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Early Silurian (Llandovery) conodonts from the Barbwire Terrace, Canning Basin, Western Australia

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The recovery of a small Early to Middle Llandovery (Early Silurian) conodont fauna from core samples in two wells (WMC Acacia 1 and WMC Boab 1) is the first documentation of Silurian rocks in the Canning Basin. The recovery of *Ozarkodina hassi* from both wells allows correlation of this fauna with the Rhuddanian to Aeronian Stages (Early to Middle Llandovery), which equates with the *acuminatus* Zone to *sedgwickii* Zone graptolite faunas.

The samples are from a stratigraphic unit defined as the Lower Carbonate Member of the Worral Formation, but lithologic characteristics and age constraints indicate that the lower portion of this carbonate is part of the underlying Sahara Formation, the uppermost unit of the Carribuddy Group. The overlying Worral Formation (restricted) is of late Early to Middle Devonian (Emsian–Eifelian) age. This relationship has implications for the resource potential of the Canning Basin.

Introduction

The identification of Early Silurian conodonts from rocks corresponding to the lithologic unit defined as the Lower Carbonate Member of the Worral Formation (Lehmann, 1984) is of importance in interpreting the depositional history of the Canning Basin. In the Barbwire Terrace area, it conclusively constrains the upper age limit of the Carribuddy Group to be no younger than latest Ordovician or earliest Silurian, rather than Late Silurian or Devonian as has generally been assumed in the literature (Playford et al., 1975; Forman & Wales, 1981; Lehmann, 1984). This is also the first unambiguous report of Early Silurian rocks in Western Australia. This extends the age range of Silurian sediments on the western continental margin downward, from Late Silurian for the Dirk Hartog Formation of the Carnarvon Basin (Philip, 1969), to the Early Silurian.

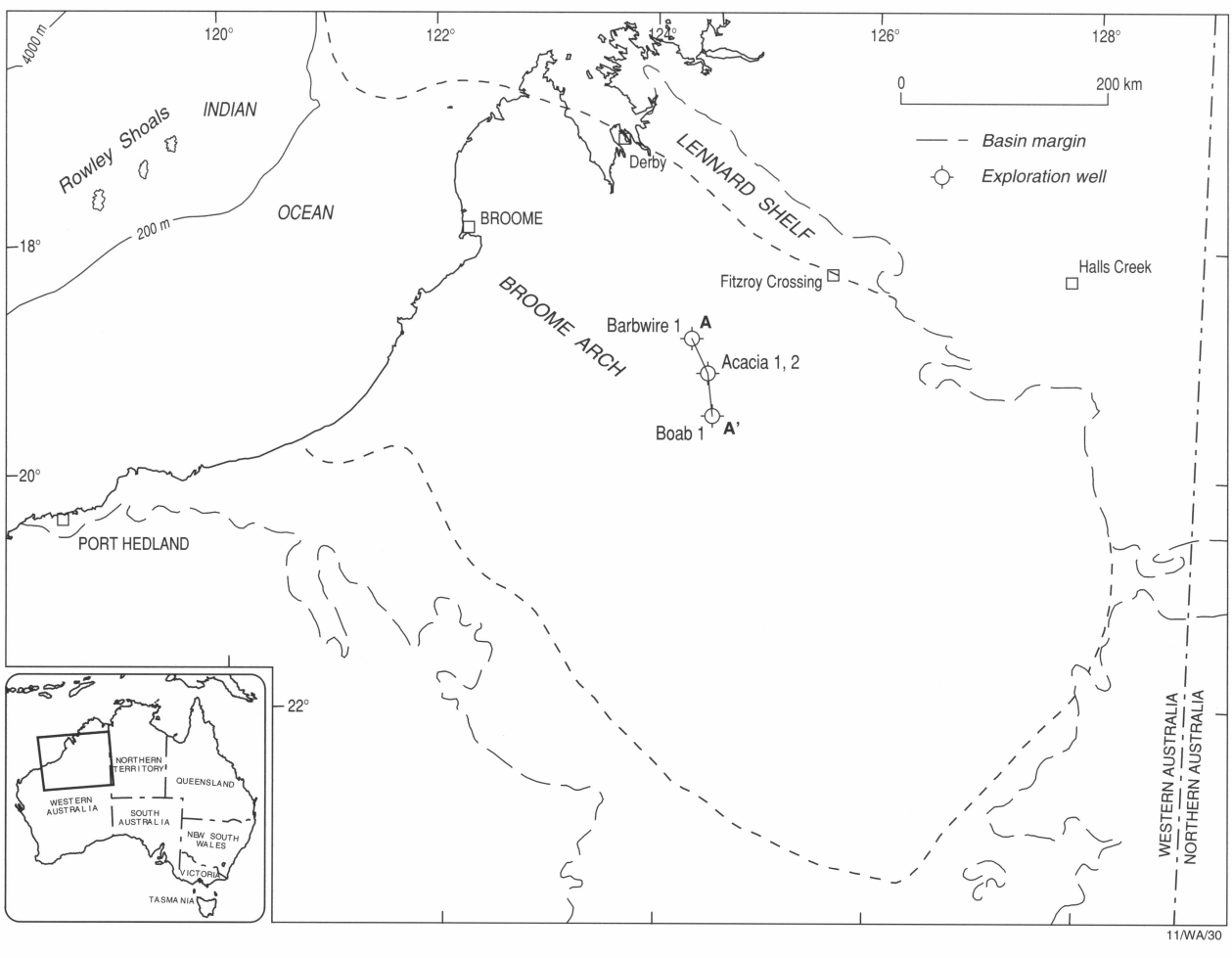

Figure 1. Locality map showing location of Canning Basin and wells discussed in text. A — A' indicates the line of section shown in Figure 2.

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Stratigraphic drilling on the Barbwire Terrace (Fig. 1) by Western Mining Corporation Limited (WMC), as part of a Canning Basin petroleum exploration program in the late 1970s and early 1980s, resulted in a number of fully cored slim-hole wells (Ashton, 1984). Some of these wells were examined for conodonts and ostracods (Jones & Nicoll, 1982; Nicoll & Jones, 1982), but the only detailed biostratigraphic study was that by Watson (1988) on Ordovician conodonts from the Santalum 1A well. Nicoll & Jones (1982) in a confidential report noted the presence of Silurian conodonts in two samples between 511 and 523 m in the Acacia 1 well (Table 1), but too few specimens were recovered for a conclusive determination. Subsequently, Watson (pers. comm., 1982) examined the same stratigraphic interval in the Boab 1 well and recovered additional conodont elements (Table 1), but this material was not available for study at that time.

As part of a review of Canning Basin subsurface conodont information (Nicoll, 1993), all conodont samples from petroleum exploration wells in the Canning Basin have been re-examined. That review included the Acacia 1 and Boab 1 wells, leading to the confirmation of the presence of the Early Silurian conodont *Ozarkodina hassi* in samples from both wells.

Table 1. Conodonts recovered from WMC Acacia 1 and WMC Boab 1.

WELL/depth	*CAI*	*Elements recovered/fauna*
ACACIA 1		
511.64–514.24 m	**1**	4 elements
		Ozarkodina hassi (1)
		1 Pa element
		indeterminate fragments (3)
515.60–516.10 m	**1**	9 elements
		Icriodella? sp. (2)
		2 Pa elements
		Oulodus sp. (1)
		1 Sa element
		Ozarkodina hassi (6)
		5 Pa elements
		1 indet. S element
519.70–522.53 m	**1**	3 elements
		Ozarkodina hassi (3)
		3 Pa elements
BOAB 1		
1012.5–1014.4 m	**1**	31 elements
		Oulodus sp. (2)
		indeterminant elements
		Ozarkodina hassi (19)
		13 Pa elements
		3 Pb elements
		2 M elements
		1 indet. S element
		indet. gen & sp. (3)
		indeterminate fragments (7)
1014.5–1015.32 m	**1**	23 elements
		Ozarkodina hassi (16)
		12 Pa elements
		2 Sc elements
		1 M element
		1 indebt S element
		Oulodus sp. (7)
		indeterminant elements

Conodont fauna and biostratigraphy

A total of 70 conodont elements, belonging to three species, were recovered from five samples in the Acacia 1 and Boab 1 wells (Table 1). The material is identified as 45 elements of *Ozarkodina hassi* (Pollock et al., 1970), nine fragments that represent broken elements of *Oulodus* sp. and two fragments that are probably Pa elements of *Icriodella*? sp. The *Oulodus* elements are too fragmented to more than suggest that they should be assigned to the genus. The two most complete elements are illustrated (Fig. 5.1–5.2).

In Acacia 1, conodonts were recovered from three samples between 511.64 and 522.53 m (Fig. 2, Table 1). In the Boab 1 well, conodonts were found in two samples between 1012.5 and 1015.32 m.

Ozarkodina hassi (Fig. 6) has been reported from Early Silurian (Llandovery) collections in North America (Pollock et al., 1970; Cooper, 1975; Nowlan, 1983), Greenland (Armstrong, 1990), and the Welsh Borderland (Aldridge, 1972, 1975). The species has not been reported from Llandovery conodont faunas in New South Wales (Nicoll & Rexroad, 1974; Bischoff, 1986).

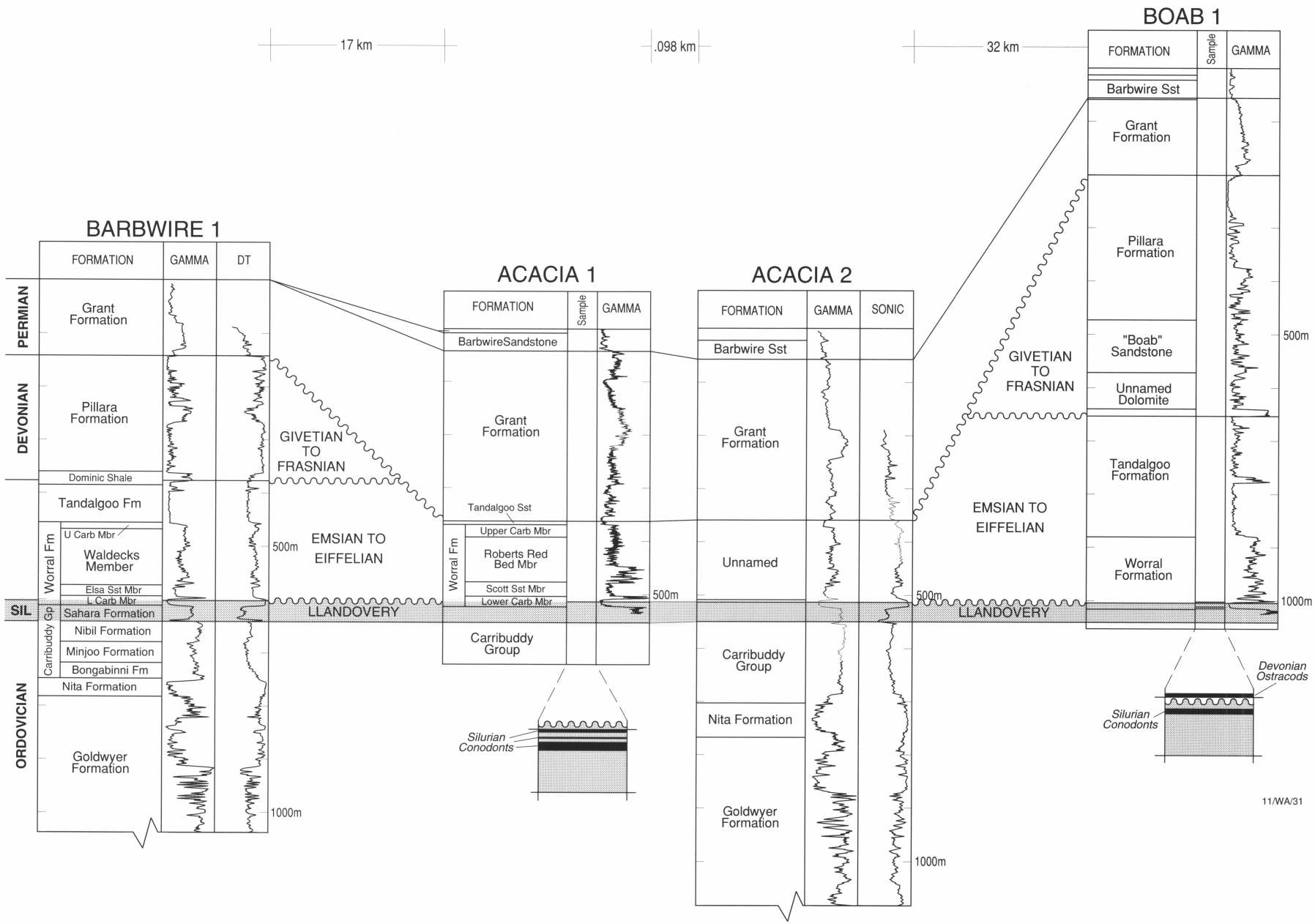
The range of *O. hassi* is not clearly defined, but it is restricted to the Llandovery. On Anticosti Island (McCracken & Barnes, 1981; Nowlan, 1982, 1983), it first appears in the *Distomodus kentuckyensis* Zone in the Becscie Formation, some distance above the Ordovician — Silurian boundary. However, Nowlan (1981) reported *O. hassi* from the unequivocally Rhuddanian Clemville Formation of the Gaspé Peninsula of Canada. In the North American Midcontinent area, *O. hassi* is reported from the Brassfield Limestone (Cooper, 1975) and the Manitoulin Dolomite (Pollock et al., 1970), both well above the Ordovician boundary. In the British Silurian, Aldridge (1975) reported *O. hassi* from the Idwian and Fronian Stages, but not from the basal Llandovery Rhuddanian Stage. In Greenland, Armstrong (1990) reported that *O. hassi* first appears in the *Aspelundia expansus* Biozone. From these studies, *O. hassi* first appears some distance above the base of the Silurian, in the middle to upper part of the *D. kentuckyensis* Zone, either in the upper part of the Rhuddanian or near the base of the Aeronian Stage. It extends upward into the *D. staurognathoides* Zone, possibly as high as the lower part of the Telychian Stage.

Age control and revised stratigraphy

Jones & Young (1993), assessing the stratigraphic framework established by Lehmann (1984), pointed out apparently conflicting age relationships in Lehmann's Devonian stratigraphy, particularly concerning the Carribuddy Group and the overlying Worral and Tandalgoo Formations. They, and Warris (1993), placed the Worral Formation in the Early Silurian based on the conodont age determinations from the Acacia 1 well report of Nicoll & Jones (1982). Both interpretations have been revised in a regional sequence stratigraphic interpretation (Romine et al., 1994) and the age information documented in this study (Figs 2,3).

The Llandovery conodonts in both the Acacia 1 and Boab 1 wells were recovered from a stratigraphic unit identified as the Worral Formation in the well-completion

Figure 2. Stratigraphic cross-section from Barbwire 1 through Acacia 1 and 2 to Boab 1 (see Fig. 1). The revised stratigraphy is shown with the gamma ray and sonic logs and the location of conodont and ostracod samples. Datum is the top of the Sahara Formation.


BARBWIRE 1
FORMATION
GAMMA
DT
PERMIAN
DEVONIAN
ORDOVICIAN
SIL
Grant Formation
Pillara Formation
Dominic Shale
Tandalgoo Fm
Worral Fm
U Carb Mbr
Waldecks Member
Elsa Sst Mbr
L Carb Mbr
Carribuddy Gp
Sahara Formation
Nibil Formation
Minjoo Formation
Bongabinni Fm
Nita Formation
Goldwyer Formation
1000m
17 km
GIVETIAN TO FRASNIAN
EMSIAN TO EIFFELIAN
500m
LLANDOVERY
ACACIA 1
FORMATION
Sample
GAMMA
BarbwireSandstone
Grant Formation
Tandalgoo Sst
Worral Fm
Upper Carb Mbr
Roberts Red Bed Mbr
Scott Sst Mbr
Lower Carb Mbr
Carribuddy Group
Silurian Conodonts
500m
.098 km
ACACIA 2
FORMATION
GAMMA
SONIC
Barbwire Sst
Grant Formation
Unnamed
Carribuddy Group
Nita Formation
Goldwyer Formation
1000m
500m
32 km
BOAB 1
FORMATION
Sample
GAMMA
Barbwire Sst
Grant Formation
Pillara Formation
"Boab" Sandstone
Unnamed Dolomite
Tandalgoo Formation
Worral Formation
GIVETIAN TO FRASNIAN
EMSIAN TO EIFFELIAN
500m
1000m
LLANDOVERY
Devonian Ostracods
Silurian Conodonts
11/WA/31

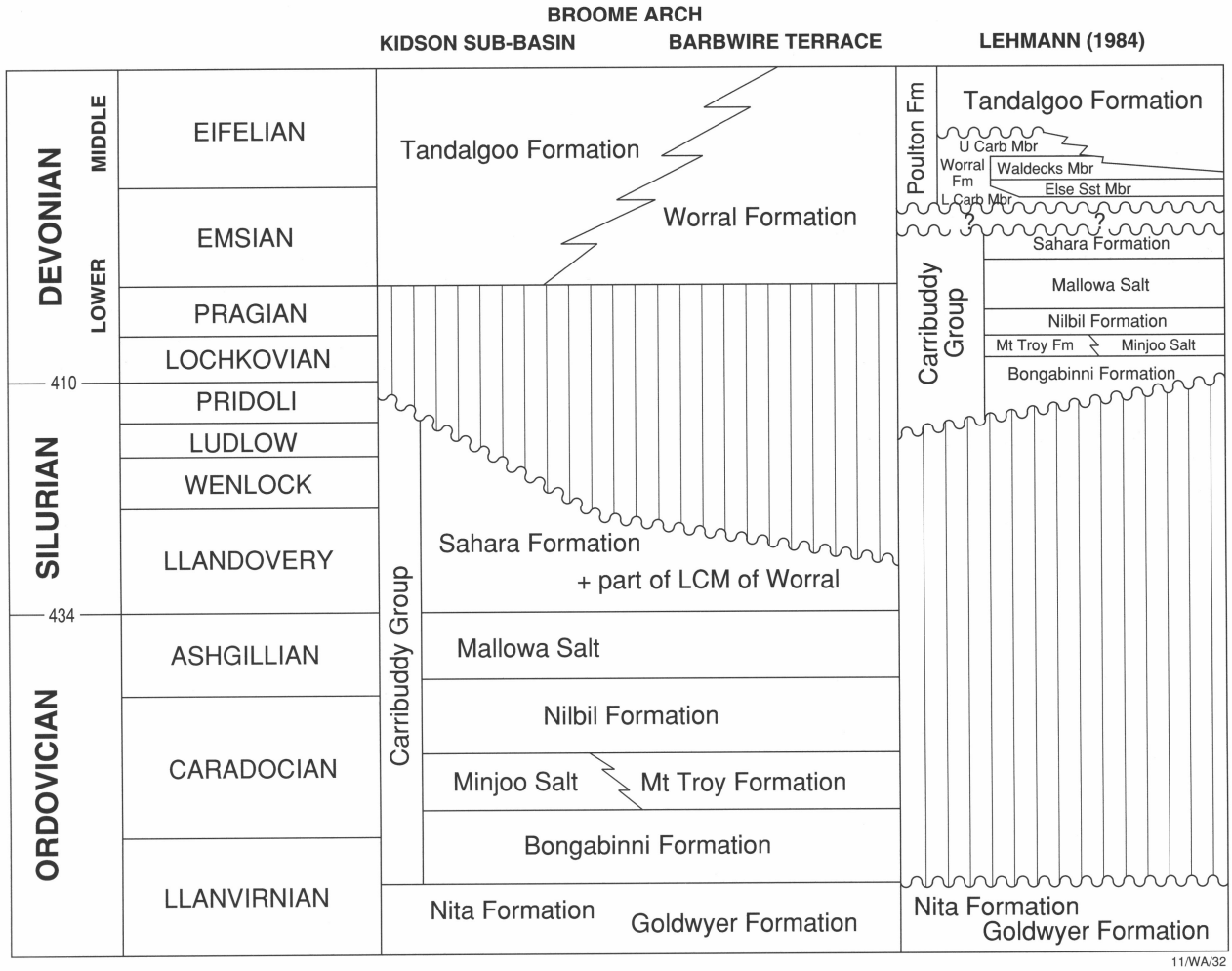


Figure 3. Revised geologic column showing age relationships of the lithostratigraphic units from the Goldwyer Formation to Tandalgoo/Worral Formations and the earlier interpretation of Lehmann (1984).

reports (Scibiorski, 1982; Watson, 1982). Subsequently, Lehmann (1984) formally defined the Worral Formation with a type section in the Barbwire 1 well. Lehmann (1984) also established four subdivisions of the formation: a Lower Carbonate Member, the Elsa Sandstone Member, the Waldecks Member, and an Upper Carbonate Member. The conodont fauna recovered in the Acacia 1 and Boab 1 samples were obtained from sediments correlative with the lower part of the Lower Carbonate Member in the Barbwire 1 well (Fig. 2).

In the Boab 1 well, Jones & Nicoll (1982) recovered ostracod steinkerns in the interval 1003.6–1005.21 m. The ostracods have close affinities to Eifelian (Middle Devonian) species from the Bashkirian region of Russia. Tentatively identified as *Rozhdestvenskayites tuimazensis* (Rozhdestvenskaya, 1959) and *Selebratina ajensis* Rozhdestvenskaya, 1962, these forms establish an unconformity in the Boab 1 well between the depths of 1005.21 and 1012.5 m (Fig. 3) that has Devonian, probably Middle Devonian (Eifelian), overlying the Early Silurian (Early to Middle Llandovery). A sample from the interval 1009.32–1010.9 m contains an unidentified scolecodont fauna, which if identifiable might reduce the uncertainty in placement of the unconformity. Age control in the equivalent interval in the Acacia 1 and Barbwire 1 wells is not available.

The palaeontological information thus suggests that the Early Silurian part of the Lower Carbonate Member is most closely related, in age, to the underlying Mallowa Salt, which Foster & Williams (1991) considered to be of Late Ordovician to Early Silurian age. Lithologic similarity of the Lower Carbonate Member and carbonate beds of the Sahara Formation provide additional support for the relationship.

Comparison of well-log information from four wells [Acacia 1, Acacia 2, Barbwire 1, and Boab 1 (Fig. 2)] and the lithologic logs based on the core in Acacia 1 and Boab 1, allow a close correlation between the wells. In these wells, the Lower Carbonate Member is easily picked and ranges in thickness from 13.35 to 20.32 m. In the Acacia 1 well, a thickness of 12.68 m is confirmed as Silurian in age by the recovery of conodonts. In the Boab 1 well, at least 4.25 m of Silurian is confirmed, and as much as 11.54 m could be of Silurian age. In all wells, the uppermost part of the Lower Carbonate Member may be of Devonian age, but this is confirmed only in the Boab 1 well.

Another tie point between the Barbwire 1 and Acacia 2 wells is a sharp spike on the gamma and sonic logs at 638.11 m (2093 ft.) and 533 m, respectively. This spike is confirmed as a dolomite bed between 550.5 and 553.3 m

in the Acacia 1 core and in the cuttings of the Barbwire 1 well. Regional well correlation (Romine et al., 1994) demonstrates that the interval 612.8–638.1 m in the Barbwire 1 well, that was previously interpreted as the Nibil Formation (Lehmann, 1984), actually belongs in the Sahara Formation and post-dates the Mallowa Salt. Thin dolomite interbeds in the Sahara Formation are common, and the new interpretation considers that the Silurian part of the Lower Carbonate member is another, slightly thicker, carbonate interval in the Sahara Formation.

Regional implications

Interpretation of stratigraphic relationships in parts of the central and southern Canning Basin, especially in the interval from the top Nita Formation to the base Grant Formation, are complicated by local and regional facies relationships, syndepositional and post-depositional structural complications, and by the lack of sufficient biostratigraphic control. This has severely hampered reconstruction of the depositional history of the basin. For example, in the 1984 Canning Basin Symposium volume (Purcell, 1984) most papers placed a major basin-wide unconformity between the Ordovician Nita or Goldwyer Formations and the overlying Carribuddy Group, which was thought to be either Late Silurian, Silurian–Devonian or Devonian in age. Evidence from this report, together with that of Foster & Williams (1991) now demonstrates that the major time break is between the Ordovician to Silurian Sahara Formation (including most of the Lower Carbonate Member of the Worral Formation) and the late Early to Middle Devonian Worral Formation rather than between the Nita Formation and the Carribuddy Group (Fig. 3).

McTavish & Legg (1976) and Nicoll (1993), using conodonts and graptolites, established a Llanvirn age, *Phragmodus–Plectodina* Zone, for the upper part of the Nita Formation. A sparse conodont fauna found in the Bongabinni Formation in the Frankenstein 1 and Kunzea 1 wells has not yielded age-diagnostic forms, but generally indicates an Ordovician age for this unit (Nicoll, 1993).

Foster & Williams (1991) were the first to publish, with good palaeontological control, that the upper part of the Carribuddy Group was probably of Late Ordovician or Early Silurian age when they identified the palynomorph *Tetrahedraletes medinensis* Strother & Traverse from the Mallowa Salt. The present identification of Early to Middle Llandovery conodonts in the Acacia 1 and Boab 1 wells, from a carbonate unit that is more properly part of the Sahara Formation, conclusively positions an unconformity above the Carribuddy Group at the base of the Worral Formation (revised, Fig. 3). On the Barbwire Terrace, the time break is between the Early Silurian (Llandovery) and the Middle Devonian (Eifelian).

The revision of the stratigraphy and the new relationship of both the Carribuddy Group and Worral Formation is here applied only in the immediate vicinity to the Acacia 1, Barbwire 1, and Boab 1 wells on the Barbwire Terrace. Extension of this relationship beyond that area is dependent on either well-log and seismic interpretation or the recovery of additional fossils from the upper part of the Sahara Formation.

This dating significantly revises the age relationships of the stratigraphic units between the top of the Nita Formation and the base of the Worral Formation (Fig. 3). It also has implications for the petroleum maturation history in the southern part of the Canning Basin. It indicates that from the time of deposition of the evaporite sequence of the Mallowa Salt in the Late Ordovician, there was an effective regional seal on the underlying hydrocarbon source beds in the Goldwyer and Nambeet Formations (Foster et al., 1986).

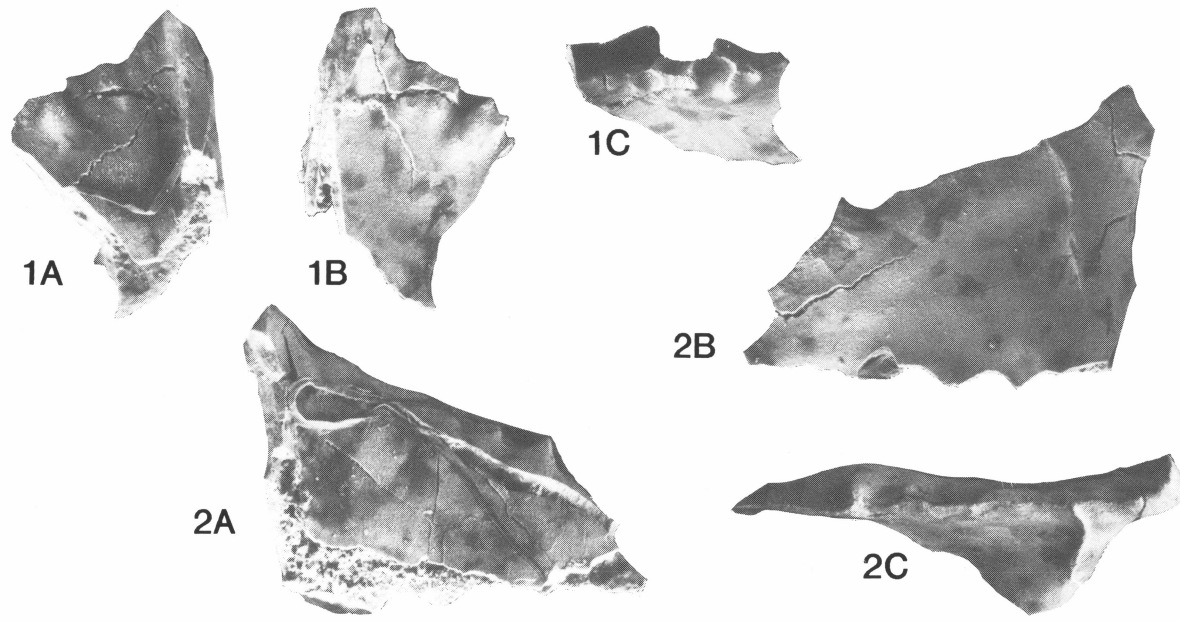


Figure 4. ***Icriodella*****? sp. All figs. X70.**
1. Pa element, (CPC 31602)[Acacia 1, 515.6–516.1 m], ?left element; a. inner lateral view; b. outer lateral view; c. oral view.
2. Pa element, (CPC 31603)[Acacia 1, 515.6–516.1 m], ?right element; a. outer lateral view; b. inner lateral view; c. oral view.

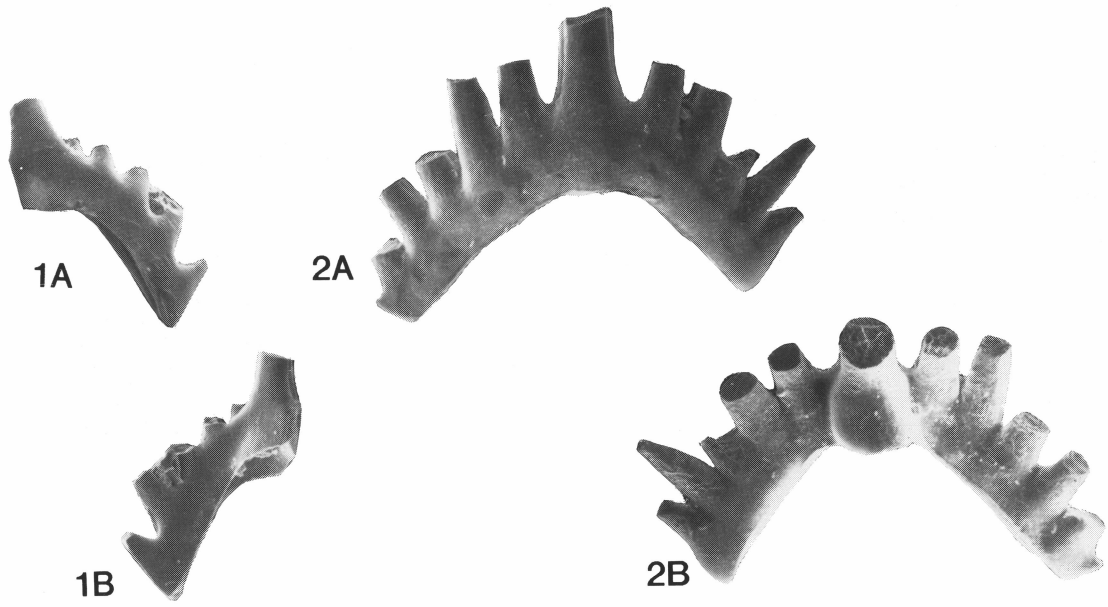


Figure 5. ***Oulodus*** **sp. All figs. X65.**
1. Sc element, (CPC 31604)[Boab 1, 1014.5–1015.32 m], right element. A. outer lateral view; B. inner lateral view.
2. Sa element (CPC 31605)[Boab 1, 1014.5–1015.32 m], symmetrical element. A. outer lateral view; B. inner lateral view.

Taxonomy

The conodont fauna recovered in this study is too limited to make major observations about the apparatus structure of *Ozarkodina hassi* and the *Oulodus* sp. and *Icriodella*? sp. elements cannot be identified to the species level. However, four of the seven elements of *O. hassi* have been identified.

Genus *Icriodella* Rhodes, 1953

Type species. *Icriodella superba* Rhodes, 1953.

Icriodella? sp.

Fig. 4

Material studied. 2 broken Pa elements.

Remarks. The two broken Pa elements recovered consist of pastinoscaphate elements, deeply excavated, and lacking a blade. There are two offset denticles on the oral margin and one of the elements has an adentate lateral process preserved. These fragments could be assigned to any of several genera, such as *Icriodella* or *Aphelognathus*. However, the offsetting of the denticles is most similar to *Icriodella* and they are questionably assigned to that genus.

Biostratigraphy. Genus ranges from the Upper Ordovician through the Early Silurian (Llandovery).

Genus *Oulodus* Branson & Mehl, 1933

Type species. *Cordylodus serratus* Stauffer, 1930

Remarks. See the discussion by Armstrong (1990) on the type species of the genus.

Oulodus sp.

Fig. 5

Material studied. 9 element fragments.

Remarks. The elements of *Oulodus* recovered are too broken, and too few element types are present to attempt to assign the material to a species.

Biostratigraphy. The genus has a long stratigraphic range (Upper Ordovician–Lower Devonian); thus, this material offers no useful biostratigraphic information.

Genus *Ozarkodina* Branson & Mehl, 1933

Type species. *Ozarkodina* typica Branson & Mehl, 1933.

Remarks. Septimembrate apparatus with M, Sa, Sc, Sb, Sd, Pb and Pa elements. See Nicoll & Rexroad (1987) or Nicoll (1985) for a demonstration of the apparatus configuration in fused cluster material.

Ozarkodina hassi (Pollock, Rexroad & Nicoll), 1970

Fig. 6

Material studied. 45 elements (Pa-34, Pb-3, M-3, Sc-2).

Remarks. In the limited material recovered for this study, only M, Sc, Pb and Pa elements are distinguished, does not significantly change existing interpretation of the species.

Ozarkodina hassi was first described as the discrete element taxon *Spathognathodus hassi* by Pollock et al. (1970), and Cooper (1975) first established a partial multielement reconstruction for the species. *O. hassi* was recently reviewed by Armstrong (1990), who confirmed the general nature of the apparatus reconstruction but disagreed with Cooper's interpretation of the M element associated with the species. The morphology of the three

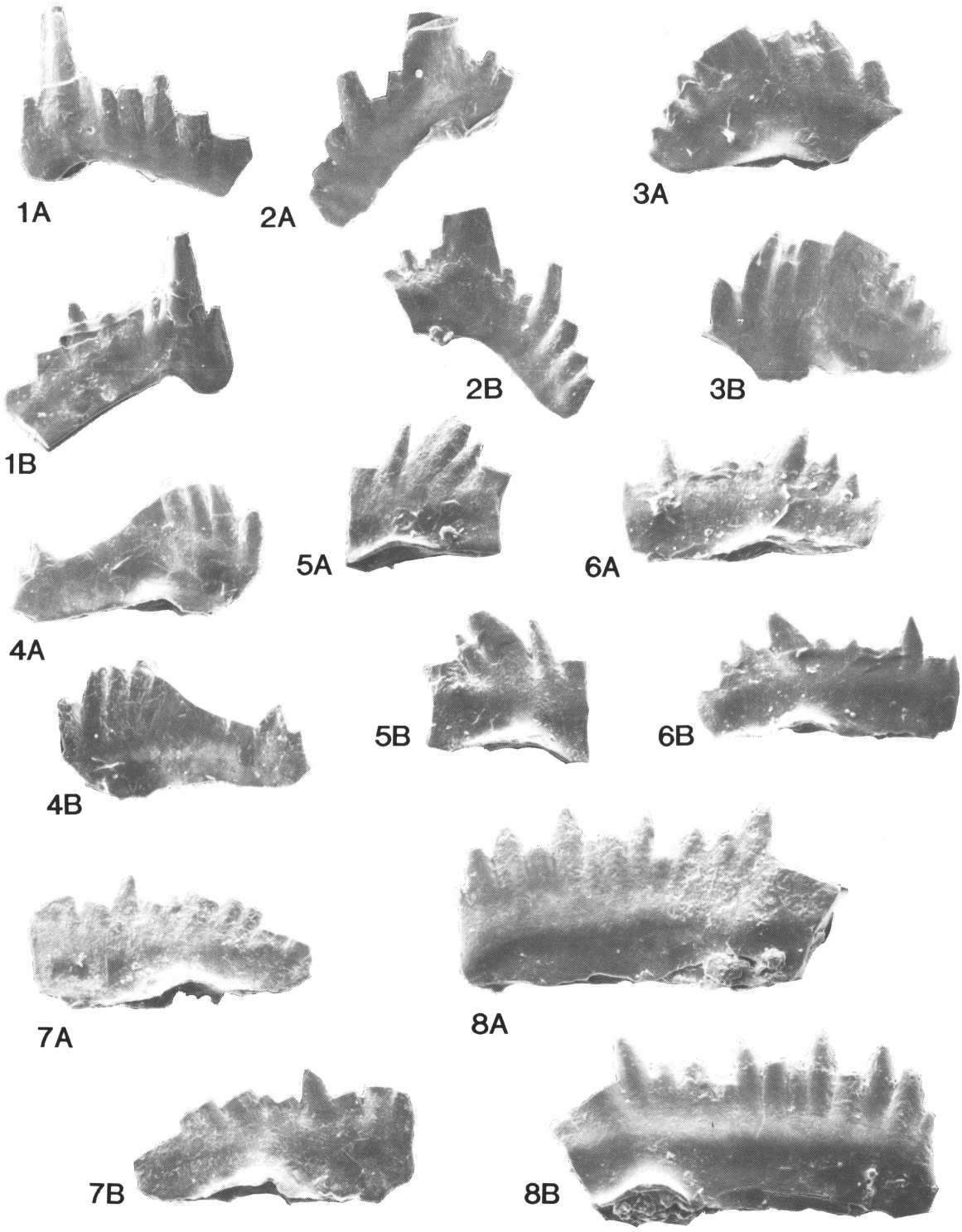


Figure 6. ***Ozarkodina hassi.*** **All figs X95.**
1. M element (CPC 31606)[Boab 1, 1014.5–1015.32 m], left element. A. anterior view; B. posterior view.
2. Sc element (CPC 31607)[Boab 1, 1014.5–1015.32 m], left element. A. outer lateral view; B. inner lateral view.
3. Pb element (CPC 31610)[Boab 1, 1012.5–1014.4 m], left element. A. inner lateral view; B. outer lateral view.
4. Pb element (CPC 31611)[Boab 1, 1012.5–1014.4 m], left element. A. inner lateral view; B. outer lateral view.
5. Pa element (CPC 31612)[Boab 1, 1012.5–1014.4 m], right element. A. inner lateral view; B. outer lateral view.
6. Pa element (CPC 31613)[Acacia 1, 519.70–522.53 m], right element. A inner lateral view; B. outer lateral view.
7. Pa element (CPC 31608)[Boab 1, 1014.5–1015.32 m], right element. A. inner lateral view; B. outer lateral view.
8. Pa element (CPC 31609)[Boab 1, 1014.5–1015.32 m], right element. A. inner lateral view; B. outer lateral view.

M elements recovered in this study are intermediate between those illustrated by Armstrong (1990, Pl. 13, fig. 13) and Cooper (1975, Pl. 3, fig. 11). The elements (Fig. 6.1) have one to two denticles on the inner lateral process and have the outer lateral process bent downward more than indicated by Armstrong, but less than shown by Cooper. The Pa elements are within the morphologic range of the elements illustrated by Pollock et al. (1970) and both Armstrong (1990) and Cooper (1975).

Biostratigraphy. Early Silurian (Llandovery), from the Rhuddanian to lower Telychian Stages, upper *Distomodus kentuckyensis* to top *D. staurognathoides* conodont Zones.

Conclusions

The recovery of Early Silurian (Early to Middle Llandovery) conodonts from the Acacia 1 and Boab 1 wells conclusively documents the presence of Silurian sedimentation in the Canning Basin. It also places an effective time cap on the deposition of the Carribuddy Group with the bulk of the unit, including both major evaporitic intervals, deposited in Late Ordovician time, not Late Silurian or possibly Devonian as had been earlier thought.

In the Barbwire Terrace area, the stratigraphic and depositional relationship of the Sahara and Worral Formations are revised, with the placement of most of the Lower Carbonate Member (Lehmann, 1984) in the Sahara Formation, and the recognition of a major unconformity between the revised Sahara and Worral Formations. This relationship means that a regional seal on the hydrocarbon prospective Ordovician section has been in place since the end of the Ordovician.

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