites, ages and identifications of which are revised here. An Aptian–Albian age is accepted here for *Hibolithes taylori*.

Parahibolites feraminensis is known from float collections at localities 26 and 29 (sheet 7187/7188) and in poorly localised or apparently mixed collections (sample 919, locality 71; sample 1057, near locality 137; Appendix 1). Most of the latter material was collected by the people of Feramin Village from their gardens near locality 137 on sheet SB/54-7. As stated above, *Parahibolites* has an Aptian–Cenomanian age on the world scene (Stevens, 1973). Glaessner (1945) considered his specimens of *Parahibolites blanfordi* to be Albian in age and Stevens (1965) suggested an Aptian–Albian age for Papua New Guinea *Parahibolites*. Little evidence of age is available from other sources and, as mentioned above, localities 26 and 29 were originally dated as Kimmeridgian–Tithonian on their belemnite content. An Albian age is adopted here for *Parahibolites feraminensis*.

The single specimen of *Dimitobelus macgregori* examined (sample HGF 25) was found within the Chim Formation where it is abundant and associated with latest Albian planktic foraminifera (locality 68, Haig 1981). *D. macgregori* is of ?late Albian–early Cenomanian age in New Zealand (Stevens, 1965) and late Albian–Cenomanian in Papua New Guinea (G. Francis, GSPNG, personal communication, 1988).

Early belemnite records

Belemnites have been recorded from the central highlands by earlier researchers. The record of *Parahibolites* by Glaessner (1945) has been discussed. In the same publication he identified *Belemnopsis gerardi* (Oppel) and *B.* cf. *indica* Kruizinga from the Kuagben Group on the Fly River (Wok Feneng). The specific name *gerardi* is not valid for Indonesian material (Stevens, 1963). The specimens from Indonesia identified as *B. gerardi* by Kruizinga (1920) and Stolley (1929) include early and late *B. galoi*, transitional forms, and *B. stolleyi* (Challinor, 1989b).

Glaessner's figured specimens of *B. gerardi* (1945, Pl. 6, figs 8, 9a,b) appear to be early *B. galoi*. This is supported by their occurrence with *Malayomaorica malayomaorica* (Krumbeck) and '*Inoceramus*'. *Belemnopsis indica* Kruizinga is a synonym of *B. moluccana* (Boehm) (Challinor, 1989b, in press) and Glaessner's description indicates his *B.* cf. *indica* is without doubt *B. moluccana*.

Banner & others (1961) recorded belemnites from the 'Tubu Shales' in the Kereru Range, later identified by W.J. Arkell as *Hibolithes lagoicus* (Boehm) and *Belemnopsis alfurica* (Boehm). To judge from the Indonesian belemnite succession (Challinor, in press) and the Papua New Guinea collections studied here, the specimens identified by Arkell are probably either *Hibolithes australis* and *Belemnopsis stolleyi* or *Hibolithes gamtaensis* and *Belemnopsis jonkeri*.

Age correlation of assemblages

This section attempts to establish ages for the belemnite assemblages discussed. Because most are known from eastern Indonesia where provisional ages have been assigned, their ages in that region are considered first.

Macrofossil evidence for belemnite ages in Indonesia

Most Jurassic and Early Cretaceous belemnites discussed here are present in eastern Indonesia, particularly Sula Islands and Misool, but the Jurassic–Cretaceous of that region has not been accurately correlated at stage level. Stage boundaries and belemnite time ranges adopted here were established during a study of belemnite distributions, mostly in the Misool Archipelago (Challinor, in press) and the evidence on which they are based is restated briefly here.

Subdivisions adopted are based mostly on macrofossils and differ in some instances from those of palynologists, particularly dinoflagellate workers. Time distributions of the correlating macrofossils have been studied by Helby & others (1988) who examined diverse source material. Their work provides a modern summary of probable distributions but uncertainties remain, and ages based on them cannot be regarded as unequivocal.

Stratigraphic distribution of the belemnites is best known from the Misool Archipelago where they are associated over parts of their ranges with other molluscs of time-diagnostic value. Identifications of the latter have been provided by F. Hasibuan, University of Auckland. Fossil occurrences and stage boundaries adopted for Misool are summarised in Figure 3. Belemnite distributions are essentially continuous throughout the sequence (within the limits imposed by incomplete outcrop) and appear in most exposures. Other molluscs appear at few outcrops separated by intervals apparently devoid of macrofossils other than belemnites. Thus the belemnites are of potentially great value as zone fossils.

Following Stolley (1929, 1935) the base of the Cretaceous system in Misool is placed at the first appearance of the belemnite genus *Duvalia*. This must be regarded as an approximate position (Challinor, in press) but is the only macrofossil evidence available at present. No other macrofossil control is available for the Neocomian. *Belemnopsis jonkeri* and *Hibolithes gamtaensis* (and other Belemnitida not recorded from Papua New Guinea; Fig. 4) are assigned ages on their apparent relative stratigraphic positions.

Only beds included in the Tithonian *sensu* Harland & others (1982) contain a significant range of molluscs other than belemnites (Fig. 3). The base of the stage is placed at a horizon containing diverse early Tithonian bivalves and ammonites. These include taxa which, on present evidence (Helby & others, 1988), are either confined to the Tithonian (*Paraboliceras, Torquatisphinctes, Retroceramus haasti*) or extend into it (*Kossmatia, R. galoi, R. subhaasti, Malayomaorica malayomaorica*).

Beds between basal Tithonian outcrops and those placed in the Oxfordian are assigned an undifferentiated Oxfordian–Kimmeridgian age. Little evidence is available for the age of this sequence.
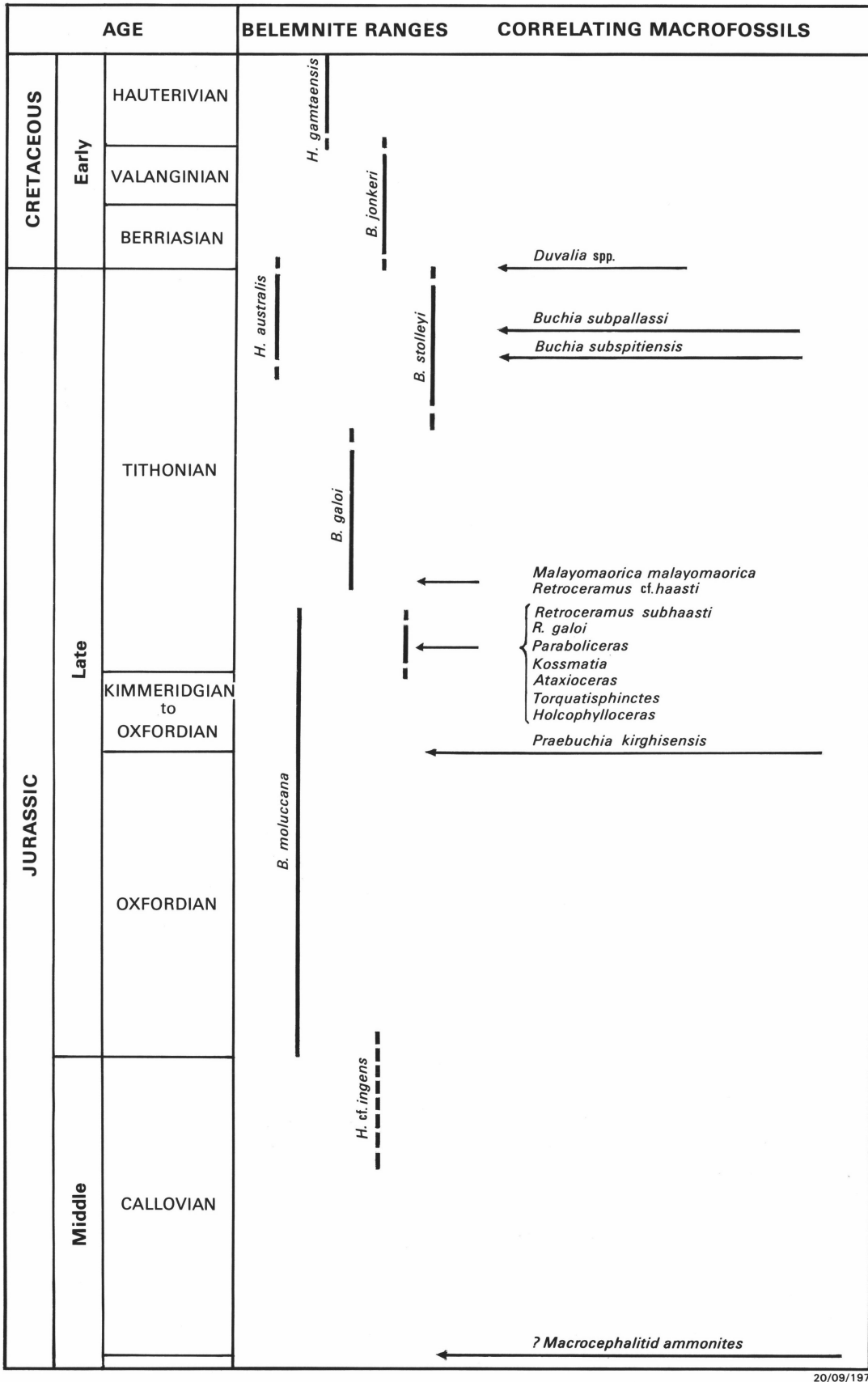
Figure 3. Time distribution of Belemnitida in eastern Indonesia.
Macrofossil evidence for position of stage boundaries in Misool indicated. Relative sedimentary thickness of each stage in Misool Archipelago indicated approximately (after Challinor, in press).

Little macrofossil evidence exists for that part of the sequence included in the Oxfordian apart from the presence of *Praebuchia kirghisensis* Sokolov (Oxfordian: Li & Grant-Mackie, 1988) at its top. No macrofossil evidence is known for basal Oxfordian which is provisionally marked by the first appearance of *Belemnopsis moluccana*, but the presence of early Oxfordian dinoflagellates (Fig. 4) suggests that its position is at least approximately correct.

The base of the Callovian in Misool has been placed at a horizon containing possibly macrocephalitid ammonites, the latter traditionally regarded as indicating early Callovian. Again, this boundary must be regarded as provisional, because recent research on the Macrocephalitinae of Sula Islands and Papua New Guinea (Westermann & Callomon, 1988) indicates they extend into at least the late Bathonian.

Dinoflagellate evidence for belemnite ages in Indonesia

Palynological research in western and northern Australia and in the Papuan basin has enabled Helby & others (1987) to develop a dinoflagellate zonal scheme which appears

BELEMNITE RANGES	FOSSIL LOCALITY	FORMATION	AGE (based on MACROFOSSILS)		DINOFLAGELLATE or SPORE POLLEN ZONES AUSTRALIAN MESOZOIC (Helby & others, 1987)	STRATIGRAPHIC POSITION OF PALYNOMORPH SPOT SAMPLE IN MISOOL SEQUENCE
		MISOOL ARCHIPELAGO				
B. jonkeri *H. gamtaensis* *H. miosensis* *Duvalia* *B. stolleyi* *H. australis* *B. galoi* *B. moluccana* *H. cf. ingens*	81 CP 112 110 111 91D 91B 108 10 107 91A 94 69 100 98 158 159 61	FACET LIMESTONE (GAMTA MBR) — LELINTA SHALE — DEMU FORMATION — YEFBIE SHALE	CRETACEOUS Early — JURASSIC Late Middle	HAUTERIVIAN — VALANGINIAN to BERRIASIAN — TITHONIAN (Late / Early) — KIMMERIDGIAN to OXFORDIAN — OXFORDIAN — CALLOVIAN (Late / Early) — PRE-CALLOVIAN JURASSIC	*Muderongia testudinaria* — *Phoberocysta burgeri* — *Senoniasphaera tabulata-Pseudoceratium iehiense* — *Dingodinium jurassicum* — *Omatia montgomeryi* — *Cribroperidinium perforans* — *Dingodinium swanense* — *Wanaea clathrata* — *Wanaea spectabilis* — *Rigaudella aemula* — *Wanaea digitata* — *Wanaea indotata* — *Dictyotosporites complex*	← *Muderongia testudinaria* (112) — ← *Cassiculosphaeridia delicata* (110) ← *Kalyptea wisemaniae* (111) — ← *Dingodinium jurassicum* (91 D) — ← Upper *Omatia montgomeryi* (108) ← *O. montgomeryi-D. jurassicum* (10) ← *C. perforans-D. swanense* (107) — ← *Wanaea clathrata* (91 A) ← *Wanaea clathrata-W. spectabilis* (94) ← *Wanaea clathrata* (69) — ← Upper *Wanaea spectabilis* (100) ← *Wanaea clathrata-W. spectabilis* (98) — ← Lower *Wanaea spectabilis* (158) ← *Wanaea digitata* (159) — ← *Dictyotosporites complex* (61)
		PRE-JURASSIC				20/09/198

Figure 4. Generalised lithostratigraphy of Jurassic and early Cretaceous of Misool Archipelago (Pigram & others, 1982) with stage boundaries positioned on macrofossil evidence (Challinor, in press).

Dinoflagellate or spore pollen zones of Australian Mesozoic (Helby & others, 1987) for these stages indicated. Arrows indicate position of dinoflagellate spot samples. Note lack of agreement between dinoflagellate zones and position of some spot samples.

applicable to the Misool Sequence. Problems with age control remain, particularly in the Late Jurassic and early Cretaceous where belemnites have been used for correlation (Helby & others, 1987, appendix 3). Most of these identifications (*Belemnopsis tanganensis, Hibolithes* cf. *obtusirostris, Acroteuthis subquadratus, Belemnopsis* cf. *aucklandica*) are almost certainly incorrect (Stevens, 1965; Challinor, in press) and others (*Belemnopsis* cf. *alfurica*) are potentially so (Challinor, 1989b). Therefore the possibility of miscorrelation exists.

Figure 4 relates the dinoflagellate zones of Helby & others (1987) to Misool stages (boundaries located by macrofossil data as discussed above). A number of spot samples from Misool have been examined for dinoflagellates by R.W. Helby (F. Hasibuan, University of Auckland, personal communication, 1988). Sampling was not continuous or closely spaced but many of the zones of Helby & others (1987) are present. The location and dinoflagellate zone of the samples is indicated in Figure 4 and a number of interesting features emerge:

(1) there is no clear evidence for Kimmeridgian strata (cf. Helby & others, 1987, fig. 12), possibly a result of discontinuous sampling;

(2) beds which on macrofossil evidence are basal Tithonian (localities 81CP69, 94) are late Oxfordian by dinoflagellate spot sample;

(3) Beds of Valanginian age on macrofossil evidence (admittedly slight) are early Berriasian by dinoflagellates.

The zones of *Cassiculosphaeridia delicata* and *Kalyptea wisemaniae* (early Berriasian: Helby & others, 1987) occur in the lower part of the division marked *Senoniasphaera tabulata* to *Pseudoceratium iehiense* (Fig. 4) but the spot samples were collected within beds assigned on macrofossil evidence to the uppermost Berriasian–Valanginian.

The ages of Misool belemnites according to their associated macrofossils and dinoflagellates are compared in Table 1.

Table 1. Age correlation of Belemnitida of Misool based on macrofossils and dinoflagellates.

Belemnite	Age based on macrofossils (Challinor, in press)	Age based on dinoflagellate zonation of Helby & others (1987)
Belemnopsis moluccana	Oxfordian–early Tithonian	Oxfordian
Belemnopsis galoi	early Tithonian	early Tithonian
Belemnopsis stolleyi	late Tithonian	late Tithonian
Hibolithes australis	late Tithonian	late Tithonian
Belemnopsis jonkeri	Berriasian–Valanginian	Berriasian
Hibolithes gamtaensis	Hauterivian	Hauterivian

Agreement on the range of *Belemnopsis moluccana* (Oxfordian–Tithonian by macrofossils; Oxfordian by dinoflagellate spot sample) and *Belemnopsis jonkeri* (Berriasian and Valanginian by macrofossils, Berriasian by dinoflagellate spot sample) is only partial but, as pointed out, macrofossil control in the Neocomian of Misool is poor. The two zonal schemes give similar ages for the remaining belemnites.

Belemnite ages in Papua New Guinea

An alternative dinoflagellate zonation for the Papuan basin has been developed by Davey (1987) based on sections on the Strickland River and tributaries. Many dinoflagellates present are endemic to the Australia–Papua New Guinea region. Correlation with western European type sections and ammonite-dated sequences is by those relatively few taxa common to Papua New Guinea and Europe. However, the ranges of some species and genera differ in the two regions (Davey, 1987, fig. 13). Furthermore, the zones from *Wanaea clathrata* to *Omatia montgomeryi* are regarded as systematically older by Davey (mid-Oxfordian to late Oxfordian–early Kimmeridgian) than by Helby & others (1987, late Oxfordian to mid-Tithonian). Again the possibility of miscorrelation exists.

G. Francis (GSPNG) has plotted the apparent distributions of bivalves and belemnites ('apparent' because few direct associations of macrofossils and dinoflagellates are known; correlation between the two is by stratigraphic and lithologic means) in relation to Davey's dinoflagellate zones (Fig. 5). Using Davey's zonal scheme and the belemnite distributions by Francis, belemnite ages are listed in Table 2.

Table 2. Age correlation of Belemnitida of Papua New Guinea based on macrofossils and dinoflagellates.

Belemnite	Age in Misool based on macrofossils (Challinor, in press)	Age in PNG based on dinoflagellates (after Davey, 1987)
Belemnopsis moluccana	Oxfordian–early Tithonian	early and mid Oxfordian
Belemnopsis galoi	early Tithonian	mid Oxfordian–late Kimmeridgian
Belemnopsis stolleyi	late Tithonian	
B. cf. stolleyi		late Kimmeridgian to mid Tithonian
Hibolithes australis	late Tithonian	early Tithonian–early Berriasian
Belemnopsis jonkeri	Berriasian–Valanginian	Berriasian
Hibolithes gamtaensis	Hauterivian	Berriasian–Valanginian
Hibolithes taylori		Aptian–Albian
Parahibolites feraminensis		Albian
Dimitobelus macgregori		?Albian–Cenomanian

Belemnite ages given here are systematically older than those from macrofossil associations in Misool. In the Oxfordian–Tithonian they are generally older than those determined by the dinoflagellate zonation of Helby & others (1987). As well, the concurrent range zone of *Retroceramus galoi, R. subhaasti* and *Malayomaorica malayomaorica* (Fig. 5) has an apparent mid-Oxfordian age. Macrofossil data in Helby & others (1988) suggest this horizon could be as young as early Tithonian.

The concurrent range zone of *B. moluccana* and *B. galoi* (Fig. 5) presents a further anomaly. There is clear evidence from Misool and Sula Islands (and elsewhere in Indonesia) that *B. galoi* is the descendant of *B. moluccana* (Challinor, 1989b) and no concurrent range zone of the two is known. *B. galoi* invariably succeeds *B. moluccana*. In one known instance the two occur at the same locality (2D, Wai Galo, Sula Islands, Challinor & Skwarko, 1982), but this locality spans some 25 m of beds (Sato & others, 1978) and lies within the transition zone between *B. moluccana* and *B. galoi*. All *B. galoi* present at locality 2D approach *B. moluccana* in morphology (Challinor, 1989b).

Glaessner's (1945) record of *B. moluccana* and *B. galoi* in the Kuabgen Group is mentioned above. *B. galoi* is associated there with *Malayomaorica malayomaorica* and *Retroceramus: B. moluccana* is present some 12 m below. This is the stratigraphic relationship of these taxa in the early Tithonian of Misool (Fig. 3) and in the Sula Islands (Challinor & Skwarko, 1982), but Glaessner's specimens are from the lower Imburu Mudstone (~20 m above base, G. Francis, GSPNG, personal communication, 1988) and are Oxfordian on stratigraphic evidence (Fig. 2).

AGE (After Davey, 1987 & others)				PAPUA NEW GUINEA MICROPLANKTON ZONES (After Davey, 1987 & others)	BELEMNITE RANGES
CRETACEOUS	Early	Late	CENOMANIAN	Late	Diconodinium dispersum	
				Early	Schizosporis reticulatus	
			ALBIAN	Late	Diconodinium cristatum	
				Mid.		
				Early	Muderongia tetracantha	
			APTIAN	Late	Diconodinium davidii	
				Early	Cassiculosphaeridia magna	
			BARREMIAN	Late		
				Mid.		
				Early	Muderongia australis	
			HAUTERIVIAN	Late		
				Early	M. testudinaria	
			VALANGINIAN	Late	Sytemataphora areolata	
				Early	Avellodinium flagellatum	
			BERRIASIAN	Late	Egmontodinium torynum	
					Leptodinium pinnosum	
					Papuadinium apiculatum	
				Early	Peridictyocysta mirabilis	
JURASSIC	Late		TITHONIAN	Late	Pseudoceratium iehiense	
				Mid.	Oligosphaeridium sp.1	
					Rhynchodiniopsis serrata	
					Broomea simplex	
				Early	Nummus similis	
			KIMMERIDGIAN	Late		
				Mid.	Nannoceratopsis pellucida	
				Early	Gonyaulacysta jurassica	
			OXFORDIAN	Late	Omatia montgomeryi	
					Cribroperidinium perforans	
				Mid.	Wanaea clathrata	
				Early		
	Middle		CALLOVIAN	Late	Wanaea digitata	
				Mid.	Ctenidodinium sellwoodii	

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Figure 5. Papua New Guinea dinoflagellate zones of Davey (1987) & others, and apparent distribution of Belemnitida in that region.

Note possible concurrent range zone of *Belemnopsis moluccana* and *B. galoi*, and apparent age of concurrent range zone of *Retroceramus galoi*, *R. subhaasti-haasti* and *Malayomaorica malayomaorica* (cf. Fig. 3).

The few samples which contain both belemnites and dinoflagellates are: JKA 600, *Belemnopsis moluccana* and dinocysts of the *Wanaea clathrata* zone; JKA 616, *B. galoi* and *W. clathrata* zone; JKA 712 and 1267, *B. galoi* and *Cribroperidinium perforans* zone (dinoflagellate determinations by A. Welsh, BP Australia). Therefore, the transition from *B. moluccana* to *B. galoi* occurs within the *W. clathrata* zone and is early to mid-Oxfordian according to Davey (1987, fig. 3), late Oxfordian to early Kimmeridgian according to Helby & others (1987, fig. 12) and early Tithonian on macrofossil evidence. Note that the dinoflagellate zones of Davey (1987) and Helby & others (1987) are not identical in concept (Davey, 1987, pp. 4, 22).

Until the conflict between the dinoflagellate ages of Helby & others (1987) and Davey (1987) is resolved, and until unequivocal evidence for age of the relevant macrofossils is available, no precise time ranges for the belemnites can be stated. Meanwhile belemnite ages determined on macrofossil evidence are accepted here.

Distribution anomalies

Apart from the apparent concurrent range zone of *Belemnopsis moluccana* and *B. galoi*, other differences are present in the belemnite assemblage of Papua New Guinea when compared with that of eastern Indonesia.

Three species of *Duvalia* (?earliest Berriasian to ?mid-Hauterivian) are present in Misool where they are associated with both *Belemnopsis jonkeri* and *Hibolithes gamtaensis* (Challinor, in press). They are not present in the BMR Papua New Guinea collections, although there are poorly documented records of the genus earlier (de Verteuil & McWhae, 1948; Stevens, 1965). *Hibolithes miosensis* Challinor is also present in the mid-Hauterivian of Misool (Challinor, in press) but is not known from Papua New Guinea. *B. jonkeri*, *H. gamtaensis* and *H. miosensis* are all present in Irian Jaya (Challinor, in press) although *Duvalia* is apparently missing.

In Misool *B. jonkeri* is thought to range through the Berriasian and Valanginian with *H. gamtaensis* confined to the Hauterivian (Fig. 4). In Papua New Guinea however they both appear in the early Berriasian. *B. jonkeri* is confined to that stage and *H. gamtaensis* extends into the late Valanginian (Fig. 5). This conflict in apparent distributions may result from the different correlations used, but an incorrect assessment of ages and collection of *H. gamtaensis* from only part of its range in Misool are possible factors.

Eight belemnite species (in addition to *B. moluccana* and *Hibolithes* cf. *ingens*) representing five genera occur in the Callovian–Oxfordian of Misool. Most are abundant and all range through half a stage or more (Challinor, in press) but none are known from Papua New Guinea. If beds regarded as Callovian and Oxfordian in Misool and Papua New Guinea are time equivalent it is difficult to explain the absence of so many taxa, particularly when species common to both regions occur in older and younger beds. The Papua New Guinea Callovian–Tithonian belemnite succession resembles that of the Sula Islands where the rich Callovian–Oxfordian fauna of Misool is also apparently missing.

Differing belemnite assemblages may be due to several factors. Provincialism may be significant but geographic proximity argues against this, as does the presence of common taxa. Selective collecting from beds containing conspicuous macrofossil assemblages (e.g. the relatively high frequency of *Belemnopsis galoi* from the *Retroceramus–Malayomaorica*

zone) may be important in Papua New Guinea. Several statements of other belemnite occurrence are present in the literature but the fossils are not present in the BMR collections studied, and it is possible they were not collected due to a presumption of no stratigraphic value. Collection failure for one reason or another seems a possibility.

Although belemnites are not thought to be strongly facies controlled elsewhere, this factor may be significant in Papua New Guinea. Belemnite occurrences appear to be more common in transgressive facies such as the lower Imburu Mudstone and Ieru Formation (G.Francis, GSPNG, personal communication, 1988). Regressive facies (Toro Sandstone, Koi-Iange Formation) may have been environmentally less suitable. The Koi-Iange Formation in particular is known to be marginal-marine to non-marine in part (White & others, 1973; Davey, 1987). A follow-up study to examine belemnite collections from Papua New Guinea held by organisations other than BMR is planned, and this may throw some light on what are poorly understood distribution problems.

Acknowledgements

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Appendix 1. Collections studied.

Map index	Locality	Sample	Taxon	Age adopted here	Unit
SB/54-7	5	7152-1355	*Hibolithes gamtaensis* n. sp.		
		1352	*Hibolithes* cf. *gamtaensis*	Berriasian–Valanginian	Feing Group
		4102	*Hibolithes* sp.		
		1055	*Belemnopsis* sp.		
	11	522	*Belemnopsis galoi* (Boehm)	early Tithonian	Maril
		4098	*Belemnopsis galoi*		
	15	4307	*Conodicoelites kalepuensis* Challinor	Bathonian	Maril
	16	603	*Conodicoelites kalepuensis*		
		619	*Conodicoelites kalepuensis*	Bathonian	Maril
		618	*Conodicoelites* cf. *kalepuensis*		
	19	5216	*Belemnopsis galoi*	early Tithonian	Maril
	22	360	*Conodicoelites kalepuensis*	Bathonian	Maril
	42	1220	*Hibolithes taylori* n. sp.		
		1221	*Hibolithes taylori*		
		1223	*Hibolithes taylori*	Aptian–Albian	Omati

Map index	Locality	Sample	Taxon	Age adopted here	Unit
	42	1230	*Hibolithes taylori*		
		1229	*Hibolithes* cf. *taylori*		
	46	3462	*Hibolithes taylori*		
		3465	*Hibolithes taylori*	Aptian–Albian	Omati
		3471	*Hibolithes taylori*		
	57	657	*Hibolithes taylori*	Aptian–Albian	Ieru
	70	4001	*Belemnopsis galoi*		
		4001	*Belemnopsis* cf. *galoi*		
		4007	*Belemnopsis* cf. *galoi*	early Tithonian	Maril
		4009	*Belemnopsis* cf. *galoi*		
		4001	*Hibolithes* juv.		
		4004	*Hibolithes* juv.		
	71	910	*Belemnopsis* cf. *stolleyi* Stevens		
		912	*Belemnopsis* cf. *stolleyi*		
		914	*Belemnopsis* cf. *stolleyi*		
		918	*Belemnopsis* cf. *stolleyi*		
		919[1]	*Belemnopsis* cf. *stolleyi*		
		2076	*Belemnopsis* cf. *stolleyi*	late Tithonian	Maril
		2082	*Belemnopsis* cf. *stolleyi*		
		2078	*Belemnopsis* cf. *mangolensis* Challinor		
		912	*Hibolithes australis* n. sp.		
		918	*Hibolithes* cf. *australis*		
		2078	*Hibolithes* cf. *australis*		
		914	*Hibolithes* sp.		
SB/54-7	82	7152-129	*Hibolithes taylori*	Aptian–Albian	Ieru
	83	763	*Belemnopsis* cf. *moluccana* (Boehm)	Oxfordian–Kimmeridgian	Ieru
	106	4048	*Conodicoelites kalepuensis*		
		4049	*Conodicoelites kalepuensis*		
		4050	*Conodicoelites kalepuensis*	Bathonian	Maril
		4051	*Conodicoelites kalepuensis*		
	107	491	*Belemnopsis* cf. *galoi*	early Tithonian	Maril
	120	1239	*Hibolithes taylori*	Aptian–Albian	Ieru
	136	1204	*Hibolithes taylori*	Aptian–Albian	Omati
Near 137		1057[2]	*Parahibolites feraminensis* n. sp.	Albian	Ieru
	147	1283	*Belemnopsis* cf. *jonkeri* Stolley	Berriasian–Valanginian	Ieru
	148	1284	*Hibolithes* sp.		
		4069	*Hibolithes* sp.	?	?
	187	7152-4016	*Hibolithes gamtaensis*		
		4019	*Hibolithes gamtaensis*		
		4020	*Hibolithes gamtaensis*		
		4021	*Hibolithes gamtaensis*	Berriasian–Valanginian	Ieru
		1163	*Hibolithes* sp.		
		4015	*Belemnopsis jonkeri* Stolley		
		4018	*Belemnopsis jonkeri*		
		4017	*Belemnopsis* cf. *jonkeri*		
		4037	*Hibolithes* sp. I		
SB/54-3	12	P 5003	*Belemnopsis galoi*	early Tithonian	Maril
	14	P 5006	*Belemnopsis* cf. *galoi*	early Tithonian	Maril
SB/54-7/5		JKA 137	*Belemnopsis galoi*	early Tithonian	Imburu
			Belemnopsis cf. *galoi*		
			Hibolithes sp.		
		JKA 146	*Hibolithes taylori*	Aptian–Albian	Omati
		JKA 583	*Belemnopsis galoi*	early Tithonian	Imburu
SB/54-7/2		JKA 384	*Hibolithes taylori*	Aptian–Albian	Omati
		JKA 453	*Belemnopsis jonkeri*	Berriasian	Toro
			Hibolithes gamtaensis		
		JKA 600	*Belemnopsis moluccana*	Oxfordian–Kimmeridgian	Imburu
SB/54-7/2		JKA 1267	*Belemnopsis galoi*	early Tithonian	Imburu
SB/54-7/6		JKA 616	*Belemnopsis galoi*	early Tithonian	Imburu
SB/54-7/5		JKA 963	*Belemnopsis galoi*	early Tithonian	Imburu
SB/54-7/2		JKA 712	*Belemnopsis galoi*	early Tithonian	?Imburu
7187/7188	24	P 5014*	*Belemnopsis moluccana*	Oxfordian–Kimmeridgian	Maril
	25	P 5008	*Belemnopsis moluccana*	Oxfordian–Kimmeridgian	Maril
	26	P 5009*	*Hibolithes taylori*	Albian	Chim
			Parahibolites feraminensis		
	29	P 5003*	*Belemnopsis jonkeri*	Berriasian–Valanginian	?

Map index	Locality	Sample	Taxon	Age adopted here	Unit
	29	P 5002*	Parahibolites feraminensis		
			Hibolithes taylori	Albian	Chim
	29	P 5004	Hibolithes taylori	Albian	Chim
SB/55-5		20NG 2635	cf. Hibolithes ingens	?Callovian–early Oxfordian	?Maril
SB/55-13		KAB 69	Hibolithes australis	late Tithonian–early Berriasian	Tubu
7885		HGF 25	Dimitobelus macgregori	Albian–Cenomanian	Chim

1 919   This collection is apparently derived from two distinct stratigraphic horizons indicating late Tithonian and Albian ages. It contains
   Parahibolithes feraminensis (Albian)
   Belemnopsis cf. stolleyi ⎫
   Hibolithes australis   ⎬ (late Tithonian)
   The matrix associated with the specimen of Parahibolites differs from that of the other specimens and their preservation is different.

2 1057   A mixed collection containing
   Parahibolites feraminensis (Albian)
   Belemnopsis cf. galoi (early Tithonian)
   Differences in matrix and preservation similar to those of sample 919 are present.

* Float collections.

Appendix 2. Systematic descriptions.

Terminology and study techniques are detailed elsewhere (Challinor & Skwarko, 1982) and broadly follow Stevens (1965). The classification of Belemnitida follows Jeletzky (1966).

Order **Belemnitida** Zittel 1895
Suborder **Belemnopseina** Jeletzky 1965
Family **Belemnopseidae** Naef 1922
Genus *Conodicoelites* Stevens 1964

Type species. *Dicoelites keeuwensis* Boehm 1912

Conodicoelites kalepuensis Challinor
Figures 6, 7a–i

1982 *Conodicoelites kalepuensis*; Challinor & Skwarko, Pl. 3, Pl. 4.

Localities and material. Approximately 15 specimens from localities 15, 16, 22, 106 (sheet SB/54-7).
Note: Conodicoelites kalepuensis was described originally from Wai Kalepu, Taliabu, Sula Islands (Challinor & Skwarko, 1982) on limited material. The collections studied here allow a slightly emended description and these comments should be read in conjunction with the earlier description.

Age. Bathonian.

Description. Guard conical, elongate, moderately robust. Estimated maximum total length ~180 mm; observed maximum length 150 mm. Postalveolar length 70–100 mm. Ratio of postalveolar length to maximum diameter 4–4.5 in mature guards; 5–6 in less fully developed specimens.

Outline elongate, conical and symmetrical (Fig. 7a,d,g). Maximum transverse diameter at extreme anterior. Anterior two-thirds of guard weakly conical; sides converge apically at 5–7.5°. Posterior region more obtusely conical; sides converge at about 11–15°. Apex acute. Profile asymmetric, conical (Fig. 7c,f). Dorsal and ventral surfaces converge apically in a similar manner and at a similar rate to flanks. Ventral surface slightly inflated in mid-apical region; apex slightly dorsally placed.

Cross-sections (Figs 6, 7h,i) usually slightly compressed anteriorly, sometimes slightly depressed; either slightly compressed to slightly depressed posteriorly. Median ventral groove narrow, shallow, V-shaped in profile, extends from anterior break almost to guard apex (Fig. 7g). Dorsal groove subequal in development (perhaps slightly narrower and shallower) terminating about 30–40 mm from apex.

Lateral lines are visible on only one fragment; double, poorly defined, situated ventro-laterally at a point about 50 mm from apex. All specimens have damaged surfaces and any weakly defined lateral lines are unlikely to have been preserved. They cannot be seen in transverse sections. Internal features as described in Challinor & Skwarko (1982). Splitting surfaces probably extend further towards apex than illustrated by them, and are visible in transverse section at a point about 50 mm from apex in one specimen.
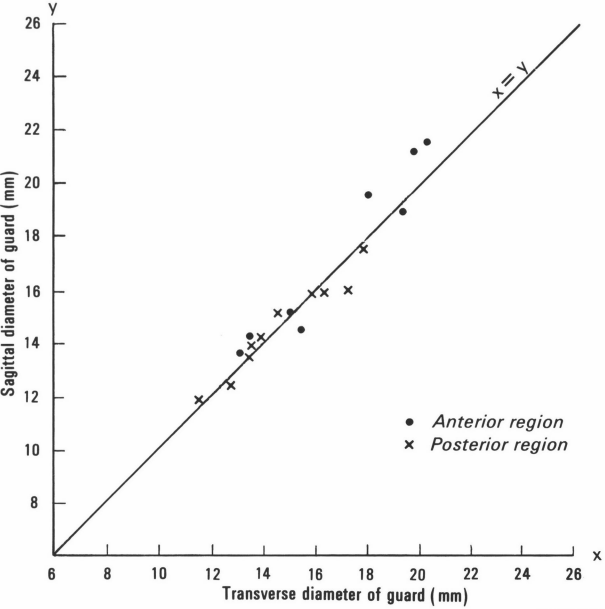

20/09/200

Figure 6. Relationship between guard diameters in *Conodicoelites kalepuensis*.

Figure 7.
Magnification ×1 unless otherwise stated.
a–c, *Conodicoelites kalepuensis* Challinor, CPC 27687, Locality 106, Lagaip River–Ok Om Junction, sheet SB/54-7. a, ventral view; b, dorsal view; c, left lateral view (ventral surface facing left). Specimen partially coated with concretionary matrix. **d–f**, *Conodicoelites kalepuensis* Challinor, CPC 27688, Locality 106, Lagaip River–Ok Om Junction, sheet SB/54-7. d, ventral view; e, dorsal view; f, left lateral view. Specimen partially coated with concretionary matrix; P, approximate position of protoconch. **g**, *Conodicoelites kalepuensis* Challinor, CPC 27689, Locality 22, tributary to Ok Om, sheet SB/54-7. Ventral view. Specimen sheared and metamorphosed, illustrating ventral groove. **h**, *Conodicoelites kalepuensis* Challinor, CPC 27690, ×3, Locality 16, Abum Stream, sheet SB/54-7. Transverse section 60 mm from apex. Dorsal and ventral splitting surfaces visible. Specimen from metamorphic zone of Maril Formation. **i**, *Conodicoelites kalepuensis* Challinor, CPC 27691, ×3, Locality 16, Abum Stream, sheet SB/54-7. Transverse section near apex. **j, k**, *Hibolithes australis* n. sp., CPC 27692, Locality KAB 69, Kereru Range, sheet SB/55-13. j, ventral view; k, right lateral view. Ventro-lateral surface of apical region eroded. P, approximate position of protoconch. **l, m**, *Hibolithes australis* n. sp., IMC 763, Locality 1 D, Wai Kronci, Taliabu, Sula Islands. l, ventral view; m, left lateral view. Immature specimen. P, approximate position of protoconch.

a b c d e f g h i j k l m
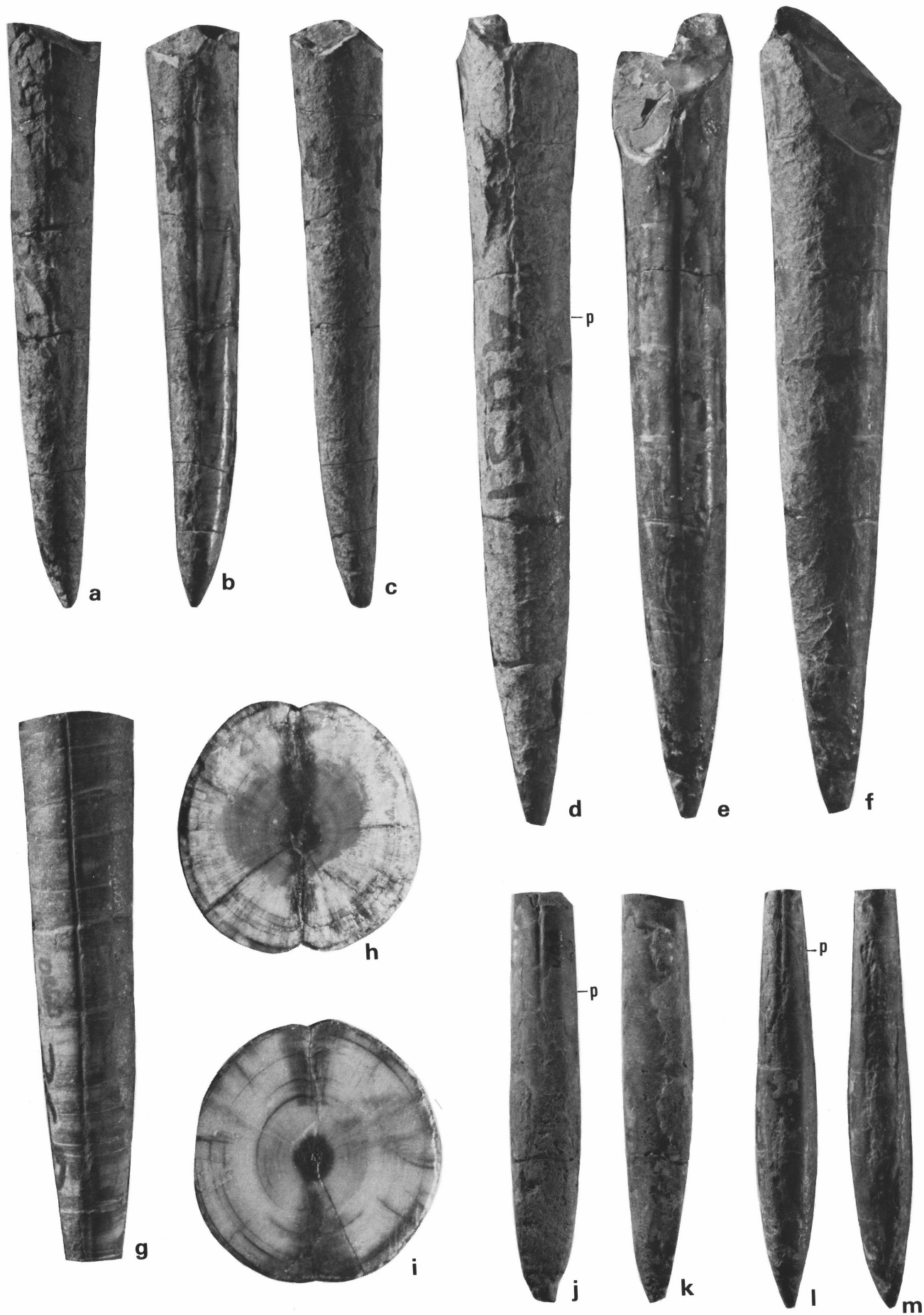
Relationship to *Conodicoelites keeuwensis* (Boehm) has not been elucidated (see Challinor & Skwarko, 1982) even though numerous specimens are available for this study. Only one specimen approaches the short conical form of *keeuwensis* but this fragment is barely 33 mm long and is probably the mid-apical region of a very large *kalepuensis*.

The Early Callovian age for *C. kalepuensis* in Sula Islands (Challinor & Skwarko, 1982) has now been revised to mid-Bathonian after re-examination of associated *Macrocephalites* and other ammonites (Westermann & Callomon, 1988). The taxon is not known from beds dated as early Callovian in Misool Archipelago (Challinor, in press) and no pre-Callovian belemnites are known from that region. The Sula Islands record may not represent the first appearance of the taxon and an unrestricted Bathonian age is proposed.

Genus *Hibolithes* Montfort 1808

Type species. *Hibolithes hastatus* Montfort

Hibolithes australis n. sp.
Figures 7j–m, 8, 9a–i

1982 *Hibolithes* sp. A Challinor & Skwarko, Pl. 8, figs 7, 8.
1982 *Hibolithes* sp. B Challinor & Skwarko, Pl. 8, figs 9, 10.
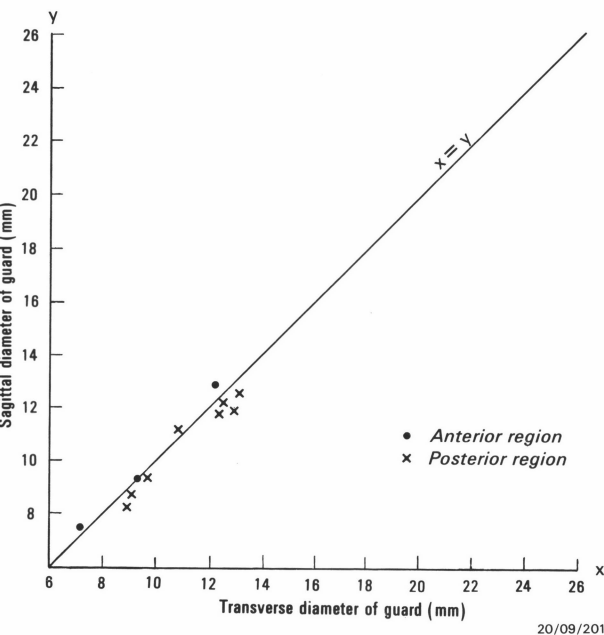
Figure 8. Relationship between guard diameters in *Hibolithes australis* n. sp.

Localities and material. 14 specimens from localities 71 (sheet SB/54-7) Papua New Guinea; KAB 69, Tubu Unit, Kereru'Range, Papua New Guinea (sheet SB/55-13): ID, 8G, 8I, Sula Islands (Sato & others, 1978); 81CP74, 91C, 93, 81R, 76M, Misool Archipelago (Challinor, in press).

Age and stratigraphic horizon. *Hibolithes australis* occurs in the Tubu Unit and Maril Formation in Papua New Guinea, in an unnamed 'marly claystone with concretions' in Sula Islands (Sato & others, 1978) and in the upper Lelinta Shale and basal Gamta Limestone in Misool Archipelago (Challinor, in press). It is of Late Tithonian–earliest Berriasian age.

Brief description. This description is based mostly on poorly preserved fragments. A few specimens are almost complete but most have surface damage. The largest guards are moderately elongate and slightly hastate (Figs 7j,k, 9c,d). Postalveolar length is about five times maximum diameter; total length estimated at 6–7 times maximum diameter.

Outline symmetrical and slightly hastate. Widest point near midpoint, apex moderately elongate; flanks converge slightly towards anterior (maximum diameter of largest specimen, Fig. 7j,k, 13.1 mm; diameter at anterior break 11.6 mm). Profile asymmetric, less hastate than outline. Ventral surface slightly inflated in apical region, apex slightly dorsally placed.

Cross-sections almost circular, slightly depressed in apical half of guard, very slightly compressed anteriorly (Figs 8, 9e,h,i). Flanks, dorsal and ventral surfaces regularly rounded. Median ventral alveolar groove shallow, moderately narrow, well defined only in alveolar region, extends onto postalveolar guard as a shallow depression; terminates well before midpoint.

Lateral lines not seen in most specimens due to poor preservation; one better preserved guard bears two well defined closely spaced lines near the midline of the apical region; they deflect ventrally at the estimated midpoint.

Apical line centrally or slightly ventrally placed. Growth lines numerous, closely spaced, usually no systematic division into major growth stages although a juvenile stage about half the diameter of the adult is sometimes clearly defined. No information on protoconch, phragmocone or alveolus available.

Ontogeny. Juvenile and immature guard much more hastate than adult (Figs 7 l,m, 9a,b). Widest point located near midguard. In late ontogeny anterior half of the guard apparently increases in diameter more rapidly than posterior half, markedly reducing hastation in the adult.

Discussion. The taxon has been recorded from eastern Indonesia as well as Papua New Guinea but all adult Indonesian specimens are fragments. The single specimen from the Tubu Unit, Papua New Guinea (Fig. 7j,k), although abraded posteriorly, is the most nearly complete adult specimen known.

H. australis may have affinities with *Hibolithes brevis* (Stolley, 1929) but this is uncertain because all Stolley's specimens are poorly preserved fragments (as are all *H. australis* from Misool and Papua New Guinea and most from Sula). Stolley's specimens were collected from Timor (locality details unknown) and their age cannot be more closely defined than Late Jurassic. *Hibolithes* sp. B is a near adult *H. australis* and *Hibolithes* sp. A an immature guard (Challinor & Skwarko, 1982).

Because *Hibolithes australis* has been described from mostly fragmentary specimens from widely separated localities, the possibility that it is a composite taxon cannot be entirely eliminated. However, the morphology of all specimens is consistent with specific identity as is the age information available.

Etymology. *Hibolithes australis* — southern *Hibolithes*.

Figure 9.
Magnification ×1 unless otherwise stated.
a, b, *Hibolithes australis* n. sp., IMC 331, Locality 8 G, Minaluli, Mangole, Sula Islands. a, ventral view; b, left lateral view. Immature specimen. **c–e,** *Hibolithes australis* n. sp., IMC 764, Locality 81CP74, Misool Archipelago. c, ventral view; d, left lateral view; e, transverse section just posterior to protoconch, ×3. **f–h,** *Hibolithes australis* n. sp., IMC 765, Locality 8 I, Minaluli, Mangole, Sula Islands. f, ventral view; g, left lateral view; h, transverse section at anterior end of specimen, ×3. **i,** *Hibolithes australis* n. sp., IMC 766, Locality 81CP74, Misool Archipelago. X3. **j, k,** *Hibolithes gamtaensis* n. sp., CPC 27693, Locality 187, Strickland River, sheet SB/54-7. j, ventral view; k, left lateral view. P, approximate position of protoconch. **l,** *Hibolithes gamtaensis* n. sp., CPC 27694, Locality 187, Strickland River, sheet SB/54-7. Transverse section in posterior half of guard, ×3. **m, n,** *Hibolithes* sp. I, CPC 27709, Locality 187, Strickland River, sheet SB/54-7. m, ventral view; n, left lateral view. **o,** *Hibolithes taylori* n. sp., CPC 27695, Locality 29, Dagiam River, sheet 7187/7188. Ventral view. P, approximate position of protoconch. **p,** *Hibolithes taylori* n. sp., CPC 27696, Locality 29, Dagiam River, sheet 7187/7188. Ventral view. Juvenile specimen coated with concretionary matrix. *Note:* Scale ×1.3, differs from that of other specimens illustrated. **q,** *Hibolithes taylori* n. sp., CPC 27697, Locality 42, Ok Tedi, sheet SB/54-7. Transverse section in apical region, ×3. **r, s,** *Hibolithes taylori* n. sp., CPC 27698, Locality 29, Dagiam River, sheet 7187/7188. r, ventral view; s, left lateral view. P, approximate position of protoconch; T, posterior termination of ventral groove. Specimen coated with concretionary matrix.

a   b   c   d   e   f   g

i   h

j   k   m   n   o   r   s

—p

—p   —p

—t

l   p   q
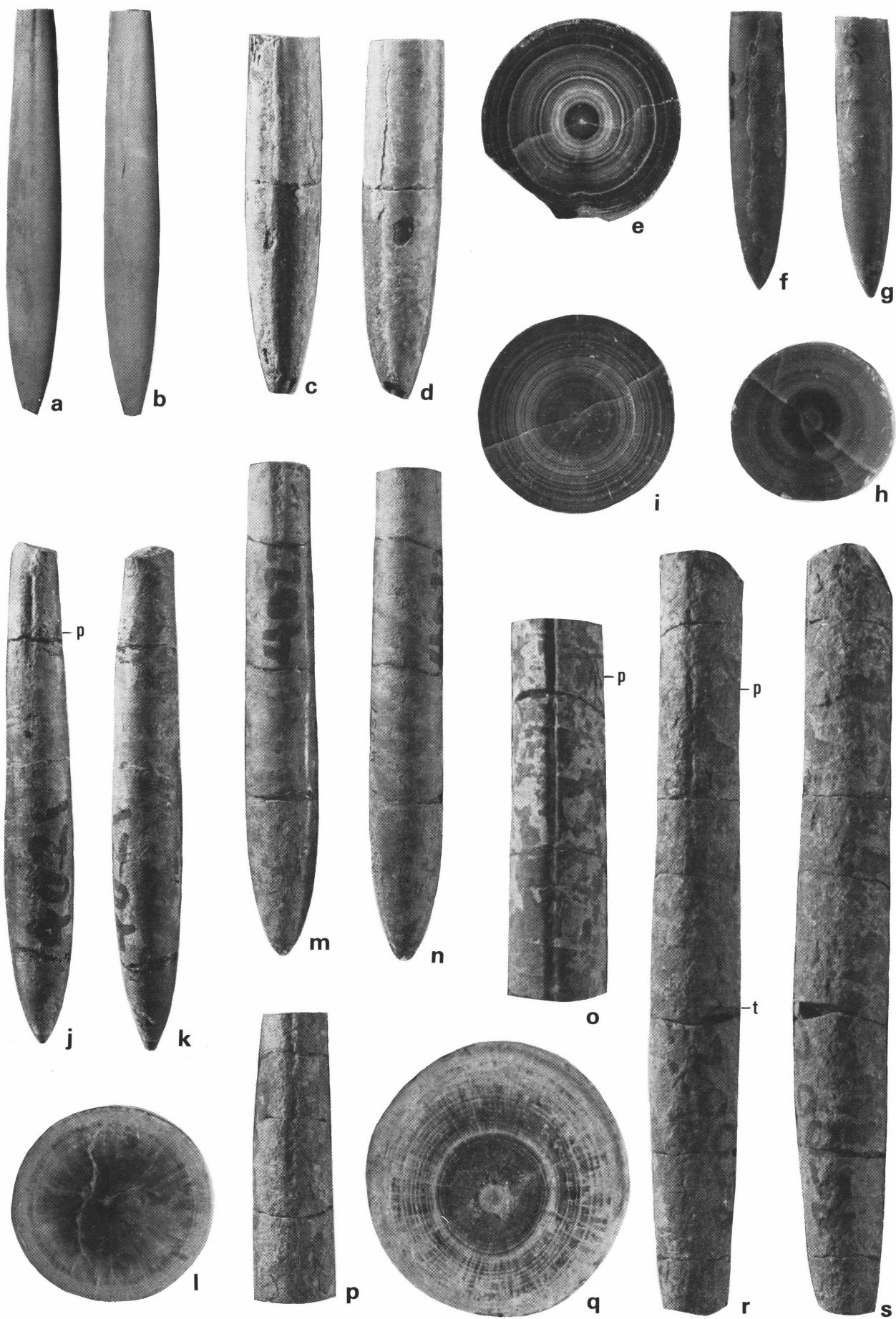
Hibolithes gamtaensis n. sp.
Figure 9j–l

1935 *Hibolithes subfusiformis* Raspail; Stolley Pl. 5, figs 7, 8: *non* fig. 6.
1989a *Hibolithes miosensis* Challinor *partim*. Pl. 2, figs 13–15, 24, 26 only; Pl. 5, figs 12, 13 only.
in press *Hibolithes gamtaensis* Challinor Pl. 14, figs 1–22.

Localities and material. Approximately 10 specimens from localities 5 and 187 (sheet SB/54-7) and collection JKA 453 (sheet SB/54-7/2).

Age and stratigraphic horizon. *Hibolithes gamtaensis* occurs in the Toro Sandstone and basal Ieru Formation in the central highlands of Papua New Guinea, in the Kembelangen group on the Mios and Ainim Rivers in the central Birds Head of Irian Jaya, and in the lower Facet Limestone (Gamta Member) of the Misool Archipelago. It is Neocomian (provisionally Berriasian–Valanginian) in age in Papua New Guinea.

Note. This brief description is published to validate the taxon for the purposes of this paper. A full description based on abundant material from the Misool Archipelago, Irian Jaya, will be published elsewhere (Challinor, in press).

Brief description. Guard slender and elongate, usually moderately hastate. Total length of a typical adult is ~80–90 mm. Widest point usually situated in posterior half of guard. Guard tapers steadily towards anterior; occasional specimens are only slightly hastate. Profile less hastate than outline. Dorsal surface often slightly more inflated near apex than ventral surface, apex then slightly dorsally placed. Cross-sections usually slightly depressed throughout (A value* 101–108 posteriorly, 99–107 anteriorly). Flanks, dorsal and ventral surfaces regularly rounded.

Median ventral groove narrow, shallow, usually confined to alveolar and immediately postalveolar region, extending a little further adapically in some adults. Double lateral lines present on most well preserved specimens. They are situated at about the guard midline throughout their length, are well defined, narrow, sharply incised and close together in the apical half of the guard, less well defined and a little further apart in the oral half. Apical line approximately centrally placed. Growth lines numerous, closely spaced, major growth stages not regularly defined. A splitting surface is present beneath the ventral groove.

Etymology. *Hibolithes gamtaensis* is named from the Gamta Islands, Misool, Indonesia.

Hibolithes taylori n. sp.
Figures 9 o–s, 10, 11a–e, 12

Localities and material. Approximately 20 specimens from localities 26 and 29 (sheets 7187/7188): 42, 46, 57, 82, 136 (sheet SB54-7) and Samples JKA 384 (sheet SB/54-7/2) and 146 (sheet SB/54-7/5).

Age and stratigraphic horizon. *Hibolithes taylori* occurs in the Ieru and Chim Formations and is of Aptian–Albian age.

$$*A = \frac{\text{Transverse diameter (mm)}}{\text{Sagittal diameter (mm)}} \times 100$$

Figure 10. Relationship between guard diameters in *Hibolithes taylori* n. sp.

Diagnosis. Guard large, elongate, relatively slender, hastate, compressed in cross-section, ventral groove extends about midway along guard.

Description. *External features.* Guard large, elongate and relatively slender; length about 8–10 times maximum diameter. Largest almost complete specimen available ~150 mm in length, 16.5 mm in maximum diameter (Fig. 9r,s). Fragments over 20 mm in diameter observed.

Outline symmetrical and hastate (Fig. 9r). Widest point located about midway along guard. Sides at first converge gradually towards apex, more rapidly over terminal 30–40 mm; apical region moderately acute. Sides converge steadily anteriorly to produce moderate transverse hastation; observed differences between maximum and minimum diameters of between 1.6 and 3.0 mm. Profile asymmetrical and hastate. Deepest point located about midway along guard (Figs 9s, 11b). Dorsal surface almost straight, converges gradually towards midline anteriorly, remains almost parallel to midline posteriorly, converges rapidly towards apex over terminal 20–30 mm. Ventral surface inflated near midguard, converges anteriorly to produce moderate sagittal hastation; converges towards apex gradually over terminal 40–60 mm, more rapidly near apex. Ventral inflation and differing position and rates of apical curvature of dorsal and ventral faces produce marked asymmetry of profile.

Cross-sections slightly to moderately compressed (A = ~95), slightly more so anteriorly (Figs 10, 11c,d). A few specimens are approximately equidimensional posteriorly (Fig. 11e). Cross-section regularly oval in posterior regions; widest point situated about midway between dorsal and ventral surfaces; flanks, dorsal and ventral surfaces regularly rounded. Cross-section slightly ovoid anteriorly (Fig. 11c,d), widest point situated nearer a wider rounded dorsal face, ventro-lateral flanks flattened, converging towards a relatively narrow ventral face.

Figure 11.
Magnification ×1 unless otherwise stated.
a, b, *Hibolithes taylori* n. sp., CPC 27699, Locality 26, Dagiam River, sheet 7187/7188. a, ventral view; b, left lateral view. **c,** *Hibolithes taylori* n. sp., CPC 27700, Locality 42, Ok Tedi, sheet SB/54-7. Transverse section near protoconch, ×3. **d,** *Hibolithes taylori* n. sp., CPC 27701, Locality 120, Hindenberg Wall, sheet SB/54-7. Transverse section in anterior region of guard, ×3. **e,** *Hibolithes taylori* n. sp., CPC 27702, Collection JKA 384, sheet SB/54-7/2. Transverse section in apical region ×3. **f, g,** *Parahibolites feraminensis* n. sp., CPC 27703, Locality 29, Dagiam River, sheet 7187/7188. f, ventral view; g, left lateral view. P, approximate position of protoconch. T, posterior termination of ventral groove. **h–j,** *Parahibolites feraminensis* n. sp., CPC 27704, Collection 1057 unlocalised, near Feramin Village, sheet SB/54-7. h, ventral view; i, left lateral view; j, view of alveolar end, ×3. P, approximate position of protoconch; T, termination of ventral groove. **k, l,** *Parahibolites feraminensis* n. sp., CPC 27705, Collection 1057 unlocalised, near Feramin Village, sheet SB/54-7. k, ventral view; l, left lateral view. P, approximate position of protoconch. **m–o,** *Parahibolites feraminensis* n. sp., CPC 27706, Collection 1057 unlocalised, near Feramin Village, sheet Sb/54-7. m, left lateral view; n, ventral view; o, transverse section near protoconch, ×3. Note pronounced lateral flattening of growth lines. **p, q,** *Parahibolites feraminensis* n. sp., CPC 27707, Collection 919, locality 71, Anamen Creek, sheet SB/54-7. p, alveolar view; q, transverse section at guard anterior, ×3. Guard fragment is 32 mm long. Note flattened growth lines on q. *Note*: Locality details uncertain (see above). **r,** *Parahibolites feraminensis* n. sp., CPC 27708, Collection 1057, unlocalised, near Feramin Village, sheet SB/54-7. Left lateral view of apical fragment illustrating apical asymmetry.
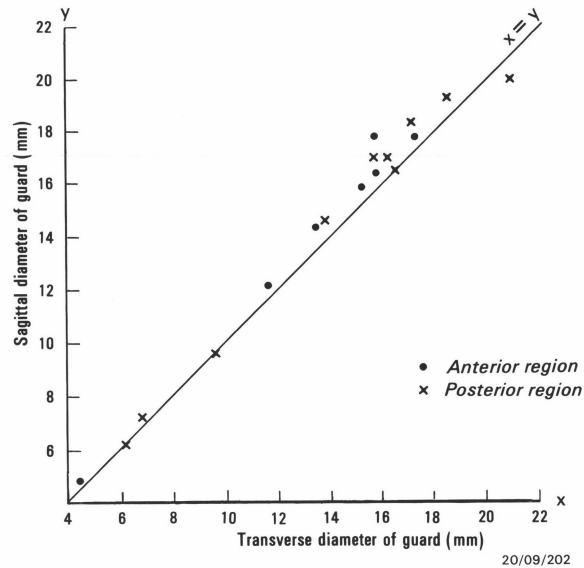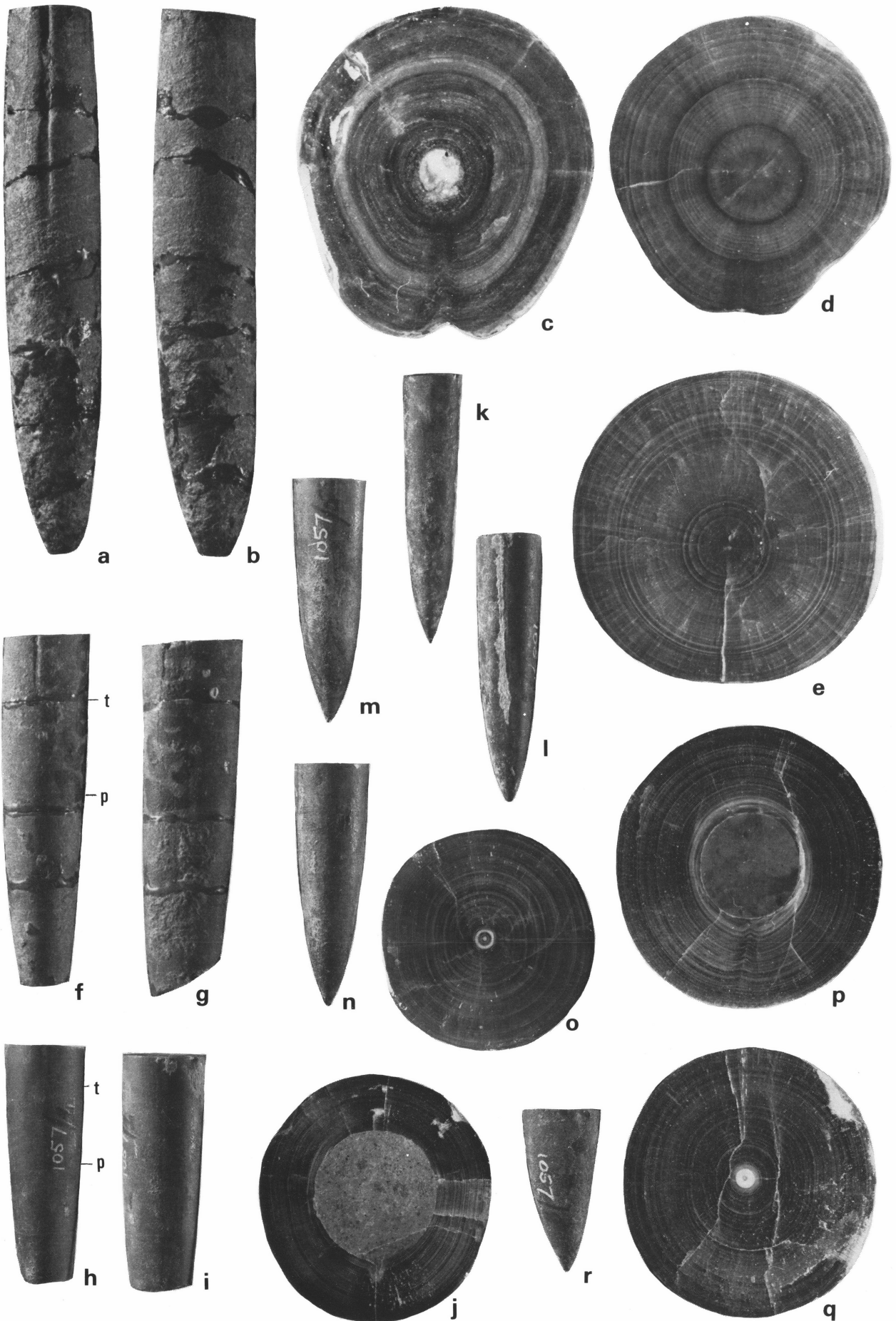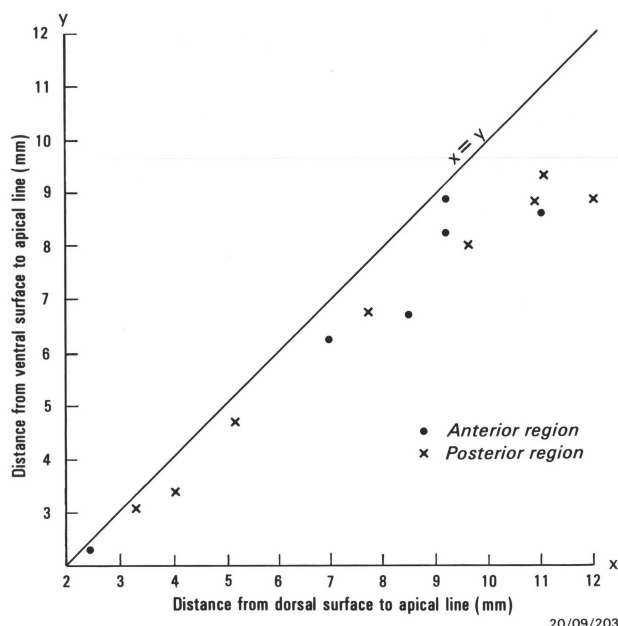
a b c d k m l e n o p f g h i j r q

20/09/203

Figure 12. Position of the apical line in *Hibolithes taylori* n. sp.

Median ventral groove commences at alveolar break, terminates between midpoint of the guard and the apex (Figs 9r, 11a). It is well defined, narrow, moderately shallow, V-shaped in section and sharply incised into guard surface in anterior one-third (Fig. 9 o). Over the guard mid to apical region it widens, shallows posteriorly and becomes imperceptible.

Lateral lines are double, situated close together, commencing on the dorso-lateral surface near the apex and passing obliquely towards the ventral surface over the posterior 60–70 mm of the guard. Near mid-guard they are visible as a single wider depression. They are visible in many transverse sections as shallow embayments in the growth lines of mid-guard fragments and their presence anteriorly is probably responsible for the ventro-lateral flattening of the flanks noted above.

Internal features and ontogeny. Alveolus short in relation to guard length. Details of phragmocone and protoconch not known. Apical line usually ventrally placed, strongly so in large specimens (Figs 9q, 11e, 12). A splitting surface underlies the ventral groove and is visible in most transverse sections of the anterior guard. Growth lines are numerous, clearly defined in transverse sections and closely spaced. A prominent line or group of lines outlines a well defined juvenile growth stage in most specimens. This probably marks the transition from early ontogeny when growth is mainly lengthwise, to late ontogeny when growth is largely diametral, a characteristic feature in the growth of belemnopseids.

Discussion. The belemnites of eastern Indonesia are now moderately well known, both stratigraphically and taxonomically (Challinor & Skwarko, 1982; Challinor, 1989a,b, in press). The youngest known *Hibolithes* of the region are early Hauterivian in age (Challinor, 1989a, in press). *Hibolithes taylori* apparently postdates these taxa and therefore has a maximum age of late Hauterivian or Barremian. However, it is associated in collections P 5002 and P 5009 with *Parahibolites*, and this genus is not known earlier than Aptian time (Stevens, 1973). Furthermore, *H. taylori* and *Parahibolites* are associated only in siltstones interpreted as Chim Formation; there is no indication they occur together in the Omati unit. New Guinea *Parahibolites* have been dated by Glaessner (1945) as Late Albian and by Stevens (1965) as Aptian–Albian. Therefore, *Hibolithes taylori* is unlikely to be older than Late Neocomian and may be as young as Late Albian. Although *Hibolithes sensu stricto* was of major importance in the Tethyan fauna from Bajocian to Tithonian time, it declined in the Neocomian and was apparently absent from the Tethys after the Barremian (Stevens, 1973) and after the early Aptian in the Boreal Realm (Mutterlose, 1988). The occurrence of *Hibolithes* in Aptian–Albian beds represents an extension of its known time range.

Hibolithes taylori is quite distinct from all previously described Indonesian and New Guinea Cretaceous *Hibolithes*. Those species from eastern Indonesia which are abundant and stratigraphically useful are depressed in cross-section, smaller, and have short ventral grooves (Challinor, 1989a, in press). A number of poorly known *Hibolithes* of Berriasian–Hauterivian age occur in the Misool Archipelago (Challinor, in press); most are represented by single specimens, are depressed in cross-section and are short grooved, but one or two are either compressed in cross-section or have long ventral grooves. They are much smaller than *Hibolithes taylori* and are quite different in form.

Hibolithes taylori resembles West Antarctic and New Zealand Late Jurassic or Early Cretaceous *Hibolithes* (e.g. *H.* aff. *arkelli*, Mutterlose 1986; *H. arkelli*, Stevens 1965; *H. antarctica*, Willey 1973) in its compressed cross-section and long ventral groove. Evidence is accumulating to suggest that New Zealand and South American Belemnitida are closely related and that New Zealand faunas migrated from the Antarctic Peninsula–southern South America region via West Antarctica (Challinor & others, in press). *Hibolithes taylori* may have followed this route and continued on into New Guinea.

Etymology. *Hibolithes taylori* is named for my late son-in-law, Bruce Alan Taylor.

Hibolithes sp. I
Figure 9m,n

Locality and material. One specimen from locality 187 (sheet SB/54-7).

Age and stratigraphic horizon. *Hibolithes* sp. I is known only from the Ieru Formation where its age is Berriasian–Valanginian.

Brief description. This description is based on a single incomplete specimen which consists of most of the postalveolar guard. It is 88 mm long, 13 mm in maximum diameter and is slightly eroded along one flank.

Guard elongate and moderately slender; postalveolar length estimated at about 7–8 times maximum diameter; total length about 9 times maximum diameter. Outline symmetrical and slightly hastate; widest point situated in posterior one-third of guard; apical regions moderately obtuse. Sides converge gradually towards anterior; maximum transverse diameter estimated at 13.0 mm, transverse diameter at anterior break 11.4 mm. Profile similar to outline; maximum sagittal diameter 13.0 mm, sagittal diameter 11.6 mm anteriorly.

Cross-section approximately equidimensional posteriorly, slightly compressed (A = 98) anteriorly. Dorsal and ventral surfaces regularly rounded, lateral surfaces slightly flattened. Median ventral alveolar groove moderately wide, shallow, broadly V-shaped. In the available specimen it extends down the guard for ~17 mm but is very weakly developed over its terminal 10 mm; it is clearly confined to the anterior one-third of the guard but its exact relationship to post-alveolar length cannot be determined because the protoconch is missing. Lateral lines are not visible, perhaps due to surface damage. Apical line centrally placed at anterior break; a narrow splitting surface extends from apical line to the base of the ventral groove.

Discussion. *Hibolithes* sp. I does not closely resemble any Jurassic or Cretaceous *Hibolithes* known from the southwest Pacific. Its informal designation as *H.* species I continues the nomenclatural practice commenced earlier (Challinor & Skwarko, 1982; Challinor, in press) to record a number of poorly known *Hibolithes* from the southwest Pacific region.

cf. *Hibolithes ingens* Stolley

cf. 1929 *Hibolites ingens* Stolley; Pl. 7, figs 1–5; Pl. 8, figs 1–5.

Locality and material. Parts of ?two poorly preserved specimens from locality 2ONG 2635, sheet SB/55-5, Ramu.

Age and stratigraphic horizon. Cf. *Hibolithes ingens* occurs in the 'Balimbu Greywacke'. This formation was dated by Bain & others

(1975) as Early Jurassic but *Hibolithes ingens* itself is of Callovian–?early Oxfordian age, suggesting the true stratigraphic position of cf. *Hibolithes ingens* is mid-Maril Formation.

Discussion. The material discussed here was received as a number of fragments sectioned by a previous worker and is interpreted as parts of two specimens. The largest appears to have had an original length of about 250 mm and a maximum diameter of about 40 mm. The specimens are strongly recrystallised and were examined in thin section.

The outline and profile are hastate, the point of maximum diameter is posteriorly placed, the cross-section is depressed with regularly rounded dorsal and lateral surfaces and a flattened ventral surface, and the apical line is ventrally placed. No evidence of a ventral or other surface groove is evident: such a groove might have been destroyed during alteration, or confined to part of the guard not preserved.

In gross shape, cross-section and apical line position the large specimens resemble *Hibolithes ingens* Stolley (1929, Pl. 7; Pl. 8, figs 1–5). The latter is the only belemnite known from eastern Indonesia which is of similar large size. The fragment interpreted as a second smaller specimen is similar to *Hibolithes* cf. *ingens* (Challinor, in press, Pl. 15, figs 8–16). It is likely that cf. *H. ingens* is *Hibolithes ingens sensu stricto*, but it is so poorly preserved that firm identification is impossible.

Genus *Parahibolites* Stolley 1915

Type species. *Neohibolites duvalaeformis* Stolley 1911

Parahibolites feraminensis n. sp.
Figures 11f–r, 13

1945 *Parahibolites blanfordi* (Spengler) Glaessner, Pl. 6, fig. 10a–c.

Localities and material. Approximately 14 specimens from localities 26 and 29 (sheet 7187/7188) and unlocalised collections (sheet SB/54-7).

Age and stratigraphic horizon. *Parahibolites feraminensis* is of ?Albian age and occurs in the Ieru and Chim Formations.
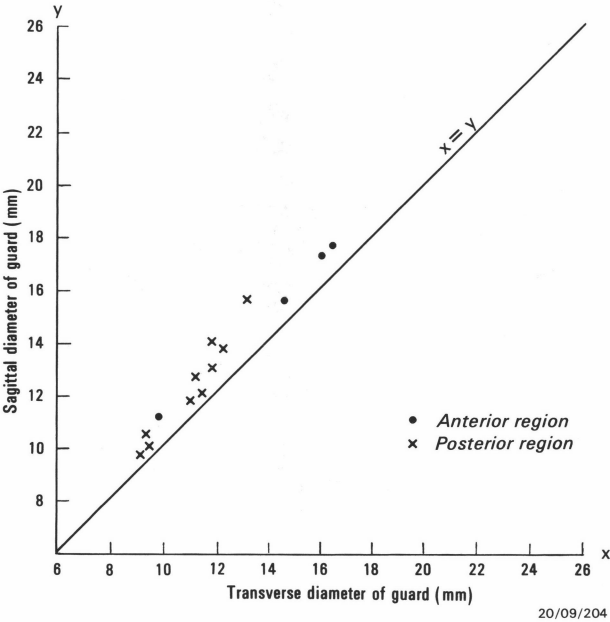
Diagnosis. Guard moderately sized, subconical, laterally compressed, double lateral lines prominent, alveolus long in relation to guard length, ventral alveolar groove very short.

Description. *External features.* Guard subconical and moderately elongate. Total length about 5 times maximum diameter, postalveolar length about 2.5 times maximum diameter in mature specimens. Largest specimen available has a maximum sagittal diameter of 17.8 mm and an estimated reconstructed length of 100 mm.

Outline symmetrical and weakly conical (Fig. 11h,k). Widest point at anterior limit; oral half of guard tapers gradually towards apex; apical half tapers more rapidly, particularly over terminal 20–30 mm; apex acute. Profile conical and asymmetrical (Fig. 11 l,r). Deepest point on guard at anterior limit. Dorsal and ventral surfaces converge steadily towards apex, more rapidly in apical half of guard. Ventral surface begins to converge towards the apex earlier than does the dorsal face, dorsal region near apex slightly inflated; apex slightly dorsally placed and moderately acute.

Cross-sections laterally compressed throughout length of guard (Table 3); slightly more so in apical half and in larger specimens (Figs 11j,o–q, 13); oval, dorsal and ventral faces regularly rounded, lateral faces slightly to markedly flattened (Fig. 11 o–q). Ventral alveolar groove narrow, shallow, V-shaped in section and confined to the anterior alveolar region (Fig. 11f). A splitting surface, best seen in polished transverse sections, is present below the groove (Fig. 11p).

Lateral lines prominent and sharply defined, beginning about 10 mm from apex, at about the midline and extending to or almost to the anterior limit of the guard; double, close together, ventral line better defined than dorsal; they are more prominent in the apical half of the guard although usually clearly visible in the alveolar region.

Internal features. Apical line and protoconch approximately centrally placed; apical line becomes dorsally placed near apex. Dorso-ventral alveolar angle about 20°, alveolus deep, extends about halfway down guard and becomes dorsally eccentric anteriorly. A pseudoalveolus is often present. Growth lines well developed, numerous, close together, clearly visible in polished transverse sections. A well defined embayment present in growth lines at mid-flank marks the position of the lateral lines.

Ontogeny. Early true guard very elongate, hastate. Juvenile and immature guards more elongate and slender than adults, growth in length dominates early ontogeny, growth in diameter late ontogeny. Due to limited material, guard development has not been fully investigated.

Discussion. The specimens conform closely in all characteristics except size to *Parahibolites* Stolley 1915. A single specimen collected earlier from the Feing Group (mid-Bawai unit near localities 129 and 130, Ok Tedi sheet) and described by Glaessner (1945) as *Parahibolites blanfordi* (Spengler) appears identical to this material and is similar in size to Figure 11k,l. However, the taxon is clearly distinct in its large size from *P. blanfordi* (recently redescribed from West Antarctica by Doyle, 1985) and from other *Parahibolites*.

No *in situ* collections of *P. feraminensis* are known but it is associated with *Hibolithes taylori* in float collections (P 5002, P 5009) at localities 26 and 29 (sheet 7187/7188). *H. taylori* also occurs *in situ* at locality 29.

Etymology. *Parahibolites feraminensis* is named from Feramin Village whose people collected most of the specimens.

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Figure 13. Relationship between guard diameters in *Parahibolites feraminensis* n. sp.

Table 3. A values for *Parahibolites feraminensis*.

	n	$\bar{x}$	$\theta n\text{-}1$
Anterior half of guard	10	89.0	3.5
Posterior half of guard	4	92.2	2.6