ABHANDLUNGEN DER GEOLOGISCHEN BUNDESANSTALT
Abh. Geol. B.-A. | ISSN 0016–7800 | ISBN 3-85316-02-6 | Band 54 | S. 107–133 | Wien, Oktober 1999
North Gondwana: Mid-Paleozoic Terranes, Stratigraphy and Biota | Editors: R. Feist, J.A. Talent & A. Daurer

Conodont Data in Relation to Time, Space and Environmental Relationships in the Silurian (Late Llandovery–Ludlow) Succession at Boree Creek (New South Wales, Australia)

PETER COCKLE*)

2 Text-Figures, 7 Tables and 5 Plates

Australia
New South Wales
Silurian
Conodonts

Contents

Conodonten und ihre zeitlichen, räumlichen und Umwelt-Beziehungen in der silurischen (oberstes Llandovery–Ludlow) Schichtfolge am Boree Creek (New South Wales, Australien)

Zusammenfassung

Eine Kombination von Conodontendaten und Neukartierung der Umgebung des Boree Creek im zentral-westlichen New South Wales unterstreicht die gegenseitige Verzahnung der Boree-Creek- und Mirrabooka-Formationen bei oftmaliger Anhäufung der Mirrabooka-Formation auf Kosten der ersteren, die geringe Winkeldiskordanz (Quarry-Creek-Hiatus) zwischen der Boree-Creek-Formation und dem Borenore-Kalk, sowie die graduelle Grenze zwischen der Mirrabooka-Formation und dem überlagernden Wallace-Schiefer (älteres Synonym für Barnby-Hills-Schiefer). Die Conodontendaten reflektieren klar das Ireviken-Aussterbeereignis im frühesten Wenlock. Sie belegen, dass die Boree-Creek-Formation von der *amorphognathoides*-Zone (spätes Llandovery–ältestes Wenlock) bis in die *ranuliformis*-Zone (frühes Wenlock) ausdauert und dass der Borenore-Kalk irgendwo in der *ranuliformis*-Zone beginnt und zumindest bis in das mittlere Ludlow (*variabilis*-Zone) reicht. Der Quarry-Creek-Hiatus war deshalb auf nur einen Teil der *ranuliformis*-Zone beschränkt und dauerte kürzer an als in benachbarten Gebieten. Die Conodontenfaunen (25 Taxa aus 138 Proben), meist aus stratigraphischen Abfolgen, werden dokumentiert wie auch vergesellschaftete phosphatische Reste anderer Organismen.

*) Author's address: PETER COCKLE, Macquarie University Centre for Ecostratigraphy and Palaeobiology, Department of Earth and Planetary Sciences, Macquarie University 2109, Australia.

Abstract

A combination of conodont data and re-mapping of the Boree Creek area of central western New South Wales highlights interfingering of the Boree Creek and Mirrabooka Formations, recurrent cannibalisation of the former during accumulation of the Mirrabooka Formation, the low-angle unconformity (Quarry Creek Hiatus) between the Boree Creek Formation and the Borenore Limestone, and the gradational boundary between the Mirrabooka Formation and the overlying Wallace Shale (senior synonym of Barnby Hills Shale). Conodont data clearly reflect the earliest Wenlock Ireviken Extinction Event. They demonstrate that the Boree Creek Formation extends from *amorphognathoides* Zone (late Llandovery–earliest Wenlock) into *ranuliformis* Zone (early Wenlock), and that the Borenore Limestone, commencing somewhere in the *ranuliformis* Zone, extends to at least the middle Ludlow (*variabilis* Zone). The Quarry Creek Hiatus was therefore restricted to only part of the *ranuliformis* Zone and was shorter in duration than in adjoining areas. The conodont faunas (25 taxa from 138 samples), mostly from stratigraphic sections, are documented, as are associated phosphatic remains of other organisms.

1. Introduction

1.1. Geological Setting

The Silurian succession in the Boree Creek-Cheesemans Creek spans most of Silurian time, possibly extending into the earliest Devonian (Lochkovian). The study area lies close to the Mirrabooka Submarine Valley hypothesised (BYRNES, 1976; BYRNES in PICKETT, 1982) to have debouched southwestwards towards the Cowra Trough. Apart from a portion of the Borenore Limestone (less than 10 %), chronologic relationships between the various lithologic units in this area of carbonate platform and adjacent slope (or submarine valley) sedimentation had not previously been closely probed. The sequence clearly spans the Ireviken (very early Wenlock) Global Extinction Event, and perhaps the mid-Ludlow, end-*siluricus* Zone (Pentamerid or Lau) Global Extinction Event as well, and was expected to display some impress of regional sedimentary-tectonic events, especially the Quarry Creek Hiatus inferred from sections southwest of the study area.

The Boree Creek-Borenore area has long been known for the diversity of its Silurian fossils, especially corals (e.g. DE KONINCK, 1876; DUN, 1907; ETHERIDGE, 1909), and for its limestones (CARNE & JONES, 1919; LISHMUND et al., 1986). Basic mapping for much of the area had been carried out principally by WALKER (1959), PARTRIDGE (1967) and, importantly, for the adjoining Cheesemans Creek area by SHERWIN (1971, q.v. for mapping of adjacent areas).

WALKER (1959) had suggested that two units could be discriminated within the limestones of the Boree Creek area: an underlying Rosyth Limestone, and a thick overlying interval, the Borenore Limestone. He noted that the latter outcrops boldly, lacks obvious bedding, and that its most prominent outcrops consist of brecciated limestone; this is especially evident in the vicinity of the Borenore Caves.

PARTRIDGE (1967) argued that the boundary in question was in fact a facies change from Borenore Limestone in the east to sandstones, shales and bedded limestones of what he called the Bunyarra Formation in the west and showed much of the area that WALKER had mapped as Panuara Formation was actually Wallace Shale.

SHERWIN (1971) mapped an area centred on Cheesemans Creek, overlapping the present area to the west. He proposed two new Silurian stratigraphic units: the Boree Creek Formation – including the Rosyth Limestone of previous workers, together with some of the limestones of PARTRIDGE's "Bunyarra Formation" – and the Mirrabooka Formation containing the sandstones, shales and remaining limestones of the "Bunyarra Formation". Three informal intervals were discriminated in the Boree Creek Formation: Limestone A (essentially the Rosyth Limestone), a Tuffaceous Trilobite Bed, and Limestone B. His Mirrabooka Formation thus overlies the Boree Creek Formation and is stratigraphically beneath the Wallace Shale.

BISCHOFF (1986) used conodont data to correlate various limestones of the region, taking particular account of the graptolite biostratigraphy presented by previous workers, especially JENKINS (1977). He noted two unconformities in the Boree Creek sequence on "Kalinga": one at the top of "Limestone B" of SHERWIN's Boree Creek Formation, and another higher in the sequence. Limestones above the first unconformity were referred to WALKER's (1959) Borenore Limestone (and thus to the Panuara Group sensu JENKINS), the sequence below being referred to as Boree Creek Formation and thus to JENKINS' (1977) Waugoola Group (cf. Table 1).

The same section on "Kalinga" was investigated by TALENT et al. (1993 – their section BOC) for evidence of the very early Wenlock Ireviken Extinction Event, originally defined from Gotland, Sweden. Carbon and oxygen isotope data from whole rock specimens, considered in conjunction with the pattern of extinction of conodont taxa, confirmed the presence of a major carbon isotope excursion and a profound extinction event, with at least 4 of the 6 phases discriminated in Gotland being identifiable in section BOC (L. JEPPSSON, pers. comm.) The extinction and isotopic events are not connected with changes in lithology either on the Gotland or in the Boree Creek sections.

Relevant studies of areas southwest of the Borenore-Boree Creek area have been undertaken by SÜSSMILCH (1906), STEVENS & PACKHAM (1952), STEVENS (1953), PACKHAM & STEVENS (1954), RICKARDS et al. (1995) and JENKINS (1977) whose stratigraphic framework for the Silurian stratigraphy of the Panuara area (Table 1) emphasised the importance of the diastems discriminated earlier by PACKHAM (1969). As no evidence of a hiatus could be found between the Mirrabooka Formation and the Wallace Shale, he proposed, contrary to SHERWIN (1971), that the Wallace Shale should be included in the Panuara Group.

VANDYKE & BYRNES (1976) proposed the name Mumbil Group for a Silurian sequence well developed west of Mumbil, about 60 km north of the area examined for the present report. They included within the Mumbil Group a basinal sequence previously referred to as the Barnby Hills Shale by STRUSZ (1960), a unit strikingly similar in lithology and of very similar age to the Wallace Shale. POGSON & WATKINS (in press), in revising stratigraphic nomenclature for the Bathurst 1 : 250,000 geological map (2nd edition), have proposed transfer of the constituents of the redefined Panuara Group to the Mumbil Group, though the name Panuara Group (however construed) has priority of publication data.

Diese Abbildung musste auf herkömmliche Weise fototechnisch reproduziert werden und liegt daher nicht in digitaler Form vor

Text-Fig. 1.
Geology of the Boree Creek area, central-western New South Wales, Australia.

Table 1.
Stratigraphic relationships in the Panuara area.

Series	Graptolite Zone	Group	Formation	Member
LUDLOW		PANUARA GROUP	Wallace Shale	
	ludensis			
			Ulah Formation	
WENLOCK	*lundgreni*			
	ellesae	"Quarry Creek Hiatus" (Packham 1969)		
	murchisoni			
LLANDOVERY	*centrifugus*	WAUGOOLA GROUP	Glendalough Formation	Ashleigh Member
				Chaucer Red Bed Member
				Burly Jackie Sandstone Member
	turriculatus		Cobblers Creek Limestone	
	sedgwickii	"Panuara Hiatus" (Packham 1969)		
	convolutus			
	argenteus	CADIA GROUP	Cadia Coach Shale	Avon Lea Mudstone Member
			Bagdad Formation	Bridge Creek Limestone Member
				Wire Gully Limestone Member
	versiculoses			
	acuminatus	"Cobblers Creek Hiatus" (Packham 1969)		
		Underlying Ordovician basement		

1.2. Scope of Present Investigation

Mapping by PARTRIDGE (1967) in the Boree Creek area and by SHERWIN (1971) in the vicinity of "Bunyarra" were fundamental starting points for the present investigation. A principal focus was the area about "Werrina" where the interfingering nature of the boundary between the Mirrabooka Formation and the Borenore Limestone is most easily investigated, and because in that area the Borenore Limestone can be readily appreciated as consisting of two members: low relief and poorly outcropping bedded limestones – from which most of the conodont samples were obtained – and boldly outcropping limestone "breccias", possibly the product of debris flow emplacement. Unequivocal limestone-charged debris flow deposits and isolated olistoliths nevertheless occur in the Wallace Shale where they were deposited in what is assumed to have been a deeper marine context. Limestone clasts from the Wallace Shale were copiously sampled but with generally disappointing results.

1.3. Conodont Zonation and Abbreviations Used

The conodont zonation schemes of BARRICK & KLAPPER (1976) and SIMPSON (1995) are employed. Because of the faunas encountered in this study, BARRICK & KLAPPER'S *variabilis* Zone was used for the early Ludlow; it equates with WALLISER's (1964) *ploeckensis* Zone used by SIMPSON (1995) in reviewing Australian conodont zones. Names for other zones used in this study are identical in both of the above zonal schemes. The graptolite zonation used by RICKARDS et al. (1995) was used in discussion of the graptolite data from the Mirrabooka Formation and the Wallace and Barnby Hills Shales. Relationships between these schemes are shown in Table 3.

The following abbreviations are used for conodont genera throughout the text, on Text-Figures and in the distribution charts:

A. = *Apsidognathus*; *B.* = *Belodella*; *C.* = *Coryssognathus*; *D.* = *Dapsilodus*; *Dis.* = *Distomodus*; *K.* = *Kockelella*; *O.* = *Ozarkodina*; *P.* = *Panderodus*; *Ps.* = *Pseudooneotodus*; *Pt.* = *Pterospathodus*; *Py.* = *Pyrsognathus*.

Table 2.
Location of measured and sampled sections.

SECTION	LOCATION	NO. OF SAMPLES
BOC	7970 2007	9
BOR/1	7959 1992	14
DSC and DSC/B	7885 2160	38
DSC/E	7884 2020	18
BN28	7878 1983	13
BUN	7540 2160	17
BUN/E	7690 2138	10
ERC	7330 2080	7
WERR	7917 2066	11
SPOT SAMPLES		
1 Bunyarra BUN/E section (loose sample)	7690 2138	
2 S bank of Boree Creek	7882 2001	
3 Breccia on S side of Boree Creek	7871 2000	
4 River Cave	7875 1999	
5 Head of eastern creek, DSC dam	7888 2055	
6 Above dam at top of DSC section	7891 2058	
7 Olistolith within Wallace Shale (ITG1)	7878 1983	
8 BN28 breccia limestone	7884 1985	

Table 3.
Australian Silurian conodont zones of SIMPSON (1995) correlated with zonation used by BARRICK & KLAPPER (1976) and graptolite zonation used by RICKARDS et al. (1995).
QCH1 = estimated range of Quarry Creek Hiatus in this study; QCH2 = Quarry Creek Hiatus according to RICKARDS et al. (1995).

	SERIES	SCHEME / STAGE	Barrick & Klapper 1976	Australian Zones Simpson 1995	Graptolite Zones Rickards *et al* 1995	Comments
SILURIAN	PRIDOLI			unzoned		
	LUDLOW	LUDFORDIAN		*crispa*	*balticus / caudatus*	
					koslowskii	Age of Barnby Hills Shales
				unzoned	*inexpectatus*	
					auriculatus	Maximum age of Wallace Shale (siluricus/crispa zones)
				siluricus	*cornutus*	
					procornutus / *aversus* — *bohemicus*	
					leintwardinensis	
		GORSTIAN	*variabilis*	*ploeckensis*	*hemiiaversu* / *invertus* — *tumescens*	
					scanicus	
					progenitor	
					nilssoni	
	WENLOCK	HOMERIAN	*stauros*	unzoned	*ludensis*	
					nassa	
					lundgreni	
		SHEINWOODIAN	*amsdeni*	*amsdeni*	*ellesae*	Quarry Creek Hiatus (Jenkins 1977)
					flexilis	
					rigidus	
					riccartonensis	
			ranuliformis	*ranuliformis*	*murchisoni*	QCH[1]
			amorphognathoides	*amorphognathoides*	*centrifugus*	QCH[2]
	LLANDOVERY	TELYCHIAN			*crenulata*	
					griestoniensis	
				celloni	*crispus*	
					turriculatus	
		AERONIAN		*Distamodus staurognathoides*	*sedgwickii*	
					convolutus	
					argenteus	
				unzoned	*magnus*	
				D. pseudopesavis *D. combinalus*	*triangulatus*	
		RHUDDANIAN			*cyphus*	
				unzoned		

Abbreviations used for stratigraphic sections are:

BOC = Boree Creek; BUN = Bunyarra; BUN/E = Bunyarra East; WERR = Werrina; BOR/1 = Borenore Section 1; DSC = Dead Sheep Creek; BN28 = Survey Tag Number for Long Cave; ERC = Elenara Road Cutting.

Spot localities are shown on Text-Fig. 1.

It should be noted that wherever the word "Zone" is used in the text, the current zonal scheme for the Silurian, based on conodonts, is implied (Table 3).

2. Sampled Sections and Conodont Data

A suite of 10 sections (3 of them fundamentally legs of a single section) was chosen for sampling according to stratigraphy and quality of outcrops; locations of these are shown in Text-Fig. 1. Conodont data from the resultant 138 samples (Table 3), supplemented by 9 spot samples are set out on Tables 4–7. Three of these sections were in the Boree Creek Limestone: BOC, BUN/E and WERR, the last through a small outcrop on "Werrina" near the top of the formation. Acid leaching of these samples (3 to 4 kg each) yielded approximately 1250 conodonts. Section BUN from a small outcrop on "Bunyarra" is apparently of Boree Creek Limestone. Section ERC is through a sequence of small limestone cobbles in Wallace Shale in a road cutting opposite "Elenara" (east of Text-Fig. 1), about 2 km W of "Bunyarra". The remaining sections were from the Borenore Limestone. Section BOR/1 was across the unconformity at the top of bedded Borenore Limestone on "Kalinga". Sections DSC, DSC/B and DSC/E were from bedded and brecciated sequences of Borenore Limestone near the facies boundary with the Mirrabooka Formation. Section BN28 was through a bedded sequence between two large outcrops of brecciated limestones high in the Borenore Limestone, apparently equivalent stratigraphically to the lower part of the Wallace Shale outcropping a few hundred metres to the west.

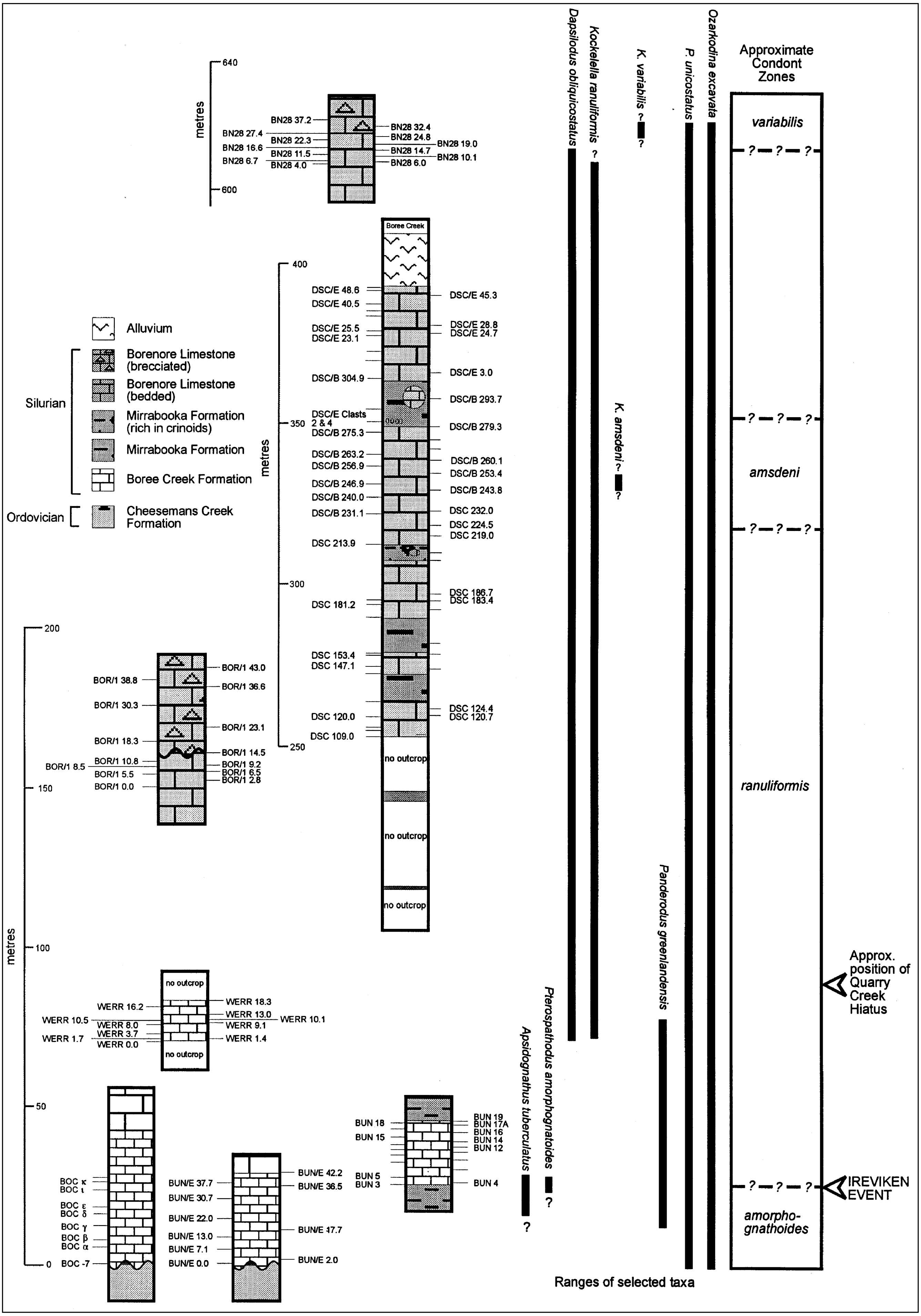
BOC

This 49.2 m section (Text-Fig. 1; Table 4) through the basal beds of the Boree Creek Formation spans SHERWIN's (1971) Limestone A (= Rosyth Limestone). It consists of thinly bedded, muddy, nodular limestones rich in fossils; numerous small brachiopods and coral fragments are released by weathering. The beds unconformably overlie Ordovician volcanics of the Cheesemans Creek Formation. Conodonts from 9 samples from this section included the short-ranging, *Distomodus staurognathoides* and *Apsidognathus tuberculatus* indicating the late Llandovery–

Table 4.
Distribution of conodonts, sections BOC, BUN/E, BUN.

Section		BOC							BUN/E								BUN						
Sample		-7	α	β	γ	δ	ι	κ	0.0	2.9	7.1	13.0	22.0	30.7	37.7	42.2	3	4	5	15	17A	18	19
Species	Element																						
Apsidognathus tuberculatus	Pa					1							1										
	arched															1							
Distomodus staurognathoides	Pb					1																	
Ozarkodina excavata excavata	Pa	1					1												4		6		2
	Pb																				1		
	Sa																				2		1
	Sb																	1			5		
	Sc						1									1					3		
	M																						
Panderodus greenlandensis	Sa				1																		
	Sb				1		1											1					
	Sc											1											
	M								1														
Panderodus recurvatus	Sa								1						1								
	Sb								2	1											1		
	Sc								1	2													
	M						1	1								1							
Panderodus unicostatus	Sa		1	1			1		2		1	1									5		
	Sb		1	3			1	1	3	1	2	1									2		
	Sc	1		1		1			1							1					3		
	M		1					1	1					1	1			2			7		
Panderodus sp.				1	1	1	1			2			4	5		1				1	2		1
Pseudooneotodus bicornis																							
Pterospathodus amorphognathoides	Pb																1						
Pterospathodus procerus	Pa													1									
Pterospathodus sp.A	Pa																1						
Pyrsognathus latus	Pa					1																	

Text-Fig. 2. ➔ ➔ ➔
Stratigraphic columns of sections BOC, BUN, BUN/E, WERR, BOR/1, DSC, BN28.
Samples barren of conodonts are shown without distance along a metric tape from the base of the section.



Alluvium
Silurian
Borenore Limestone (brecciated)
Borenore Limestone (bedded)
Mirrabooka Formation (rich in crinoids)
Mirrabooka Formation
Boree Creek Formation
Ordovician
Cheesemans Creek Formation
metres
640
600
BN28 37.2
BN28 27.4
BN28 22.3
BN28 16.6
BN28 11.5
BN28 6.7
BN28 4.0
BN28 32.4
BN28 24.8
BN28 14.7
BN28 6.0
BN28 19.0
BN28 10.1
Boree Creek
400
350
300
250
DSC/E 48.6
DSC/E 40.5
DSC/E 25.5
DSC/E 23.1
DSC/B 304.9
DSC/E Clasts 2 & 4
DSC/B 275.3
DSC/B 263.2
DSC/B 256.9
DSC/B 246.9
DSC/B 240.0
DSC/B 231.1
DSC 213.9
DSC 181.2
DSC 153.4
DSC 147.1
DSC 120.0
DSC 109.0
DSC/E 45.3
DSC/E 28.8
DSC/E 24.7
DSC/E 3.0
DSC/B 293.7
DSC/B 279.3
DSC/B 260.1
DSC/B 253.4
DSC/B 243.8
DSC 232.0
DSC 224.5
DSC 219.0
DSC 186.7
DSC 183.4
DSC 124.4
DSC 120.7
no outcrop
no outcrop
no outcrop
200
150
100
50
0
BOR/1 38.8
BOR/1 30.3
BOR/1 18.3
BOR/1 10.8
BOR/1 8.5
BOR/1 5.5
BOR/1 0.0
BOR/1 43.0
BOR/1 36.6
BOR/1 23.1
BOR/1 14.5
BOR/1 9.2
BOR/1 6.5
BOR/1 2.8
no outcrop
WERR 16.2
WERR 10.5
WERR 8.0
WERR 3.7
WERR 1.7
WERR 0.0
WERR 18.3
WERR 13.0
WERR 9.1
WERR 1.4
WERR 10.1
no outcrop
BOC κ
BOC ι
BOC ε
BOC δ
BOC γ
BOC β
BOC α
BOC -7
BUN/E 37.7
BUN/E 30.7
BUN/E 22.0
BUN/E 13.0
BUN/E 7.1
BUN/E 0.0
BUN/E 42.2
BUN/E 36.5
BUN/E 17.7
BUN/E 2.0
BUN 18
BUN 15
BUN 5
BUN 3
BUN 19
BUN 17A
BUN 16
BUN 14
BUN 12
BUN 4
Dapsilodus obliquicostatus
Kockelella ranuliformis
K. variabilis
K. amsdeni
P. unicostatus
Ozarkodina excavata
Panderodus greenlandensis
Pterospathodus amorphognatoides
Apsidognathus tuberculatus
Ranges of selected taxa
Approximate Condont Zones
variabilis
amsdeni
ranuliformis
amorpho-gnathoides
Approx. position of Quarry Creek Hiatus
IREVIKEN EVENT

earliest Wenlock *amorphognathoides* Zone. The numbers of conodonts recovered was small (72 from 9 samples) but the heavily pyritised acid-insoluble residues are rich in foraminifers and microscopic gastropods.

BUN/E

This 42.2 m section (Text-Fig. 1; Table 4) is through the same limestone interval (Member A) as section BOC. The limestone lithologies are similar and are overlain by Mirrabooka Formation sandstones and shales. Conodont yields were low. The salient forms *Apsidognathus tuberculatus* and *Pterospathodus procerus* indicate the late Llandovery-earliest Wenlock *amorphognathoides* Zone.

BUN

This section (Text-Fig. 1, Table 4) through a limestone pod (SHERWIN's [1971] Limestone I) in the Mirrabooka Formation consists of two distinct intervals: a lower interval of 18.5 m of medium grained, grey to white limestone, and an upper thinner interval of about 9 m of limestone breccia. Contact of the limestone with surrounding shales is sharp with no sign of a gradation from limestone to shale; this accords with it being an allochthonous block, older than the enclosing sediments. Graptolites from immediately below the outcrop give an age of *scanicus* to *leintwardinensis* zones (SHERWIN, 1971, 1976). Conodont yields through this limestone (total 113 specimens) were variable; mostly from two beds: a limestone at the base, and a breccia towards the top of the section. Conodonts from the base of the section included fragments of several large, robust ramiform elements including a Pa element of *Pt. amorphognathoides* (zonal form for the *amorphognathoides* Zone). Sample BUN 17A from 25 m above the base of the section yielded 62 % of the entire conodont fauna from the section. The conodonts, strikingly smaller and more delicate than conodonts from other horizons in the section, included numerous *Ozarkodina excavata excavata* and several small coniform *Panderodus*.

Sudden disappearance of the diverse conodont fauna at the level of sample 5 and recolonisation of the environment by cosmopolitan species at sample 17A accords with the Ireviken Extinction Event (end of the *amorphognathoides* Zone) having occurred in the intervening interval. The *amorphognathoides* Zone conodont fauna of the lower cluster (samples 3 to 5) is much more diverse than the basically two-species fauna of the higher cluster (samples 17A to 19). As with typical Ireviken Event sequences on Gotland, there is no obvious change in lithology connected with this event.

WERR

This section (Text-Fig. 1, Table 5) through the Boree Creek Formation (18.3 m; 11 samples) is across an isolated limestone outcrop at the base of a small basalt hill. The outcropping limestone is well bedded and highly fos-

Table 5.
Distribution of conodonts, sections WERR, BOR/1.

Section		WERR										BOR/1												
Sample		0.0	1.4	1.7	3.7	8.0	9.1	10.1	10.5	16.2	18.3	0.0	2.8	5.5	6.5	8.5	9.2	10.8	14.5	18.3	23.1	30.8	36.6	38.8
Species	Element																							
Dapsilodus obliquicostatus	Sa		1													1			1					
	Sc		2													1								
	M		4		1	1				1			1		1	1		5	3					
Kockelella latidentata	Pa		1																					
Kockelella n sp. A	Pa		2																					
Kockelella n sp. cf. n sp A	Pa		1									1												
Kockelella ranuliformis	Pa		2			1										1								
	Sb				1																			
Ozarkodina excavata excavata	Pa	1	3	2	1			4				1				2			1					
	Pb		1		1	1		1	1		1							1						
	Sa														1									
	Sb		2								1		1									1		
	Sc															1								
	M															1								
Panderodus greenlandensis	Sa		6	1	1			1																
	Sb		2																					
	Sc		1																					
	M		5	1																				
Panderodus recurvatus	Sa		2			1			1															
	Sb	1	1						1		1	1		2							1			1
	Sc		1															2			1			
	M															5	1							
Panderodus unicostatus	Sa				1		2				2	1	1	2	1	5		1			5	6	2	5
	Sb					1		2		1		1			2			1		2	2	2		6
	Sc		6	1	2	3													1		2	1		2
	M		1	1	2		1	1			1					2		2	4		2	1		6
Pseudooneotodus beckmanii								1																
Pseudooneotodus tricornis			1		1																			

siliferous with some silicification of brachiopods and corals. Thin sections show large numbers of sponge spicules, bryozoans and algae consistent with a shallow water environment. This section proved to be quite rich in conodonts (total 300 elements) especially low in the section. One sample, WERR 1.4, produced 148 conodonts including *Dapsilodus obliquicostatus*, *Kockelella ranuliformis*, *K. latidentata*, *K.* n.sp. A, *Pseudooneotodus tricornis*, *Panderodus greenlandensis*, *P. unicostatus*, *P. recurvatus* and *Ozarkodina excavata excavata*. The assemblage is indicative of the *ranuliformis* Zone, consistent with its position towards the top of the Boree Creek Limestone (SHERWIN's Limestone B).

DSC

This section (Text-Fig. 1; Table 6) extends through the entire Borenore Limestone on the northern side of Boree Creek on "Werrina".

Sampling was along three offset segments: The first leg of the section (DSC) commences 109 m S of the east–west fenceline above a small dam (grid reference 7885 2058) with the first appearance of limestone. Between the fenceline and the start of the section are two outcrops of Mirrabooka Formation, a narrow interval of thin-bedded highly cleaved shale, and a bed of a green tuff with large feldspar crystals. From the first occurrence of limestone (DSC109) the section extends for 123 m on a bearing of 210°. In this section 24 horizons of limestone were sampled. The section crosses four tongues of Borenore Limestone interfingering with the sandstones and shales of the Mirrabooka Formation.

The first tongue of limestone (19 m thick; horizons DSC 109.0 to DSC 128.1) consists mostly of light grey medium grained limestones, the last few metres consisting of brecciated limestone. The 20 m interval of Mirrabooka Formation above this limestone is exposed in two creek beds running roughly at right-angles to strike towards Boree Creek. It consists of poorly sorted, course-grained, feldspathic sandstone. The sandstone is thinly bedded; some horizons contain small eroded fragments of limestone.

The second tongue of limestone (about 10 m thick; horizons DSC 143.0 to 158.3) also consists of fine to medium grained grey limestones becoming darker grey and brecciated towards the top of the interval; the cause of brecciation is problematic. The overlying tongue of Mirrabooka Formation consists of another 20 m of sandstone (lithologically similar to the preceding sandstone interval), fining upwards gradually into a fine-grained but thicker bedded sandstone with thin interbeds of mudstone.

The third tongue of limestone (30 m thick; horizons DSC 174.0 to 205.1) is very similar to the two preceding limestones but displays increasing abundance of crinoid debris. It ends with brecciated limestone, but is overlain by about 15 m of "crinoidal conglomerate" with large amounts of well preserved crinoid material, coral fragments and occasional conjoined brachiopods. A large limestone clast about 3 m in diameter (DSC alloc. 199) from this interval was sampled.

The fourth tongue of limestone (about 55 m; DSC 213 to DSC 232) is similar to the preceding limestone tongues but includes well bedded (ca. 50 cm) beds of limestone at DSC 232. From DSC 232 the section was offset 120 m eastwards to the start of the DSC/B leg of the section.

DSC/B

Sampling of this leg commenced at the top of the fourth limestone tongue. The section passes through a fine-grained, light grey fossiliferous limestone capped by a layer of pinkish limestone breccia before passing up into Mirrabooka Formation shale. The latter becomes increas-

Table 6.
Distribution of conodonts, sections DSC, DSC/B, DSC/E.

Section		DSC											DSC/B									DSC/E								
Sample		109.0	120.0	120.8	147.1	153.4	181.2	183.4	213.9	219.0	224.5	232.0	231.1	243.8	246.9	253.4	256.9	260.1	266.3	275.3	304.9	Clast2	Clast4	3.0	23.1	24.7	28.8	40.5	45.3	48.6
Species	Element																													
Belodella sp. A	triang.									1																				
Dapsilodus obliquicostatus	Sa						1																							
	Sb																													
	M						2		1																		1			
Kockelella amsdeni	Sa														1															
Kockelella ranuliformis	Pa																1													
Kockelella sp.	Sb						1																							
Ozarkodina excavata excavata	Pa					1		1																						
	Pb			1							1		1		1	1			1											
	Sa													1																1
	Sb										1							1								1				
	Sc													1							1									1
	M					1																								
Panderodus recurvatus	Sa								1																					
	Sb	3				1		1															2		1			1		
	Sc	1		1	1																									
	M																1													
Panderodus unicostatus	Sa	1								1	1			1		2							4	2			2	2		
	Sb	1		1										1		2	3	1						1					1	2
	Sc		1			1										2														1
	M		1	3		1						1		3		1		2		1		1	5	1				5		1

ingly calcareous eastwards, eventually grading into limestone with a large number of limestone clasts up to 20 cm in diameter; four of these were sampled for conodonts.

DSC/E

The final leg of the DSC section (17 horizons sampled) was offset 110 m to the E of DSC/B 304.9 and continued to the last outcrop of limestone about 50 m from Boree Creek The limestones are fine-grained, grey to white and contain numerous crinoids, trilobite fragments and brachiopods; they are overlain 28 m above the base of this interval by brecciated limestone; the latter persists to the end of the section. Samples of limestone clasts from Mirrabooka lithologies 26 m upslope from the start of this leg are included in results for the section.

Conodont yields for this section were poor compared to some other sections with conodonts being small, usually less than 500 microns, and very light in colour (CAI of 1). An Sa element of *Kockelella amsdeni* from DSC/B 246.9 indicates *amsdeni* Zone (early to middle Wenlock); elements of *K. ranuliformis* from DSC 124.0 and 181.2 are consistent with this age. Low yields of conodonts preclude tight age-constraints on the lower part of the section.

BN28

This section (37 m; 13 samples; Text-Fig. 1; Table 7), extending through bedded limestone, is the stratigraphically highest sequence of Borenore Limestone sampled. It takes its name from cave BN28 in brecciated limestone near the end of the section. Limestones along this section vary from fine-grained grey to highly brecciated reddish. As with the DSC section, the conodont yield was low (152 conodonts) and the elements, especially the coniforms, are very small and light in colour with CAI of 1. Many of the elements are obviously juveniles. A Ludlow form of *Kockelella ranuliformis* (a juvenile specimen) similar to those described by BISCHOFF (1986, Pl. 14, Fig. 10) was obtained from BN28/6.7; the Ludlow age suggested is consistent with the Ludlow age indicated by *K. variabilis* higher in the section at BN28/37.2. A fragment of an S element of *K. variabilis* was also recovered from BN28/27.4. This gives an age of at least *variabilis* Zone (early Ludlow) for this portion of the Borenore Limestone. A similar age is hypothesised for the Wallace Shale occurring along strike to the west of this interval.

BOR/1

This section (Text-Fig. 1, Table 5) crosses the disconformity between bedded and prominently outcropping brecciated limestones described by BISCHOFF (1986) as a talus slope deposit. The section crosses medium grained, grey, well bedded limestones (7 horizons sampled: BOR/1 0.0 to BOR/1 10.8) for 14.5 m to the disconformity, then for another 29.5 m (BOR/1 14.5 to BOR/1 43.0) through red, crinoid-rich limestone breccia.

From the above 14 samples 228 conodonts were recovered. At the start of the section (BOR/1 0.0) a single large Pa element was obtained of what appears to be a variant of *Kockelella* n.sp. A, found in the WERR section (Pl. 2, Figs. 16, 17, compare with Figs. 11, 12, 14 and 15). Specimens of *K. ranuliformis* were recovered from BOR/1 8.5 and *Dapsilodus obliquicostatus* from most samples up to and including BOR/1 14.5. The limestone breccias yielded only long-ranging species.

Section		BN28															
Sample		6.0	6.7	10.1	11.5	14.7	16.6	19.0	22.3	24.8	27.4	32.4	37.2	Spot 1	Spot 3	Spot 6	Spot 7
Species	Element																
Bellodella anomalis	triangular																8
	lenticular																7
Belodella coarctata	Sa																4
	Sb																8
	Sc																1
	M																1
Belodella sp.	U/F																11
Coryssognathus dubius	Pc																1
Dapsilodus obliquicostatus	M					1											
Kockelella ranuliformis	Pa		1														
Kockelella variabilis	Sb												1				
	Sc										1						
Kockelella sp.	S					1											
Ozarkodina excavata excavata	Pa							1					1	1		1	
	Pb																
	Sa									1							1
	Sb																
	Sc																
	M									1							
Panderodus greenlandensis	Sa													2			
Panderodus recurvatus	Sa	3			1												
	Sb	6			3	1	1		1						2		
	Sc	3			1										2		
	M	2													1		
Panderodus unicostatus	Sa		4	1	2	1		1	1	4			1		2	1	3
	Sb	2	1		3	2	3	1	5	2		1			1	3	6
	Sc					1		1	3			1					
	M	2	5	1	2	1	3	1	4	2	1		1			1	2
Panderodus sp.														2			
Pseudooneotodus bicornis														2			

Table 7.
Distribution of conodonts, sections BN28 and spot samples.

ERC

This section of Wallace Shale exposed in a road cutting west of the mapped area (see Table 2 for coordinates) has thin beds with small limestone clasts up to 80 cm in diameter. From 7 samples taken over 75 m, only one, yielded conodonts but these were too fragmentary or too poorly preserved for identification.

Spot Samples

Five of the spot samples yielded significant numbers of conodonts. Sample 1 (BUN/E 1, Table 4) produced conodonts consistent with being broadly the same age as the BOC section. Samples 3 (BCC Res 1, Table 7) and 6 (DSC 38A and DSC 38B: both Table 6), yielded only long-ranging species. The conodonts include *Pseudooneotodus bicornis*, and *Panderodus greenlandensis*, the former particularly indicating the *amorphognathoides* Zone.

Spot sample 7 (Table 7, ITG/1), from an allochthonous limestone block in the Wallace Shale about 100 m above the boundary with the Mirrabooka Formation on the south side of Boree Creek opposite section DSC, produced a collection of elements of two species of *Belodella* – *B. anomalis* and *B. coarctata* – plus two Pb elements of *Coryssognathus dubius*. These are the only occurrences of these two species of *Belodella* in any samples collected. COOPER (1974) suggests an age of late Ludlow (*siluricus* to *crispa* zones) for *B. anomalis* in Australia, whereas JEPPSSON (1989) gives an age of early Pridoli for this form in Europe. The latter describes *B. coarctata* (*B. mira*) as being rare in the Ludlow; BARRICK & KLAPPER (1992) assign it to the Pridoli in the United States. *C. dubius* is broadly consistent with the age indicated though JEPPSSON (1975) and MILLER & ALDRIDGE (1993) regard it as late Ludlow. Block ITG1 is therefore possibly younger than the age-spectrum indicated by conodont data from the Borenore Limestone on section BN28. The age indicated for inception of Wallace Shale sedimentation is therefore well up in the Ludlow.

3. Stratigraphy and Inferences from Conodont Data

3.1. Boree Creek Formation

The Boree Creek Formation (SHERWIN, 1971; total thickness approx. 90 m), unconformably overlying Ordovician volcanics of the Cheesemans Creek Formation (SHERWIN, 1971), consists of three distinct but not formally named members. The lowest member, Limestone A (the Rosyth Limestone of WALKER [1959]), approximately 40 m in thickness, is a well bedded fine grained impure marly richly fossiliferous limestone with abundant corals, brachiopods, calcareous algae, gastropods, foraminifers and ostracodes; much of the smaller fauna, especially the foraminifers, gastropods and ostracodes are pyritised. The basal beds contain a considerable amount of reworked red volcanic material, presumably from the underlying Cheesemans Creek Formation (Ordovician), in a calcareous matrix (sample BOC-7). Two sections, BUN/E and BOC (Table 4), produced at various levels *Apsidognathus tuberculatus*, *Pterospathodus procerus*, *Distomodus staurognathoides*, *Pseudooneotodus bicornis* and *Pyrsognathus latus* typical of BISCHOFF's (1986) *Pt. amorphognathoides-Pyrs. latus* interval of the late Llandovery-earliest Wenlock *amorphognathoides* Zone.

The overlying interval, SHERWIN's (1971) Tuffaceous Trilobite Beds, is about 20 m of tuffaceous sandstone consisting of subrounded volcanic fragments in calcite cement; some beds are conspicuously rich in chlorite. *Kockelella ranuliformis*, *K. latidentata*, *K.* n.sp. A, *Pseudooneotodus beckmanii* and *Ps. tricornis* imply allocation to the *ranuliformis* Zone of the early Wenlock.

The third interval of the Boree Creek Formation, SHERWIN's (1971) Limestone B consists of approximately 30 m of limestones, conspicuously thicker bedded than those of his Limestone A; some of the beds are partially dolomitised (WERR 9 and WERR 10). Towards the top of the section the limestones tend to be sandy calcarenite; these impure limestones make up the final 7–10 m of the member and are unconformably overlain by the Borenore Limestone. Inarticulate brachiopods and calcareous algae occur in the upper levels of section WERR.

3.2. Borenore Limestone

This unit can be divided into two broadly defined subunits: a bedded unit with subdued outcrop, and a more massive limestone breccia forming areas of bold outcrop within the bedded limestone. The limestone breccia is reddish in colour; this has been attributed to iron oxides connected with penecontemporaneous exposure (LISHMUND et al., 1986) but, because the limestone breccia extends into the deeper water deposits of the Wallace Shale, presumably downslope, it is hypothesised here that at least some of it (and perhaps all of it) is the product of debris flow emplacement. Thin sections show the presence of numerous stylolites; this contrasts with the conspicuously less stylolitic bedded limestones. On its western margin, bedded Borenore Limestone interfingers with feldspathic sandstones and shales of the Mirrabooka Formation indicating contemporaneity of the two units. The boundary between the Mirrabooka Formation and the Wallace Shales is not exposed; it is covered by alluvials.

Conodont data from bedded Borenore Limestone (DSC, DSC/B, DSC/E and BN28) indicate that it ranges in age from early Wenlock (*ranuliformis-amsdeni* Zones) through to at least the *variabilis* Zone of the early Ludlow, but possibly to as young as the late Ludlow *siluricus* Zone.

3.3. Mirrabooka Formation

The contact between the Mirrabooka Formation (SHERWIN, 1971) and the underlying Boree Creek Formation is not exposed in the study area, but SHERWIN (1971) reported that in the Cheesemans Creek area there is evidence that the two units are unconformable. An unconformity, however, is clearly displayed between the top of SHERWIN's Limestone B and the overlying Borenore Limestone in the vicinity of section BOC. Because of demonstrable contemporaneity between the Borenore Limestone and the Mirrabooka Formation, this unconformity is inferred to be the same as the one clearly displayed farther west where Mirrabooka Formation rests on Boree Creek Formation. Both SHERWIN (1971) and BISCHOFF (1986) ascribed this unconformity to PACKHAM's (1969) Quarry Creek Hiatus. In the "Werrina" area, the Mirrabooka Formation consists of highly cleaved thinly bedded shales overlain by c. 50 m of poorly sorted angular feldspathic sandstone with one or possibly two thin (3 m) beds of tuff near its base. The sandstones pass upwards through a richly fossiliferous sandy bed into a fine grained almost cherty shale then into finer grained sandstones with interbeds of mudstone. The boundary with the overlying Wallace Shale is not exposed. No conodont data hinting at an age younger than the *amsdeni* Zone (early to middle Wenlock) were obtained for this section.

SHERWIN (1971) reported several limestones pods in the Mirrabooka Formation. One of these, Limestone I (section BUN) is about 30 m thick and completely enclosed within shales of the Mirrabooka Formation, less than 100 m below the base of the Wallace Shale. Graptolites from shales beneath this pod (SHERWIN, 1971) indicate a mid-Ludlow age (*scanicus* to *leintwardinensis* Zones), equivalent to the upper part of the *variabilis* Zone). Conodont data from the limestone are indicative of an early Wenlock age, underlining its allochthonous nature relative to the enclosing Mirrabooka Formation. Though its age accords with that of SHERWIN's Limestone A, it contrasts lithologically with preserved sequences of Limestone A, being thick- rather than thin-bedded and marly. Derivation from upper horizons of the Boree Creek Formation accords with the conodont data.

3.4. Wallace Shale

The Wallace Shale (STEVENS & PACKHAM, 1952), conformably overlying the Mirrabooka Formation, ranges from 250–300 m near the Borenore Caves to around 400–600 m north of Cheesemans Creek (WALKER, 1959). BYRNES (in PICKETT, 1982) suggested that this variation in thickness may be a reflection of deposition in submarine valleys or canyons. Due to similarity in lithologies between the two formations, there may be difficulties in defining the Mirrabooka Formation-Wallace Shale (WALKER, 1959; PARTRIDGE, 1967; SHERWIN, 1971).

SHERWIN (1971) reported *Monograptus* cf. *ultimus* and *M. bouceki* from the Wallace Shale giving a late Ludlow age. *Kockelella variabilis* from section BN28 high in the Borenore Limestone provides a maximum age for the Wallace Shale, early Ludlow *variabilis* Zone. Conodonts from sample ITG1 within the Wallace Shale give a slightly younger age – *siluricus* to *crispa* Zones (agreeing with the graptolite data). *K. variabilis* has however been reported from the *siluricus* Zone (COOPER, 1977).

3.5. Quarry Creek Hiatus

JENKINS (1977) inferred, from data from the Panuara area, that the Quarry Creek Hiatus (PACKHAM, 1969) extended from the *centrifugus* Graptolite Zone in the upper beds of the Ashleigh Member of the Glendalough Formation to the *lundgreni* Graptolite Zone in the basal beds of the Ulah Formation. RICKARDS et al. (1995) suggested that the hiatus extended through 2 to 4 graptolite zones, from the *crenulata* to lower part of the *riccartonensis* Graptolite Zones.

If the Panuara stratigraphy is extended to the present study area, the Boree Creek Formation would be placed in the Waugoola Group, everything above it, including the Wallace Shale, being placed in the Panuara Group. BISCHOFF (1986) inferred that the hiatus extended from somewhere in the *ranuliformis* Zone through the *amsdeni* Zone. Data from just below the hiatus, in section WERR, accords with this, showing that the break did not commence in the Boree Creek area until after the start of the *ranuliformis* Zone. The presence of *Kockelella amsdeni* in section DSC above the hiatus is consistent with the hiatus having ended within and possibly towards the end of the *amsdeni* Zone. The hiatus is therefore inferred to span possibly no more than two graptolite zones in the Boree Creek area: the *murchisoni* and lower part of the *riccartonensis* Graptolite Zones.

3.6. "Barnby Hills Shale"

The Barnby Hills Shale (STRUSZ, 1960; 420 m thick) has produced graptolites indicative of the late Ludlow *inexpectatus*/*kozlowskii* Zones from 70–120 m above the base of the formation at Neurea (RICKARDS & WRIGHT, 1997), north of the area investigated here. This is broadly consistent with the SHERWIN's (1971) identifications of graptolites from the Cheesemans Creek-Boree Creek, and is only slightly younger than the *variabilis* maximum-age obtained from conodont data from low in the Wallace Shale reported here from Boree Creek. It is suggested that, because of virtual contemporaneity and the relatively small area between outcrop-tracts of the two stratigraphic units in question, that the term Barnby Hills Shale be viewed as a junior synonym of Wallace Shale and its use be discontinued, as also advocated by TALENT & MAWSON (1999).

4. Taxonomic Comments

4.1. Conodonts

As most of the conodont taxa in this study have been documented in the Catalogue of Conodonts (ZIEGLER 1973, 1975, 1977, 1981, 1991) or described fully in earlier papers (e.g. ARMSTRONG, 1990; BARRICK, 1977; SIMPSON & TALENT, 1995), documentation is limited to illustrations, comments on variation, and relevant discussion. The classification used follows SWEET (1988). Figured specimens are housed in the palaeontological collections of the Australia Museum, Sydney, catalogued with the prefix AMF. Precise horizon and locality data for each sample number can be obtained by reference to Text-Fig. 2 and Tables 4–7.

Order: Belodellida SWEET, 1988
Family: Belodellidae KHODALEVICH & TSCHERNICH, 1973
Genus: *Belodella* ETHINGTON, 1959

Type Species: *Belodus devonicus* STAUFFER, 1940.

Belodella anomalis COOPER, 1974

(Pl. 4, Figs. 1, 2, 5, 6, 9, 10)

Remarks: For synonymy see SIMPSON & TALENT (1995, p. 124–125). Both the triangular and lenticular elements displaying the diagnostic feature of marginal denticles along both anterior and posterior margins (as described by COOPER, 1974), were recovered from sample ITG1. COOPER (1976), described this species from Late Silurian (late Ludfordian) limestones at Yarrangobilly, south-eastern Australia. Other occurrences of this species have been reported by JEPPSSON (1989) from the Czech Republic, and SIMPSON et al. (1993) from Cowombat, northeastern Victoria. JEPPSSON (1989) suggested that slight differences between the Australian and European forms may indicate discrete subspecies.

Belodella coarctata BARRICK & KLAPPER, 1992

(Pl. 4, Figs. 3, 4, 11, 12)

1989 *Belodella mira* KHODALEVICH & CHERNIKH – JEPPSSON p. 24–25, Pl. 1, Figs. 1–5.
1992 *Belodella coarctata* n. sp. BARRICK & KLAPPER, p. 42–43, Pl. 2, Figs. 3, 4, 8, 9, 12–14.

Remarks: JEPPSSON (1989) reported this species from the *eosteinhornensis* Zone in the stratotype section for the Silurian–Devonian boundary at Klonk in the Czech Republic. BARRICK & KLAPPER (1992) found it to be restricted to the Pridoli in the Hunton Group of Oklahoma. Elements recovered at Boree Creek were from a spot sample from a olistolith low in the Wallace Shale, occurring in association with *B. anomalis* and *C. dubius*, both Late Silurian species.

Family: Dapsilodontidae SWEET, 1988
Genus: *Dapsilodus* COOPER, 1976

Type Species: *Distacodus obliquicostatus* BRANSON & MEHL, 1933.

Dapsilodus obliquicostatus (BRANSON & MEHL, 1933)

(Pl. 4, Figs. 13–19)

Remarks: For synonymy see ARMSTRONG (1990, p. 70). The apparatus of this species was reconstructed as a bimembrate form by SERPAGLI (1970) who described the striations along the lower margins of the elements (cf. Pl. 4, Fig. 19 herein). These striations are used to differentiate between Ordovician and Silurian forms. SERPAGLI (1970) assigned the apparatus to *Acontiodus*, grouping previously named forms: *Acodus inortatus* ETHINGTON & FURNISH, *A. mutus* SERPAGLI and *A.* cf. A. *inortus* NICOLL & REXROAD to constitute the *Acodus*-like element (Sc), and grouping conodonts previously described as *Distacodus obliquicostatus* BRANSON & MEHL, *D. procerus* ETHINGTON, and *D.*? n. sp. of NICOLL & REXROAD (1968), and *Acontiodus procerus* SERPAGLI, to constitute the *Acontiodus*-like (M) elements. COOPER (1976) added a further two elements to the apparatus and assigned it to a new genus *Dapsilodus*. ARMSTRONG (1990) restored the species to being a trimembrate apparatus (Sa, Sc, and M) suggesting that COOPER's (1976) Sb element belonged to two other species *D. praecipuus* and *D. sparsus*. In the Boree Creek area, *D. obliquicostatus* occurs in faunas with ages ranging from *ranuliformis* Zone to *variabilis* Zone. Elsewhere *D. obliquicostatus* has been reported from the Llandovery of Greenland (ARMSTRONG, 1990) and from Early Silurian to Early Devonian in Europe, North America, North Africa and Australia (COOPER, 1976).

Order: Protopanderodontida SWEET, 1988
Family: Protopanderodontidae LINDSTRÖM, 1970
Genus: *Pseudooneotodus* DRYGANT, 1974

Type Species: *Oneotodus*? *beckmanni* BISCHOFF and SANNEMANN, 1958.

Remarks: DRYGANT (1974) described three squat elements from the Siluro-Devonian of Podolia, *Ps. beckmanni* with one denticle, *Ps. bicornis* with two denticles and *Ps. tricornis* with three denticles. BARRICK (1977) emended the general diagnosis and reconstructed the apparatus of *Ps. bicornis* and *Ps. tricornis* to include a slender conical element, a squat conical element plus either a squat bi- or tri-denticulated element and suggested that there may be a third species with a single denticulate squat conical element. BISCHOFF (1986) reverted to recognition three discrete species. ARMSTRONG's (1990) material from Greenland supported BARRICK's(1977) trimembrate apparatus. The small sample-size from the Boree Creek Formation does not allow useful input on the unimembrate versus trimembrate question.

Pseudooneotodus beckmanni (BISCHOFF & SANNEMANN, 1958)

(Pl. 1, Figs. 1, 2)

Remarks: For synonymy see ARMSTRONG (1990, p. 112). The squat, conical element from the Boree Creek Formation is identical to those illustrated by ARMSTRONG (1990, Pl. 18, Figs. 11, 12). It occurs in a fauna from the *ranuliformis* Zone.

Pseudooneotodus bicornis DRYGANT, 1974

(Pl. 1, Figs. 3, 4)

Remarks: For synonymy see ARMSTRONG (1990, p. 114). The 2 bidenticulate elements accord with the description given by BARRICK (1977) and are consistent with material illustrated by BISCHOFF (1986) and ARMSTRONG (1990). BARRICK (1977) argued that *Ps. bicornis* was derived from *Ps. tricornis* through loss of one of the apical denticles. ARMSTRONG (1990) and JEPPSSON (1997) agree with this observation, noting that in many sections *Ps. tricornis* is replaced by *Ps. bicornis*. JEPPSSON (1997) uses this replacement event to mark the end of the *amorphognathoides* Zone and suggests introduction of two new zones, the lower *Ps. bicornis* and the upper *Ps. bicornis* zones of the Sheinwoodian. MABILLARD & ALDRIDGE (1985) suggest *Ps. bicornis* is found commonly in near-shore environments.

Pseudooneotodus tricornis DRYGANT, 1974

(Pl. 1, Figs. 5, 6)

Remarks: For synonymy see ARMSTRONG (1990, p. 114). The two tridenticulate elements accord with the description given by BARRICK (1977) who gives the range as from the *amorphognathoides* Zone to possibly the base of the *ranuliformis* Zone. JEPPSSON (1997) agrees with this range, noting a considerable drop in frequency above the *amorphognathoides* Zone. MABILLARD & ALDRIDGE (1985) show it declining very early in the Wenlock in contrast to *Ps. bicornis* which persists in larger numbers. Specimens of *Ps. tricornis* in this study are from faunas from early in the *ranuliformis* Zone.

Order: Panderodontida SWEET, 1988
Family: Panderodontidae LINDSTRÖM, 1970
Genus: *Panderodus* ETHINGTON, 1959

Type Species: *Paltodus unicostatus* BRANSON & MEHL, 1933.

Panderodus greenlandensis ARMSTRONG, 1990

(Pl. 3, Figs. 15–20)

Remarks: For synonymy see ARMSTRONG (1990, p. 102). Specimens of *P. greenlandensis* are represented in faunas from the *amorphognathoides* to the *ranuliformis* Zones in the Boree Creek Formation but do not appear to carry over the Quarry Creek Hiatus into the Borenore Limestone. In Australia the species has been reported from the Kildrummie Formation, New South Wales (DE DECKKER, 1976), the Cowombat Formation in the Claire Creek-

Stoney Creek of eastern Victoria (SIMPSON & TALENT, 1995), and from a limestone fan/channel fill in the Wallace Shale, west of Canobla on Nubrigyn Creek, NSW (TALENT & MAWSON, in press).

Panderodus recurvatus (RHODES, 1953)

(Pl. 5, Figs. 9–14)

Remarks: For synonymy see SIMPSON & TALENT (1995, p. 117). Occurs in all sections sampled. A relatively large number of specimens came from both the Boree Creek Formation and the Borenore Limestone, but in smaller numbers and slightly less frequency than *P. unicostatus*. All elements conform to BARRICK's (1977) description of the individual elements in the apparatus. A similar change in morphology across the Quarry Creek Hiatus to that described for *P. unicostatus* is evident. Elements from the Boree Creek Formation are on the whole larger and more robust than those from the Borenore Limestone. This long-ranging species, originally described by RHODES (1953) from faunas of Ludlow age, has been reported from horizons as old as Llandovery (ARMSTRONG, 1990) and as young as Emsian (MAWSON, 1987).

Panderodus unicostatus (BRANSON & MEHL, 1933)

(Pl. 5, Figs. 1–8)

Remarks: For synonymy see SIMPSON & TALENT (1995, p. 118–119). Four of the five elements described by SWEET (1979) were recovered from the limestones of the Boree Creek area: SWEET's tortiform element was not identified from the faunas recovered. *P. unicostatus* was found in all the sections sampled from the late Llandovery–early Wenlock Boree Creek Formation to the early to middle Ludlow of the Borenore Limestone. They were also present in the ITG1 spot sample from which the *Belodella* fauna suggests an age of *siluricus* Zone to *crispa* Zone.

P. unicostatus from these localities exhibited a feature that paralleled other species that crossed the Quarry Creek Hiatus of the *ranuliformis-amsdeni* zones. Those recovered from below the hiatus were much larger and had a more robust appearance than those recovered from samples taken above the hiatus that were typically very small in size, some as tiny as 200 microns. The CAI of conodonts also varied across this boundary with those below being darker (CAI of 2 to 3) and those above lighter (CAI of around 1). As suggested earlier, this might have been caused by re-population after the Iriviken Extinction Event.

Order: Prioniodontida DZIK, 1976
Family: Distomodontidae KLAPPER, 1981
Genus: *Coryssognathus* LINK & DRUCE, 1972

Type Species: *Cordylodus*? *dubius* RHODES, 1953 (OD).

Coryssognathus dubius (RHODES, 1953)

(Pl. 4, Fig. 20)

Remarks: For synonymy see MILLER & ALDRIDGE (1993, p. 242–244) and SERPAGLI et al. (1997, p. 240). Two Pc elements of *C. dubius* were recovered from the spot sample ITG1 in association with *Belodella anomalis* and *B. coarctata*. These elements resemble the Pc element described by MILLER & ALDRIDGE (1993), having more strongly developed processes than those of the very similar Pb element. SERPAGLI et al. (1997) reported *C. dubius* from the Late Silurian of southern Sardinia, noting in particular the highly variable appearance of the Pc element. *C. dubius* is known to occur in horizons of late Llandovery age (MABILLARD & ALDRIDGE, 1983) through to the early Pridoli (MILLER, 1995). Australian occurrences of *C. dubius* include Cowombat Flat, Victoria (SIMPSON et al., 1993); Claire Creek-Stoney Creek and overlying Cowombat Formation and Native Dog Plain, Victoria (SIMPSON & TALENT, 1995) and from TEZ section in limestone channel fill within the Wallace Shale, west of "Canobla" on Nubrigyn Creek, NSW (TALENT & MAWSON, 1999).

Genus: *Distomodus* BRANSON & BRANSON, 1947

Type Species: *Distomodus kentuckyensis* BRANSON & BRANSON, 1947 (OD).

Distomodus staurognathoides (WALLISER, 1964)

(Pl. 1, Fig. 18)

Remarks: For synonymy see ARMSTRONG (1990, p. 73–74). A single Pb element of *D. staurognathoides* was recovered from the *amorphognathoides* Zone in the BOC section in the Boree Creek Formation; it closely resembles those illustrated by BISCHOFF (1986).

Order: Ozarkodinida DZIK, 1976
Family: Spathognathodontidae HASS, 1959
Genus: *Ozarkodina* BRANSON & MEHL, 1933

Type Species: *Ozarkodina typica* BRANSON & MEHL, 1933 (OD).

Ozarkodina excavata excavata (BRANSON & MEHL, 1933)

(Pl. 3, Figs. 1–14)

Remarks: For synonymy see SIMPSON & TALENT (1995, p 147–152). BISCHOFF (1986, p. 135, 136), lists the range of variation observed in the elements of the apparatus of *O. excavata excavata*, noting that he could observe no relationship between the morphological changes and stratigraphy. Several of these variations were observed in material collected in this study. Some Pa elements were lower in height with pronounced ledges running the length of the blade at the base of the denticles (Pl. 3, Figs. 4–5) which have a peg-like appearance. Some Pb elements (Pl. 3, Figs. 7–9) similarly showed variation in height of the blade, ledging of the blade and shape of the denticles and, additionally, the height of the cusp and degree of arching of the blade. Specimens of *O. excavata excavata* were recovered from faunas ranging from *amorphognathoides* Zone in the Boree Creek Formation to the *variabilis* Zone in the Borenore Limestone and from a spot sample high in the sequence dated as a later Ludlow age, possibly *siluricus* Zone or *crispa* Zone.

Family: Kockelellidae KLAPPER, 1981
Genus: *Kockelella* WALLISER, 1957

Type Species: *Kockelella variabilis* WALLISER, 1957 (OD).

Kockelella amsdeni BARRICK & KLAPPER, 1976

(Pl. 2, Fig. 10)

Remarks: For synonymy see BISCHOFF (1986, p. 215). A single Sa element only of *K. amsdeni* was obtained. BARRICK & KLAPPER (1976) used the incoming of species as the base of the *amsdeni* Zone (early to middle Wenlock). KLEFFNER (in SWEET, 1988) indicates *K. amsdeni* to have a very short range, confined almost entirely to the uppermost *ranuliformis-amsdeni* Zone, making it a useful species for correlations.

Kockelella latidentata BISCHOFF, 1986

(Pl. 2, Figs. 1–3)

1986 *Kockelella latidentata* n. sp. BISCHOFF, p. 216–218, Pl. 13, Figs. 27–39.

Remarks: A single Pa element of this species was obtained from section WERR. It can be differentiated from the very similar Pa element of *K. ranuliformis* by the latitudinal elongation of the denticles. It occurs in a fauna assigned to the *ranuliformis* Zone.

Kockelella ranuliformis (WALLISER, 1964)

(Pl. 2, Figs. 4–8)

Remarks: For synonymy see SIMPSON & TALENT (1995 p. 135–136). The specimen from BN28 6 (Pl. 2, Figs. 6–8) is a juvenile which under the light microscope bears a striking resemblance to *Ozarkodina snajdri*, especially in upper view. It was only when viewed laterally (Pl. 2, Figs. 7, 8) that it could confidently be identified as *K. ranuliformis* as the blade does not continue to the end of the basal cavity, and the denticles are not fused. Compare the figures herein with those in VIIRA & ALDRIDGE (1998, Pl. 3, Figs. 12–21) for similarities and differences. In the Boree Creek area this species was obtained from faunas ranging in age from the *ranuliformis* Zone through to the *variabilis* Zone. This accords with the age range given by BISCHOFF (1986, p. 220) who gave the range for *K. ranuliformis* as "*P. amorphognathoides-P. latus* Assemblage Zone to ?lower *K. variabilis* Zone" (Wenlock to ?early Ludlow).

Kockelella variabilis (WALLISER, 1957)

(Pl. 2, Fig. 9)

Remarks: For synonymy see SIMPSON & TALENT (1995, p.137–138). The two elements of *K. variabilis* recovered from high in the Borenore Limestone conform with Sb and Sc elements in WALLISER's (1964) Conodont Apparat G and BARRICK & KLAPPER's (1976) reconstruction of the species. It has been reported by BISCHOFF (1986), also from the Borenore Limestone. SIMPSON & TALENT (1995) report *K. variabilis* from the Cowombat Formation in the Claire Creek-Stoney Creek area of north-eastern Victoria.

Kockelella n. sp. A KLAPPER & MURPHY, 1974

(Pl. 2, Figs. 11–13)

Remarks: For synonymy see SIMPSON & TALENT (1995, p. 138). Two Pa elements recovered from the Boree Creek area are very similar in appearance to those described and illustrated by KLAPPER & MURPHY (1974) having one bifurcating lateral process. KLEFFNER (1994) suggested that specimens with nodose ornament and two bifurcating lateral processes illustrated by BISCHOFF (1986, Pl. 15, Figs. 16–18) as *Kockelella* n. sp. A KLAPPER & MURPHY, are probably forms transitional to *K. patula*.

Kockelella sp. A
cf. *K.* n. sp. A KLAPPER & MURPHY, 1974

(Pl. 2; Figs. 14, 15)

Description: The single Pa element has a straight, thick anterior free blade bearing more than 6 denticles (the anteriormost third of the blade was broken). The cusp is not prominent being no larger than any of the other denticles on the blade, but is identified by the presence of two short transverse ridges connecting with the lateral processes on the platform on either side of the cusp. Posterior of the cusp, the blade curves slightly and bears 3 small denticles. The pattern of denticles on the lateral processes is irregular with bifurcation of the denticle ridges commencing proximal to the cusp. The platform is much narrower on one side of the blade, the narrow platform bearing 9 denticles, the wider 13 denticles. The basal cavity, continuing to the anterior of the blade, is subquadrate and highly asymmetrical with slight development of sinuses on the inner, outer and posterior basal margins.

Remarks: This element differs from the Pa element of *Kockelella* n. sp. A KLAPPER & MURPHY in that the shape of the platform and distribution of the denticles is more irregular, bifurcation of the lateral denticle ridges commences proximal to the cusp, and the basal cavity shows the development of sinuses. The specimen was found in association with *Kockelella* n. sp. A, *K. ranuliformis* and *K. latidentata*, a fauna considered to be referable to the *ranuliformis* Zone.

Kockelella sp. B
cf. *K.* n. sp. A KLAPPER & MURPHY, 1974

(Pl. 2, Fig. 16–18)

Description: The single Pa element recovered from section BOR has a straight, thick anterior free blade. The number of denticles is uncertain as the anterior portion of the free blade is broken. The cusp is prominent with transverse ridges connecting the lateral ridges of denticles on the large platform on either side of the cusp. The basal cavity is subquadrate with the posterior and one lateral margin showing slight development of sinuses. The blade posterior of the cusp is slightly curved towards the smaller of the lateral platforms. Two rows of denticles emanate from the transverse ridge from the cusp, one directed anteriorly and one posteriorly. On the smaller platform a single row of denticles is directed anteriorly from the transverse ridge, the platform coming to a point at the end of this row of denticles. Each corner of the posterior margin of the basal cavity has an inward-curving projection.

Remarks: This element appears to be derived from the Pa element of *Kockelella* n. sp. A by reduction in bifurcation of the platform ridges and invagination of the basal margins. It is possibly an intermediate form between *Kockelella* n. sp. A and *K. variabilis*. It was obtained from an Early Wenlock horizon dated as from *ranuliformis* Zone to *amsdeni* Zone.

Family: Pterospathodontidae COOPER, 1977
Genus: *Apsidognathus* WALLISER, 1964

Type Species: *Apsidognathus tuberculatus* WALLISER, 1964 (OD).

Apsidognathus tuberculatus tuberculatus WALLISER, 1964
(Pl. 1, Figs. 7–10)

Remarks: For synonymy see ARMSTRONG (1990, p. 41–42). The first of the three elements obtained from the Boree Creek Formation is a lyriform element (Pl. 1, Fig. 10) with reticulate ornament as described by ARMSTRONG (1990). The second is a fragment of a platform element with surface ornament conforming with that described by BISCHOFF (1986). Another, complete, platform element (Pl. 1, Figs. 7–9) without surface ornament, recovered from the Boree Creek Formation on "Bunyarra", has its ornament eroded; this apart, it closely resembles material illustrated by BISCHOFF (1986) and ARMSTRONG (1990). *A. tuberculatus tuberculatus* occurs in BISCHOFF's (1986) *Pterospathodus amorphognathoides-Pyrsognathus latus* assemblage of the *amorphognathoides* Zone.

Genus: *Pterospathodus* WALLISER, 1964

Type Species: *Pterospathodus amorphognathoides* WALLISER, 1964 (OD).

Pterospathodus amorphognathoides WALLISER, 1964
(Pl. 1, Figs. 13, 14)

Remarks: For synonymy see SIMPSON & TALENT (1995, p. 171–173). The single Pb element recovered from section BUN differs from those described and illustrated by BISCHOFF (1986, Pl. 30, Fig. 20; Pl. 31, Fig. 18) in having a much wider inner platform and a straighter blade.

Pterospathodus procerus (WALLISER, 1964)
(Pl. 1, Figs. 15–16)

Remarks: For synonymy see BISCHOFF 1986 (p. 204, 205).

Pterospathodus sp. A
(Pl. 1, Fig. 11, 12)

Description: The single Pa element recovered has an outer, wide, lobate lateral process originating from the posterior third of the blade; there are 3 anteriorly directed denticles on this process. A small, triangular, inner lateral process is present at the midpoint of the blade. The blade is straight, increasing in height anteriorly. A narrow platform surrounds the entire blade.

Remarks: A single Pa element of this species was recovered. It bears some similarity to some of BISCHOFF's (1986) small *Pt. latus* specimens, except the outer lateral process is more rounded, the inner triangular process is smaller, and it lacks the upturned margin on the surrounding ledge. The specimen was found in association with *Pt. amorphognathoides* and *P. greenlandensis* indicating an age of *amorphognathoides* Zone.

Genus: *Pyrsognathus* BISCHOFF, 1986

Type species: *Pyrsognathus latus* BISCHOFF, 1986.

Pyrsognathus latus BISCHOFF, 1986
(Pl. 1, Figs. 17, 19)

Remarks: For synonymy see BISCHOFF (1986, p. 207). The single Pa element of *Py. latus* has little preserved surface ornament but in other details closely fits the description and illustrations given by BISCHOFF (1986, especially Pl. 32, Fig. 17). The S-type element is also similar in appearance to material illustrated by BISCHOFF (1986) with the cusp exhibiting several sharp lateral, subparallel costae, and a moderately curved and deeply excavated cusp. The broad basal band appears to lack platform ledges and the posteriolateral process evident on some of BISCHOFF's (1986) illustrations.

4.2. Faunal Elements Other than Conodonts

The acid-insoluble residues produced very diverse faunas including several species of foraminifers, such as *Hyperammina* (Pl. 5, Fig. 18), bryozoans, sponges, holothurians (Pl. 5, Figs. 19, 22), the calcareous green algae *Lancicula* (Pl. 5, Fig. 20), and small inarticulate brachiopods, *Opsiconidion* and *Acrotretella* (Pl. 5, Figs. 15, 16). Thin sections display many other faunal elements including an abundance of crinoid ossicles (Fig. 10a), trilobites, (Fig. 10b), stromatoporoids (Fig. 11a), filamentous algae, (Fig. 11b), tabulate corals (Fig. 12a), and sponge spicules (Fig 13b). A calcareous outcrop in the Mirrabooka Formation on the southern bank of Barton Creek (Fig. 3, loc. 10) produced thermally mature and brittle, extremely compressed chitinozoans with highly eroded ornament. The poor preservation makes taxonomic assignment difficult (Theresa WINCHESTER-SEETO, pers. comm.). No other organic-walled microfossils were recovered.

Acknowledgements

Mapping by Alan PARTRIDGE (1969) and Lawrence SHERWIN (1971) provided a valuable framework for probing specific problems. The FETHER, GOODRIDGE and MCLEAN families generously gave access to their properties, "Werrina", "Kalinga" and "Bunyarra" respectively. Andrew SIMPSON gave much guidance with taxonomy of Silurian conodonts; Alan GILES of the University of Technology Sydney assisted with thin section photography, and Elizabeth MORGAN and Lawrence SHERWIN of the Department of Mineral Resources, Orange, were generous with information and time. Macquarie University colleagues Margaret ANDERSON, Tom BRADLEY, Glenn BROCK, James DANIEL, Michael ENGELBRETSEN, David MATHESON, Peter MOLLOY, Ruth MAWSON, Ross PARKS, John TALENT, George WILSON, and Theresa WINCHESTER-SEETO, were more than helpful – and admirably patient. Financial support was provided by Linnean Society of New South Wales through a grant from the Betty Mayne Scientific Research Fund for Earth Sciences.

References

ARMSTRONG, H.A. (1990): Conodonts from the Upper Ordovician–Lower Silurian carbonate platform of North Greenland. – Grønlands Geologiske Undersøgelse Bulletin, **159**, 1–151, Copenhagen.

BARRICK, J.E. (1977): Multielement simple-cone conodonts from the Clarita Formation (Silurian), Arbuckle Mountains, Oklahoma. – Geologica et Palaeontologica, **11**, 274–300, Marburg.

BARRICK, J.E. & KLAPPER, G. (1976): Multielement Silurian (late Llandoverian–Wenlockian) conodonts of the Clarita Formation, Arbuckle Mountains, Oklahoma, and phylogeny of *Kockelella*. – Geologica et Palaeontologica, **10**, 59–100, Marburg.

BARRICK, J.E. & KLAPPER, G. (1992): Late Silurian–early Devonian conodonts from the Hunton Group (Upper Henryhouse, Haragan, and Bois d'Arc Formations), South-central Oklahoma. – In: CHAPLIN, J.R. & J. E. BARRICK, J.E. (eds.): Special papers in paleontology and stratigraphy: A tribute to Thomas W. Amsden, Bulletins of the Oklahoma Geological Survey, **145**, 19–65, Norman.

BISCHOFF, G.C.O. (1986): Early and middle Silurian conodonts from midwestern New South Wales. – Courier Forschungsinstitut Senckenberg, 89, 1–337, Frankfurt am Main.

BYRNES, J.G. (1976): Silurian environments of the northern Molong Rise. – Bulletin of the Australian Society of Exploration Geophysicists, **7**(1), 18–22, Melbourne.

CARNE, J.E. & JONES, L.J. (1919): The limestone deposits of New South Wales. – Mineral Resources, Geological Survey of NSW, 25. xii + 411 pp, Sydney.

COOPER, B.J. (1975): Multielement conodonts from the Brassfield Limestone (Silurian) of southern Ohio. – Journal of Paleontology, **49**(6), 984–1008, Tulsa, OK.

COOPER, B.J. (1976): Multielement conodonts from the St. Clair Limestone (Silurian) of Southern Ohio. – Journal of Paleontology, **50**(2), 205–217, Tulsa, OK.

COOPER, B.J. (1977): Upper Silurian conodonts from the Yarrangobilly Limestone, southeastern New South Wales. – Proceedings of the Royal Society of Victoria, **89**(1,2), 183–191, Melbourne.

DE DECKKER, P. (1976): Late Silurian (Late Lludlovian) conodonts from the Kildrummie Formation, south of Rockley, New South Wales. – Proceedings of the Royal Society of New South Wales, **109**, 59–69, Sydney.

DE KONINCK, L.G. (1876): Recherches sur les fossiles paléozoiques de la Nouvelle Galles du Sud (Australie). – Mémoires Societé Royale Liège, ser. 2, **2**(7), 1–135. [English translation published in 1898: Description of the Palaeozoic fossils of New South Wales, New South Wales Geological Survey, Memoir Palaeontology, **6**, 298 pp., Sydney].

DRYGANT, D.M. (1974): Prostye konodony silura i nizov devona Volyno-Podol'ia (Simple conodonts from the Silurian and lowermost Devonian of the Volyno-Podolia). – Paleontologisheskiy sbornik, **10**(2), 64–70, L'vov.

DUN, W.S. (1907): Notes on the Palaeozoic brachiopoda and pelecypoda from New South Wales. – Records of the New South Wales Geological Survey, **8**(3), 265–269, Sydney.

ETHERIDGE, R. (1909): The trilobite Illaenus in the Silurian rocks of New South Wales. – Records of the Geological Survey of New South Wales, **8**(4), 319–321, Sydney.

JENKINS, C.J. (1977): Llandovery and Wenlock stratigraphy of the Panuara Area, Central New South Wales. – Proceedings of the Linnean Society of New South Wales, **102**(3), 109–130, Sydney.

JEPPSSON, L. (1975): Aspects of Late Silurian conodonts. – Fossils and Strata, **6**, 1–54, Oslo.

JEPPSSON, L. (1989): Latest Silurian conodonts from the Klonk, Czechoslovakia. – Geologica et Palaeontologica, **23**, 21–37, Marburg.

JEPPSSON, L. (1997): A new latest Telychian, Sheinwoodian and Early Homerian (Early Silurian) standard conodont zonation. – Transactions of the Royal Society of Edinburgh: Earth Sciences, **88**, 91–114, Edinburgh.

KLAPPER, G. & MURPHY, M.A. (1974): Silurian–Lower Devonian conodont sequence in the Roberts Mountains Formation of central Nevada. – University of California Publications in Geological Sciences, **111**, 1–62, Berkeley.

KLEFFNER, M.A. (1994): Conodont biostratigraphy and depositional history of strata comprising the Niagran Sequence (Silurian) in the northern part of the Cincinnati Arch Region, west-central Ohio, and evolution of *Kockelella* walliseri (Helfrich). – Journal of Paleontology, **68**(1), 141–153, Ithaca, NY.

LISHMUND, S.R., DAWOOD, A.D. & LANGLEY, W.V. (1986): The limestone deposits of New South Wales. – Geological Survey of New South Wales, Mineral Resources No. **25**, 2nd Edition, Sydney.

MABILLARD, J.E. & ALDRIDGE, R.J. (1983): Conodonts from the Coralliferous Group (Silurian) of Marloes Bay, south-west Dyfed, Wales. – Geologica et Palaeontologica, **17**, 29–43, Marburg.

MABILLARD, J.E. & ALDRIDGE, R.J. (1985): Microfossil distribution across the base of the Wenlock Series in the type area. – Palaeontology, **28**(1), 89–100, London.

MAWSON, R. (1987): Early Devonian conodont faunas from Buchan and Bindi, Victoria, Australia. – Palaeontology, **30**, 251–297, London.

MILLER, C.G. (1995): Ostracode and conodont distribution across the Ludlow/Pridoli Boundary of Wales and the Welsh Borderland. – Palaeontology, **38**(2), 341–384, London.

MILLER, C.G. & ALDRIDGE, R.J. (1993): The taxonomy and apparatus structure of the Silurian distodontid conodont *Coryssognathus* Link & Druce, 1972. – Journal of Micropalaeontology, **12**(2), 241–255, London.

NICOLL, R.S. & REXROAD, C.B. (1968): Stratigraphy and conodont paleontology of the Salamonie Dolomite and Lee Creek Member of the Brassfield Limestone (Silurian) in southeastern Indiana and adjacent Kentucky. – Bulletin, Indiana Geological Survey, **40**, 75 pp, Bloomington.

PACKHAM, G.H. (ed.) (1969): The geology of New South Wales. – Journal of Geological Society of Australia, **16**(1), 1–654, Sydney.

PACKHAM, G.H. & STEVENS, N.C. (1954): The Palaeozoic stratigraphy of Spring and Quarry creeks, west of Orange, NSW. – Journal and Proceedings of the Royal Society of New South Wales, **88**(1–4), 55–60, Sydney.

PARTRIDGE, A.D. (1967): Geology of Boree Creek, west of Borenore NSW. – B.Sc. (Hons) Thesis, University of Sydney, Sydney (unpublished).

PICKETT, J. (ed.). (1982): The Silurian system in New South Wales. – Geological Survey of New South Wales Bulletin, **29**, 1–264, Sydney.

POGSON, D.J. & WATKINS, J. (eds). (In press): Bathurst 1 : 250,000 Geological Sheet SI/55–8: Explanatory Notes. – Geological Survey of New South Wales, Sydney.

RHODES, F.H.T. (1953): Some British Lower Palaeozoic conodont faunas. – Philosophical Transactions of the Royal Society of London, series B, **237**, 261–334, pls 20–23, London.

RICKARDS, R.B., PACKHAM, G.H., WRIGHT, A.J. & WILLIAMSON, P.L. (1995): Wenlock and Ludlow graptolites faunas and biostratigraphy of the Quarry Creek district, New South Wales. – Memoirs of the Association of Australasian Palaeontologists, **17**, 69 pp., Brisbane.

RICKARDS, R.B. & WRIGHT, A.J. (1997): Graptolites of the Barnby Hills Shale (Silurian, Ludlow), New South Wales, Australia. – Proceedings of the Yorkshire Geological Society, **51**(3), 209–277, Leeds.

SERPAGLI, E. (1970): Uppermost Wenlockian–Upper Ludlovian (Silurian) conodonts from Western Sardinia. – Bollettino della Societá Paleontologica Italiana, **9**(1), 76–96, Modena.

SERPAGLI, E., CORRADINI, C. & OLIVIERI, R. (1997): Occurrence and range of Silurian conodont *Coryssognathus dubius* (RHODES, 1953) in southern Sardinia. – Bollettino della Societá Paleontologica Italiana, **35**(3), 239–243, Modena.

SHERWIN, L. (1971): Stratigraphy of the Cheesemans Creek District, NSW. – Records of the Geological Survey of New South Wales, **13**(4), 199–237, Sydney.

SHERWIN, L. (1976): Stratigraphic boundaries of the Mirrabooka Formation and the Wallace Shale. – Palaeontological Report No. **76**/23, Geological Survey of New South Wales, Sydney, (Unpublished).

SIMPSON, A. (1995): Silurian conodont stratigraphy in Australia: A review and critique. – Courier Forschungsinstitut Senckenberg, **182**, 324–345, Frankfurt am Main.

SIMPSON. A.J. & TALENT, J.A. (1995): Silurian conodonts from the headwaters of the Indi (upper Murray) and Buchan rivers, southeastern Australia, and their implications. – Courier Forschungsinstitut Senckenberg, **182**, 79–215, Frankfurt am Main.

SIMPSON, A.J., BELL, K.N., MAWSON, R & TALENT, J.A. (1993): Silurian (Ludlow) conodonts and foraminifers from Cowombat, SE Australia. – Memoirs of the Association of Australasian Palaeontologists, **15**, 141–159, Brisbane.

STEVENS, N.C. (1953): A note on the geology of Panuara and Angullong, south of Orange N.S.W. – Proceedings of the Linnean Society of New South Wales, **78**, 262–268, Sydney.

STEVENS, N.C. & PACKHAM, G.H. (1952): Graptolite zones and associated stratigraphy at Four Mile Creek, south-west of Orange, NSW. – Journal and Proceedings of the Royal Society of New South Wales, **86**(1–4), 94–99, Sydney.

STRUSZ, D.L. (1960): The geology of the Parish of Mumbil, near Wellington, NSW. – Journal and Proceedings of the Royal Society of New South Wales, **93**, 127–136, Sydney.

SÜSSMILCH, C.A. (1906): Note on the Silurian and Devonian rocks occurring to the west of the Canobolas Mountains near Orange, N.S.W. – Journal and Proceedings of the Royal Society of New South Wales, **40**, 130–141, Sydney.

SWEET, W.C. (1979): Late Ordovician Conodonts and Biostratigraphy of the Western Midcontinent Province. – Brigham Young University Geological Studies, **26**(3), 45–85, Provo, UT.

SWEET, W.C. (1988): The Conodonta: Morphology, taxonomy, paleoecology, and evolutionary history of a long-extinct animal phylum. – Clarendon Press, Oxford.

TALENT, J.A. & MAWSON, R. (1999): North-eastern Molong Platform and adjacent Hill End Trough, New South Wales: mid-Palaeozoic conodont data and implications. – Abh. Geol. B.-A., **54**, 49–105, Wien.

TALENT, J.A., MAWSON, R., ANDREW, A.S., HAMILTON, P.J. & WHITFORD, D.J. (1993): Middle Palaeozoic extinction events: Faunal and isotope data. – Palaeogeography, Palaeoclimatology, Palaeoecology, **104**, 139–152, Amsterdam.

VANDYKE, A. & BYRNES, J.G. (1976): Palaeozoic succession beneath the Narragal Limestone, Oakdale Anticline near Mumbil. – Records of the Geological Survey of New South Wales, **17**(2), 123–134, Sydney.

VIIRA, V. & ALDRIDGE, R.J. (1998): Upper Wenlock to Lower Pridoli (Silurian) conodont biostratigraphy of Saaremaa, Estonia, and a correlation with Britain. – Journal of Micropalaeontology, **17**, 33–50, London.

WALKER, D.B. (1959): Palaeozoic stratigraphy of the area to the west of Borenore, NSW. – Journal and Proceedings of the Royal Society of New South Wales, **93**(1–4), 39–46, Sydney.

WALLISER, O.H. (1964): Conodonten des Silurs. – Abhandlungen des Hessischen Landesamtes für Bodenforschung, **41**, 106 pp, Wiesbaden.

ZIEGLER, W. (1973): (Ed.) Catalogue of conodonts Volume I. – E. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart.

ZIEGLER, W. (1975): (Ed.) Catalogue of conodonts Volume II. – E. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart.

ZIEGLER, W. (1977): (Ed.) Catalogue of conodonts Volume III. – E. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart.

ZIEGLER, W. (1981): (Ed.) Catalogue of conodonts Volume IV. – E. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart.

ZIEGLER, W. (1991): (Ed.) Catalogue of conodonts Volume V. – E. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart.

Manuskript bei der Schriftleitung eingelangt am 2. Oktober 1998

Plate 1

Figs. 1,2: ***Pseudooneotodus beckmanni* (BISCHOFF & SANNEMANN, 1958).**
- Fig. 1: Lateral view of AMF105007. WERR 10.0 (×100).
- Fig. 2: Upper view of AMF105007. WERR 10.0 (×100).

Figs. 3,4: ***Pseudooneotodus bicornis* DRYGANT, 1974.**
- Fig. 3: Lateral view of AMF105008. BUN/E1 (×100).
- Fig. 4: Upper view of AMF105008. BUN/E1 (×100).

Figs. 5,6: ***Pseudooneotodus tricornis* DRYGANT, 1974.**
- Fig. 5: Lateral view of AMF105009. WERR 1.4 (×100).
- Fig. 6: Upper view of AMF105009. WERR 1.4 (×100).

Figs. 7–10: ***Apsidognathus tuberculatus tuberculatus* WALLISER, 1964.**
- Fig. 7: Upper view of Pa element AMF105010. BOC δ **(**×60).
- Fig. 8: Oblique lateral view of Pa element AMF105010. BOC δ **(**×60).
- Fig. 9: Lateral view of Pa element AMF105010. BOC δ **(**×60).
- Fig. 10: Upper view of lyriform element AMF105011. BUN/E 42.2 (×40).

Figs. 11,12: ***Pterospathodus* sp. A**
- Fig. 11: Upper view of Pa element AMF105012. BUN 5, (×40).
- Fig. 12: Oblique outer lateral view of Pa element AMF105012. BUN 5 (×40).

Figs. 13,14: ***Pterospathodus amorphognathoides* WALLISER, 1964.**
- Fig. 13: Upper view of Pb element AMF105013. BUN 3 (×40).
- Fig. 14: Lateral view of Pb element AMF105013. BUN 3 (×40).

Figs. 15,16: ***Pterospathodus procerus* (WALLISER, 1964).**
- Fig. 15: Upper view of Pa element AMF105014. BUN/E 30.7 (×40).
- Fig. 16: Oblique outer lateral view of Pa element AMF105014. BUN/E 30.7 (×40).

Figs. 17,19: ***Pyrsognathus latus* BISCHOFF, 1986.**
- Fig. 17: View if S3 element AMF105015. BOC δ **(**×120).
- Fig. 19: View of Pa element AMF105016. BOC δ **(**×65).

Fig. 18: ***Distomodus staurognathoides* (WALLISER, 1964).**
View of Pb element AMF105107. BOC δ **(**×60).

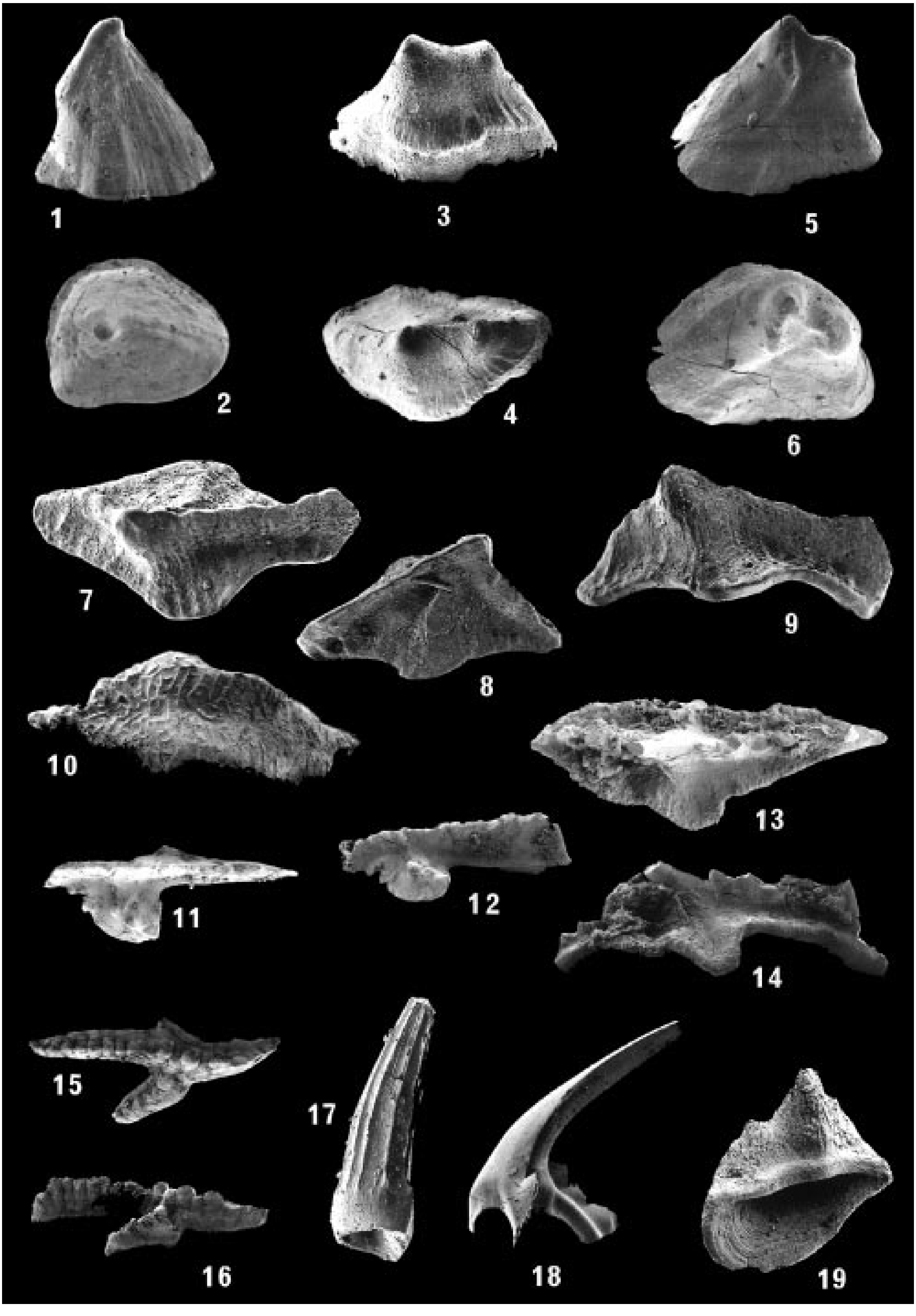

1
3
5
2
4
6
7
9
8
10
13
11
12
14
15
17
16
18
19

Plate 2

Figs. 1–3: ***Kockelella latidentata*** **BISCHOFF, 1986.**
Fig. 1: Upper view of Pa element AMF105018.
WERR 1.4 (×60).
Fig. 2: Oblique lower view of Pa element AMF105018.
WERR 1.4 (×60).
Fig. 3: Lateral view of Pa element AMF105018.
WERR 1.4 (×60).

Figs. 4–8: ***Kockelella ranuliformis*** **(WALLISER, 1964).**
Fig. 4: Upper view of Pa element AMF105019.
WERR 8.0 (×60).
Fig. 5: Lateral view of Pa element AMF105019.
WERR 8.0 (×60).
Fig. 6: Upper view of juvenile Pa element AMF105020.
BN28 6.7 (×80).
Fig. 7: Lateral view of juvenile Pa element AMF105020.
BN28 6.7 (×80).
Fig. 8: Oblique lateral view of juvenile Pa element AMF105020.
BN28 6.7 (×80).

Fig. 9: ***Kockelella variabilis*** **(WALLISER, 1964).**
Lateral view of Sb element AMF105021.
BN28 37.2 (×40).

Fig. 10: ***Kockelella amsdeni*** **BARRICK & KLAPPER, 1976.**
Lateral view of Sa element AMF105022.
DSC/B 246.9 (×60).

Figs. 11–13: ***Kockelella*** **n. sp. A KLAPPER & MURPHY, 1974.**
Fig. 11: Upper view of Pa element AMF105023.
WERR 1.4 (×40).
Fig. 12: Lower view of Pa element AMF105023.
WERR 1.4 (×40).
Fig. 13: Lateral view of Pa element AMF105023.
WERR 1.4 (×40).

Figs. 14,15: ***Kockelella*** **sp. A cf. n. sp. A KLAPPER & MURPHY, 1974.**
Fig. 14: Upper view of Pa element AMF105024.
WERR 1.4 (×40).
Fig. 15: Lower view of Pa element AMF105024.
WERR 1.4 (×40).

Figs. 16–18: ***Kockelella*** **sp. B cf. n. sp. A KLAPPER & MURPHY, 1974.**
Fig. 16: Upper view of Pa element AMF105025.
BOR/1 0.0 (×40).
Fig. 17: Lower view of Pa element AMF105025.
BOR/1 0.0 (×40).
Fig. 18: Detail of basal cavity showing concentric growth lines, Pa element AMF105025.
BOR/1 0.0 (×40).

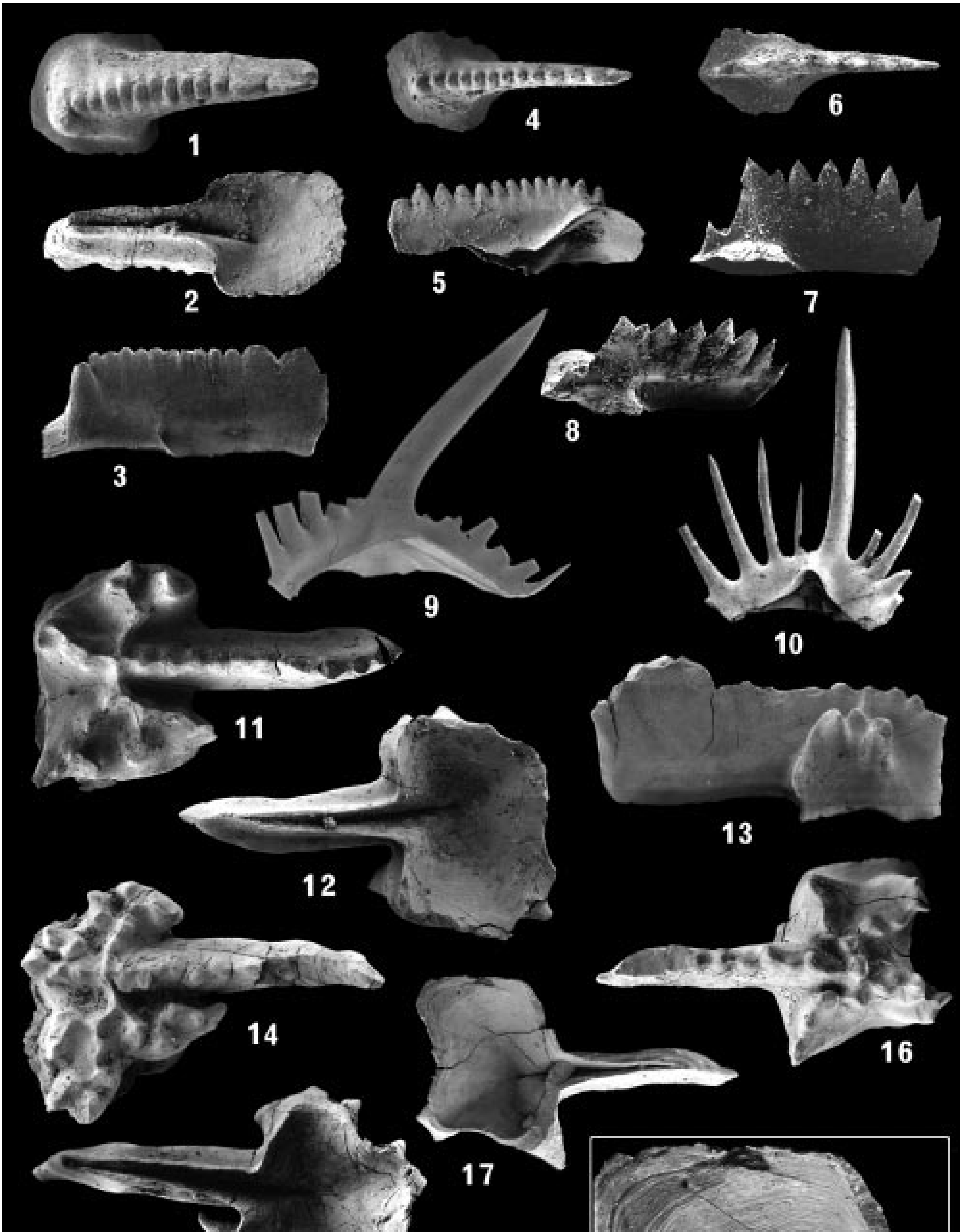

1
4
6
2
5
7
3
8
9
10
11
13
12
14
16
17
15
18

Plate 3

Figs. 1–14: ***Ozarkodina excavata excavata*** **(Branson & Mehl, 1933).**
Fig. 1: Lateral view of Pa element AMF105026.
Spot sample 1 (×60).
Fig. 2: Lateral view of Pa element AMF105027.
BUN 19A (×60).
Fig. 3: Lateral view of juvenile Pa element AMF105028.
BUN 17A (×80).
Fig. 4: Lateral view of Pa element AMF105029.
DSC 38A (×60).
Fig. 5: Lateral view of Pa element AMF105030.
BOR/1 (×60).
Fig. 6: Lateral view of juvenile Pa element AMF105031.
BN28 19.0 (×80).
Fig. 7: Lateral view of Pb element AMF105032.
WERR 10.1 (×40).
Fig. 8: Lateral view of Pb element AMF105033.
DSC/B 253.4 (×40).
Fig. 9: Lateral view of Pb element AMF105034.
DSC/B 266.3 (×40).
Fig. 10: Lateral view of Sa element AMF105035.
BUN 19 (×80).
Fig. 11: Lateral view of Sa element AMF105036.
BUN 17A (×80).
Fig. 12: Lateral view of Sb element AMF105037.
BUN 17A (×80).
Fig. 13: Lateral view of juvenile M element AMF105038.
BN28 24.8 (×60).
Fig. 14: Lateral view of Sc element AMF105039.
BUN 17A (×40).

Figs. 15–20: ***Panderodus greenlandensis*** **Armstrong, 1990.**
Fig. 15: Inner lateral view of Sa element AMF105040.
WERR 1.7 (×60).
Fig. 16: Outer lateral view of Sa element AMF105040.
WERR 1.7 (×60).
Fig. 17: Inner lateral view of M element AMF105041.
WERR 1.4 (×60).
Fig. 18: Outer lateral view of M element AMF105041.
WERR 1.4 (×60).
Fig. 19: Inner lateral view of Sc element AMF105042.
WERR 1.4 (×60).
Fig. 20: Outer lateral view of Sc element AMF105042.
WERR 1.4 (×60).

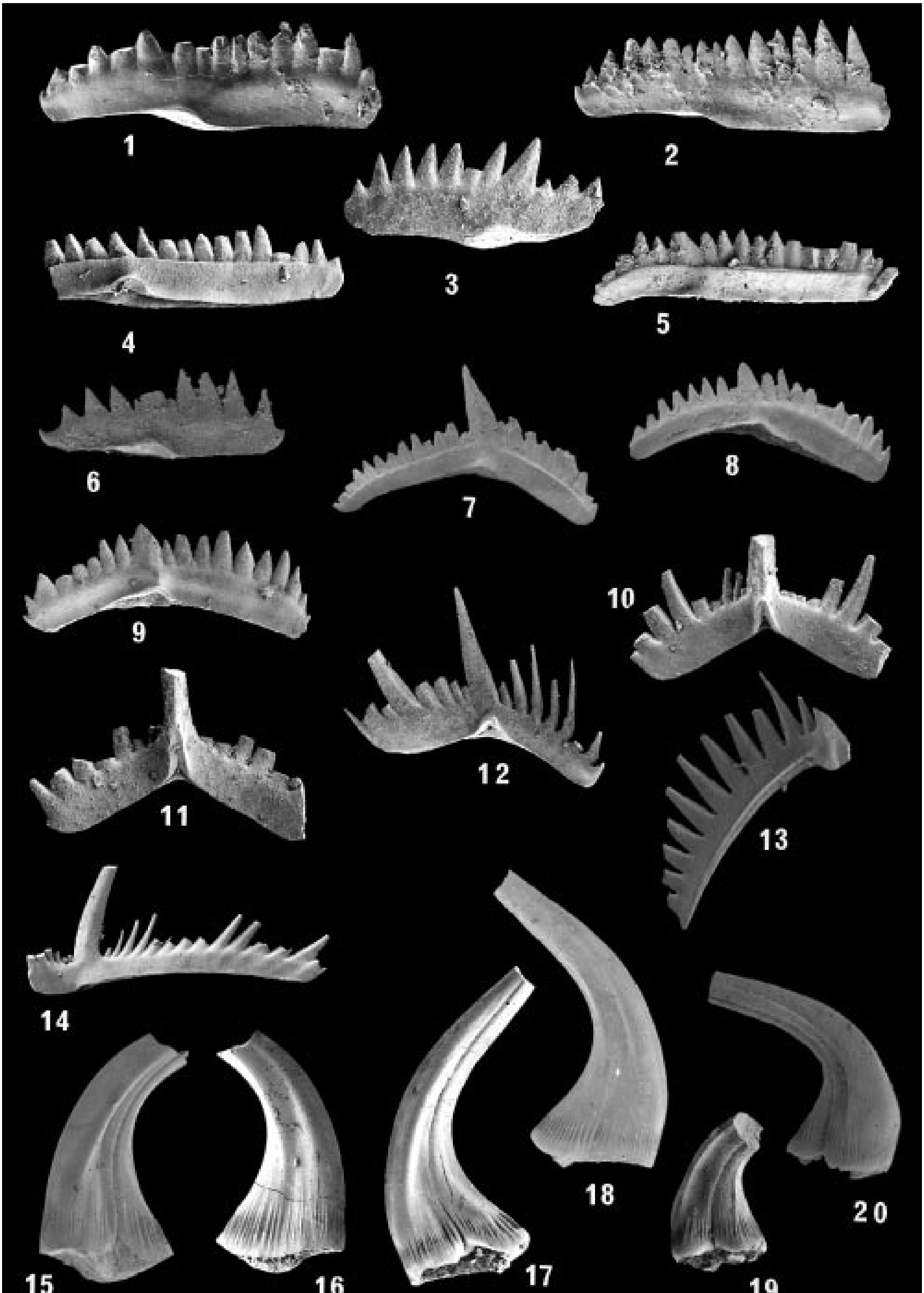

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20

Plate 4

Figs. 1,2,5,6,9,10: ***Belodella anomalis*** **Cooper, 1974.**

Fig. 1: Inner lateral view of triangular element AMF 105043. Spot Sample 7, ITG1 (×140).
Fig. 2: Outer lateral view, of triangular element AMF105043. Spot Sample 7, ITG1 (×140).
Fig. 5: Outer lateral view of triangular element AMF105044. Spot Sample 7, ITG1 (×120).
Fig. 6: Inner lateral view of triangular element AMF105044. Spot Sample 7, ITG1 (×120).
Fig. 9: Lateral view of lenticular element AMF105045. Spot Sample 7, ITG1 (×80).
Fig. 10: Lateral view of lenticular element AMF105045. Spot Sample 7, ITG1 (×80).

Figs. 3,4,11,12: ***Belodella coarctata*** **Barrick & Klapper, 1992.**

Fig. 3: Lateral view of Sa element AMF1050046. Spot Sample 7, ITG1 (×100).
Fig. 4: Lateral view of Sa element AMF1050046. Spot Sample 7, ITG1 (×100).
Fig. 11: Lateral view of Sb element AMF1050047. Spot Sample 7, ITG1 (×80).
Fig. 12: Lateral view of Sb element AMF1050047. Spot Sample 7, ITG1 (×80).

Figs. 7,8: ***Belodella*** **sp. A.**

Fig. 7: Lateral view of element AMF1050048. DSC 219.0 (×200).
Fig. 8: Lateral view of element AMF1050048. DSC 219.0 (×200).

Figs. 13–19: ***Dapsilodus obliquicostatus*** **(Branson & Mehl 1933).**

Fig. 13: Lateral view of M element AMF105049. WERR 1.4 (×120).
Fig. 14: Lateral view of M element AMF105049. WERR 1.4 (×120).
Fig. 15: Lateral view of Sc element AMF105050. WERR 1.4 (×80).
Fig. 16: Lateral view of Sc element AMF105050. WERR 1.4 (×80).
Fig. 17: Lateral view of M element AMF105051. BOR/1 0.0 (×80).
Fig. 18: Lateral view of M element AMF105051. BOR/1 0.0 (×80).
Fig. 19: Lateral view of M element AMF105052.

Fig. 20: ***Coryssognathus dubius*** **(Rhodes, 1953).**

Oblique lateral view of Pc element AMF105053. Spot sample 7 (×100).

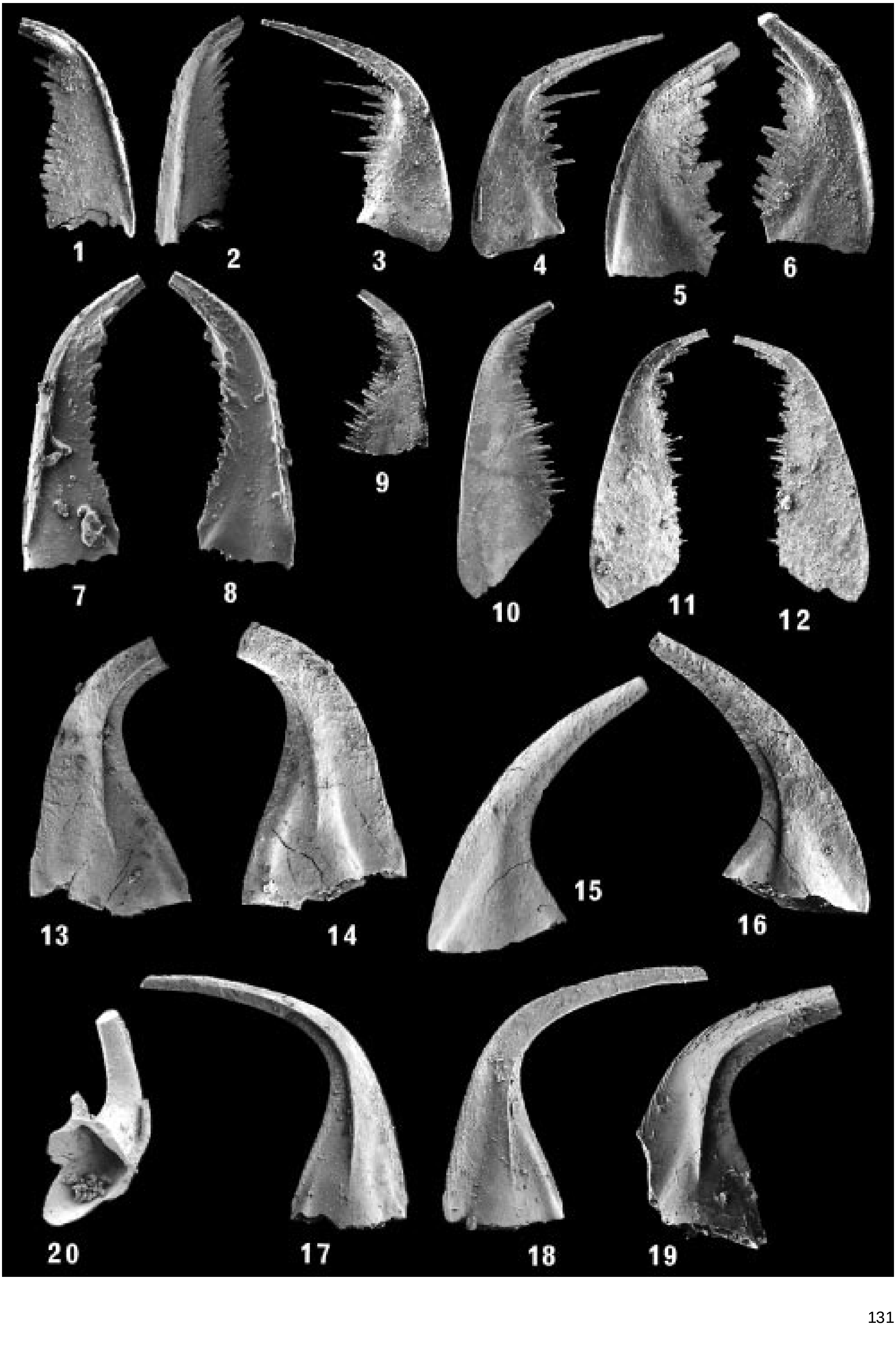

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20

Plate 5

Figs. 1–8: ***Panderodus unicostatus* Branson & Mehl, 1933.**

Figs. 1,8: Outer and inner lateral view respectively of M element AMF105054. BOC α ($\times$100).

Figs. 2,7: Inner and outer views respectively of Sc element AMF105055. DSC 153.4 ($\times$80).

Figs. 3,6: Outer and inner views respectively of Sb element AMF105056. BOC α ($\times$100).

Figs. 4,5: Outer and inner views respectively of Sa element AMF105057. BOC α ($\times$100).

Figs. 9–14: ***Panderodus recurvatus* (Rhodes, 1953).**

Figs. 9,14: Inner and outer views respectively of Sa element AMF105058. DSC 153.4 ($\times$80).

Figs. 10,13: Outer and inner views respectively of Sb element AMF105059. DSC 183.4 ($\times$80).

Figs. 11,12: Outer and inner views respectively of M element AMF105060. BOC κ ($\times$120).

Fig. 15: ***Opsiconidion* sp.**
Inner view of brachial valve of inarticulate brachiopod, AMF105061.
DSC 219.0 ($\times$40).

Fig. 16: ***Acrotretella* sp.**
Inner view of brachial valve of inarticulate brachiopod AMF105062.
DSC 109, ($\times$40).

Fig. 17: **Gastropod undet.**
AMF105064, ERC 6 ($\times$80).

Fig. 18: ***Hyperammina* sp.**
Agglutinated foraminifer AMF105064.
BOR/1 ($\times$80).

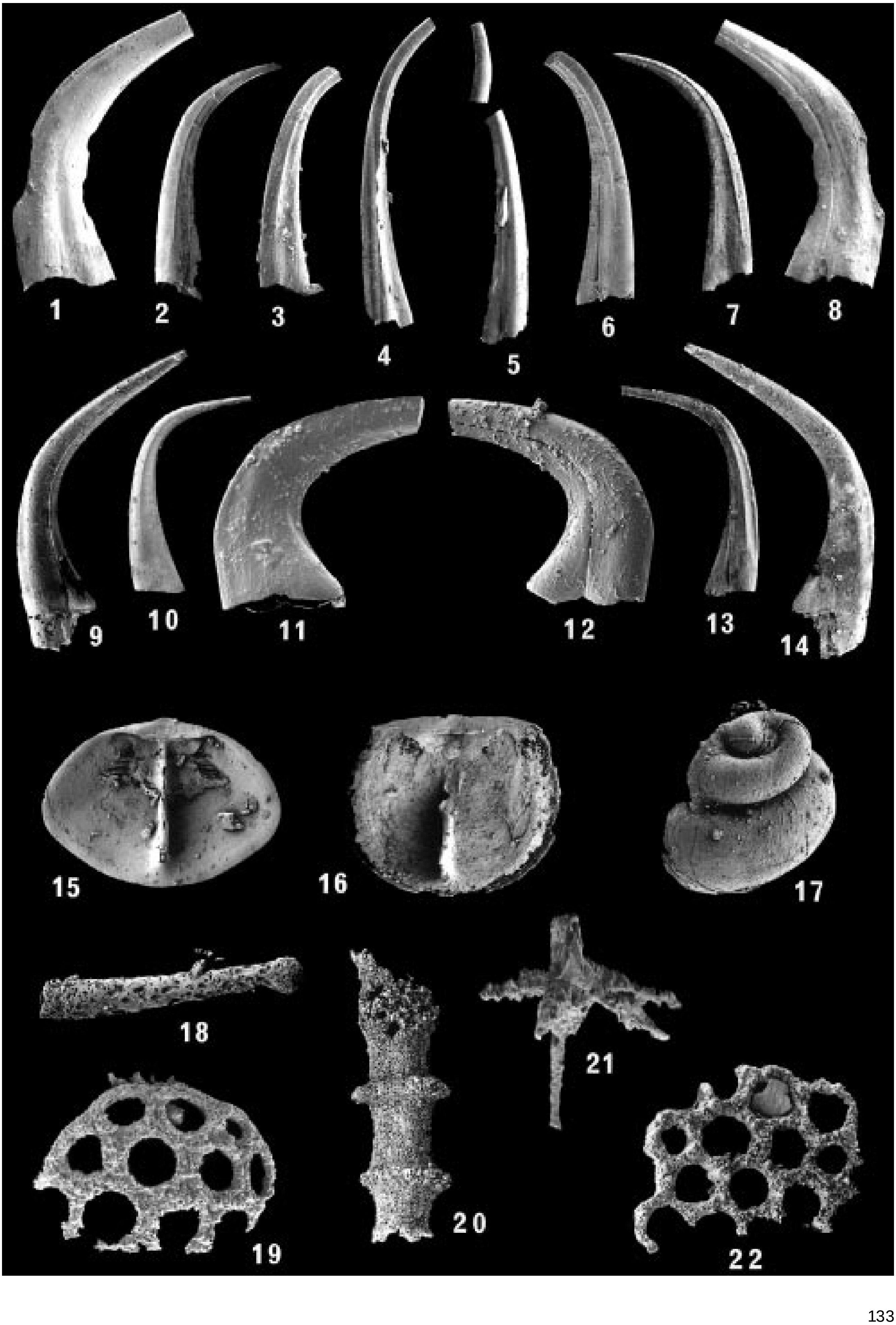
Figs. 19,22: **Holothurian spicules.**

Fig. 19: AMF105065. DSC/E Clast 4 ($\times$80).

Fig. 22: AMF105066. DSC 124.2 ($\times$80).

Fig. 20: ***Lancicula* sp.**
Calcareous algae, AMF105067.
DSC/B 260.1 ($\times$40).

Fig. 21: **Sponge spicule.**
AMF105068.
DSC/E 48.6 ($\times$40).


1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22