Cambrian and Ordovician stratigraphy and biostratigraphy of the Arafura Basin, offshore Northern Territory

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ZHEN, Y.Y., LAURIE, J.R. & NICOLL, R.S., 2011:12:23. Cambrian and Ordovician stratigraphy and biostratigraphy of the Arafura Basin, offshore Northern Territory. *Memoirs of the Association of Australasian Palaeontologists 42*, 437-457. ISSN 0810-8889.

Recovery of conodonts and other fossils from four petroleum exploration wells (Esso Tasman 1 and Torres 1; Petrofina Goulburn 1 and Arafura 1), drilled in the Goulburn Graben of the Arafura Basin off the northern coast of Australia, have extended the known distribution of both Ordovician and Cambrian sediments across part of the northern Australian continental margin. The Cambrian and Ordovician sediments in the Arafura Basin comprise the four formations of the Goulburn Group. The recovered fossils indicate that in the offshore, the Jigaimara Formation is most likely of middle to late Templetonian age, the Naningbura Dolomite is Furongian to early Tremadocian, the Milingimbi Formation is middle Tremadocian, and the Mooroongga Formation is of late Tremadocian to middle Floian age.

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Keywords: Arafura Basin, stratigraphy, biostratigraphy, Cambrian, Ordovician, conodonts, trilobites

THE ARAFURA BASIN is a mainly offshore Neoproterozoic to Permian sedimentary basin, at least 350,000 sq km in areal extent, that underlies much of the Arafura Sea to the north of the Northern Territory, Australia (Fig. 1). To the south the basin extends inland up to about 80 km where it unconformably overlies the Palaeoproterozoic to Mesoproterozoic McArthur Basin in the east and the Palaeoproterozoic Pine Creek Inlier to the west (Totterdell 2006). The northward extent of the basin and its Palaeozoic sediments are not well defined, but seismic interpretation suggests that Cambrian to Devonian or Carboniferous rocks probably extend northward toward the Aru Ridge and Merauke Rise to the south of Papua, Indonesia (Moss 2001). Offshore to the west, the Arafura Basin is unconformably overlain by the Middle Jurassic to Holocene Money Shoal Basin, and to the east it is unconformably overlain by the Mesozoic to Cenozoic Carpentaria Basin (Bradshaw *et al*. 1990).

Fossils from the Central Range of Papua (Fortey & Cocks 1986; Nicoll & Bladon 1991) indicate the presence of early Palaeozoic (Ordovician to Silurian) marine sediments. This, coupled with the interpretation of seismic data, suggest that Palaeozoic sediments once probably extended uninterrupted across an extensive continental shelf to a continental margin, as indicated by the presence of Ordovician deep water graptolitic black shales (Fortey & Cocks 1986) in central Papua. This is supported by the recovery of Early Ordovician conodonts from the wells Noordwest 1 and Cross Catalina 1 in central Papua (Nicoll 2002).

The Arafura Basin consists of a northern platform and a southern platform separated by the WNW trending Goulburn Graben which has been the focus of petroleum exploration in the basin. The major phase of petroleum exploration in the Goulburn Graben was undertaken between 1983 and 1986, with the drilling of Tasman 1, Torres 1, Arafura 1, Kulka 1 and Goulburn 1 (Bradshaw *et al*. 1990). A subsequent phase during the early 1990s resulted in the drilling of Tuatara 1, Chameleon 1 and Cobra 1A.

SAMPLING

Rocks of Cambrian and Ordovician age have been intersected in four wells (Tasman 1, Torres 1, Arafura 1 and Goulburn 1) drilled in the Goulburn Graben (Figs 2-3). This study is based on cuttings samples obtained from all four wells and core from Arafura 1 (Table 1). Core from Tasman 1 and Torres 1 was also examined for phosphatic material, but proved barren.

The details of the wells are as follows:

Esso Tasman 1: 133.1837 degrees E, 10.7098 degrees S, drilled in 66 metres of water to a total depth of 2720 metres in February-April 1983.

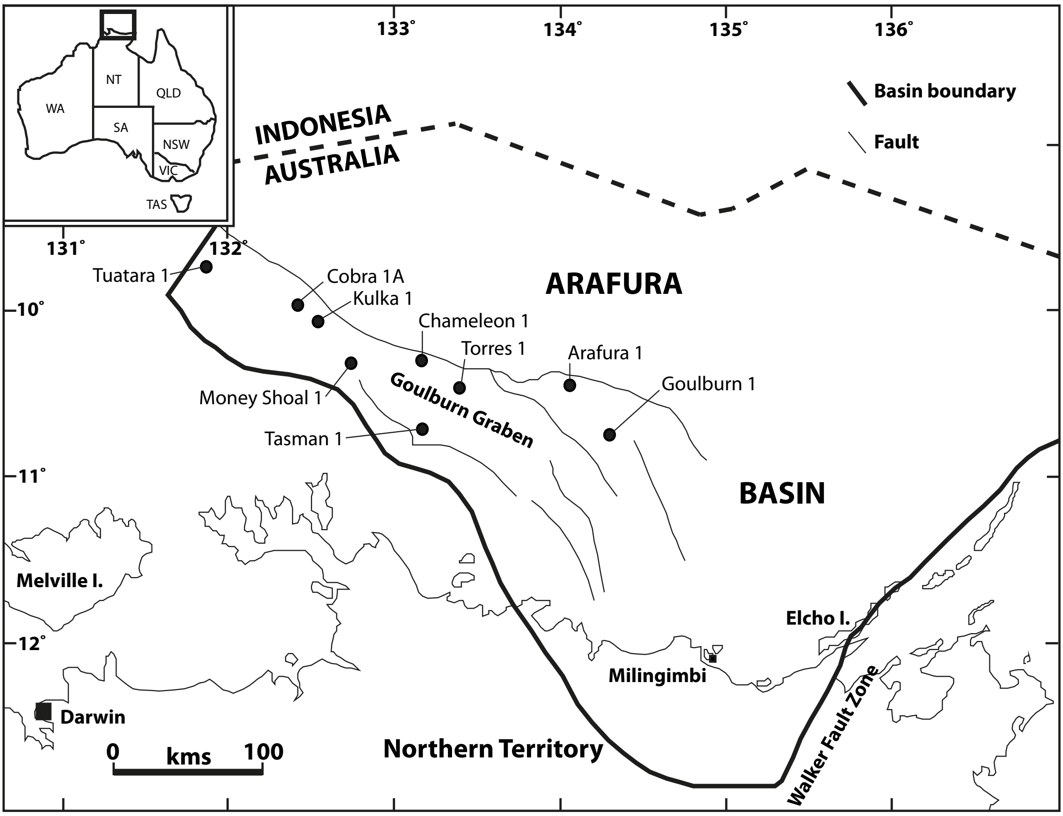

Figure 1. Location of Arafura Basin and relevant wells.

Esso Torres 1: 133.3950 degrees E, 10.4670 degrees S, drilled in 67 metres of water to a total depth of 2758 metres in June-August 1983.

Petrofina Arafura 1: 134.0575 degrees E, 10.4508 degrees S, drilled in 64.4 metres of water to a total depth of 3635 metres in January-April 1983.

Petrofina Goulburn 1: 134.2968 degrees E, 10.7464 degrees S, drilled in 65.5 metres of water to a total depth of 1304 metres in February-March 1986.

STRATIGRAPHY

The Arafura Basin succession is divided into four groups which, in ascending order, are the Neoproterozoic Wessel Group, the Cambrian to Ordovician Goulburn Group, the Late Devonian Arafura Group and the Carboniferous to Permian Kulshill Group. Only the Wessel Group and the lower part of the basal unit of the Goulburn Group outcrop in Arnhem Land, with the remainder being recorded only from offshore wells. The stratigraphic scheme followed in this study is that of Rawlings *et al*. (1997) and Haines (1998).

Wessel Group

The Wessel Group (Plumb et. al. 1976) consists of four formations (Fig. 2), which, in ascending order, are the Buckingham Bay Sandstone, Raiwalla Shale, Marchinbar Sandstone and Elcho Island Formation. The Wessel Group consists of siliciclastic marine sediments, mostly quartz sandstones and shales, and has an aggregate thickness of about 1500 m.

Buckingham Bay Sandstone. This unit comprises mostly fine to coarse grained, medium to thick bedded sandstone commonly with a basal conglomerate, and is estimated to be about 350 m thick. No body fossils have been found in the unit and the purported *Skolithos* trace fossils recorded by Plumb (1963, p. 6) and Dunnet (1965), and used to suggest a Cambrian age for the entire Wessel Group by Plumb *et al*. (1976), are now considered to be caused by dewatering of fluidised sand, and are therefore abiogenic (Rawlings *et al*. 1997).

Raiwalla Shale. This unit consists mostly of interbedded mudstone and very fine to medium grained sandstone, and is estimated to be about 1000 m thick. No metazoan or trace fossils have been recorded, but Haines (1998) has described *Chuaria* from the unit, which indicates a Neoproterozoic age (Rawlings *et al*. 1997).

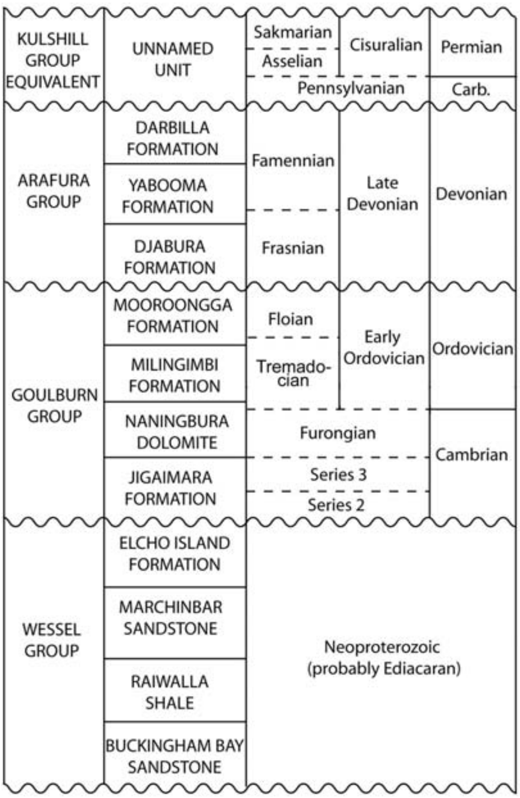

Figure 2. Stratigraphy of Arafura Basin.

Marchinbar Sandstone. This unit consists almost entirely of clean, white, medium grained quartz sandstone. No body or trace fossils have been found in the unit and its Neoproterozoic age is based entirely on its stratigraphic position (Rawlings *et al*. 1997).

Elcho Island Formation. This formation was named by Plumb (1965) and Dunnet (1965) and was defined by Plumb & Roberts (1992). Haines (in Rawlings *et al*. 1997, p. 108) subsequently redefined the Elcho Island Formation to exclude a younger succession named the Jigaimara Formation (see below) that was included in the overlying Goulburn Group. As redefined, the formation comprises up to 700 m of fine to coarse grained sandstone interbedded with minor mudstone and contains no body or trace fossils. It outcrops extensively along and near the north coast of Arnhem Land and on some of the adjacent islands. Sandstones and siltstones belonging to this unit have also been intersected in Arafura 1 and extend from 3596 m down to the bottom of the well at 3635 m (i.e. 39 m in thickness).

McDougall *et al*. (1965) radiometrically dated glaucony from low in the Elcho Island Formation and obtained ages of about 770 Ma (K-Ar) and 790 Ma (Rb-Sr), indicating a Neoproterozoic age for the unit (Rawlings *et al*. 1997).

Goulburn Group

The Goulburn Group was proposed by Petroconsultants Australasia Pty Ltd (1989) to include a predominantly dolomitic carbonate interval, of presumed Ordovician age. Bradshaw *et al*. (1990) recognised three subdivisions of the Goulburn Group and named, but did not define, the upper two units (Milingimbi and Mooroongga formations). Nicoll *et al*. (1996) expanded the original concept of the group to include the Jigaimara Formation at its base, and also named, but did not define, the overlying Naningbura Dolomite. The Goulburn Group is here formally subdivided into four stratigraphic units, in ascending order, the Jigaimara Formation, Naningbura Dolomite, Milingimbi Formation and Mooroongga Formation (see also Rawlings *et al*. 1997, p. 78). The Jigaimara Formation rests disconformably or unconformably on the underlying Elcho Island Formation of the Wessel Group, while the top of the Mooroongga Formation is an erosional unconformity and is overlain by the Djabura Formation of Late Devonian age (Bradshaw *et al*. 1990; Nicoll 2006).

Jigaimara Formation. This formation was named and defined by Haines (in Rawlings *et al*. 1997, p. 78, p. 109) for a fossiliferous succession found in a number of localities along the northwest coast of several of the Wessel Islands and to the north and northeast of Milingimbi. In outcrop it is silicified and consists of brecciated white to grey chert and cherty siltstone (presumably after limestone and calcareous siltstone) and is only a few metres thick as it dips gently offshore (Rawlings *et al*. 1997, p. 109). This unit was intersected in Arafura 1 and extends from 3126 m down to 3596 m (i.e. 470 m thick) and comprises dolostone, limestone, claystone and dolomitic sandstone.

The Jigaimara Formation is very fossiliferous and contains trilobites, bradoriids, hyoliths, lingulate brachiopods and sponge spicules. Shergold (in Plumb *et al*. 1976) listed eight species of trilobite and several other fossils from Elcho Island which led him to consider that the fauna was middle Cambrian in age, but that it was older than *Triplagnostus gibbus* Zone. He also noted that the fauna was very similar to that from the Beetle Creek Formation in the Georgina Basin. Laurie (2006a) analysed the material recorded by Plumb *et al.* (1976) from Warnga Point on Elcho Island as well as material from similar stratigraphic levels on Banyan Island and Howard Island and came to a similar conclusion.

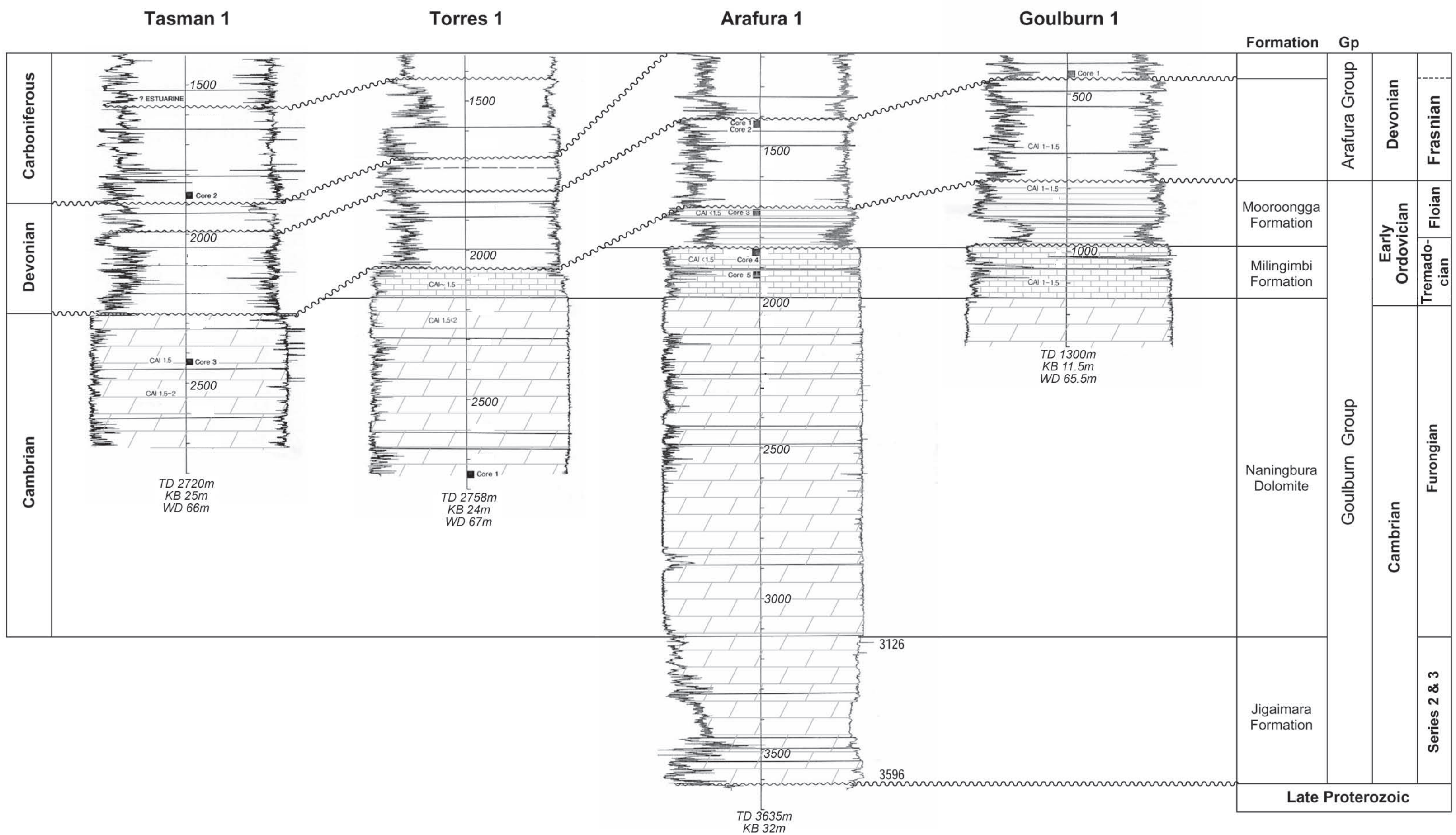

Figure 3. Cross section showing stratigraphic units related to gamma ray and sonic logs of wells used herein. Well log information is from Petroconsultants Australasia Pty Ltd (1989).

Well	Arafura 1						Goulburn 1												T.	
Formation	Mooroongga				Mi		Mooroongga											Mi	Na	
Species \ Samples	Core 3 (1714.58-1715.26)	Core 3 (1716.55-1717.17)	Core 3 (1719.65-1720.25)	Core 3 (1720.91-1721.53)	Core 4 (1843.97-1844.75)	Core 4 (1941.31-1941.90)	Goulburn 1 (778)	Goulburn 1 (780)	Goulburn 1 (782)	Goulburn 1 (790)	Goulburn 1 (838)	Goulburn 1 (854)	Goulburn 1 (856)	Goulburn 1 (870)	Goulburn 1 (878)	Goulburn 1 (916)	Goulburn 1 (976)	Goulburn 1 (1096)	Torres 12150-2160	**TOTAL**
Acodus deltatus	46	16	11	9				1		2	3	1	3	2		3				**97**
Bergstroemognathus extensus	1	1	1	1								2	1	2						**9**
***Colaptoconus* sp.**					2															**2**
***Cooperignathus*? sp.**								1												**1**
***Cordylodus* sp.**																			1	**1**
Cornuodus longibasis	9	16	1	1		1					1	1	1	8			1			**40**
Drepanodus ?reclinatus	6	4		3													5			**18**
Drepanoistodus forceps	13	14	4										1	9			2			**43**
***Drepanoistodus* sp.**					2													2		**4**
Gen. et sp. Indet. 1				1																**1**
Gen. et sp. Indet. 2		1																		**1**
Jumudontus brevis													2			1				**3**
Lissoepikodus nudus	1																			**1**
Nasusgnathus dolonus	1	2	2																	**5**
Oepikodus cleftus							2	2												**4**
Oepikodus communis											17									**17**
***Oistodus* sp.**	1	1																		**2**
***Paltodus* sp.**		1																		**1**
Paroistodus proteus	1	2	2	2										2						**9**
Prioniodus ?adami	32	27	10					1		3	5	8	6	11	4					**107**
Protopanderodus gradatus	3	5	1	2								1								**12**
Protoprioniodus simplicissimus	1	2	1																	**4**
Scolopodus houlianzhaiensis		1											2			1				**4**
Scolopodus striatus	5	1	2	1							1	2		4		1	3			**20**
Semiacontiodus* sp. cf. *S. tersus		4		1				3								1	1			**10**
***Semiacontiodus* sp.**							1													**1**
Serratognathus bilobatus	1		1	2									3							**7**
Teridontus nakamurai						5														**5**
Triangulodus zhiyii	1	2	1														1			**5**
***Tropodus* sp.**										4	8		3	1	4		2			**22**
Total	**122**	**100**	**37**	**23**	**4**	**6**	**3**	**8**	**fr.**	**9**	**35**	**15**	**22**	**39**	**8**	**7**	**15**	**2**	**1**	**456**

Table 1. Distribution of conodont specimens recovered from the cores of two wells in the Arafura Basin (fr. = unidentified conodont fragments only; T. = Torres 1; Mi = Milingimbi Formation; Na = Naningbura Dolomite).

Naningbura Dolomite. This unit was named after Naningbura Point on Elcho Island (11° 45' S, 135° 52' E), but was not defined by Nicoll *et al*. (1996). It consists of up to 1128 m of dominantly dolostone with silty dolomitic intervals and was deposited in a predominantly shallow marine environment. The type section (selected herein) is seen in Arafura 1 where the top of the formation is intersected at 1998 m and the base at 3126 m, the only well to have penetrated the entire thickness (1128 m) of the unit. In Torres 1 the formation is 601 m thick and extends from 2157 m to total depth at 2758 m. In Goulburn 1 the unit is 154 m thick and extends from 1146 m to total depth at 1300 m. In Tasman 1 the unit is 443 m thick and extends from 2277 m down to total depth at 2720 m. Most of the material recovered from the formation comprises drill cuttings, however core from the unit was recovered from Tasman 1 (core 3) and Torres 1 (core 1).

The Naningbura Dolomite was referred to as the "unnamed dolomite overlying the Elcho Island Formation" by Bradshaw *et al*. (1990, p. 115), the Jigaimara Formation not having been erected at that time. It also corresponds to units O1 to O7 of Petroconsultants Australasia Pty Ltd (1989, p. 14-15). The unit is apparently conformable on the underlying Jigaimara Formation and is apparently conformably overlain by the Milingimbi Formation.

Petroconsultants Australasia Pty Ltd (1989, p. 14-15) considered the unit to be Ordovician, but when named by Nicoll *et al*. (1996) the formation was interpreted as Furongian in age. Bradshaw *et al*. (1990, p. 115) noted that the unit lacked biostratigraphic control but based on the presence of Tremadocian conodonts in the base of the overlying Milingimbi Formation, the top of the Naningbura Dolomite "must be located within a very few metres of the base of the Ordovician".

Milingimbi Formation. The Milingimbi Formation was named (but not defined) by Bradshaw *et al*.

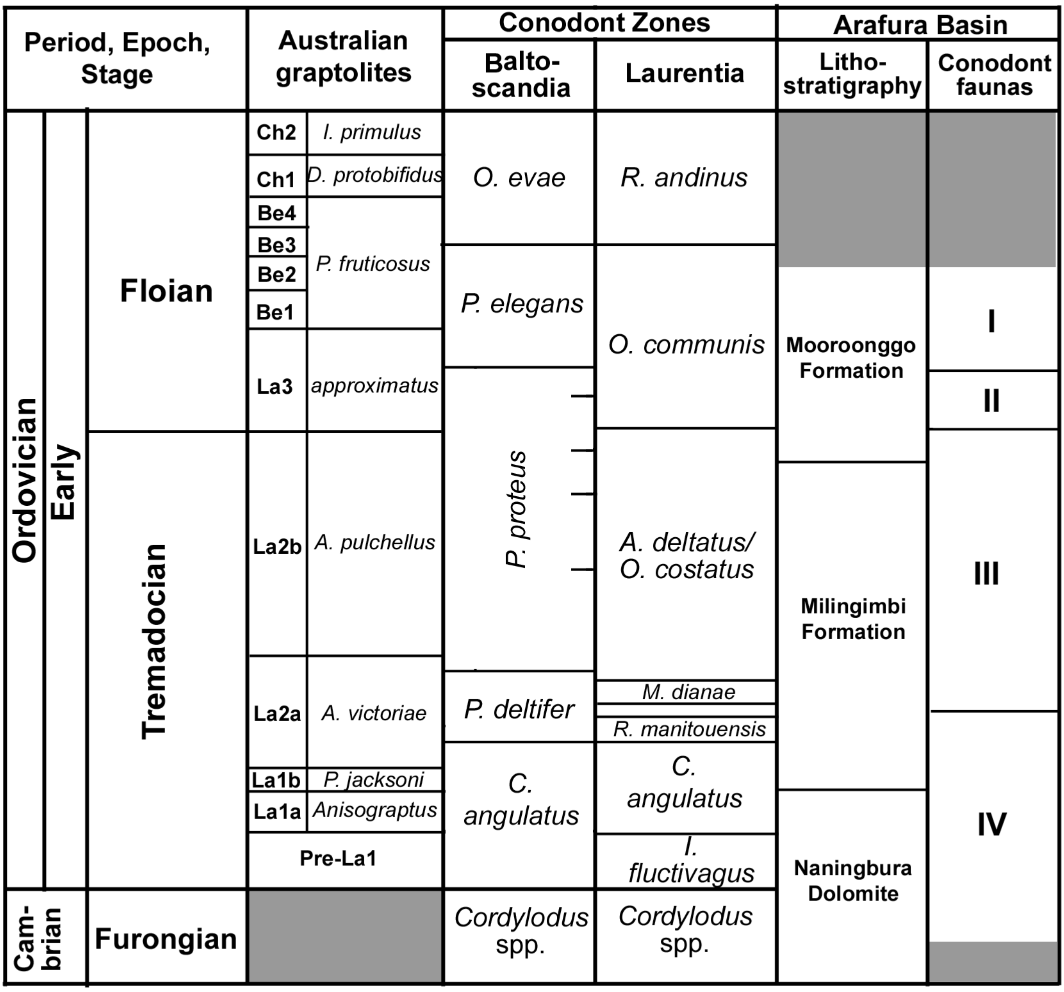

Figure 4. Late Cambrian to Ordovician biostratigraphy and correlation of the Arafura Basin. Ages are from Shergold & Cooper (2004) and Cooper & Sadler (2004).

(1990) after Milingimbi Island off the north coast of Arnhem Land. The island, located about 500 km east of Darwin at 12° 06’ S, 134° 55’ E, belongs to the Crocodile Island Group and has a small settlement, also called Milingimbi, on its eastern shore. The formation is of mixed lithology ranging from silty dolostone to limestone, glauconitic sandstone and shale, deposited predominantly in a shallow marine environment. The lower part of the unit is dolomitic, but it becomes more terrigenous upward, with thin glauconitic sandstones interbedded with dolostone, limestone and shale (Bradshaw *et al*. 1990, p. 115). The type section (selected herein) is in Arafura 1 where the unit is 163 m thick; the top of the unit is at 1835 m while the base is at 1998 m. In Goulburn 1 the unit is 169 m thick and extends from 977 m to 1146 m depth. However, in Torres 1, where the top of the formation is truncated by erosion below the unconformity at the base of the Devonian section, the unit is only 95 m thick and extends from 2062 m to 2157 m depth. In Tasman 1 the unit has been completely removed by pre-Late Devonian erosion. Most of the material recovered from the formation comprises drill cuttings, but cores 4 and 5 from Arafura 1 are from the Milingimbi Formation.

The Milingimbi Formation corresponds to units O8 and O9 of Petroconsultants Australasia Pty Ltd (1989, p. 15-16). The formation rests conformably on the underlying Naningbura Dolomite and is thought to be conformably overlain by the Mooroongga Formation.

Bradshaw *et al*. (1990, p. 115) stated that a conodont fauna of Tremadocian age had been recorded in the basal Milingimbi Formation. However, Nicoll *et al*. (1996) gave the age of the same conodont fauna less specifically as Early Ordovician.

Mooroongga Formation. The Mooroongga Formation was named (but not defined) by Bradshaw *et al*. (1990, p. 115) after Mooroongga Island off the north coast of Arnhem Land. It is located at 11° 56' S, 135° 05' E, about 25 km to the northeast of Milingimbi settlement. The unit consists of shale at its base, grading up into limestone, with some thin sandstones and minor chert. Glauconite is common and parts of the formation are dolomitic. The unit was deposited in a predominantly shallow marine setting. The type section (selected herein) is in Arafura 1 where it is 131 m thick, extending from 1704 m to 1835 m depth. The only other section penetrated is in Goulburn 1 where the unit is 201 m thick, extending from 776 m to 977 m depth. The formation has been removed by pre-Late Devonian erosion in Tasman 1 and Torres 1. The material recovered from the formation comprises mostly drill cuttings, but Core 3 from Arafura 1 is from the Mooroongga Formation.

The Mooroongga Formation corresponds to units O10 to O13 of Petroconsultants Australasia Pty Ltd (1989, p. 16). The formation rests conformably on the underlying Milingimbi Formation and is unconformably overlain by the Late Devonian Djabura Formation.

Petroconsultants Australasia Pty Ltd (1989) indicated a Caradocian age based on meagre conodont evidence from cuttings samples. Bradshaw *et al*. (1990, p. 115) reinterpreted the age of the Mooroongga Formation as ranging up to the mid Arenig, whereas Nicoll *et al*. (1996) stated that the unit contained early Arenig conodonts. The Mooroongga Formation is now considered to be of early Floian age based on a limited, but diagnostic conodont fauna.

Arafura Group

The Goulburn Group is unconformably overlain by the Devonian Arafura Group. Nicoll (2006) documented two Late Devonian conodont faunas from the Djabura and Yabooma Formations.

BIOSTRATIGRAPHY

Conodonts

A total of 456 identifiable conodont specimens were recovered in this study (Table 1). Only small samples were obtained and most weighed under 500 g. Preservation of conodonts from the core samples is relatively good, but many of the elements have a thin phosphatic overgrowth. Material from the cuttings samples from Goulburn 1 well is very poorly preserved with most of the elements broken. Conodonts are relatively abundant in samples from the Mooroongga Formation, but are very rare in the Naningbura Dolomite and the Milingimbi Formation. Chronostratigraphic subdivisions used herein are taken from recent revisions of the Cambrian and Ordovician timescale as presented by Ogg *et al*. (2008).

Four discrete conodont faunas are recognised (Fig. 4). The oldest conodont fauna, Fauna IV, is represented by only a few specimens recovered from the top of the Naningbura Dolomite in Torres 1 and the lower half of the Milingimbi Formation in Torres 1, Goulburn 1 and Arafura 1 (Table 1). The fauna consists of a single element of *Cordylodus* sp., five elements of *Teridontus nakamurai*, one element that may be questionably assigned to *Teridontus* sp., two fragments of *Drepanoistodus* sp. and a couple of indeterminate fragments. Fauna IV is thought to range in age from the latest Cambrian (late Furongian, Stage 10) to the Early Ordovician (early Tremadocian) based on the range of *Cordylodus* and *Teridontus* (Shergold & Cooper 2004; Cooper & Sadler 2004; Nicoll 1990, 1994).

Fauna III is represented by a total of five elements recovered from the upper part of the Milingimbi Formation in Arafura 1. The fauna consists of two fragments of *Drepanoistodus* sp., two fragments of *Colaptoconus* sp. and a single indeterminate fragment (Table 1). Based on stratigraphic position and the absence of other faunal elements like *Cordylodus*, *Scolopodus* and *Panderodus*, Fauna III is thought to be of middle to late Tremadocian age.

Conodont Fauna II is represented by a total of some 388 identifiable specimens found in Goulburn 1 between 838 and 976 m and in Arafura 1 from core 3 (1714-1722.7 m). The fauna consists of a diverse range of species, including *Bergstroemognathus extensus*, *Jumudontus brevis*, *Paroistodus proteus*, *Oistodus* sp., *Prioniodus* ?*adami*, *Protoprioniodus simplicissimus*, *Serratognathus bilobatus*, *Scolopodus striatus*, *S. huolianzhaiensis* and *Triangulodus zhiyii*. This fauna is typical of the upper part of the *P. proteus* Zone, ranging from the upper part of the Tremadocian Stage to the lower part of the Floian Stage. These taxa are typical elements of the *Serratognathus* fauna which is also recorded in the upper Emanuel Formation in the Canning Basin (Zhen & Nicoll 2009). *Serratognathus bilobatus* has also been recorded from the Liangjiashan Formation in the North China Platform and Korea (Lee 1970; An *et al*. 1983; Zhen *et al*. 2009b), and coeval units in south China (An 1987; Wang 1993; Zhen *et al*. 2009a, b), and Malaysia (Metcalfe 1980, 2004). In north China, *Scolopodus houlianzhaiensis* (Fig. 7F-K) was recorded as a common species in association with *Serratognathus bilobatus* and two other species of *Serratognathus* in the Liangjiashan Formation (An *et al*. 1983, tables 6-7). It has also been reported in the Honghuayuan Formation of south China

(Zhen *et al.* 2009a), and in the Emanuel Formation of the Canning Basin (Zhen & Nicoll 2009). *Jumudontus brevis* was originally reported in the Emanuel Formation of the Canning Basin (Nicoll 1992), and was also recorded from Utah and Texas (Ethington & Clark 1982), Newfoundland (Stouge & Bagnoli 1988), Baltoscandia (Bergström 1988) and Greenland (Smith 1991) with a stratigraphic range from the upper *P. proteus* Biozone to lower *O. communis* Biozone. *Prioniodus adami* co-occurs with *Tetragraptus approximatus* in the lower and middle part of Bed 9 of the Cow Head Group in western Newfoundland. Stouge & Bagnoli (1988) established the *P. adami* Biozone within this interval and correlated it to the upper *P. proteus* Biozone of the Baltoscandian conodont succession and the *T. approximatus* graptolite Biozone, which is early Floian in age. Occurrence of *Serratognathus bilobatus* in this fauna is most significant, as the first appearance of this morphologically distinctive species was often utilised as the indicator for the base of the Floian in North China and the Canning Basin of Western Australia (Zhen *et al.* 2009b).

The uppermost conodont fauna, Fauna I, is found only in the interval 778 to 838 m (upper Mooroongga Formation) in Goulburn 1 well. The fauna contains *Oepikodus communis, O. cleftus* and *Cooperignathus* sp. This fauna is representative of the *Oepikodus communis* Zone and is middle Floian in age.

Other Fauna

Fossils other than conodonts have been found at several levels in Arafura 1 well, and include the following:

1714-1723m: coprolites

2748-2750m: phosphatised internal moulds of tubes

3150-3152m: ?cyclostome bryozoan, indet. trilobite fragments, echinoderm fragments, indet. phosphatic brachiopod

3264m: obolid brachiopod

3268m: indeterminate agnostid 1, *Pentagnostus shergoldi*, *Pagetia* sp., indeterminate eodiscid, ?*Acrothele* sp.

3300m: indeterminate agnostid 2, indeterminate polymerid 1

3324m: indeterminate polymerid 2, chancelloriid spicules, echinoderms, ?*Amictocracens* sp.

3499m: ?*Oryctocephalites* sp.

3548-3550m: indeterminate ?eodiscid, chancelloriid spicule, ?acrotheline brachiopod

Laurie (2006c) recorded the very distinctive *Pentagnostus shergoldi* Laurie, 2004, *Pagetia* sp. and an indeterminate agnostoid from cuttings samples in Arafura 1 at a depth of 3268 m. The presence of *P. shergoldi* immediately indicates a Templetonian *Pentagnostus shergoldi* Zone age (see Fig. 2) for this level. The presence of *Pagetia* sp. is not inconsistent with this age, and the indeterminate agnostid 1 from this interval is of a morphology which is also not inconsistent with this age. From cuttings at a depth of 3300 m in Arafura 1, Laurie (2006c) recorded an indeterminate polymerid and two indeterminate agnostoid pygidia. The polymerid is only a very young individual and cannot be assigned to any species or genus, and consequently it is not age diagnostic. The two agnostid pygidia probably belong to the same species, with the smaller specimen being a juvenile. They are very similar in appearance to pygidia of *Euagnostus* spp., a morphotype which arose in the very early middle Cambrian and did not survive beyond the Floran. In cuttings from a depth of 3324 m in Arafura 1, Laurie (2006c) recorded an indeterminate polymerid glabella which is most likely a dolichometopid and therefore is probably of late early Cambrian to early Furongian in age. Given its stratigraphic position below the other two horizons it is probably closer to the former rather than the latter age.

One other trilobite, from 3499m, can be tentatively assigned to a genus (?*Oryctocephalites* sp.) which is only known from the early middle Cambrian.

Several phosphatic brachiopods are also recorded. Among these, two can tentatively be assigned to a genus. The upper one, ?*Acrothele* sp., from 3268m confirms a middle Cambrian age indicated by the associated agnostids. The lower one, ?*Amictocracens* sp., from 3324m, also indicates a middle Cambrian age, probably no younger than Undillan.

The lowest fossiliferous horizon, at 3548-3550m, contains one trilobite fragment (indeterminate ?eodiscid), a phosphatic brachiopod (?acrotheline) and chancelloriid spicules. The trilobite and the chancelloriids indicate an early or middle Cambrian age whereas the brachiopod is unlikely to be older than earliest middle Cambrian

It therefore appears that at least the interval from 3268m to 3550m in Arafura 1 well, which lies entirely within the Jigaimara Formation, was deposited during the early middle Cambrian

THERMAL MATURATION

The conodont colour alteration index (CAI) (Epstein *et al*. 1977) was determined for all conodonts recovered in this study. All of the CAI values obtained are in the range of CAI 1 to 2. Bradshaw *et al*. (1990, fig. 14) plotted CAI values against depth in all wells. Based on limited data the CAI 1 interval ranges from the surface to a depth of about 1500 m and represents the

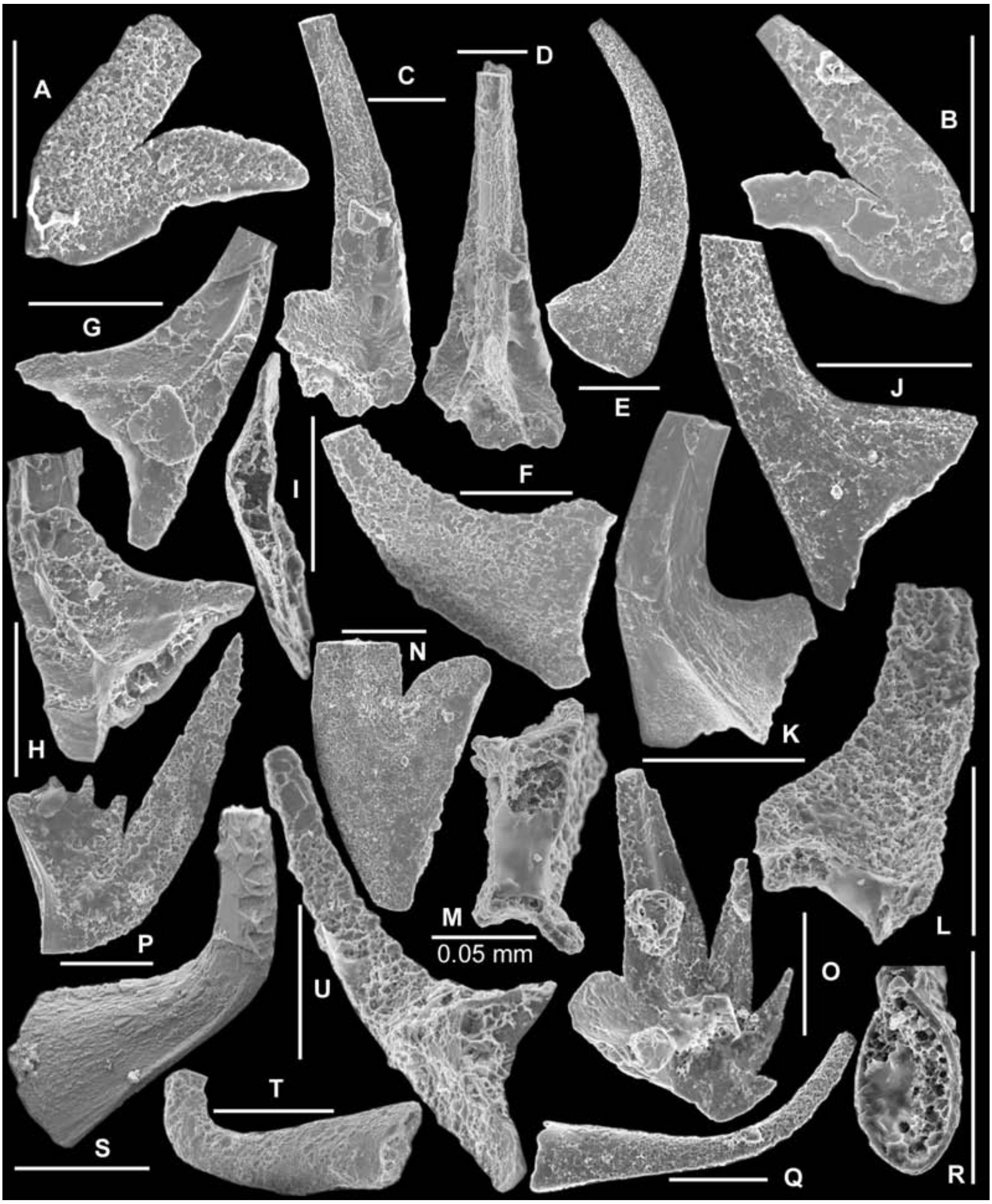

Figure 5. **A**-**M**, *Acodus deltatus* Lindström, 1955. A-B, M element, **A**, CPC41239, 1716.55-1717.17 m, anterior view (IY110-038); **B**, CPC41240, 1714.58-1715.26 m, anterior view (IY112-008). **C**-**D**, Sa element, CPC41241, 1714.58-1715.26 m, **C**, lateral view (IY111-024), **D**, posterior view (IY111-025). **E**-**F**, Sc element, **E**, CPC41242, 1716.55-1717.17 m, outer lateral view (IY112-027); **F**, CPC41243, 1720.91-1721.53 m, inner lateral view (IY113-041). **G**-**I**, Sd element, CPC41244, 1714.58-1715.26 m, **G**, outer lateral view (IY111-028), **H**, inner lateral view (IY111-030), **I**, basal view (IY111-029). **J**-**K**, P element, **J**, CPC41245, 1716.55-1717.17 m, inner lateral view (IY111-040); **K**, CPC41246, outer lateral view (IY111-023), 1714.58-1715.26 m. **L**-**M**, Sd element, CPC41247, 1720.91-1721.53 m, **L**, inner lateral view (IY113-037); **M**, basal view (IY113-038). **N**, Gen. et sp. indet. 2, M element, CPC41248, 1716.55-1717.17 m, posterior view (IY113-002). **O**-**P**, *Bergstroemognathus extensus* (Graves & Ellison, 1941). **O**, Sc element, CPC41249, 1714.58-1715.26 m, inner lateral view (IY110-014); **P**, M? element, CPC41250, 1720.91-1721.53 m, posterior view (IY113-030). **Q**-**T**, *Cornuodus longibasis* (Lindström, 1955). **Q**-**R**, CPC41251, 1716.55-1717.17 m, Sa element, **Q**, lateral view (IY110-020); **R**, basal view (IY110-022). **S**, Sb element, CPC41252, 1716.55-1717.17 m, inner lateral view (IY131-029). **T**, Sa element, CPC41253, 1719.65-1720.25 m, lateral view (IY113-027). **U**, *Lissoepikodus nudus* Nicoll & Ethington, 2004. Sb element, CPC41254, 1714.58-1715.26 m, outer lateral view (IY111-027). All from Arafura 1, Mooroongga Formation. Scale bars 100 µm, unless indicated otherwise.

Figure 6. **A-G**, *Drepanodus* ?*reclinatus* (Lindström, 1955). **A**, Sc element, CPC41255, 1714.58-1715.26 m, inner lateral view (IY112019). **B**, Pa element, CPC41256, 1720.91-1721.53 m, inner lateral view (IY113031). **C-D**, Sb element, CPC41257, 976 m, Goulburn 1, **C**, inner lateral view (IY114017); **D**, outer lateral view (IY114018). **E-F**, Pb element, 1714.58-1715.26 m, **E**, CPC41258, inner lateral view (IY111006); **F**, CPC41259, outer lateral view (IY111007); **G**, ?M element, CPC41260, 1714.58-1715.26 m, posterior view (IY112018). **H-N**, *Drepanoistodus forceps* (Lindström, 1955). **H**, Sc element, CPC41261, 1716.55-1717.17 m, outer lateral view (IY111034); **I-J**, Sb element, **I**, CPC41262, 1714.58-1715.26 m, outer lateral view (IY111031); **J**, CPC41263, 1716.55-1717.17 m, inner lateral view (IY112023). **K-N**, M element, **K-L**, CPC41264, 1714.58-1715.26 m, **K**, basal view (IY111010), **L**, posterior view (IY111011); **M**, CPC41265, 1714.58-1715.26 m, posterior view (IY111012); **N**, CPC41266, 1716. 55-1717.17 m, anterior view (IY111039). All from Arafura 1 unless otherwise indicated. All from Mooroongga Formation. Scale bars 100 µm.

immature hydrocarbon recovery zone. The CAI 1.5 interval extends from 1500 to about 2500 m and the CAI 2 interval is found below 2500 m. Both of these CAI intervals are indicative of the oil generation window where oil would be the expected hydrocarbon recovered. The base of the CAI 2 interval is not determined in this study. Based on comparison with the Canning Basin conodont data it would be expected that the top of the CAI 3 interval would be at about 3500 m.

In the Arafura Basin the oil generation window thus appears to be between about 1500 and 3500 m. This means that in the eastern part of the Arafura Graben only the lower of the penetrated section, mostly the Devonian and older rocks, would be expected to be targets for hydrocarbon exploration.

The CAI values also indicate that present burial depth of sediments in the Arafura Basin is close to the maximum depth of burial. This has implications about the timing of structural development of the anticlines in the graben and the extent of thick Permian or Permo-Triassic sediments. It suggests that structural growth of the central graben anticline took place contemporaneously

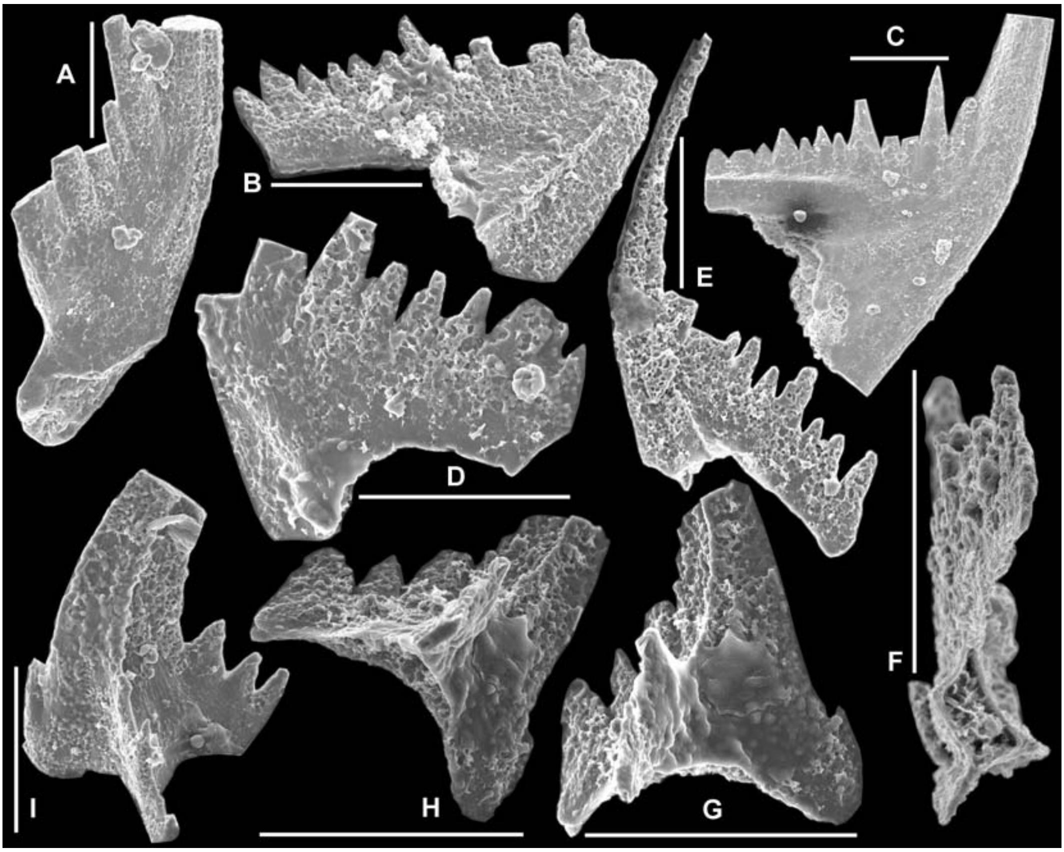

Figure 7. *Prioniodus* ?*adami* Stouge & Bagnoli, 1988. **A**, Sa element, CPC41267, postero-lateral view (IY110028). **B**, Sb element, CPC41268, outer lateral view (IY110031). **C-D**, Sc element; **C**, CPC41269, inner lateral view (IY112026); **D**, CPC41270, outer lateral view (IY110034). **E-F**, Sd element, CPC41271, **E**, inner lateral view (IY110029), **F**, basal view (IY110030). **G-I**, P element; **G-H**, CPC41272, **G**, antero-outer lateral view (IY110036); **H**, basal-outer lateral view (IY110035); **I**, CPC41273, outer lateral view (IY111002). All from sample 1716.55 m, except I (from 1714.58). All from 1716.55-1717.17 m in Arafura 1 except I, 1714.58-1715.26. All from Mooroongga Formation. Scale bars 100 µm.

with graben margin sedimentation and that post-Carboniferous sediments were never very thick in the central portion of the graben.

SYSTEMATICS OF SELECTED TAXA

All specimens are deposited in the Commonwealth Palaeontological Collection (prefix CPC) held at Geoscience Australia, Canberra.

Class CONODONTA Pander, 1856

Acodus Pander, 1856

Type species. Acodus erectus Pander, 1856

Acodus deltatus Lindström, 1955 (Fig. 5A-M)

Material. 97 specimens from 11 samples (Table 1). Illustrated specimens include CPC41239-41247.

Remarks. This is one of the dominant species in the fauna (Table 1). There might be more than one species of *Acodus* present. However, as most specimens are rather poorly preserved, further differentiation is impossible. The better preserved specimens (Fig. 5A-M) are comparable with *A. deltatus* from the Emanuel Formation (McTavish 1973; Zhen & Nicoll 2009).

Prioniodus Pander, 1856

Type species. Prioniodus elegans Pander, 1856.

Prioniodus ?adami Stouge & Bagnoli, 1988 (Fig. 7A-I)

Material. 107 specimens from 10 samples (Table 1). Illustrated specimens include CPC41267-41273.

Figure 8. **A-C**, *Protopanderodus gradatus* Serpagli, 1974. **Sb** element, CPC41274, 1719.65-1720.25 m, **A**, basal view (IY113022); **B**, inner lateral view, close up showing the basal end of the costa and furrow (IY113026); **C**, inner lateral view (IY113025). **D**, *Jumudontus brevis* Nicoll, 1992. P element, CPC41275, 916 m, Goulburn 1, inner lateral view (IY114003). **E-F**, *Nasusgnathus dolonus* (An in An *et al*., 1981), 1716.55-1717.17 m. **E**, Sd element, CPC41276, inner lateral view (IY113016). **F**, Sc element, CPC41277, inner lateral view (IY113014). **G,** *Oistodus* sp. M element, CPC41278, 1714.58-1715.26 m, anterior view (IY111032). **H**, *Paltodus* sp. M element; CPC41279, 1716.55-1717.17 m, H, posterior view (IY111035). **I-L**, *Paroistodus proteus* (Lindström, 1955). **I**, Sa element, CPC41280, 1716.55-1717.17 m, lateral view (IY113015). **J**, M element, CPC41281, 1720.91-1721.53 m, posterior view (IY113040). **K**, Sb element, CPC41282, 1716.55-1717.17 m, inner lateral view (IY113010). **L**, Pa element, CPC41283, 1719.65-1720.25 m, outer lateral view (IY113029). **M-N**, Gen. et sp. indet. 1, CPC41284, 1720.91-1721.53 m, **M**, antero-lateral view (IY110012); **N**, upper view (IY110010). All from Arafura 1 unless indicated otherwise. All from Mooroongga Formation. Scale bars 100 µm, unless indicated otherwise.

Remarks. *Prioniodus* elements are common in the current material, but with denticulated processes rarely preserved. They are regarded as belonging to a single species, although it is possible that there might be more than one species. Better preserved specimens are all illustrated (Fig. 7). The illustrated S elements show some resemblance to the type material of *P*. *adami* from the Cow Head Group of western Newfoundland but with larger and more prominent denticles on the posterior process, and the P elements (Fig. 7G-I) also exhibit a shorter anterior process in comparison with the type material of *P*. *adami*. Therefore they are only doubtfully designated to *P. adami*.

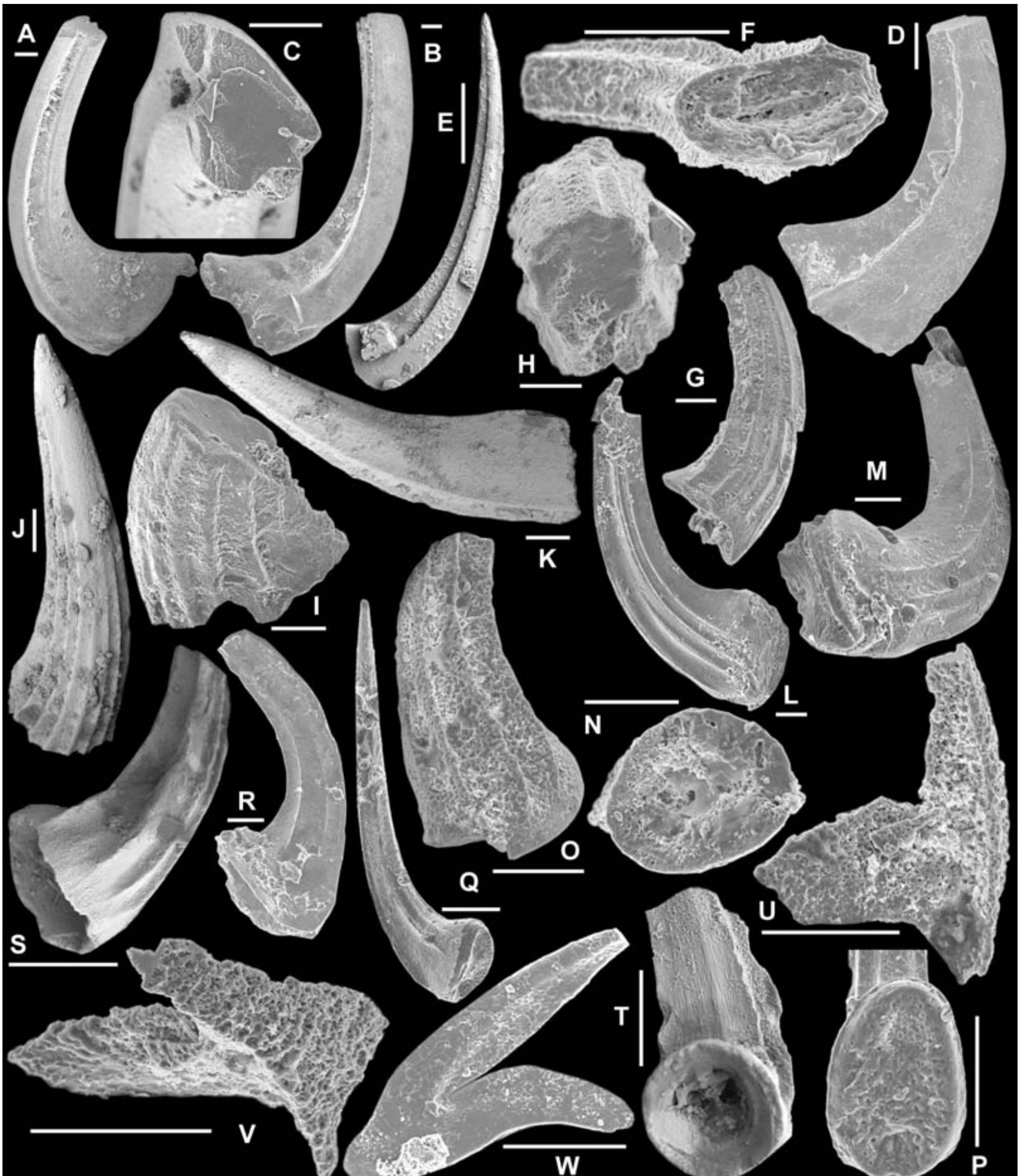

Figure 9. **A-E**, *Protopanderodus gradatus* Serpagli, 1974. **A-C**, Sb element, CPC41285, 1716.55-1717.17 m, **A**, inner lateral view (IY110016), **B**, outer lateral view (IY110017); **C**, postero-upper view showing the cross-section of the cusp (IY110015). **D**, Sc element, CPC41286, 856 m, Goulburn 1, inner lateral view (IY114024); **E**, M? element, CPC41287, 1716.55-1717.17 m, posterior view (IY131-028). **F-K**, *Scolopodus houlianzhaiensis* An & Xu in An *et al*., 1983. **F**, Sc element, CPC41288, 1719.65-1720.25 m, basal view (IY113017); **G**, Sb element, CPC41289, 856 m, Goulburn 1, outer lateral view (IY114028); **H-I**, Sb element, CPC41290, 916 m, Goulburn 1, **H**, upper view showing cross-section of the cusp (IY114007); **I**, outer lateral view (IY114006); **J-K**, Sc element, CPC41291, 856 m, Goulburn 1, **J**, outer lateral view (IY131-007), **K**, inner lateral view (IY131-006). **L-T**, *Scolopodus striatus* Pander, 1856. **L-M**, Sb element, CPC41292, 1714.58-1715.26 m, **L**, inner lateral view (IY111016); **M**, basal-outer lateral view (IY111017). **N-O**, Sc element, CPC41293, 1720.91-1721.53 m, **N**, basal view showing basal cavity (IY113032); **O**, outer lateral view (IY113034). **P-Q**, Sc element, CPC41294, 1714.58-1715.26 m, **P**, basal view showing basal cavity (IY111021); **Q**, inner lateral view (IY111019). **R**, M element, CP41295, 1716.55-1717.17 m, inner lateral view (IY111041). **S-T**, Sa element, CPC41296, 780 m,, Goulburn 1, **S**, lateral view (IY131-021); **T**, postero-basal view (IY131-019). **U-W**, *Protoprioniodus simplicissimus* McTavish, 1973. **U-V**, Sb element, CPC41297, 1716.55-1717.17 m, **U**, outer lateral view (IY110025); **V**, upper-outer lateral view (IY110023);. **W**, M element, CPC41298, 1719.65-1720.25 m, posterior view (IY113028). All from Arafura 1 unless otherwise indicated. All from Mooroongga Formation. Scale bars 100 µm.

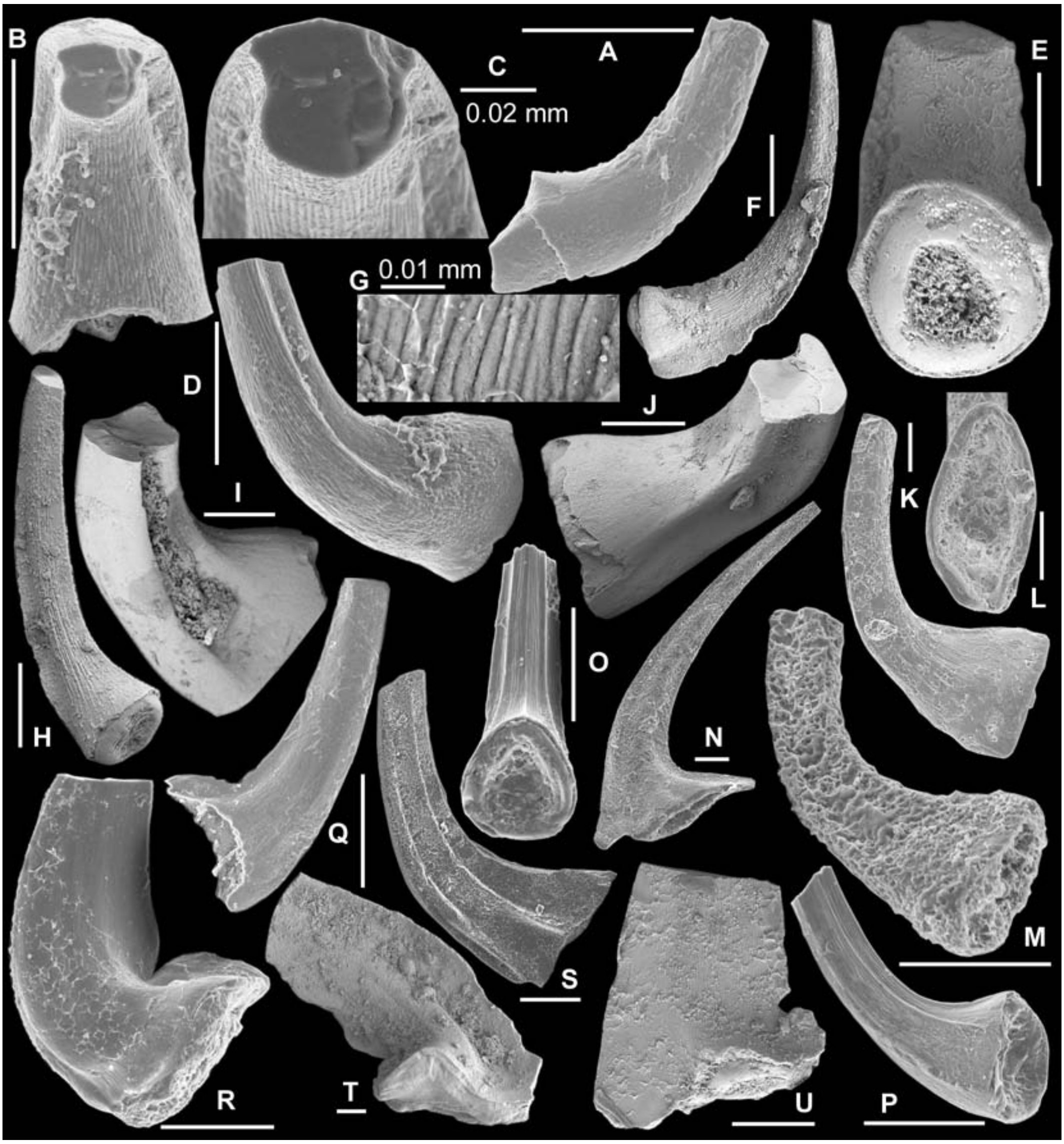

Figure 10. **A**, *Teridontus nakamurai* (Nogami, 1967). CPC41299, 1914.31-1914.90 m, Arafura 1, Milingimbi Formation, lateral view (IY114002). **B-M**, *Semiacontiodus* sp. cf. *S. tersus* (Zhang in An *et al*., 1983), From Goulburn 1 unless indicated otherwise. **B-D**, Sa element, CPC41300, 976 m, **B**, upper-posterior view (IY114011); **C**, upper view, close up showing cross-section of the cusp (IY114012); **D**, lateral view (IY114010). **E**, Sb element, CPC41301, 856 m, postero-basal view (IY131-012). **F-H**, P element; **F-G**, CPC41302, 870 m, **F**, inner lateral view (IY131-015), **G**, close up showing surface striae (IY131-016); **H**, CPC41303, 870 m, inner lateral view (IY131-017). **I-J**, Sd element, CPC41304, 976 m, **I**, inner lateral view (IY131-009), **J**, outer lateral view (IY131-011). **K-M**, Sb element, **K-L**, CPC41305, 1716.55-1717.17 m, Arafura 1, **K**, inner lateral view (IY112021), **L**, basal view of the basal cavity (IY112020); **M**, CPC41306, 1720.91-1721.53 m, Arafura 1, inner lateral view (IY113047). **N-S**, *Triangulodus zhiyii* Zhen in Zhen *et al*., 2006. From Arafura 1 unless indicated otherwise. **N**, Pb element, CPC41307, 1719.65-1720.25 m, inner lateral view (IY111042). **O-Q**, Sd element; **O-P**, CPC41308, 1716.55-1717.17 m, **O**, posterior view (IY113003), **P**, lateral view (IY113005); **Q**, CPC41309, 1714.58-1715.26 m, lateral view (IY111005). **R**, Pa element, CPC41310, 976 m, Goulburn 1, inner lateral view (IY114020). **S**, M element, CPC41311, 1716.55-1717.17 m, posterior view (IY113008). **T-U,** *Tropodus* sp., Goulburn 1, **T**, M element, CPC41312, 838 m, posterior view (IY131-004); **U**, P element, CPC41313, 838 m, inner lateral view (IY131-005). All from Mooroongga Formation unless indicated otherwise. Scale bars 100 µm, unless indicated otherwise.

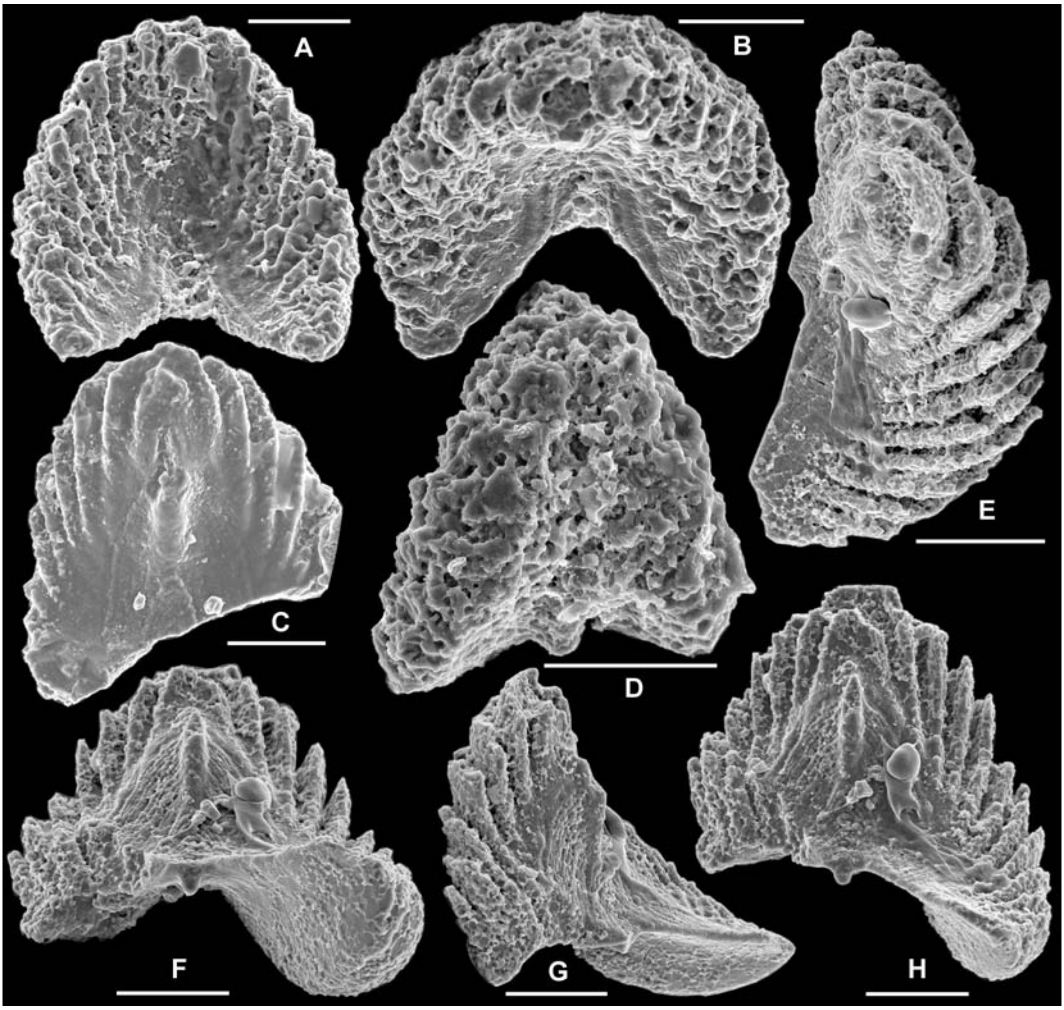

Figure 11. *Serratognathus bilobatus* Lee, 1970. **A-B**, Sa element, CPC41314, 1720.91-1721.53 m, **A**, posterior view (IY110007), **B**, upper view (IY110008). **C-D**, Sb element; **C**, CPC41315, 1714.58-1715.26 m, posterior view (IY110001); **D**, CPC41316, 1720.91-1721.53 m, anterior view (IY110009). **E-H**, Sc element, CPC41317, 1719.65-1720.25 m, **E**, upper view (IY110006), **F**, basal posterior view (IY110004), **G**, postero-inner lateral view (IY110005), **H**, posterior view (IY110003). All from Mooroongga Formation in Arafura 1. Scale bars 100 µm.

Scolopodus Pander, 1856

Type species. *Scolopodus sublaevis* Pander, 1856.

Scolopodus houlianzhaiensis An & Xu in An *et al*., 1983 (Fig. 9F-K)

2009 *Scolopodus houlianzhaiensis* An & Zhu; Zhen & Nicoll, p. 17, fig.10A-K

Material. Four specimens from three samples (Table 1). Illustrated specimens include CPC41288-41291

Remarks. *Scolopodus houlianzhaiensis* can be differentiated from *S. striatus* by having a distinctive Sc element (compressed paltodiform of Tolmacheva 2006) with costae only developed on the outer lateral face (Fig. 9J) or near the anterior margin of the inner lateral face (Fig. 9K), and having more costae on the other, less compressed S elements (Fig. 9H-I).

Scolopodus striatus Pander, 1856 (Fig. 9L-T)

Material. 20 specimens from nine samples (Table 1). Illustrated specimens include CPC41292-41296

Remarks. In revising this species, Tolmacheva (2006) proposed a quinquimembrate apparatus, including scandodiform (M), subrounded (Sa), paltodiform (S), compressed paltodiform (S), and acontiodiform (P) elements, and considered both *S. quadratus* Pander, 1856 and *S. rex* Lindström,

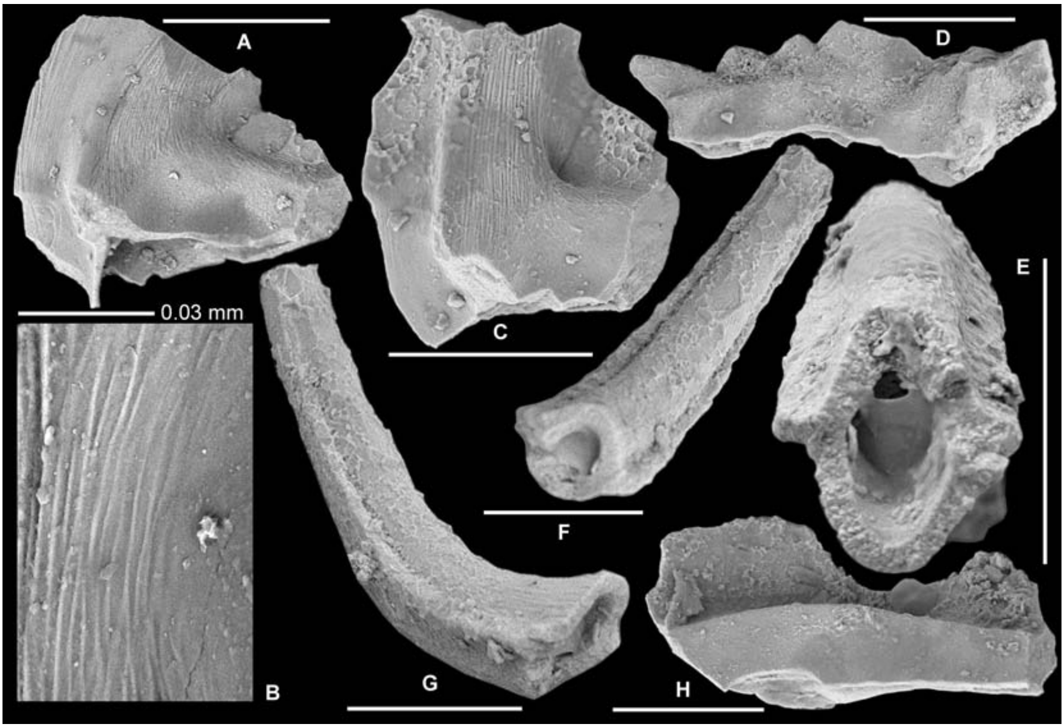

Figure 12. **A-C**, *Oepikodus communis* (Ethington & Clark, 1964). Pa element; **A-B**, CPC41318, 838 m, **A**, outer lateral view (AF last003), **B**, close up show fine surface striae (AF last 0002). **C**, CPC41319, 838 m, outer lateral view (AF last006). **D**, *Oepikodus cleftus* Nicoll & Ethington, 2004; Pa element, CPC41320, 778 m, outer lateral view (AF last009). **E-G**, *Semiacontiodus* sp., Sa element, CPC41321, 778 m, **E**, basal view (AF last012), **F**, posterior view (AF last016), **G**, lateral view (AF last017). **H**, *Cooperignathus?* sp. indet., fragmentary, CPC41322, 780 m, outer lateral view (AF last011). All from Mooroongga Formation in Goulburn 1. Scale bars 100 µm, unless otherwise indicated.

1955 as junior synonyms of *S. striatus*.

Semiacontiodus Miller, 1969

Type species. *Acontiodus (Semiacontiodus) nogamii* Miller, 1969.

Semiacontiodus sp. cf. S. tersus (Zhang in An *et al*., 1983) (Fig. 10B-M)

Material. 10 specimens from five samples (Table 1). Illustrated specimens include CPC41300-41306

Remarks. Five morphotypes can be recognised among the specimens assigned to this species, representing the Sa (symmetrical, Fig. 10B-D), Sb (weakly asymmetrical, Fig. 10E), Sc (laterally compressed with a more or less suberect cusp and a long base, Fig. 10K-M), Sd (asymmetrical with a twisted cusp, Fig. 10I-J) and P (laterally compressed with proclined cusp, Fig. 10F-H) elements. It resembles some of the elements of *S. tersus* from the lower part of the Liangjiashan Formation of North China, but the holotype of *S. tersus* (Zhang in An *et al*. 1983, pl. 11, fig. 14) is a symmetrical element (Sd of our interpretation) showing sharp anterior and posterior margins, and a diamond-shaped cross section of the cusp distally.

Triangulodus van Wamel, 1974

Type species. Multielement *Scandodus brevibasis* (Sergeeva, 1963) emend. Lindström (1971).

Triangulodus zhiyii Zhen in Zhen *et al*., 2006 (Fig. 10N-S)

Material. Five specimens from four samples (Table 1). Illustrated specimens include CPC41307-41311

Remarks. Although only a few specimens representing the M, Sd, Pa and Pb elements (Fig. 10N-S) were recovered, they are identical with the type material of *T. zhiyii* from the Honghuayuan Formation of Guizhou, South China (Zhen *et al*. 2006).

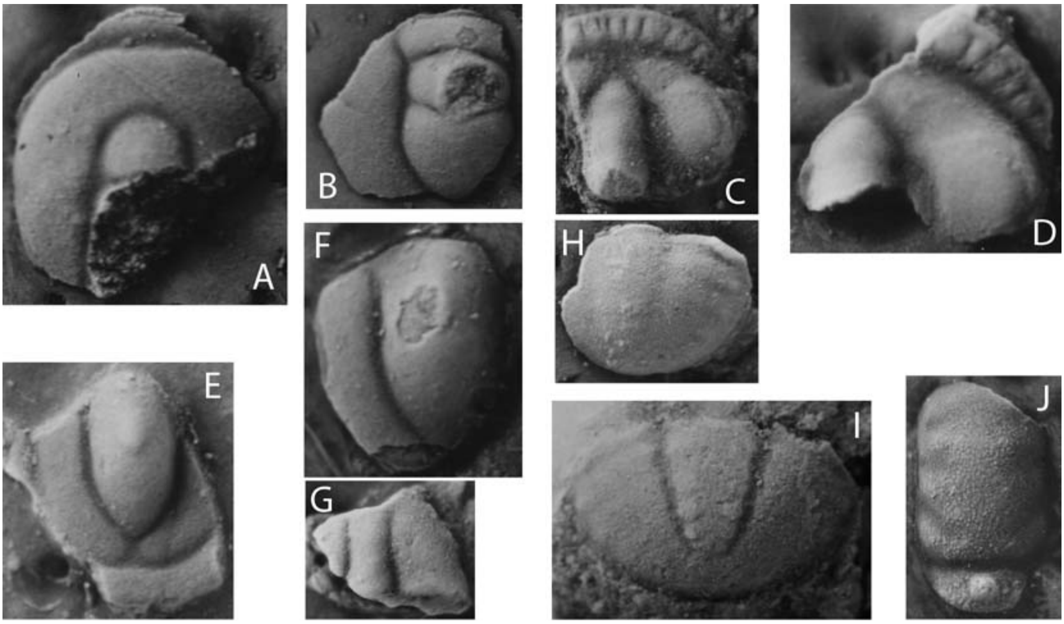

Figure 13. Macrofossils from Arafura 1 well. All x24. **A**, indeterminate agnostid 1, partial cephalon, CPC41323, 3268 m. **B**, *Pentagnostus shergoldi* partial pygidium, CPC41324, 3268 m. **C-D**, *Pagetia* sp., **C**, partial cranidium, CPC41325, 3268 m. **D**, partial cranidium, CPC41326, 3268 m. **E-F**, indeterminate agnostid 2, **E**, partial pygidium, CPC41327, 3300 m. **F**, partial pygidium, CPC41328, 3300 m. **G**, indeterminate polymerid 2, meraspid cranidium, CPC41329, 3324 m. **H-I**, indeterminate eodiscid, **H**, pygidium, CPC41330 3268 m. **I**, pygidium, CPC41331, 3268 m. **J**, indeterminate polymerid 1, partial cranidium, CPC41332, 3300 m.

Phylum ARTHROPODA Latreille, 1829
Class uncertain
Order AGNOSTIDA Salter, 1864
Superfamily AGNOSTOIDEA M'Coy, 1849
Family PTYCHAGNOSTIDAE Kobayashi, 1939

Pentagnostus Lermontova in Vologdin *et al*., 1940

Type species. *Pentagnostus anabarensis* Lermontova in Vologdin *et al*., 1940.

Pentagnostus shergoldi Laurie, 2004 (Fig. 13B)

Material. Single pygidium (CPC41324) from cuttings at a depth of 3268 m (Jigaimara Formation) in Arafura 1.

Remarks. This partial pygidium has a strongly waisted axis with an hexagonal M2 and a broad, forwardly curved M1. This, coupled with the bulbous posteroaxis, is most like *Pentagnostus shergoldi*, a species found in the middle to late Templetonian of the Georgina Basin (Laurie 2004, 2006b).

Indeterminate agnostid 1 (Fig. 13A)

Material. Single partial cephalon (CPC41323) from cuttings at a depth of 3268 m (Jigaimara Formation) in Arafura 1.

Remarks. Although most of the glabella is missing in this specimen, the anteroglabella is clearly defined and is most like some of the early species of *Euagnostus* (e.g. *E. interstrictus*, *E.* aff *interstrictus* and *E. doylei*) from the Georgina Basin (Laurie 2006b).

Indeterminate agnostid 2 (Fig. 13E-F)

Material. Two partial pygidia (CPC41327-41328) from cuttings at a depth of 3300 m (Jigaimara Formation) in Arafura 1

Remarks. These pygidia are similar in most respects to those of species of *Euagnostus*. It is suspected that these two specimens are conspecific and that the smaller of the two is a juvenile, as it has a relatively short, highly vaulted axis, and a wide border. The larger of the two has an axis characteristic of *Euagnostus*, with its very slight constriction opposite M2, effaced F1 and F2, subdued axial node and an ogival posteroaxis. It is possible that these specimens are conspecific with Indeterminate agnostid 1.

Class TRILOBITA Walch, 1771
Order EODISCIDA Kobayashi, 1939
Superfamily EODISCOIDEA Raymond, 1913
Family EODISCIDAE Raymond, 1913

Pagetia Walcott, 1916

Type species. *Pagetia bootes* Walcott, 1916.

Pagetia sp. (Fig. 13C-D)

Material. Two partial cranidia (CPC41325-41326) from cuttings at a depth of 3268 m (Jigaimara Formation) in Arafura 1.

Remarks. These two partial cranidia are similar to those assigned to *P*. cf *sinesulcata* and *P. prolata* by Laurie (2006b) in that they do not have the wide border with clearly defined outer rim characteristic of later forms (e.g. *P. morrisi*, *P. baldwinensis* and *P. oepiki*). They are therefore likely to be of middle to late Templetonian age.

Indeterminate eodiscid (Fig. 13H-I)

Material. Two partial pygidia (CPC41330-41331) from cuttings at a depth of 3268 m (Jigaimara Formation) in Arafura 1.

Remarks. These specimens are presumed to be conspecific because they are of similar shape and both have poorly defined pleural furrows. One specimen appears to have the shell attached, while the other is exfoliated. Despite having similar pleural rib definition, the exfoliated specimen has a very clearly defined axis, while the other specimen has a poorly defined axis. Despite coming from the same level in Arafura 1 as the two cranidia assigned to *Pagetia* sp., they are unlike pygidia of *Pagetia* and are considered not to be conspecific.

Order CORYNEXOCHIDA Kobayashi, 1935
?Family DOLICHOMETOPIDAE Walcott, 1916

Indeterminate polymerid 1 (Fig. 13J)

Material. One partial cranidium (CPC41332) from cuttings at a depth of 3300 m (Jigaimara Formation) in Arafura 1.

Remarks. Indeterminate polymerid 1 comprises only the glabella which is damaged on the right anterior margin. Its parallel-sided nature, arrangement of the glabellar furrows and the presence of an occipital node, indicates that it is a corynexochid and most likely a dolichometopid.

Order uncertain

Indeterminate polymerid 2 (Fig. 13G)

Material. One partial cranidium (CPC41329) from cuttings at a depth of 3374 m (Jigaimara Formation) in Arafura 1.

Remarks. This specimen is clearly a very young individual and is likely to be an early meraspid. It is unable to be assigned to a genus or species.

Conclusions

Conodont faunas from wells in the Goulburn Graben of the Arafura Basin demonstrate that the Naningbura Dolomite is Furongian to early Tremadocian in age. The conodont fauna from the Milingimbi Formation indicates it is middle Tremadocian in age, while faunas from the Mooroongga Formation extend from the late Tremadocian to middle Floian. Meagre macrofossil faunas from the Jigaimara Formation in Arafura 1 are probably of middle to late Templetonian age and are consistent with the early Templetonian age indicated by faunas obtained from the base of the unit outcropping on Elcho, Howard and Banyan Island (Laurie 2006a). Conodont colour alteration data indicates that only rocks of Devonian or older age have been within the oil generation window.

ACKNOWLEDGEMENTS

A grant from the Betty Mayne Scientific Research Fund of the Linnean Society of New South Wales to YYZ helped his travel to Canberra. Scanning electron microscope photographs of the conodonts were prepared in the Electron Microscope Unit of the Australian Museum (Sydney). Ian Percival and Peter Haines are thanked for their constructive and helpful comments. Work on an initial version of this study by the late Günther Bischoff (1928-1999) of Macquarie University, is greatly appreciated. This is a contribution to IGCP Project 591: The Early to Middle Palaeozoic Revolution.

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