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The Royal Society of Victoria, 127, 7–16, 2015
10.1071/RS15014

EARLY DEVONIAN FOSSILS FROM THE BROADFORD FORMATION, CENTRAL VICTORIA

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ABSTRACT: The Broadford Formation of central Victoria, Australia, hitherto lacked an identifiable fossil record but has, nevertheless, recently been considered to be wholly Silurian. Shelly fossil localities below and within the Broadford Formation reported in this study have yielded *Boucotia australis* and other brachiopods, indicating that much of the formation has a maximum age of Early Devonian.

Keywords: Early Devonian, Victoria, Broadford Formation, *Boucotia australis*

Central Victoria contains a number of Palaeozoic geological formations that are poorly exposed and hence have uncertain boundaries, as well as having little or no known fossil content. Estimates for the ages of such formations vary considerably in the literature. This paper is one of a planned series aiming to create a basic palaeontological record for some formations in an effort to eliminate gaps in the biostratigraphic context for central Victoria (e.g. Earp 2012).

The name Broadford Formation was first used on the MELBOURNE 1:250 000 mapsheet (Anon. 1970). It remained just a name until Edwards et al. (1997) formally defined the unit, but it still lacked a type locality or any recorded fossil content. Consequently, there has been considerable variability in estimates for the age of the formation.

The Broadford Formation was defined as late Silurian based purely on its supposed stratigraphic relationships. However, a correlation chart published later (VandenBerg et al. 2000: fig. 2.106) shows an age range of Pridoli–Lochkovian. More recently, the age range has been extended to cover almost the entire Silurian (Welch et al. 2011).

On the other hand, Sandford (2002) regarded the definition of the unit to be so deficient as to recommend against its use, and instead used trilobites to assign at least some of the formation outcrop to the Early Devonian upper part of the Mount Ida Formation.

Garratt (1983a) used four species of endemic notanopliid brachiopods (with associated brachiopod assemblages) to define a biostratigraphic sequence for those parts of central Victoria where there is an absence of more accurate index fossils. While this scheme lacks the precision of biozones based on globally occurring graptolites or conodonts, it remains the only practical means of obtaining an approximate date in those areas.

This paper is the first report of identifiable brachiopods from the Broadford Formation, allowing correlation using Garratt's biostratigraphic zones.

All fossil specimens and significant new localities described in this paper are registered with Museum Victoria (institutional acronym NMV), denoted by registration numbers beginning P and PL respectively. The abbreviation GSV refers to localities registered by the Geological Survey of Victoria.

As the object of this study is mainly to record new occurrences of previously described species, the systematic section contains only brief descriptions.

PREVIOUS STUDIES

The first use of the Broadford Formation in the map legend for the MELBOURNE 1:250 000 geological mapsheet was apparently based on the Broadford Conglomerate, an open-framework boulder conglomerate first noted by Noel W. Schleiger (Edwards et al. 1997). The unit was described as 'interbedded siltstone and sandstone with minor greywacke–conglomerate intervals (turbidites)' and was given a Gedinnian–Siegenian age range. On the BENDIGO 1:250 000 mapsheet, King and Wilkinson (1975) correlated it with the upper two-thirds of the Mount Ida Formation, in the same age range.

Garratt (1983b) considered the Broadford Conglomerate to be one of the sedimentary units he dated as 'Early' Pragian, but relied on specific determinations which are now obsolete. The dacryoconarid *Nowakia acuaria* was assumed to be 'Late' Lochkovian, but this is based on the erroneous synonymy of Bouček (1964: 67), who lumped the late Pragian to early Emsian *Alaina matlockiensis* together with the (wholly Pragian) *N. acuaria* and late Lochkovian homoctenids (Alberti 1997). Similarly, the 'Early' Pragian conodont *Eognathodus sulcatus sulcatus* from the Lilydale Limestone (Philip & Pedder 1967) has

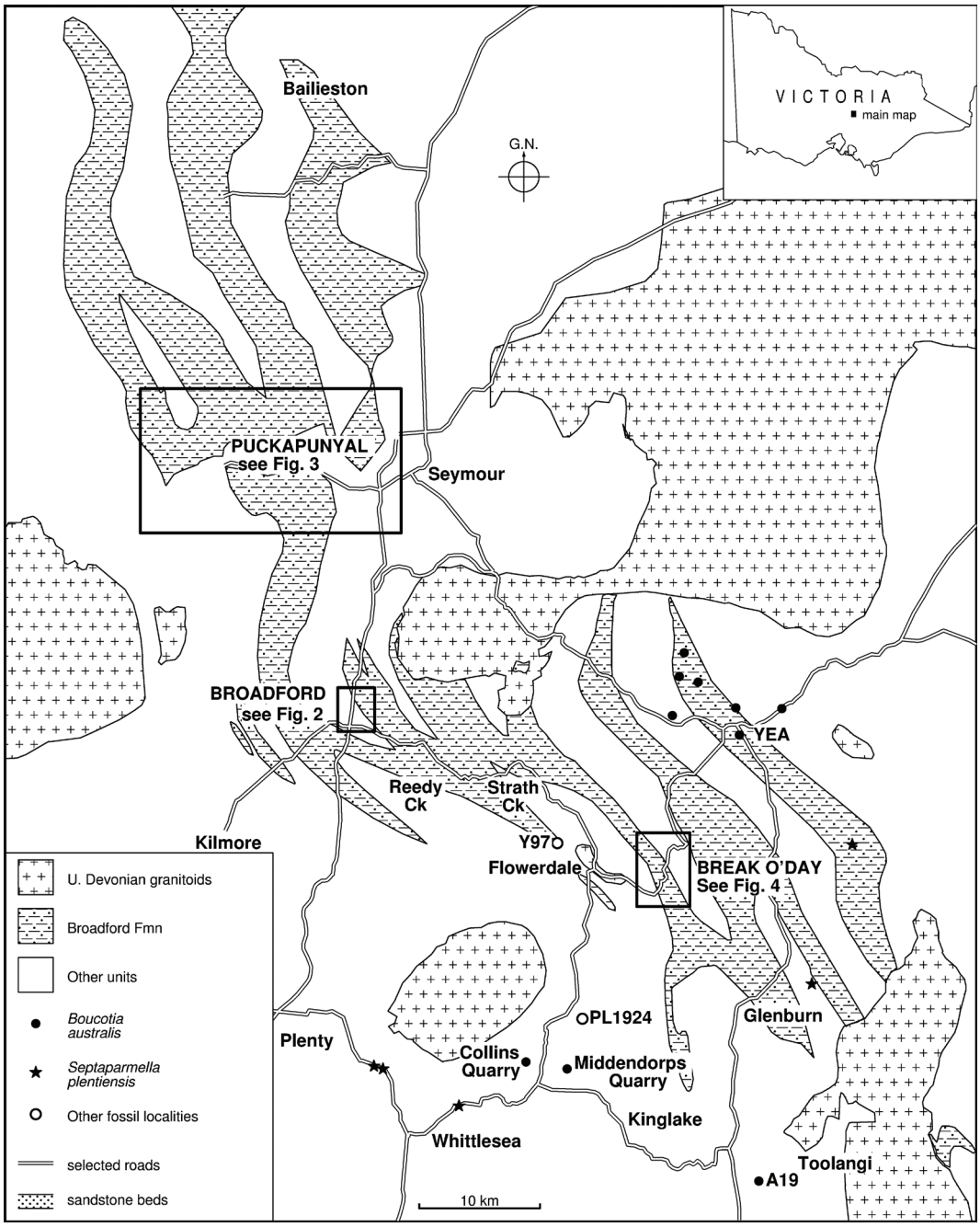

Figure 1: Locality sketch map of central Victoria on grid MGA94 showing supposed extent of the Broadford Formation (after Welch et al. 2011). Considerable dissection of the outcrop north of Puckapunyal is not shown. Localities mentioned in the text are labelled. Unlabelled localities (black dots and stars) illustrate occurrences of the *Boucotia australis* (Lochkovian) and underlying *Notoparmella plentiensis* (Pridoli) biozones of Garratt (1983a); those in the Yea area were mentioned by Earp (2007); others are listed by Garratt (1980a). Map legend applies to this and all other maps in this paper.

been redetermined as *Eognathodus sulcatus kindlei* (mid Pragian) and the Lilydale Limestone actually ranges up to the *Polygnathus dehiscens* zone (early Emsian) (Wall et al. 1995).

Edwards et al. (1997) formally defined the Broadford Formation and explicitly included the Broadford Conglomerate. The age was considered to be constrained by the underlying Dargile Formation (mid to late Silurian) in the Bailieston Anticline, and by Humevale Siltstone interfingering and overlying the Broadford Formation in some areas (for example, in the core of a syncline immediately east of Broadford).

Although the text of VandenBerg et al. (2000: 141) stated that the Broadford Formation and overlying Puckapunyal Formation were correlatives of the (wholly Silurian) McIvor Sandstone, their chart (VandenBerg et al. 2000: fig. 2.106) placed both formations above the McIvor Sandstone, correlating with the Mount Ida Formation, and

with an age range of Pridoli–Lochkovian.

Subsequently, Morand (2010) synonymised the Dargile Formation in the Bailieston area with the Humevale Siltstone, resulting in a maximum age for the Humevale Siltstone of Llandovery on the basis of graptolites reported from that area (Sandford & Rickards 1999). It appears that, because of siltstone still assumed to be Humevale Siltstone overlying the Broadford Formation (e.g. in a syncline at Broadford, see Figure 2A), the maximum age for the latter has now also been interpreted as Llandovery by Welch et al. (2011). These authors depicted Broadford Formation in the core of the Yea Anticline, replacing the undefined Yea Formation of Garratt (1977, 1983a, 1983b), but in the Yea area they showed it as immediately underlying the Pragian to early Emsian Wilson Creek Shale and Easts Lookout Siltstone. There is no field evidence of any discontinuity as might be expected between Silurian and Pragian units.

Figure 5 shows the age ranges and correlations for the Broadford Formation reported in a number of previous works. However, those works are not always internally consistent. This has been noted above in the case of VandenBerg et al. (2000), while in Edwards et al. (1997: figs 5, 6) two slightly different age ranges are shown on opposite pages. The ranges shown in Sandford (2005), although said to follow Sandford (2002), are again slightly different.

LOCALITIES

This study of the palaeontology of some central Victorian localities in the area mapped by Welch et al. (2011) as Broadford Formation has been carried out based on new collections and on material already held by Museum Victoria.

Broadford

The Broadford Conglomerate outcrops immediately east of Broadford, along Marchbanks Road near the intersection with Davis Road (Figure 2A). The boulder conglomerates, with very well-rounded lithic clasts, are fossiliferous but the shelly fossils (crinoid columnals and bivalve fragments) are too poorly preserved to be of any use (Figure 2B shows one of the more distinctive fragments). Indeterminate vascular plant fragments also occur in this diamictite.

Noel Schleiger collected fossils from sandstone at a cutting on a road (then unnamed, now known as Elliot Road) along Chain of Ponds Creek (Figure 2A), in an area now mapped within the Broadford Formation (Welch et al. 2011). As his collection in Museum Victoria contains evident *Boucotia,* I re-collected from the locality for this study. The fossils occur at the base of a graded sandstone bed that is 8 cm thick, within an exposed interval of mostly thin-bedded siltstone that is 1.75 m thick. Identifiable

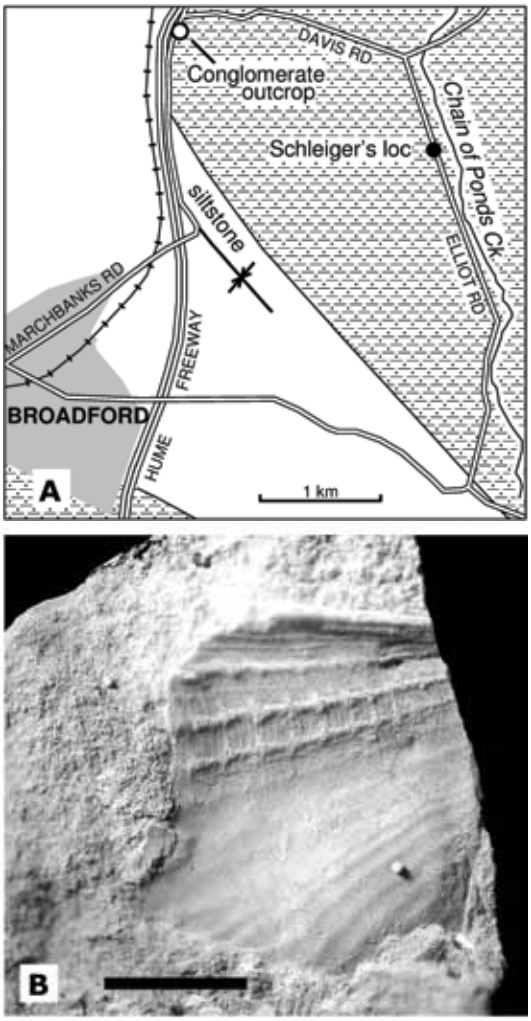

Figure 2: A: Detail of the Broadford area showing localities mentioned in the text. B: NMV P321639, fragment of an unidentified bivalve with heavily lamellose concentric ornament near the hinge, Broadford Conglomerate, Marchbanks Road; scale bar 5 mm.

fossils are *Boucotia australis* (Gill), *Howellella* sp. A, *Australina lenticulata* (Philip) and *Decacrinus* sp.

Puckapunyal

Collections made by Schleiger from coarse sandstone turbidites at Buckler Hill, 1 km north-east of Puckapunyal (Figure 3), contain *Boucotia australis* (identified by E.D. Gill as *Notanoplia* in specimen notes with the collection in Museum Victoria, and confirmed in this study). Originally mapped as entirely Broadford Formation (King & Wilkinson 1975), this locality now appears to have been given a small admixture of the overlying Puckapunyal Formation by Welch et al. (2011).

Sandford (2002) noted in the Puckapunyal area a trilobite fauna of *Echidnops hollowayi* Sandford accompanied by acastids, proetids and calymenids, and suggested correlation with the Stoddart Member of the upper Mount Ida Formation (*Boucotia australis* biozone:

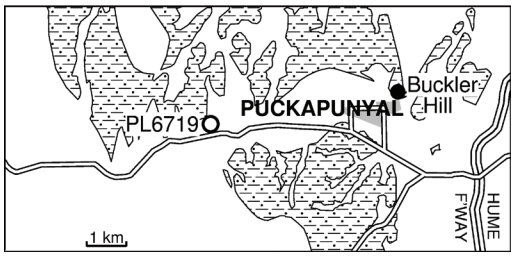

Figure 3: Detail of the Puckapunyal area showing localities mentioned in the text. The positions shown are approximate because of a lack of precision in the relevant Museum Victoria records.

Edwards et al. 1998). This area was originally mapped as entirely Broadford Formation (Anon. 1970), but the locality PL6719 mentioned by Sandford is uncertainly placed in the more recent mapping (Welch et al. 2011) and could be in Humevale Siltstone close to the boundary with Broadford Formation (Figure 3).

Flowerdale

The type locality of the Flowerdale Member (Williams 1964: loc. Y97), now mapped in the Broadford Formation (Welch et al. 2011; see Figure 1), was not visited in this study but Williams' collection in Museum Victoria was thoroughly examined. Although Williams reported a boulder conglomerate similar to the Broadford Conglomerate, the fossil collection is wholly in siltstone. The fossils are randomly oriented, indicating deposition by mass flow, and are predominantly moulds of large (> 10 mm) disarticulated shells, many with a thickness possibly indicating gerontism. Orthids, strophomenids and gastropods predominate, but there are also tabulate corals and calymenid trilobite fragments. Some of the corals closely resemble *Ligulodictyum* sp. I, described from the Mount Ida Formation by Plusquellec (2007).

Some of the fragmentary brachiopods appear similar to *Isorthis festiva* Philip and *Mesoleptostrophia affinalata* (Gill), consistent with remarks by Garratt (1983a: 88) who, however, placed the locality in the *Boucotia loyolensis* biozone. Others appear to fall within the range of specimens assigned by Garratt (1980b) to '*Hysterolites*' *lilydalensis*. A single specimen of *Plectodonta bipartita* was found, but no notanopliids, which probably reflects the sorting regime. A remark by Williams (1964: 288) that *Boucotia australis* had been found in the Flowerdale Member refers to an extended concept of the unit rather than to the type locality.

Break O'Day

Williams' collections along the line of the Break O'Day Syncline contain only poorly preserved crinoid columnals and shell fragments, and road cuttings are mostly

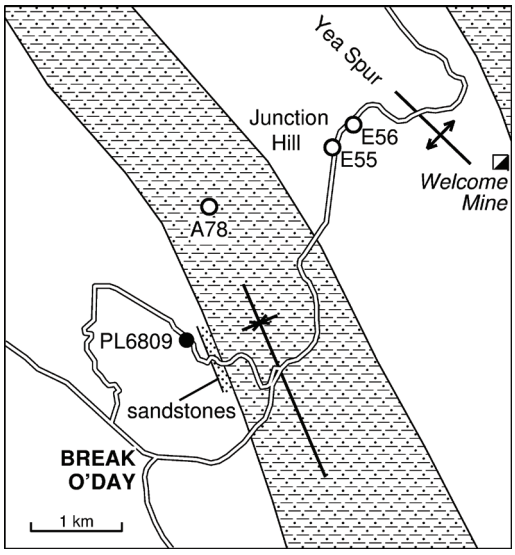

Figure 4: Detail of the Break O'Day–Junction Hill area showing localities mentioned in the text. Those localities of Williams (1964) which fall within the map and for which adequate map references are available are also shown.

unfossiliferous. However, a new locality (NMV PL6809; Figure 4) was discovered in this study, in Humevale Siltstone 60 m stratigraphically below the incoming of thick-bedded sandstones bordering the area mapped by Garratt (1977) as Flowerdale Sandstone and as Broadford Formation by Welch et al. (2011).

The fossils occur in a thin diamictite bed within a sequence which is otherwise thin-bedded (even shaly) siltstone. Specimens of *Boucotia australis*, *Plectodonta bipartita* and *Australina lenticulata* were recovered; other fossils include calymenid? trilobite fragments and vascular plant fragments.

CONCLUSIONS

The fossils of the Broadford Formation clearly indicate a biostratigraphic age in the *Boucotia australis* biozone of Garratt (1983a) for the localities examined in this paper.

The palaeontology supports an age for these localities similar to that of the Stoddart Member of the Mount Ida Formation at Heathcote. The Broadford Formation is not known to contain *Notoconchidium*, a characteristic brachiopod of the lower parts of the Mount Ida Formation regarded as late Silurian by Wright & Garratt (2013). A similar situation occurs in Tasmania, where the notanopliid-bearing upper parts of the Bell Shale are faunally distinct from the *Notoconchidium*-bearing, stratigraphically lower Florence Sandstone (Clarke 1969).

The palaeontology also supports the idea that there is lateral equivalence between the Lochkovian parts of the Humevale Siltstone and the Broadford Formation, as both contain the distinctive combination of *Boucotia australis*, *Plectodonta bipartita* and *Australina lenticulata*. This

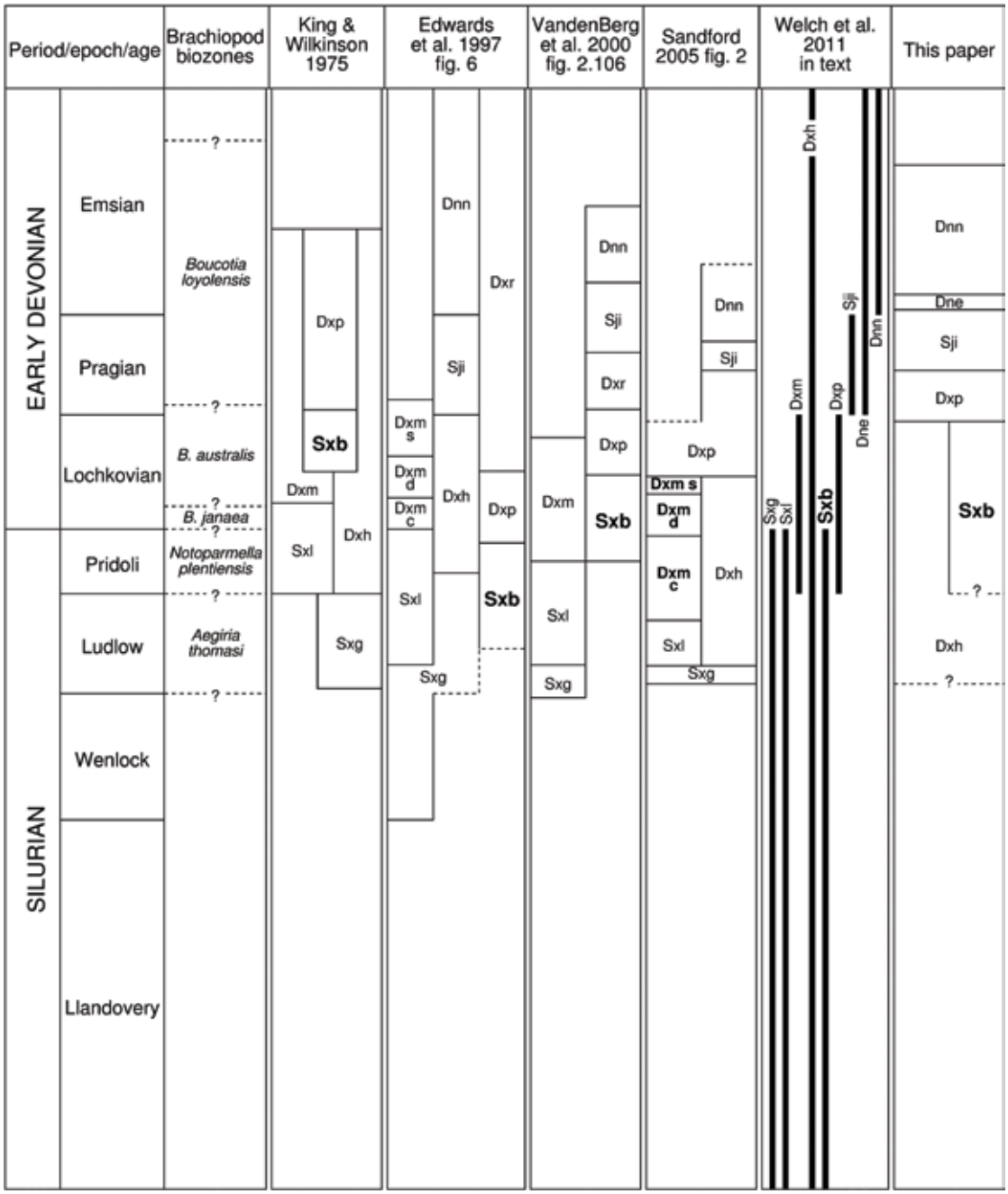

Figure 5: Correlation and age range charts for the Broadford Formation and adjacent units as given by previous workers and in this paper, plotted against a common scale. Symbols for the units represent: Dne - Easts Lookout Siltstone, Dnn - Norton Gully Sandstone, Dxh - Humevale Siltstone, Dxm - Mount Ida Formation (members c - Cornella, d - Dealba, s - Stoddart), Dxp - Puckapunyal Formation, Dxr - Waranga Formation, Sji - Wilson Creek Shale, Sxb - Broadford Formation, Sxg - Dargile Formation, Sxl - McIvor Sandstone. Sandford's (2002, 2005) units have been mapped to their nearest Geological Survey equivalents. Since Welch et al. (2011) did not give an actual chart, age ranges have been taken from their stratigraphic tables.

assemblage is common in the upper Humevale Siltstone (Sandford 2002), and can be found as far east as GSV locality A19 near Toolangi.

Figure 5 shows age ranges suggested by the evidence in this paper compared with those asserted by previous workers.

The assemblage has been given a biofacies interpretation as the 'Notanopliid Community' by Strusz & Garratt (1999: 189–190), but opinion is divided about whether the occurrences are autochthonous or allochthonous. It has been claimed (e.g. Jell 1992, Sandford 2002) that sandstone facies within the laterally adjacent Humevale Siltstone are of tempestite origin with a more or less autochthonous fauna. On the other hand, it has been argued that isolated specimens from the siltstone facies are possibly transported attached to nekton (Talent et al. 2000: 248).

The revised age for at least the major part of the formation removes the difficulty of the Yea area requiring

stratigraphic continuity between the Broadford Formation and the overlying Pragian or later units. The Yea area contains better exposures and more fossils than other areas of the Broadford Formation, and preliminary data (Earp 2007) show the formation may extend down to the late Silurian *Notoparmella plentiensis* biozone of Garratt (1983a). A detailed study of the Yea data is in progress.

These conclusions show the need for caution in automatically assigning graded fossiliferous sandstones of central Victoria to the Norton Gully Sandstone, as has been suggested in the past (e.g. Edwards et al. 1997 for the Flowerdale Member and sandstones along the Break O'Day Syncline). At the present time, *Plectodonta bipartita* has not been found in the Norton Gully Sandstone, and its presence is therefore a good indicator of a Lochkovian (or earlier) rather than Pragian–Emsian age.

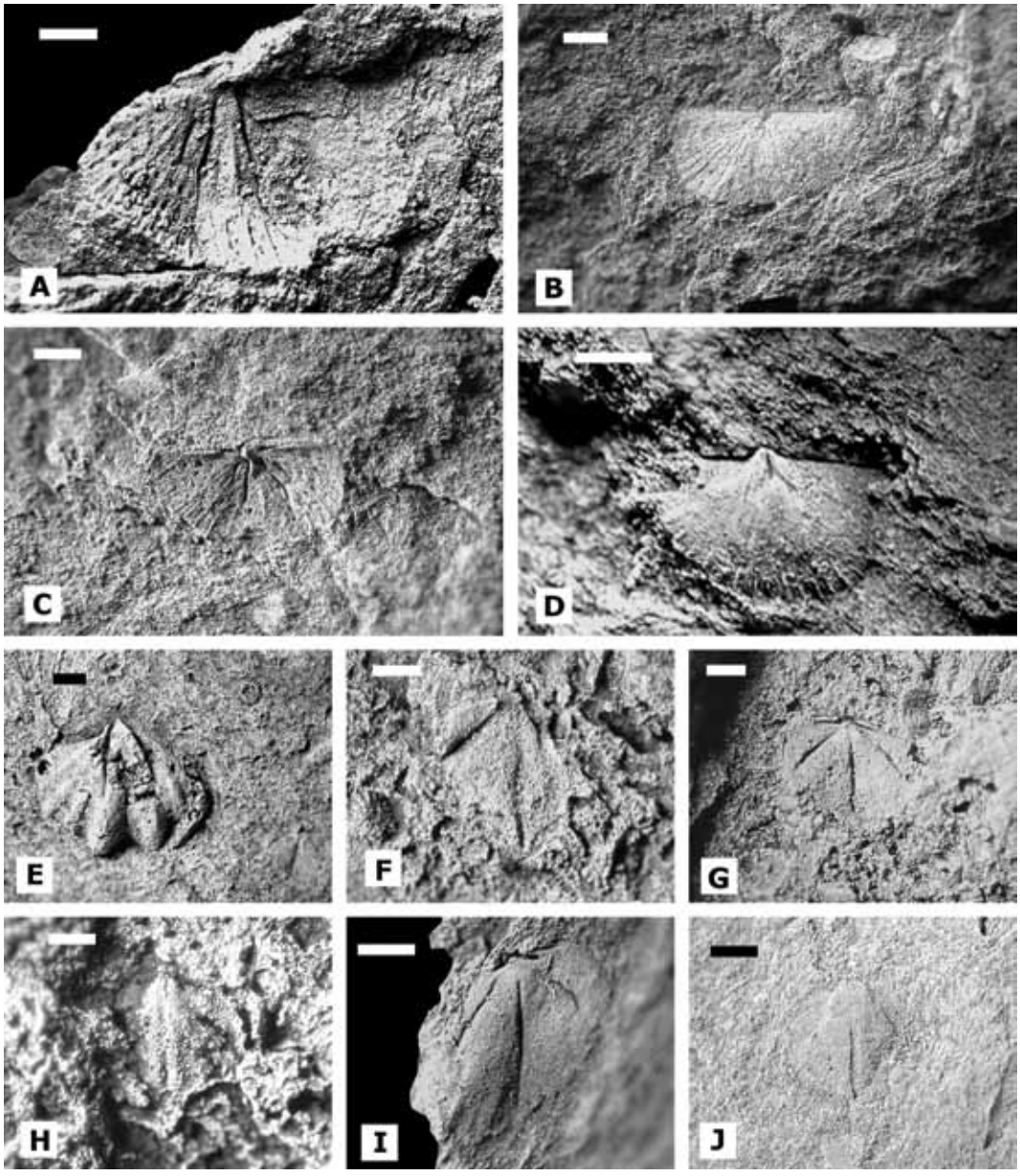

Figure 6: A–D. *Plectodonta bipartita* (Chapman). A: NMV P321611, dorsal valve internal mould, loc. Y97. B, C: P321684, dorsal valve internal and external moulds, loc. PL6809. D: P321685, ventral valve internal mould, loc. PL6809. E: *Howellella* sp. A: P321625, ventral valve internal mould (also *Boucotia australis* fragment at bottom right), Elliot Road, Broadford. F–J: *Boucotia australis* (Gill). F, G: P321622, P321623, dorsal valves internal moulds, and H: P321621, ventral valve internal mould, from Elliot Road, Broadford. I: P321682, tectonically deformed dorsal valve internal mould, and J: P321683, compressed ventral valve internal mould, from loc. PL6809. Scale bars all 1 mm.

SYSTEMATIC PALAEONTOLOGY

Phylum Brachiopoda
Order Strophomenida
Family Sowerbyellidae Öpik 1930
Plectodonta Kozlowski 1929
Plectodonta (Plectodonta) bipartita (Chapman 1913)

Figures 6A–D

Chonetes bipartita Chapman 1913: 104, pl. 10 figs 8–10.
Stropheodonta bipartita (Chapman) Gill 1942: 41, pl. 5 figs 7, 9, pl. 6 fig. 10.
Plectodonta bipartita (Chapman) Gill 1948: 13. – Gill 1950: 249, pl. 1 figs 21–23. – Philip 1962: 204–205, pl. 31 figs 18–19. – Talent 1963: 67, pl. 30 figs 11–24, pl. 40 figs 19–22. – Williams 1964: 282, table 1. – Savage 1974: – Garratt 1983a: 87–89, figs 5–7. – Jell 1992: 10. – Garratt in Sandford 2002: 6.
Plectodonta (Plectodonta) bipartita (Chapman) – Strusz 2003: 21–25, figs 14A–E, 15A–J. – Strusz 2010: figs 3C'–3E'.
For a more detailed synonymy see Strusz (2003).

Material. Ventral valve NMV P321685 from PL6809; dorsal valves NMV P321684 from PL6809 and P321611 from Y97.

Remarks. The lowest stratigraphic occurrence recorded in Victoria is in the Bullung Siltstone (Ludlow: VandenBerg 1975) but the shelly fossils from that formation are in need of critical examination. Strusz (2003, 2010) reported the species from the Pridoli of Canberra but accepted an age for the species from Pridoli to Pragian. Garratt (1983a: figs 5–7) showed occurrences ranging from the *plentiensis* to the *loyolensis* brachiopod biozones, and other citations in the synonymy are in agreement with a Pridoli–Lochkovian to latest Pragian age.

Order Spiriferida
Family Delthyrididae
Howellella Kozlowski, 1946
Howellella (Howellella) sp. A

Figure 6E

pars *Howellella nucula* subsp. nov. Garratt 1983a: 98, figs 5, 6 (name only).

Description. A small ventribiconvex *Howellella* with 3 or rarely 4 pairs of costae which are strong medially and very faint laterally. Micro-ornament of concentric lamellae fringed with spines. Ventral interior with dental lamellae on the lateral flank of the first pair of costae, from one-third to one-half valve length; thread-like myophragm. Dorsal interior with a ctenophoridium at the posterior end of the notothyrium.

Material. Ventral valve NMV P321625 from Elliot Road, Broadford. Additional dorsal and ventral valves from the Yea area, P321631–P321634, have been used to formulate the description above.

Remarks. These specimens fall within the range illustrated by Garratt (1980b) for a new species from the Humevale Siltstone of southeast Melbourne, although Garratt's specimens are from two different localities and appear to differ significantly in the number of plications (cf. Garratt 1980b: fig. 127). Garratt compared the species to *H. nucula australis* (Savage 1974). However, Savage's species has a bilobed cardinal process rather than a ctenophoridium and is currently placed, along with *H. nucula* itself, in *Rufispirifer* (Talent et al. 2001). Given the extraordinarily large number of species assigned to *Howellella*, probably now approaching 200, many being poorly described and figured, I refrain from adding to the taxonomic confusion and leave this species in open nomenclature.

Order Uncertain
Family Notanopliidae Gill 1969

The affinities of the Notanopliidae remain uncertain. Talent et al. (2001) supported the long-standing hypothesis that they belong in the Atrypida. Racheboeuf (2006) included them in the Spiriferida as an uncertain group, with the comment that they also showed affinities with the Orthida and Orthotetidina.

Genus Boucotia Gill 1969
Boucotia australis (Gill 1942)

Figures 6F–J

Anoplia australis Gill 1942: 38–39, pl. 4, fig. 8.
Notanoplia australis (Gill) – Gill 1951: 64. – Williams 1964: 282, table 1. – Couper 1965: 7, table 1.
Boucotia australis (Gill) – Gill 1969: 1227–1229, pl. 143 figs 9–21, pl. 144 figs 1–11, 13, 14. – Garratt 1980a: 30–33, pl. 7 figs 11–16, 18–31. – Garratt 1983a: 87–88, figs 5–7. – Jell 1992: 10. – Garratt in Sandford 2002: 6. – Earp 2012: 137, figs 1A–E.
For complete synonymy to 1980 and an amended diagnosis see Garratt (1980a).

Material. One ventral valve NMV P321621 and two dorsal valves, P321622 and P321623, from Elliot Road, Broadford (also unregistered specimens in Schleiger's original collection). One distorted dorsal valve P321682 and one ventral valve P321683 from PL6809. Schleiger's Buckler Hill collection, specimen numbers 253 and 369.

Remarks. The species is widespread in the Humevale Siltstone of the Kinglake area, often occurring as single or articulated valves. As well as the occurrences mentioned by Sandford (2002) there are records from Middendorp's Quarry (Jell 1992) and Collins' Quarry (e.g. NMV

P321686, registered during this study). At the latter locality, the fossiliferous facies is coarse gritty sandstone with some similarities to a turbidite, but the faunal assemblage is generally different from either the Broadford Formation or Norton Gully Sandstone, with a high percentage of articulated echinoderms and trilobites.

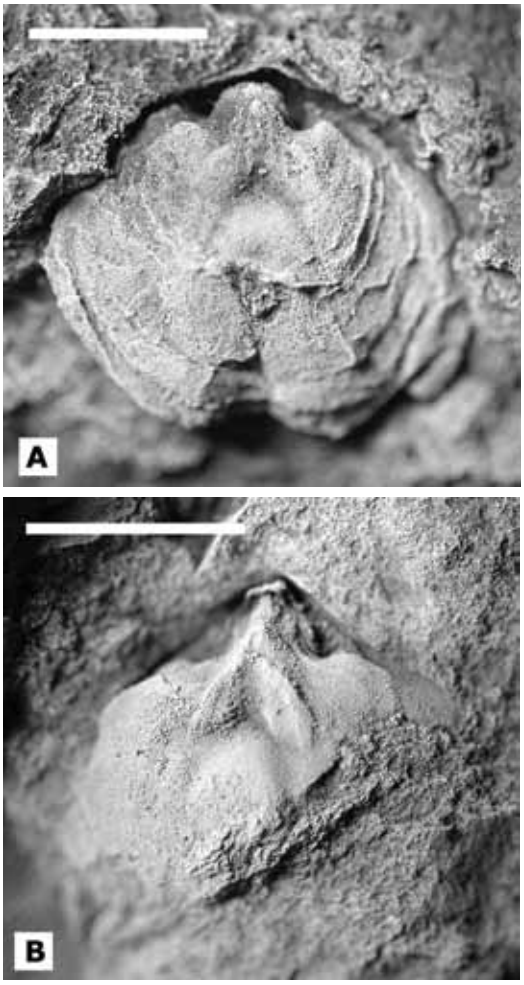

Figure 7: A, B: *Australina* cf. *lenticulata* (Philip). A: P321620, ventral view of articulated specimen, Elliot Road, Broadford. B: P321681, ventral valve internal mould fragment, loc. PL6809. Scale bars 5 mm.

Order Athyridida
Family Lissatrypidae Twenhofel, 1914
Australina Clarke, 1912
Australina sp. cf. A. lenticulata (Philip 1962)

Figures 7A–B

Lissatrypa lenticulata Philip 1962: 220–221, text fig. 16, pl. 34 figs 4, 17–21. – Williams 1964: 282, table 1. – Savage 1974: 38–29, text fig. 12, pl. 10 figs 16–30. – Garratt 1983a: 86, 93, figs 5–7. – Jell 1992: 10.
Lissatrypa cf. *lenticulata* Philip and *Lissatrypa* spp. – Talent 1964: 35, pl. 8 figs 1, 2, 4–6, 8–10.
Australina? lenticulata (Philip) – Lenz & Johnson 1985: 82, pl. 8 figs 1–12. – Talent et al. 2001: 150, 153, 155, 158.

Material. Ventral valve NMV P321681 from PL6809 and articulated valves P321620 from Elliot Road, Broadford.

Remarks. Garratt (1983a) considered the species long-ranging, from the *Jonesea thomasi* biozone (Ludlow) to *Boucotia loyolensis* biozone (Pragian). According to Talent (1964a; also in Talent et al. 2001) the present taxon may contain a number of species.

Phylum Echinodermata
Class Crinoidea Miller 1821
Informal Classification 'Crinoid columnals'
Group Pentamerata Stukalina 1966
Order Strialata Stukalina 1978
Family Decacrinidae Yeltysheva 1957
Decacrinus Yeltysheva 1957
Decacrinus sp.

Figure 8

Figure 8: *Decacrinus* sp., P321624, Elliot Road, Broadford (also *Boucotia australis* fragment at bottom mid-right). Scale bar 2 mm.

Material. NMV P321624 from Elliot Road, Broadford.

Description. Small to medium sized pentagonal columnals, diameter 3.5–6 mm. Lumen not seen. Areola ten-lobed, alternating long acute lobes at the angles of the pentagon almost reaching the edge with short rounded lobes at the centre of each side reaching only halfway to the edge. Fine culmina and crenellae emanate from the sides of all lobes and cover the remainder of the surface; those from near the ends of each lobe proceed radially and reach the edge of the columnal at nearly right angles. Lobes coalesce at their bases.

The appearance is very similar to that of the type species of *Decacrinus*, *D. pennatus* Yeltysheva, from the Pribalkhash 'gorizont' of Kazakhstan (see e.g. Stukalina 1988: pl. 12 figs 3–7) which is Lochkovian–Pragian (Talent et al. 2001: 62).

Remarks. This or a similar species occurs at PL1924 in the Kinglake area in sandstone assigned to the *Boucotia australis* biozone (Jell 1999: 108, 113) and in a similar biofacies at Yea (unpub. data). It is suggested here that columnals of *Decacrinus pennatus* type may be taken as characteristic of the *B. australis* assemblage in addition to the brachiopods listed by Garratt (1983a).

Acknowledgements

The late Noel Schleiger encouraged my work in this area of Victoria and first showed me the outcrop of his Broadford Conglomerate. I wish to thank the anonymous referees for their suggestions, and thanks also to Bill Birch for helping resolve some technical difficulties.

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