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Late Ordovician (Eastonian) conodonts from the Early Devonian Drik Drik Formation, Woolomin area, eastern Australia

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Abstract – The Early Devonian (Emsian) Drik Drik Formation of the Tamworth Group, that crops out between Tamworth and Nundle in northeast New South Wales, comprises mainly coarse sedimentary rocks that host limestone masses of a range of ages. Several blocks from one locality are richly fossiliferous and yielded a fauna of 1024 Late Ordovician conodonts. The fauna includes *Belodina confluens*, *Phragmodus undatus*, *Yaoxianognathus* sp. cf. *Y. ani*, *Y. tunguskaensis* and *Drepanoistodus suberectus*, indicating an Eastonian age. Similar faunas are known from the olistostromal Wisemans Arm Formation and are characteristic of the Late Ordovician "Australasian Faunal Province".

INTRODUCTION

The principal aims of this study were to locate and obtain conodonts from an Ordovician limestone locality within the Early Devonian Drik Drik Formation reported by Cawood (1980) and to compare the fauna with other New England and east Australian faunas to establish biogeographic affinity and possible sources of the Ordovician limestone olistoliths. A further aim was to determine whether the Ordovician limestone blocks, known to occur at several places in the Drik Drik Formation, were derived from the Haedon Formation, an Ordovician unit unconformably underlying the Drik Drik Formation (Cawood 1980, 1983).

The Drik Drik Formation is exposed close to the eastern margin of the Tamworth Belt in northeastern New South Wales (Figure 1). The belt comprises a meridionally trending Palaeozoic magmatic arc and flanking basin assemblage bounded on the west by the Mooki Thrust and to the east by the Peel Fault System. It contains approximately 13,000 m of Cambrian to Early Permian volcaniclastic sedimentary rocks and mafic to silicic extrusives (Crook 1961, 1964). Sedimentary units in the eastern part of the Tamworth Belt comprise an early Palaeozoic sequence (Figure 2) first recognised by Cawood (1976, 1980) that is unconformably overlain by the Tamworth Group (Crook 1961), a Devonian unit reaching a maximum thickness of 3700 m and comprised predominantly of breccia, conglomerate, arenites and tuff, mostly of basaltic and andesitic provenance (Crook 1961; Cawood 1980, 1983).

The lowest unit in the Tamworth Group is the Drik Drik Formation, comprising up to 550 m of generally haematite-pigmented, red breccia (originally named the "Nemingha Red Breccia" by Benson 1913) and conglomerate containing clasts of andesite and dacite (and volumetrically minor limestone), red sandstone and siltstone. In excising the Northcotte Formation from the Drik Drik Formation (sensu Crook 1961), Cawood (1980) adjusted the Type Section thus: 173366–171364 (AMG grid system) along Sandy Creek, then trending WNW for 250m to 168365, Woolomin 1:25000 Sheet. Prominent lenses of andesite (Copes Creek Andesite) interstratified within the Drik Drik Formation represent syn-sedimentary submarine intrusions and extrusions (Morgan 1997). Limestone lenses, formerly termed the "Nemingha" and "Loomberah" Limestone members (Crook 1961) cropping out at various levels within the formation (and in the stratigraphically higher Northcotte and Silver Gully formations) have been shown to represent olistostromes and olistoliths (Furey-Greig 1995). Documented ages of limestone blocks in the Drik Drik Formation range from Ordovician to Early Devonian (Emsian) (Philip and Pedder 1967; Cawood 1980; Webby 1988; Furey-Greig 1994, 1995). An Emsian age as indicated by conodonts and dacryoconarids for the youngest clasts (Furey-Greig 1994, 1995), is also the age of the Drik Drik Formation, for a Late Emsian conodont fauna has been recognised in autochthonous limestone in the stratigraphically higher Silver Gully Formation (Mawson *et al.* 1995).

Philip (1966) was the first to document a Late Ordovician fossil fauna of conodonts and corals from what he termed the "Trelawney Beds", located south-east of Tamworth (Figure 1). He considered the "Trelawney Beds" to be a fault-bounded Late

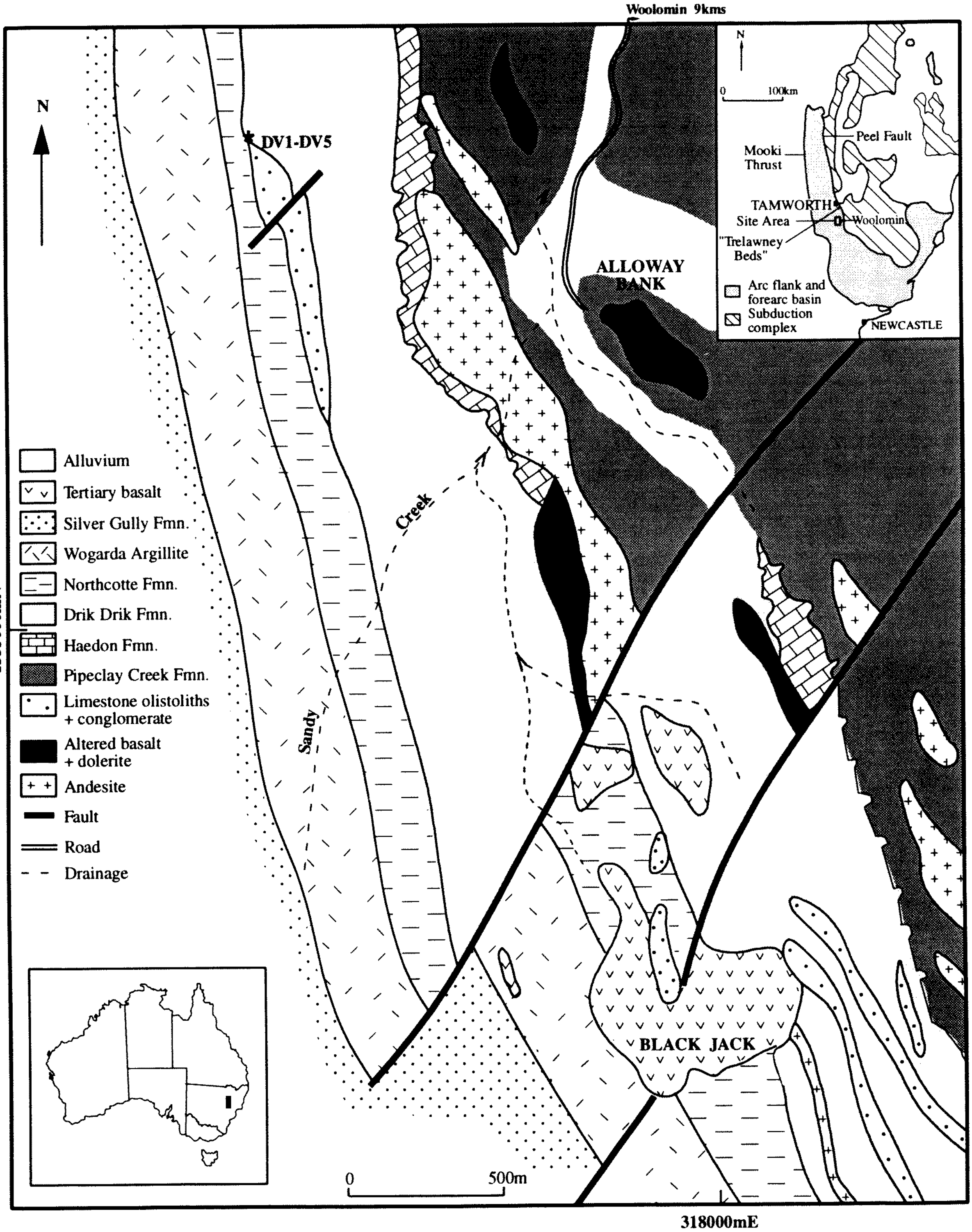

Figure 1 Geology of study area showing the location of Ordovician conodont locality Dv1–5 (adapted from Cawood 1980).

Ordovician unit, but detailed mapping by Cawood (1980) demonstrated that the unit was based on allochthonous blocks embedded in the Drik Drik Formation, analogous with the rocks examined here.

Since Philip's paper, there has been a growing list of reports (summarised by Furey-Greig, in press, Table 1) of Ordovician fossils from isolated localities in the Tamworth region, most indicating Late Ordovician ages and derived from allochthonous limestone masses. One exception is Packham's report (1969, p. 231) of the Bendigonian graptolite *Didymograptus ?minuta* from arenites close to the Peel Fault adjacent to the "Trelawney

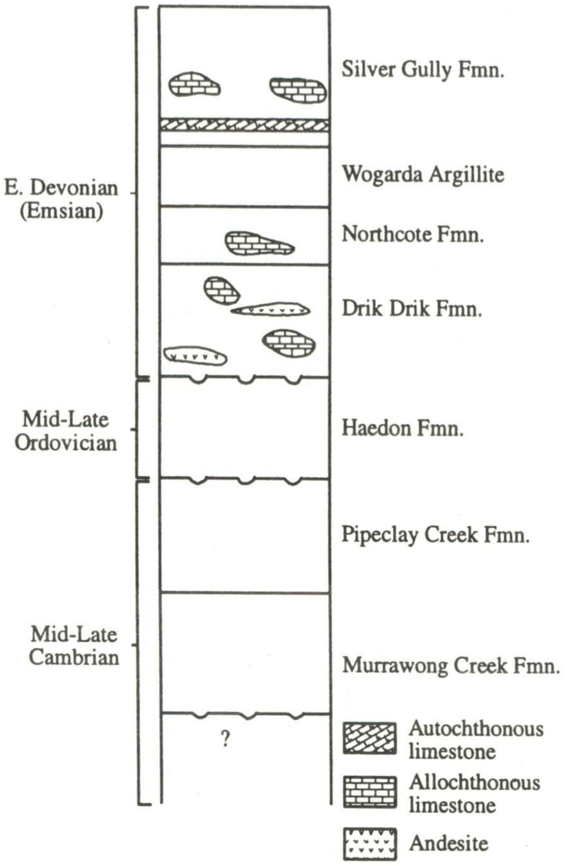

Figure 2 Early Palaeozoic and Tamworth Group stratigraphy in the Woolomin area. Sources: Cawood 1976, 1980; Furey-Greig 1995; Mawson *et al.* 1995; Stewart 1995 and Morgan 1997.

Beds" locality. Study of conodonts from a large number of limestones in the southern New England Fold Belt has recently led to recognition of a considerable number of Late Ordovician (Eastonian) localities between Warialda and Tamworth (Barclay *et al.* 1999; Furey-Greig 1999 and in press).

DISCUSSION

The limestone studied occurs as a group of blocks that appear to represent a single large olistolith approximatley 5 m in length. It is richly fossiliferous pale brown packstone (Figure 3), and is easily distinguishable from the other, Early Devonian limestone at the locality, a red pigmented wackestone with bioclasts made up predominantly of crinoid fragments. Field relations are obscured as the matrix is recessive, but as the Drik Drik Formation is characterised by red pigmented matrices, and the Ordovician block lies at the northern margin of a 900 m long lens of Early Devonian limestone blocks, it is clearly allochthonous. In hand specimen, the limestone is quite similar to that documented from the "Trelawney Beds" (B. Webby, pers. comm.). A clast of superficially identical limestone that produced equivalent conodont species was recently documented from the Wisemans Arm Formation east of the Peel Fault (clast 7, Locality 8 of Furey-Greig 1999).

BIOSTRATIGRAPHY AND CORRELATION

The fauna is comparable to others, of Eastonian age, recently documented from the Wisemans Arm Formation in the Tablelands Complex east of the Peel Fault (Barclay *et al.* 1999; Furey-Greig 1999 and in press), though being less diverse. The presence of *Phragmodus undatus*, *Belodina confluens* and *Drepanoistodus suberectus* does not tightly constrain the age of the fauna, but Gen. et. sp. nov. A has a known range in eastern Australia of Eastonian 2 to

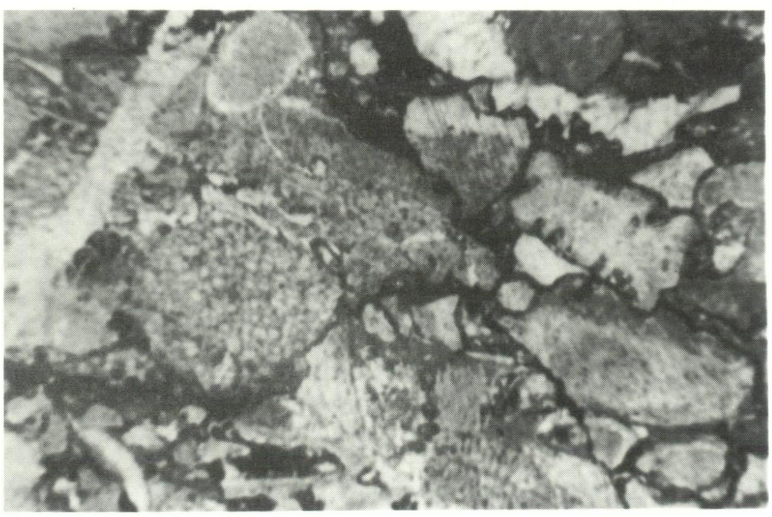

Figure 3 Photomicrograph of fossiliferous, conodont producing limestone from 316600/6537400, Woolomin 1:25,000 Sheet. Crossed polars, base of frame = 10 mm.

3 (Pickett and Furey-Greig, in press). Thus, the Ordovician limestone discussed here can be constrained to the same range.

A fauna reported from the "Trelawney Beds" (Philip 1966) includes *P. undatus* and *B. confluens* and, with rocks discussed herein, indicates that such Eastonian limestone blocks were probably deposited throughout the Drik Drik Formation as they occur at different horizons within the sequence.

The low diversity of the fauna may reflect the original depositional environment of the limestone. The limestone from Woolomin is richly fossiliferous, containing abundant, sub-rounded coral and bryozoan allochems and is poorly sorted indicating a relatively high energy depositional environment (Figure 3). The limestone reported from the Wisemans Arm Formation and producing more diverse faunas is interpreted to be relatively deeper water, well sorted and fine grained.

Trotter and Webby (1995) observed that *P. gracilis*, virtually absent from the present fauna, was indicative of relatively deep water while *P. undatus* and *B. confluens* were characteristic of "the warm water realm" (of Sweet and Bergström 1984), a relationship that is borne out in this research. This disparity in conodont diversity is possibly then related to depth and is not considered an impediment to correlations proposed here.

The southern New England Fold Belt conodont faunas are similar to those described from the northeast Lachlan Fold Belt, including the Malongulli Formation (Trotter and Webby 1995), Cliefden Caves Limestone (Zhen and Webby 1995), the Bowan Park succession (Zhen *et al.* 1999), the northern Rockley-Gulgong Volcanic Belt (Percival 1999) and the allochthonous blocks of Reedy Creek Limestone within the Barnby Hills Shale (Farrell 1996).

Other similar faunas are known from the Fork Lagoons Beds (Palmieri 1978) and the Carriers Well Formation (Simpson 1997) in north-eastern and central-eastern Queensland. Late Ordovician conodont faunas in eastern Australia comprise a distinct mixture of species that characterised several of Bergström's (1990) Late Ordovician "faunal provinces" (eg, Trotter and Webby 1995; Zhen and Webby 1995; Simpson 1997; Zhen *et al.* 1999; Furey-Greig 1999and in press), but are now considered to constitute the recently defined "Australasian" faunal province (Nowlan *et al.* 1997).

The Drik Drik fauna thus provides a further biogeographic link between the Lachlan and New England fold belts during the Late Ordovician that may eventually help improve understanding of regional relationships between these two tectonic entities, presently hampered by a lack of spatial linkages (Fergusson 1999).

The Drik Drik Formation unconformably overlies the Ordovician Haedon Formation (Cawood 1980), but the conodont fauna reported here bears no resemblance to that presently being examined from the latter. Indeed, the Haedon Formation is probably significantly older than the Late Ordovician limestone in the Drik Drik Formation (unpublished data) and, on that basis, was not the source of the limestone herein. The growing number of Late Ordovician limestone occurrences reported from both sides of the Peel Fault between Warialda and Nundle seems to indicate that the source of such blocks was laterally extensive though no in situ Eastonian limestone is, as yet, known in the region.

METHODS

Five samples (approximately 70 kg in total) of limestone were digested in 10% acetic acid and separated using the method described by Anderson *et al.* (1995). Processed limestones yielded 1024 conodont elements and rare acrotretid brachiopod valves (Table 1). Conodont images were digitally

Table 1 Distribution of conodonts derived from samples Dv1–Dv5 from the Drik Drik Formation of the Tamworth Group between Tamworth and Nundle, northeast New South Wales.

Taxon/ Sample	Dv1	Dv2	Dv3	Dv4	Dv5
Belodina confluens	5	8	1	19	11
Belodina sp.	1				
Gen. et sp. nov. A	5	23	16	7	86
Drepanoistodus suberectus	6	4	1	11	
Istorinus? sp.	5	7	38		
Panderodus gracilis	1	4			
Periodon sp.	4	7	7	9	42
Phragmodus undatus	19	97	73	32	232
Pseudobelodina dispansa	1	1	7		
Pseudooneotodus beckmanni	1	3			
Yaoxianognathus sp. cf. Y. ani	1	15	8	10	57
Yaoxianognathus? tunguskaensi	3	3	6	6	17
unassigned elements/fragments	12	36	13	24	109

acquired using a JEOL 35CF SEM and Moran Scientific Instruments software at the University of Technology Sydney Microstructural Analysis Unit. Photographic figures (Figures 5, 6) were created digitally using Paint Shop Pro (Ver. 3.0) and Corel Draw (Ver. 6.0) and printed with a Fuji "Digital Pictography System". Specimens documented herein are curated at the Australian Museum, Sydney, prefixed with "AMF" and sequential numbers.

SYSTEMATIC PALAEONTOLOGY

Phylum Conodonta Pander, 1856

Class Conodonta Pander, 1856

Genus *Belodina* Ethington, 1959

Type species
Belodus compressus Branson and Mehl, 1933

Belodina confluens Sweet, 1979
Figures 5.1–4

Belodina confluens: Zhen *et al.* 1999: pl. 1, figs 7–9

Belodina confluens: Furey-Greig 1999: pl. 1, figs 4–9

Belodina confluens: Furey-Greig (in press): fig. 5, A–E
See Furey-Greig (1999) for earlier synonymy.

Material
Forty-four elements.

Remarks
Elements in this collection are typical of the species and comprise 4.5% of the fauna.

Belodina sp.
Figure 5.5

Material
One element from sample Dv2.

Remarks
The single grandiform element illustrated differs from *B. confluens* herein in displaying a distinct recurving of its anterior margin at about 40% from the base, and in having prolate denticles.

Gen. et sp. nov. A
Figures 5.9–15

Gen. et sp. indet. B: Furey-Greig 1999: pl. 4, fig. 19

Material
One hundred and forty-four elements.

Description
Three bladed, with a posterior process generally up to 50% longer than the others, accommodating 5 or more denticles of slightly laterally compressed circular cross-section. Cusp angled posteriorly at about 40° from the vertical, approx. three times the height of denticles and laterally compressed. Anterior process angled slightly inward from axis of posterior process, accommodating 4 or 5 denticles of similar shape to others. Outer lateral process shorter than or of similar dimension and denticulation as anterior process, angled at about 80° from same. A thin but distinct costa flanks the anterior margin of the cusp and, in some elements, is developed into a small, smooth inner lateral process. Outer lateral process ending bluntly, others ending in a sharp tip. Basal cavity wide, extending beneath denticulate processes for almost their entire length.

Remarks
This species comprises approximately 14% of the Drik Drik fauna. It is here left in open nomenclature as it is being described elsewhere from both New England and Lachlan Fold Belt localities (Pickett and Furey-Greig in press). Three elements of this species were assigned "indeterminate" in a fauna from the Wisemans Arm Formation that is constrained to an Eastonian (Ea3) age (Furey-Greig 1999). This species is known to occur in faunas that range from Eastonian 2 to 3 (Pickett and Furey-Greig in press). A single Sa element (Figure 5.18) may belong to this species but is left unassigned here as only one was recovered.

Genus *Drepanoistodus* Lindström, 1971

Type species

Oistodus forceps Lindström, 1955

Drepanoistodus suberectus (Branson and Mehl, 1933)
Figure 5.8

Drepanoistodus sp.: Fowler and Iwata 1995: fig. 2.13

Drepanoistodus suberectus: Furey-Greig 1999: pl. 2, figs 1–3
See Furey-Greig (1999) for earlier synonymy.

Material
Twenty-five elements.

Remarks
The elements from Woolomin closely resemble material documented from elsewhere in New England (Furey-Greig 1999).

Genus *Istorinus* Knüpfer, 1967

Type species

Istorinus erectus Knüpfer, 1967

Istorinus? sp.
Figure 5.16

Material
Fifty elements.

Remarks
All elements in this collection are broken, but display sufficient similarity to previously documented material for tentative assignment to this genus (e.g., Trotter and Webby 1995, p. 482, pl. 3, figs 29–32).

Genus *Panderodus* Ethington, 1959

Type species

Paltodus unicostatus Branson and Mehl, 1933

Panderodus gracilis (Branson and Mehl, 1933)
Figure 5.17

Panderodus gracilis: Furey-Greig 1999: pl. 2, figs 4–11

Panderodus gracilis: Furey-Greig (in press): Fig. 5.I–M

See Furey-Greig (1999) for earlier synonymy.

Material
Five elements.

Remarks
It is noteworthy that this species is very rare in this fauna, though being a major constituent in other Late Ordovician New England faunas (Furey-Greig 1999 and in press). This aspect is considered in the Discussion.

Genus *Periodon* Hadding, 1913

Type species

Periodon aculeatus Hadding, 1913

Periodon sp.
Figures 6.1–3

Material
Sixty-nine elements.

Remarks
Only ramiform elements were recovered, and though being similar to some elements of *P. grandis* reported from the Wisemans Arm Formation (Furey-Greig 1999, pl. 2, fig. 21), they are not considered sufficient for assignment at specific level.

Genus *Phragmodus* Branson and Mehl, 1933

Type species

Phragmodus primus Branson and Mehl, 1933

Phragmodus undatus Branson and Mehl, 1933
Figures 6.4–10

Phragmodus undatus: Trotter and Webby 1995: p. 485, pl. 6, figs 2–11

Phragmodus undatus: Zhen *et al.* 1999: pl. 5, figs 1–4

Phragmodus undatus: Furey-Greig 1999: pl. 3, figs 3–9

Phragmodus undatus: Furey-Greig (in press): Fig. 6, D

See Furey-Greig (1999) for earlier synonymy.

Material
Four hundred and sixty elements.

Remarks
P. undatus comprises 45% of the fauna. S elements of this species in the collection mostly preserve basal "extensions" of varying length. This extension is most remarkable in one specimen (Figures 4, 6.7) where it is clearly complete. The extension closely follows the outline of the basal margin and is of similar length to the height of the conodont. It bifurcates at about 2/3 from the element's basal margin, forming two blunt terminations that appear (one is obscured) to have a slight cleft on their bases. Various "basal attachment" features are known, for example, attachment cones on elements of *Drepanoistodus* (Nicoll 1995, figs 7, 8); the material documented here, especially the element discussed, may be an important example of a "root" like attachment for at least some conodont species (elements of *Yaoxianognathus? tunguskaensis* herein, Figures 6.16–18 have similar, incomplete features).

Genus *Pseudobelodina* Sweet, 1979

Type species
Belodina kirki Stone and Furnish, 1959

Pseudobelodina dispansa (Glenister, 1957)
Figures 5.6, 7

Pseudobelodina dispansa: Furey-Greig 1999: pl. 3, figs 10–12

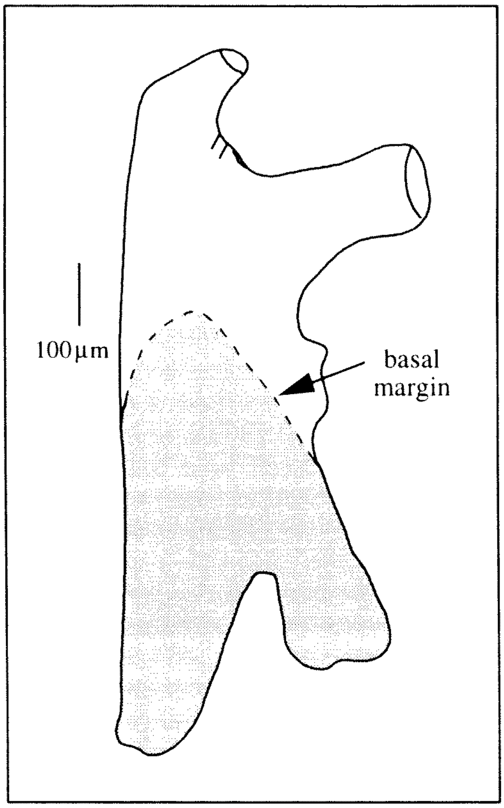

Figure 4 Line drawing of Sc element of *Phragmodus undatus*, showing basal "root", see Figure 6.7.

Pseudobelodina dispansa: Furey-Greig (in press): Fig. 6.E–G

See Furey-Greig (1999) for earlier synonymy.

Material

Nine elements.

Remarks

The material is typical of the species.

Genus *Pseudooneotodus* Drygant,1974

Type species

Oneotodus? beckmanni Bischoff and Sannemann 1958

***Pseudooneotodus beckmanni* (Bischoff and Sannemann, 1958)**

Figure 6.11

See Furey-Greig (1999) for synonymy.

Material

One element.

Remarks

The element is typical of the species. The presence, in this large fauna, of a single specimen is typical of all New England correlative faunas (Furey-Greig 1999 and in press).

Genus *Yaoxianognathus* An, 1985

Type species

Yaoxianognathus yaoxianensis An, 1985

***Yaoxianognathus* sp. cf. *Y. ani* Zhen, Webby and Barnes 1999**

Figures 6.12–15

Material

Ninety-three elements.

Remarks

The material is similar to elements of *Y. ani* reported from the Wisemans Arm Formation (Furey-Greig 1999 and in press). It differs in that the basal margin of Pa elements is slightly curved compared with the straight base of *Y. ani* Pa elements and that the angle between anterior and posterior parts of Pb elements is smaller, viewed laterally.

***Yaoxianognathus? tunguskaensis* (Moskalenko 1973)**

Figures 6.16–18

Yaoxianognathus? tunguskaensis: Zhen *et al.* 1999: pl. 6, fig. 14, pl. 7, fig. 24, pl. 8, figs 17–22.

Yaoxianognathus? tunguskaensis: Furey-Greig 1999: pl. 4, figs 15–17.

See Furey-Greig (1999) for earlier synonymy.

Material

Thirty-five elements.

Remarks

The material is typical of the species, though not including any of the additional elements recently recognised by Zhen *et al.* (1999). A noteworthy feature here is the partial preservation of considerable, varying portions of basal "roots" that compare with those illustrated of *P. undatus* herein (Figures 6.4–7).

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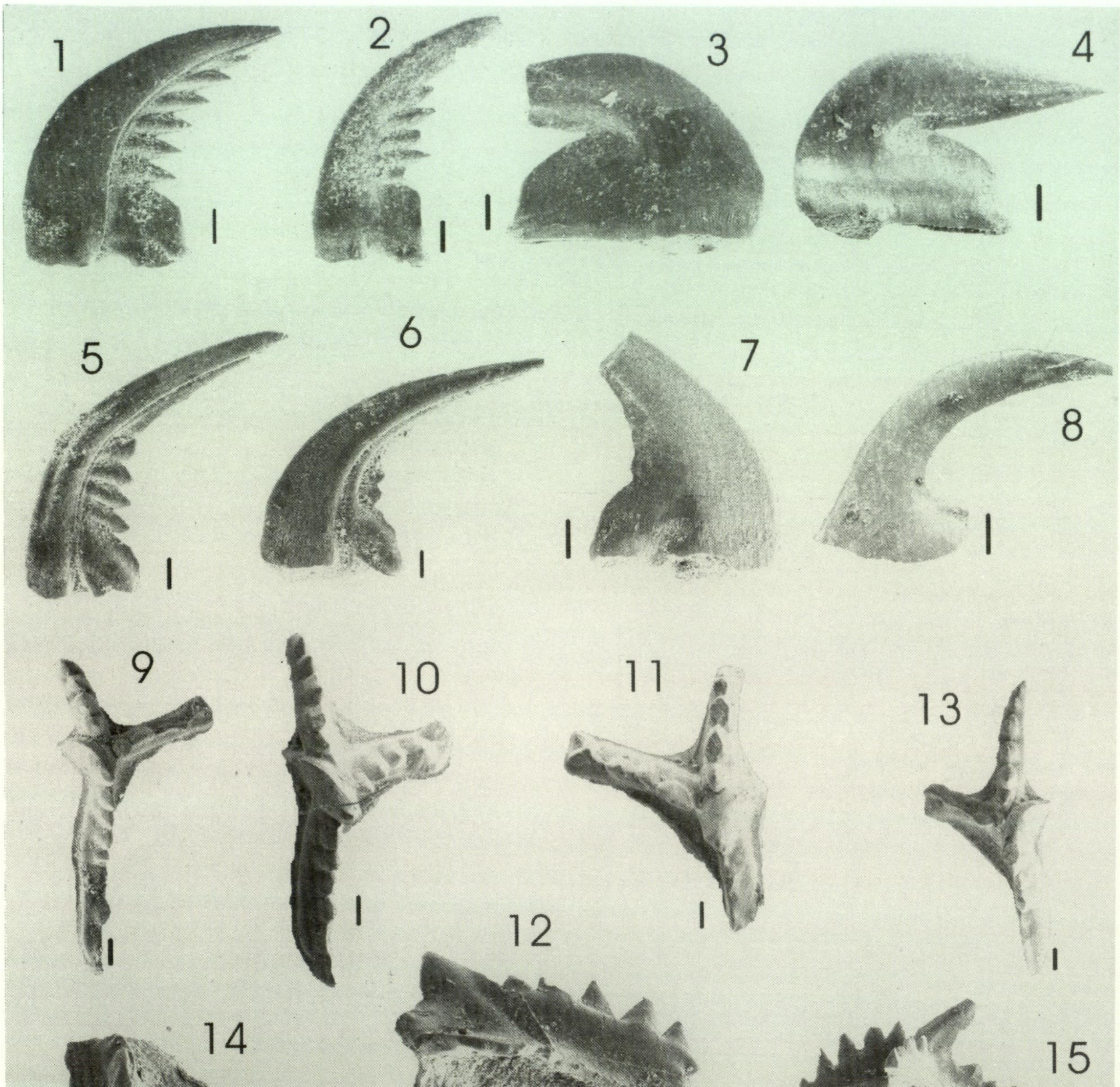

Figure 5 All scale bars = 100 microns. Dvn = sample number. **1–4**, *Belodina confluens* Sweet. **1**, compressiform element, AMF106866 from Dv1. **2**, grandiform element, AMF106867 from Dv1. **3–4**, eobelodiniform elements, AMF106868, AMF106869 from Dv2. **5**, *Belodina* sp., grandiform element, AMF106870 from Dv5. **6–7**, *Pseudobelodina dispansa* (Glenister). **6**, compressiform element, AMF106871 from Dv5. **7** grandiform element, AMF106872 from Dv5. **8**, *Drepanoistodus suberectus* (Branson and Mehl), AMF106873 from Dv2. **9–15**, Gen. et. sp. nov. A. **9–11**, **13–14**, dorsal view, respectively AMF106874, AMF106875, AMF106876, AMF106877, AMF106878, all from Dv5. **12**, oblique ventral view, AMF106879 from Dv3. **15**, outer lateral view, AMF106880 from Dv2. **16**, *Istorinus?* sp., AMF106881 from Dv5. **17**, *Panderodus gracilis* (Branson and Mehl), M element, AMF106882 from Dv4. **18**, unassigned Sa element, AMF106883 from Dv5.

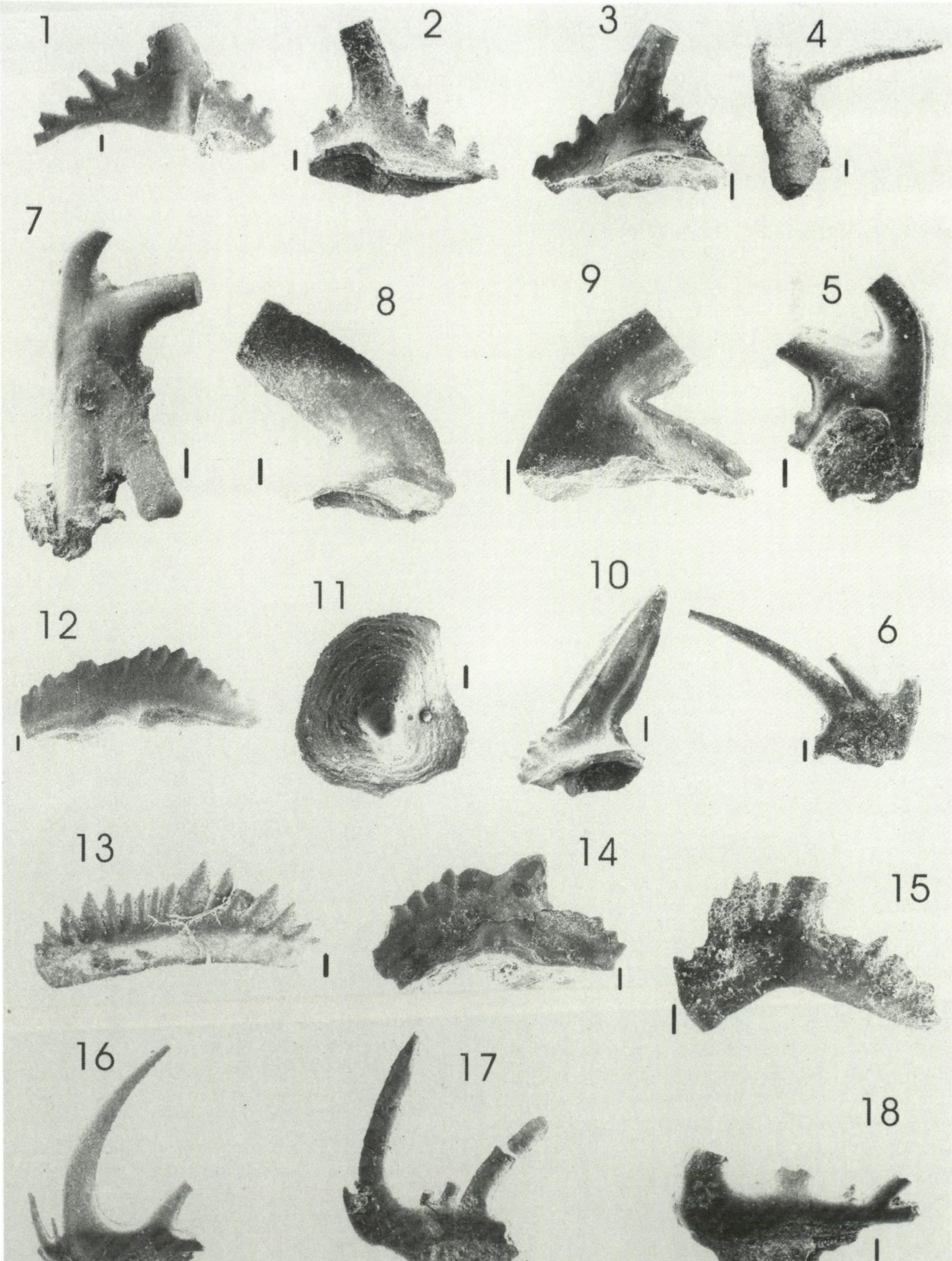

Figure 6 All scale bars = 100 microns. Dvn = sample number. **1–3**, *Periodon* sp., ramiform elements, AMF106884, AMF106885, AMF106886 from Dv5. **4–10**, *Phragmodus undatus* (Branson and Mehl). **4–7**, Sc elements, AMF106887 from Dv5; AMF106888, AMF106889 from Dv2; AMF106890 from Dv3. **8–9**, oistodontiform elements, AMF106891, AMF106892 from Dv5. **10**, Pb element, AMF106893 from Dv5. **11**, *Pseudooneotodus beckmanni* Bischoff and "Sannemann", AMF106894 from Dv3. **12–15**, *Yaoxianognathus* cf. *Y. ani* Zhen *et al*. **12–13**, Pa elements, AMF106895, AMF106896 from Dv5. **14, 15**, Pb elements, AMF106897, AMF10689 from Dv2. **16–18**, *Yaoxianognathus tunguskaensis* (Moskalenko). Sc elements, AMF106899 from Dv3; AMF106900, AMF106901 from Dv5.

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