Watsonella crosbyi from the lower Cambrian (Terreneuvian, Stage 2) Normanville Group in South Australia

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Abstract – Correlation of lower Cambrian strata is often confounded by provincialism of key fauna. The widespread occurrence of the micromollusc Watsonella crosbyi Grabau, 1900 is therefore an important biostratigraphic signpost with potential for international correlation of lower Cambrian successions. Previous correlations of W. crosbyi from Australia (Normanville Group) suggested an Atdabanian- to Botoman-equivalent age. However, in the upper part of the Mount Terrible Formation, stratigraphic ranges of W. crosbyi and Aldanella sp. cf. golubevi overlap prior to the incoming of vertically burrowed ‘piperock’, which is indicative of an age no earlier than Cambrian Stage 2. The stratigraphic range of W. crosbyi in the Normanville Group, South Australia correlates with the ranges of the taxon in China, France, Mongolia and Siberia (though not Newfoundland). The new Australian data add further support for considering the first occurrence of W. crosbyi a good potential candidate for defining the base of Cambrian Stage 2. The stratigraphic range of W. crosbyi through the lower Cambrian Normanville Group has been determined based on collections from measured sections. Although rare, W. crosbyi is part of an assemblage of micromolluscs including Bemella sp., Parailsanella sp. cf. murenica and a sinistral form of Aldanella (A. sp. cf. A. golubevi). Other fauna present include Australohalkieria sp., Eremactis mawsoni, chancelloriids and Cupitheca sp.

Keywords: Normanville Group, Aldanella, biostratigraphy, Sunnaginia, Stansbury Basin.

1. Introduction

Definition of the base of early Cambrian Stage 2 (Terreneuvian Series) has become a subject of considerable controversy, especially regarding the reliability and biostratigraphic utility of the micromollusc Watsonella crosbyi Grabau, 1900. This taxon has a widespread distribution, and can be correlated across pre-trilobitic successions of both carbonate and siliciclastic facies in South China, Siberia, Mongolia, Avalonia and west and east Gondwana (online Supplementary Table S1, available at http://journals.cambridge.org/geo). For this reason W. crosbyi has been suggested as a suitable index fossil for global correlation of the as yet undefined Cambrian Stage 2 (Li et al. 2011; Peng & Babcock, 2011). Watsonella crosbyi often co-occurs with the dextrally coiled shells of the stem group mollusc, Aldanella attleborensis (Shaler & Foerste, 1888), which shares a similar geographical distribution and has also been suggested as a potential candidate to define the base of Cambrian Stage 2 (Parkhaev, 2014).

Comprehensive regional biostratigraphic schemes are crucial for constraining local geo- and bioevents and for developing workable global correlations (Betts et al. 2016). However, biostratigraphic correlation and concomitant temporal subdivision can be undermined by taphonomic and taxonomic inconsistencies and the diachronism of First Appearance Data (FAD) (see discussion by Landing et al. 2013). These factors are especially evident in lowermost Cambrian strata, where many pre-trilobitic biotas (i.e. small skeletal fossils, archaeocyaths and acritarchs) exhibit strong provincialism and facies-controlled distribution (Landing et al. 2013). Consequently, there has been an emphasis on chemostratigraphic methods (i.e. carbon and oxygen isotopes) in combination with U–Pb zircon geochronology as an independent (or primary) means of global correlation (e.g. Maloof et al. 2010a; Kouchinsky et al. 2012; Landing et al. 2013; but see Parkhaev, 2014). Non-biostratigraphic methods have previously been suggested as supplementary proxies for calibration (e.g. the ZHUCE (Zhu, Babcock & Peng, 2006)/I’ (Brasier et al. 1994) positive δ13C excursion above the incoming of Watsonella; Li et al. 2011; Landing et al. 2013), although Landing et al. 2013 emphasizes...
integration of biostratigraphic and chemostratigraphic data. Maloof et al. (2010a) applied a multiproxy approach to constrain occurrences of skeletal metazoan taxa during the Terreneuvian Series using a $\delta^{13}$C-CaCO$_3$ age model calibrated with U–Pb ID-TIMS (isotope dilution thermal ionization mass spectrometry) dates of zircons from five separate ash beds in Morocco (Maloof et al. 2005, 2010b) and China. By assigning time bins in 2 Ma intervals, first appearance data of Watsonella from sections in Siberia, Mongolia and China indicate a FAD no older than c. 530 Ma within the Nemakit-Daldynian Stage of the Siberian regional timescale. Expanding on this work, Landing & Kouchinsky (2016) suggested that the lower occurrences of W. crosbyi in South China, France and Avalonia, as well as in northern Siberia, are approximately coeval within upper Fortunian deposits.

Landing et al. (2013) proposed that the $\Gamma$/L4/ZHUCE $\delta^{13}$C positive isotope excursion, occurring just above the first appearance of Watsonella crosbyi and Aldanella attleborensis and the Skiagia ornata–Fimbrioglomerella membranacea acratherch, represents the best multi-proxy approach for defining the base of Cambrian Stage 2. The use of independent time constraints as suggested by Landing et al. (2013) is the most workable means to more accurately define this important Cambrian Stage boundary. However, it is important that all chemostratigraphic signals (especially bulk rock) are carefully evaluated using robust protocols to ensure they are not influenced by local depositional conditions, cryptic disconformities (Miall, 2014; Parkhaev, 2014), alteration by fluid–rock interactions during subaerial exposure or by diagenesis in the vadose or phreatic zones ( Kaufman & Knoll, 1995; Derry, 2010; Swart, 2015).

Tracking changes in ichnodiversity and ichnodispersity during the Ediacaran–Cambrian transition has also proven an effective independent means of broadly correlating key phases of the Cambrian radiation (Seilacher, 1956; Crimes, 1987; Seilacher, Buatois & Mángano, 2005; Mángano & Buatois, 2014). Trace fossils reveal two distinct phases in body-plan diversification and the establishment of a Phanerozic-style ecological structure (Mángano & Buatois, 2014). The Fortunian Stage records a rapid diversification with a global maximum of 42 ichnogenera. Extent of bioturbation was relatively low, and assemblages were dominated by horizontal traces. The transition to Cambrian Stage 2 records a dramatic increase in maximum burrowing depth and the appearance of vertical burrows, especially Skolithos and Diplocraterion ‘piperock’ (Mángano & Buatois, 2014). The utility of ichnofossils for global chronostratigraphic schemes is problematic, particularly with respect to the Cambrian period (Babcock et al. 2014, but see Landing et al. 2013). Their key limitation is a strong lithofacies dependence, which is exemplified by the almost exclusive appearance of Skolithos in moderate- to high-energy nearshore clastic deposits (Desjardins et al. 2010, see table 1; Mángano & Buatois, 2014). Nevertheless, the diversity of ichnotaxa and changes in burrow morphology may prove useful as a broad indicator of age in the absence of small shelly fossils (SSF) (especially in siliciclastic-rich deposits), particularly ‘piperock’ style burrowing that first appears within Cambrian Stage 2.

Documentation of stratigraphic ranges of taxa such as Watsonella crosbyi or Aldanella attleborensis across multiple geographic regions and through various carbonate and siliciclastic successions increases their potential as candidate index fossils to define the base of Cambrian Stage 2. The final task is to integrate biostratigraphic and chemostratigraphic data to build a consistent, robust time-significant signature and to attempt to explain any differences in stratigraphic range which may limit the stratigraphic utility of these taxa.

The occurrence of Watsonella crosbyi in Australia has long been recognized (Daily, 1976a, b; Daily et al. 1976; Gravestock & Shergold, 2001; Parkhaev in Gravestock et al. 2001; Jenkins, Cooper & Compston, 2002) but lack of formal documentation and poorly understood stratigraphic context has led to confusion about the stratigraphic range and the consequent correlation of this taxon in Cambrian East Gondwana. Landing et al. (2013) and Parkhaev (2014) suggested that the stratigraphic range of W. crosbyi in Australia correlates with the Abadiella huoi trilobite Zone in the basal part of Cambrian Series 2, Stage 3 (broadly equivalent to the Atdabanian Stage in Siberia). However, a new shelly fossil biostratigraphy for lower Cambrian strata of South Australia clearly indicates the strata hosting W. crosbyi are considerably older (Bets et al. 2016). The aim of this paper is to rigorously establish stratigraphic context of W. crosbyi (and Aldanella sp. cf. golubevi) from measured stratigraphic sections through the lower part of the Normanville Group on Fleurieu Peninsula, eastern Stansbury Basin, South Australia. In addition, Watsonella crosbyi and Aldanella sp. cf. golubevi are formally described and the stratigraphic ranges of other key SSF are reassessed.

2. Geological setting and locality

The lower Cambrian Normanville Group (Fig. 1) is a sedimentary package of mixed carbonates, argillites and sandstones exposed along a c. 16 km NE–SW-trending coastal tract in the Sellicks Hill–Normanville area on Fleurieu Peninsula, c. 50 km south of Adelaide. Early geological and stratigraphic investigations into the Cambrian rocks of this region include the work of Howchin (1897) and Madigan (1925, 1927) with detailed mapping and stratigraphy by Abele & McGowan (1959) and Daily (1963, 1972, 1976b).

The Normanville Group consists of an approximately 1 km thick succession of predominantly marine shelf to ramp/slope limestones and shales, with minor arkosic and calcareous sandstones towards the base and significant deposits of black, pyritic shale towards the top. The entire succession represents a transgressive marine event (sequence set C1 of Gravestock, 1995) beginning with a shallow subtidal environment at the base, followed by a shallow shelf setting.
with archaeocyathan-microbial bioherms, through to a deep-water environment and eventually a mudstone-dominated, basinal setting at the top (Alexander & Gravestock, 1990; Jago, Dyson & Gatehouse, 1994; Gravestock & Gatehouse, 1995; Gravestock et al. 2001; Jenkins, Cooper & Compston, 2002).

In their detailed study of the lithology and stratigraphy of lower Cambrian rocks in the Sellicks Hill–Normanville region, Abele & McGowran (1959) recognized four distinct and predominantly calcareous units (in ascending order with true thickness): Wangkonda Formation (110 m); Sellick Hill Formation (210 m); Fork Tree Limestone (300 m); and Heatherdale Shale (300 m). Subsequently, Daily (1963) proposed the name Mount Terrible Formation to define a c. 92 m thick package of dominantly clastic rocks resting unconformably above the Ediacaran ABC Range Quartzite (Wilpena Group) and below the Wangkonda Formation. The lower ‘Hyolithes sandstone’ of Abele & McGowran (1959, p. 304), originally placed within the Wangkonda Formation, was recognized as the top member of the Mount Terrible Formation by Daily (1963). Together, these five lithostratigraphic units constitute the Normanville Group (Daily & Milnes, 1973, p. 4), which is overlain unconformably by the extensive greywackes and shales of the lower Cambrian Kanmantoo Group (Jago et al. 2003; Haines et al. 2009).

Almost all of the fossil material described here comes from collections originally made by the late Brian Daily (Section 1 in Fig. 1 = ‘New Sellicks Hill Road’, now Main South Road). Unfortunately, Daily (1963) did not provide details on the exact location of his section through the Mount Terrible Formation. Despite changes caused by re-alignment and widening of the Main South Road since the early 1960s, it is possible to closely approximate the position of his stratigraphic section from his existing field notebooks combined with detailed geological mapping by Abele & McGowran (1959). This clearly shows where the ‘Hyolithes sandstone’ (= upper member, Mount Terrible Formation of Daily, 1963) intersects the Main South Road (Fig. 1). Daily’s field notebooks indicate

Figure 1. Regional geological map of the Normanville Group between Sellicks Hill and Normanville along the Fleurieu Peninsula, South Australia. Measured stratigraphic sections indicated.
some of his original sampling along the road section was about 0.8 km NNE along strike in Mount Terrible Gully.

In an attempt to supplement the lithostratigraphic and palaeontological details described by Daily (1963), another section (Section 2, Figs 1, 2) was measured through the Mount Terrible Formation cropping out along Old Sellicks Hill Road, immediately south of Sellicks Hill Quarry and c. 2.8 km NNE of Daily’s original section. Despite some minor differences in the thickness of the members, the lithologies are remarkably similar (Fig. 1). Unfortunately, despite targeted sampling in the middle and upper members, the section produced very little fossil material (Eremactis mawsoni Bengtson & Conway Morris in Bengtson et al. 1990, indeterminate chancelloriids and phosphatic tubes).

3. Lithostratigraphy

3.a. Mount Terrible Formation

Daily (1963, 1972, 1976a, b) recognized three informal members of the Mount Terrible Formation. While there is some variation in thickness of the members along strike (Fig. 1), the characteristic lithofacies of all members as described by Daily (1963, 1972, 1976a, b) and summarized by Gravestock & Cowley (1995), Gravestock et al. (2001, p. 25) and Gravestock & Shergold (2001) are readily identified in the field.

The Mount Terrible Formation is interpreted to be part of a transgressive systems tract (Є1.0 of Zang et al. 2004), equivalent to the Uratanna sequence of Mount & McDonald (1992). Despite original claims of conformity (Daily 1963, p. 595), there is clearly a disconformable surface separating the lowest member of the Mount Terrible Formation from the underlying quartzites of the Ediacaran ABC Range Quartzite (see also Thomson & Horwitz, 1961). The incised nature of the contact (later noted by Daily, 1976a, p. 48) and the absence of upper Ediacaran rocks between the ABC Range Quartzite and the lowest Cambrian deposits (including the fossiliferous Ediacaran Member in the Rawnsley Quartzite) in the Flinders Ranges indicate a considerable time gap at this stratigraphic level on the Fleurieu Peninsula.

3.a.1. Basal member

The basal member is a feldspathic to quartz-rich sandstone ranging from 12 m to 17 m thick, characterized by thin, planar-tabular bed sets with scoured bases. The basal 3–4 m are comparatively feldspathic, although each bed consists of medium- to coarse-grained quartzfeldspathic arenites with a pebbly, phosphatized base and a bioturbated pyritic siltstone top. Low-angle cross-beds and concordant lineations indicate high-energy conditions in a transgressive marine (possibly marginal marine) environment (Daily, 1963, 1976b; Gravestock & Shergold, 2001).

Microfacies reveal a coarse-grained sandstone consisting of a moderately well-sorted mosaic of angular to sub-rounded grains (> 1 mm across), predominantly quartz and rare feldspar (plagioclase represents 5–10%...
of the sample) (Fig. 2a–c). The grains are either tightly packed with no obvious authigenic cement (Fig. 2a) or with a very fine calcareous cement containing iron oxides (possibly hematite; Fig. 2b). The iron oxides are concentrated in some areas to form a dark cement, red at the edges (observable as framoidal clusters), or are coating the quartz grains and filling intergranular spaces (Fig. 2b, c). Some beds (>30 mm thick) exhibit weakly graded bedding which coarsens upwards.

The sediments of the basal member fill small holes and fissures, presumably erosional in origin, in the underlying Ediacaran ABC Range Quartzite (Daily, 1976a). Bioturbation is evident in the pyritic siltstone at the top of the lower member down to 5 m above its base (Daily, 1976a; Gravestock & Shergold, 2001).

3.a.2. Middle member

The middle member ranges in thickness from 60 m to 67 m and comprises grey, highly bioturbated and occasionally phosphatic to slightly ferruginized siltstones to very fine sandstones with weathered, elliptical caverns produced by dissolution of carbonate nodules towards the top of the member. Daily (1963) reported the first shelly fossils (hyoliths) at 20 m above the base of the Main South Road section (Fig. 3) and imprints of indeterminate tubes at 25 m above the base within bands of phosphatic shale (Callen, 1971; Daily, 1976a; Gravestock & Shergold, 2001). This package is interpreted as a highstand systems tract (Daily et al. 1976; Gravestock & Shergold, 2001).

Microfacies of the middle member show the transition to intense sediment mixing, with the original fabric often impacted or destroyed by pervasive, mainly horizontal, bioturbation. In some horizons the fine-grained mottled fabric is represented by uniform, subangular quartz grains (>125 μm) within a frequently hematite-stained calc-silt matrix (Fig. 2d, e). Fabrics unaffected by intensive bioturbation have repeated interlaminae (1–3 mm thick) which are very fine grained and quartz rich, and fine upwards into homogenous silts and micrites (Fig. 2g). Elongate to ovoid clasts within these laminae, often of different lithology to the surrounding matrix, may be compressed in filled horizontal burrows (Fig. 2f).

3.a.3. Top member

In Daily’s (1963) section on Main South Road, the top member consists of a 20–30 m package of strongly cavernous, fine-grained calcareous sandstones with pyritic and argillaceous siltstone interbeds. The same lithostratigraphic package in Section 2 (Fig. 3) only exposes the basal beds followed by a c. 20 m covered interval obscuring the contact with the overlying Wangkonda Formation, suggesting the upper member could be slightly thicker than originally measured by Daily (1963). The sandstone is bioturbated, with shelly fossils occurring as phosphatic steinkerns located within a 6 m interval in Section 1 in a weathered band of muddy calcareous siltstone (Daily, 1963, 1969; Gravestock & Shergold, 2001; Fig. 3). Microfacies display a predominantly homogeneous fabric of very fine sand- to silt-sized, moderately rounded quartz grains (Fig. 2h, i). Hematite staining is pervasive but forms mainly as irregular wavy solution seams and laminae throughout the unit (Fig. 2h, i).

4. Biostratigraphy

4.a. Regional correlation

4.a.1. Previous work

There has been considerable confusion regarding the age and correlation of the Normansville Group in recent literature. Most contention is traced back to poorly constrained biostratigraphy in the Sellick Hill Formation and the conformably overlying Fork Tree Limestone. Alexander & Gravestock (1990) conducted a thorough sedimentological study of the Sellick Hill Formation and described five Facies Associations (A to E; oldest to youngest) from coastal exposures along the Fleurieu Peninsula. Although Alexander & Gravestock (1990) reported the presence of trilobites in Facies Association D of the Sellick Hill Formation, subsequent attempts to locate trilobites in this unit have been unsuccessful.

As far as is known there are no substantiated records of trilobites from either the Sellick Hill Formation or the Fork Tree Limestone. Archaeocyaths from the upper Sellick Hill Formation (Facies Association D to E) and lower Fork Tree Limestone have previously been correlated with the Atdabanian–Botoman stages of Siberia (Debrenne & Gravestock, 1990). However, based on the shelly fossil data presented by Betts et al. (2015, 2016) and the data presented here this correlation requires close investigation. Gravestock (1984) and Kruse & Shi (in Brock et al., 2000, p. 14) indicate that the oldest archaeocyaths in the Arrowie Basin are equivalent to Daily’s (1956) Faunal Assemblages 1–2, which they suggest are late Atdabanian equivalent in age. However, difficulties including strong endemism (Kruse & Shi in Brock et al., 2000) and identification of archaeocyaths (Gravestock et al., 2001) remain a primary concern regarding their utility for regional correlation (Jenkins, Cooper & Compston, 2002; Peng, Babcock & Cooper, 2012).

Adding to the confusion surrounding the age of the Normansville Group succession are the assemblage ‘zones’ (especially molluscan zones) erected by Gravestock et al. (2001) based on drill cores and stratigraphic sections measured in the Stansbury Basin. Gravestock et al. (2001) correlated the upper Wangkonda Formation and lower Sellick Hill Formation (Facies Association A of Alexander & Gravestock, 1990) with their Bemella communis zone and the remainder of the Sellick Hill Formation (uppermost Facies Association A to C) to the Stenotheca drepanoida zone. These molluscan zones were suggested to have an Atdabanian age and to correlate with the Abadiella huoi (for discussion
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Figure 3. Lithostratigraphic column and biostratigraphy of faunas from the Mount Terrible Formation for Section 1 (after Gravestock & Shergold, 2001, fig. 6.3) and Section 2.

of genus see Paterson & Brock, 2007, p. 127; Landing et al. 2013, p. 159) and Pararaia tatei trilobite zones of the Arroie Basin, despite the fact that trilobites are completely unknown from the Wangkonda and Sellick Hill formations. This correlation was reported in subsequent publications (e.g. Gubanov, 2002; Parkheev, Karlova & Rozanov, 2012; Landing et al. 2013). However, the molluscan biozones of Gravestock et al. (2001) have very poorly defined boundaries and are based on poorly preserved, long-ranging taxa. Close inspection of the data given by Gravestock et al. (2001) reveals clear temporal discrepancies between the sections on the Yorke and Fleurieu peninsulas (Betts et al. 2016). For instance, Gravestock et al. (2001, p. 38) state that ‘the lower boundary of the Bemella communis ‘zone’ is established by the appearance of Bemella communis . . . and Aroonia seposita’ in the Aquitaine SYC-101 well, while in the SADME Minlaton 1 drillhole, they state that the base of the B. communis zone is equivalent to the first appearance of the index species only (p. 44). In fact, no species recorded in the B. communis zone, not even the eponym, is common to
all records of that zone. Indeed, the only species represent-ative of the *B. communis* zone in the Yalkalpo-2 drill core is *Pelagiella subangulata* (Tate, 1892), which is the eponym of the zone below the *B. communis* zone. The holotype of *B. communis* (PIN 4664/1331) is a poorly preserved phosphatic steinkern (Gravestock et al. 2001, pl. XXIX, fig. 2a–c) from sample SH22 in Facies Association A of the Sellick Hill Formation at a level taken to correspond to the boundary between the *B. communis* and *S. drepanoides* zones.

4.12. Current study

Shelly fossils were recovered from two stratigraphic levels within the Mount Terrible Formation: from the topmost silty-sandstone layer within the middle member, about 63 m above the base of the section; and an approximately 4 m interval (at 79–83 m above the base of the section) within the top member (= Section 1, Fig. 3). The fauna is composed mainly of molluscs (*W. crosbyi, Aldanella* sp. cf. *golubevi, Bemella* sp., *Paralسانالْيَنْا* sp. cf. *murena* Zhegallo in Esakova & Zhegallo, 1996), as well as *Eremactis mawsoni* Bengtson & Conway Morris in Bengtson et al. 1990, *Australo halkieria* sp., *Hyolithellus micans* Billings, 1871 and *Cupitheca* sp. This assemblage represents the oldest known shelly fossil assemblage from Australia. Micromolluscs *W. crosbyi* and *A. sp. cf. A. golubevi* are described in detail below (Section 5, Systematic palaeontology). Other faunal elements are illustrated for completeness, but poor preservation precludes assignment to species for most taxa (Fig. 4).

The univalved molluscs *Bemella* sp. and *W. crosbyi* range from the middle member of the Mount Terrible Formation (Fig. 3) into Facies Association C of the Sellick Hill Formation (see Gravestock et al. 2001, fig. 17). Jenkins, Cooper & Compston (2002) reported (but did not figure) *Watsonella sibirica* (Missarzhevsky, 1974) from the middle member of the Mount Terrible Formation in a restudy of material collected by Brian Daily. *Watsonella sibirica* is now considered a synonym of *Watsonella crosbyi* (Landing, 1989; Kouchinsky, 1999; Li et al. 2011; Devaere et al. 2013). The halkieriid *Australo halkieria* sp. originally described (as *Halkieria* sp. A) by Bengtson et al. (1990, p. 77) is now known to range from the middle member of the Mount Terrible Formation up into the Wangkonda Formation (Fig. 3; Bengtson et al. 1990, fig. 49A–I). The coeloscleritophoran *Eremactis mawsoni* ranges from the middle member of the Mount Terrible Formation to Facies Association D of the Sellick Hill Formation in the Normanville Group.

Regional correlation of the Mount Terrible Formation and lithostratigraphic equivalents, including the Winulta Formation (Daily, 1990) in the western Stansbury Basin (Yorke Peninsula) and at least, partially, the Uratanna Formation (Daily, 1973) in the Arrowie Basin, has been hampered by lack of fossils (Daily, 1972). Faunal ties between the lowermost Cambrian units on Yorke and Fleurieu peninsulas are limited to indeterminate, long-ranging hyoliths and chancellorids. The enigmatic sabellitids (organic-walled tubes) were reported by Daily (1976a) from the Mount Terrible Formation (lower part of the top member) and from the Uratanna Formation (lower 100–150 m) by Mount & McDonald (1992), but these are taxonomically intractable and consequently difficult to utilize for correlation.

The coarse-grained and intensely bioturbated facies of the lowermost *c. 60 m* of the Mount Terrible Formation was not conducive to the preservation of shelly fossils. The predominance of siliciclastics in the eastern Stansbury and the Arrowie basins explains the absence of *W. crosbyi* and associated shelly taxa from these regions. The local first occurrence and range of *W. crosbyi* in the Mount Terrible Formation therefore track lithofacies changes into calcareous sandstone, so are clearly lithofacies-specific (Jacquet, Betts & Brock, 2016). While the occurrence of *W. crosbyi* in the Mount Terrible Formation is clearly within Stage 2, this cannot be construed as necessarily correlating with the first appearance of the taxon on a global scale.

Siliciclastic depositional settings are often conducive to the preservation of trace fossils. In the absence of diverse early Cambrian skeletal fauna, the potential for using trace fossils for intra- and inter-basin correlation in South Australian successions has long been recognized (Daily, 1972; Gravestock & Shergold, 2001). The predominantly shallow-marine to sub-tidal siliciclastic strata of the basal Cambrian successions in Australia record a transition from an assemblage dominated by shallow-burrowing, architecturally complex traces to an assemblage which is monospecific or of low-diversity and characterized by significantly increased burrowing depth (>1 m) (Màngano & Buatois, 2014). Màngano & Buatois (2014) have demonstrated that a clear change in behaviour and benthic community structure, with the emergence of vertical U-shaped burrows (with spreite) such as *Diplocrafterion*, is widespread during the Cambrian Radiation.

While bioturbation is pervasive in the middle member of the Mount Terrible Formation, no ichnotaxa can be clearly identified. In contrast, trace fossils present in the contemporaneous Uratanna Formation in the Arrowie Basin are well documented and include important ichnogenera and species such as *Trichophy cus pedum* (used to define the Ediacaran–Cambrian boundary) and *Rusophycus* spp. in the uppermost part (Daily, 1972, 1976a; Mount, 1989; Gravestock & Cowley, 1995). These ichnotaxa also extend into the lower Parachilna Formation (Jensen, Gehling & Droser, 1998; Gravestock & Shergold, 2001). Trace fossils have also been reported from outcrop in the Winulta Formation (*Trichophycus pedum, Plagiog mus arcuatus* and *Diplocraterion* sp.) (Gravestock & Shergold, 2001), the Arumbera Sandstone in the Amadeus Basin (*Rusophycus* sp., *R. pedum, Diplich nites* sp. and *Plagiogmus* sp.) and the Mount Baldwin Formation in the Georgina Basin (*Bergaueria*...
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Figure 4. (a, b) Indeterminate chancellorid sclerites; (a) SAM P53318, plan view; (b) SAM P53319, basal view. (c–f) *Eremactis mawsoni* Bengtson & Conway Morris in Bengtson et al. 1990; (c, d) SAM P53320; (c) lateral view; (d) oblique lateral view; (e, f) SAM P53321; (e) lower surface; (f) oblique view of foramen. (g–m) *Australohalkieria* sp. (g–h) SAM P53322, palmate sclerite; (g) lateral view; (h) lower surface. (i) SAM P53323, palmate sclerite, lower surface. (j, k) SAM P53324, cultrate sclerite; (j) lower surface; (k) upper surface. (l, m) SAM P53325, top member of the Mount Terrible Formation; cultrate sclerite; (l) upper surface; (m) lateral view. (n–r) *Bemella* sp. (n, o) SAM P53326; (n) lateral view; (o) apical view. (p–r) SAM P53327; (p) supra-apical view; (q) lateral view; (r) apical view. (s–u) *Parailsanella* sp. cf. *murenica* Zhegallo in Esakova & Zhegallo, 1996, SAM P53328. (s) apical view; (t) lateral view; (u) supra-apical view. (v–w) *Cupitheca* sp. (v) SAM P53329; (w) SAM P53330.

sp., *Helminthopsis* sp., *Treptichnus* sp. and *Diplocraterion parallelum* (Glaessner, 1969; Daily, 1972; Gravestock & Shergold, 2001). *Diplocraterion* burrows first appear in the sandy interbeds of the Wangkonda Formation on the Fleurieu Peninsula (Daily, 1976a), and traces identified as *D. parallelum* are extremely abundant in beds in the lower part of the Parachilna Formation in the Arrowie Basin (Gravestock & Cowley, 1995; Mángano & Buatois, 2014).

The global shift to an advection-dominated system resulting from deep-tiering benthic communities forming straight and U-shaped burrow systems is characteristic of the Terreneuvian, Stage 2 (Mángano & Buatois, 2014, fig. 1). This provides some measure of biostratigraphic control for the Mount Terrible Formation, with the first appearance of *Watsonella crosbyi* below that of *Diplocraterion* piperock in the overlying Wangkonda Formation therefore indicating an interval broadly equivalent with Cambrian Stage 2.

*Watsonella crosbyi* was reported from two horizons in Facies Association A and C of the Sellick Hill Formation, which overlies the Wangkonda Formation (Parkhaev in Gravestock et al. 2001, pl. XLII, figs 15, 16). Revaluation of the taxa occurring within the upper range of *Watsonella crosbyi* in the Sellick Hill Formation illustrated by Gravestock et al. (2001) include *Bemella communis* Parkhaev in Gravestock et al. (2001), *B. incomparabilis* Parkhaev in Gravestock et al. (2001), *Obtsosconus brevis* Zhegallo in Esakova &
arthropods (Isoxys) (Jago et al. 2006; Paterson et al. 2010) suggests a P. janeae Zone age for the upper part of the Heathdale Shale.

4.b. Global correlation

Daily (1972, 1976a) first suggested the Mount Terrible Formation could be correlated with the Tommotian Stage of Siberia based on shelly faunas (including Watsonella) and sabellitids. This view was later supported by Jenkins, Cooper & Compston (2002) who proposed that the occurrence of W. sibirica (= W. crosbyi) in the middle member of the Mount Terrible Formation was evidence of an early–middle Tommotian-equivalent age. Our correlation is mainly based on the occurrence of Watsonella crosbyi and Aldanella sp. cf. golubevi as well as the shelly fauna and trace fossils in overlying strata. Watsonella crosbyi is widely distributed in upper Terreneuvian strata (discussed further below), and A. golubevi is known only from transitional Fortunian Stage 2 strata of Siberia. However, other species of Aldanella have longer stratigraphic ranges in the Terreneuvian (Parkhaev & Karlova, 2011; Parkhaev, 2014). Other taxa recovered from the Mount Terrible Formation are long-ranging and are therefore less useful for global correlation. However, the stratigraphic range of S. imbricata has previously been used to define a biozone in the pre-trilobite Bonavista Group in Newfoundland which succeeds the Watsonella crosbyi Zone of the underlying Chapel Island Formation (Fig. 6) (Landing, 1988; Landing et al. 1989; Palacios et al. 2011). Similarly, the interval with Sunnaginia imbricata in Facies Association C though to E of the Sellick Hill Formation (c. 50 m above the last local appearance of W. crosbyi in the lower part of Facies Association C) provides strong evidence that the Mount Terrible Formation represents the early part of Cambrian Stage 2 (Fig. 6).

In connection with recent efforts to define the chronostratigraphic divisions of the Cambrian period, the stratigraphic range of Watsonella crosbyi has been extensively studied. Watsonella crosbyi is one of the most widely distributed shelly fossils in the early part of the Cambrian period (Terreneuvian) with a near-global distribution (online Supplementary Table S1, available at http://journals.cambridge.org/geo) and has been suggested as a suitable index fossil to define the lower boundary of the Cambrian Stage 2 (Terreneuvian Series) (Li et al. 2011; Peng & Babcock, 2011). However, the utility of W. crosbyi for global correlation has also been questioned because of the supposed long stratigraphic range of the taxon (Parkhaev, Karlova & Rozanov, 2012; Landing et al. 2013). Re-study of the stratigraphic range of W. crosbyi in France (Devaere et al. 2013), Siberia (Landing & Kouchinsky, 2016), Mongolia (Brasier et al. 1996) and Australia (this article) suggests that it is restricted to early–middle Stage 2 (Fig. 6). However, in Avalonia W. crosbyi has been reported to range from Member 3 of

Figure 5. Sunnaginia imbricata Missarzhevsky in Rozanov et al. 1969 from the Sellick Hill Formation (SHL section base coordinates: 35°22’36.30” S; 138°22’5.30” E); scale bars: 200 μm. (a, b) Dextral sclerites from SHL/82.5, 56.3 m true thickness, Facies Association E; (a) apical view, SAM P53342; (b) apical view, SAM P53343. (c–f) Dextral sclerites from SHL/50.9, 34.7 m true thickness, Facies Association D; (c) apical view, SAM P53344; (d) adapical view, SAM P53345; (e) apical view, SAM P53346; (f) adapical view, SAM P53347.
the Chapel Island Formation (\textit{W. crosbyi Zone}) into the Fosters Point Formation (\textit{Camenella baltica Zone}) in horizons suggested to correlate with the first appearance of trilobites in Siberia (Landing, 1989; Landing et al. 2013).

In Siberia, the first appearance of \textit{W. crosbyi} has usually been suggested to coincide with the base of the Tommotian Stage (\textit{Nochorolyctus sunnaginicus Zone}; Rozanov et al. 2008). However, it has recently been shown that \textit{W. crosbyi} occurs substantially below the base of the Tommotian Stage in northern Siberia (Fig. 6) (Nagovitsyn et al. 2015; Landing & Kouchinsky, 2016). As a complication, the base of the Tommotian remains poorly defined; it is ultimately based on the simultaneous incoming of numerous taxa, co-occurring with a hiatus at the base of the Pestrotsvet Formation in the stratotype Dvortsy section in southern Siberia (Landing et al. 2013; Landing & Kouchinsky, 2016).

The \textit{W. crosbyi} Assemblage Zone in South China (Steiner et al. 2007; Li et al. 2011) is usually correlated with the basal Tommotian Stage of Siberia, although Landing & Kouchinsky (2016) suggest that it is better correlated with pre-Tommotian strata in northern Siberia (the Ary-Mas-Yuryakh and Kotujkan River sections). The stratigraphic range of \textit{W. crosbyi} in Mongolia has also been controversial, with some authors correlating strata in the upper Bayangol Formation containing \textit{W. crosbyi} with either the Atkadanian (Brasier et al. 1996; Landing et al. 2013) or Tommotian (Esakova & Zhegallo, 1996) stages of Siberia. These views have recently been challenged by Smith et al. (2015) who argue that this interval is pre-Tommotian based largely on new carbon chemostratigraphic isotope data. Similarly, in the Montagne Noire of France, strata containing \textit{W. crosbyi} have been correlated with the Botoman (Kerber, 1988), Tommotian (Devaere et al. 2013) and pre-Tommotian stages of Siberia (Landing & Kouchinsky, 2016).

The global first appearance of \textit{W. crosbyi} is now demonstrated to occur in strata that pre-date the base of the Tommotian Stage of Siberia (as defined by the FAD of \textit{N. sunnaginicus}) based on carbon isotope stratigraphy from Mongolia, South China, Siberia and Avalonia (Fig. 6) (Smith et al. 2015; Landing & Kouchinsky 2016). In all these regions, the FAD of \textit{W. crosbyi} occur below significant positive $\delta^{13}$C excursions (L4 in China, Li et al. 2009; L1 in Bol’shaya Kounamka and the Ary Mas Yuryakh section of northern and eastern Siberia, Knoll et al. 1995, Kouchinsky et al. 2001, Landing & Kouchinsky, 2016; and F in Mongolia, Brasier et al. 1996) which correlate with the 6p excursion in Morocco following Maloof et al. (2010a).

Caution is advised when correlating carbon isotope curves between continents, especially in the absence of comprehensive biostратigraphic data. Carbon isotope data are lacking for strata containing \textit{W. crosbyi} in the Montagne Noire of France, but the associated fauna closely corresponds with that from the \textit{W. crosbyi} Zone of South China (Devaere et al. 2013) and is therefore likely pre-Tommotian equivalent.

In Australia, the Mount Terrible Formation consists predominantly of siliciclastics and is therefore unsuitable for $\delta^{13}$C chemostratigraphic analyses. Betts et al. (2015) presented preliminary carbon-isotope che-
mostraligraphy measured through the upper 62 m of the Sellick Hill Formation (Facies Association C to E) in the SHL section, Myponga (Fig. 1). The isotopic curve has values from −2 to −4 per mil, presenting a distinctly negative trend similar to the global Shiyan-tou carbon isotope excursion (SHICE) (Zhu, Babcock & Peng, 2006). More comprehensive sampling and isotopic analyses of carbonates from the Wangkonda and Sellick Hill formations above the Mount Terrible Formation on Fleurieu Peninsula will be presented elsewhere.

The apparently disjunct occurrences of W. crosbyi in France (Kerber, 1988), Mongolia (Brasier et al. 1996) and South Australia (Gravestock et al. 2001) have been used as arguments for the supposed diachronieity of the FAD of W. crosbyi (Rozanov et al. 2008; Parkhaev, Karlova & Rozanov, 2012; Landing et al. 2013). However, revision of anomalous occurrences has shown that the range of W. crosbyi correlates most closely with the late Nemakit–Daldynian and early Tommotian stages of Siberia (Devaere et al. 2013; Smith et al. 2015; this article). In fact, the only area where W. crosbyi has a range that includes strata above upper Tommotian deposits are in Avalonian Newfoundland. There, W. crosbyi is reported to have a 650 m thick composite stratigraphic interval (Chapel Island to Fosters Point Formation; Landing, 1989; Landing et al. 2013). However, this range includes the unfossiliferous strata of the Random Formation (Fig. 6). Based on the changes in the perceived stratigraphic ranges and correlations of W. crosbyi in Mongolia, France, Siberia and Australia, the long stratigraphic range of the species in Avalonia seems to invite reinvestigation, especially since the record of this taxon is largely based on relatively poorly preserved specimens on bedding surfaces (Bengtson & Fletcher, 1983).

5. Systematic palaeontology

All specimens are housed in the palaeontological collections of the South Australian Museum (Prefix SAM P).

Phylum MOLLUSCA Linnaeus, 1758
Class, Order and Family Unknown
Genus WATSONELLA Grabau, 1900
Type species. Watsonella crosbyi Grabau, 1900

Remarks. The orientation used here for descriptive purposes is that suggested by Devaere et al. (2013, fig. 13). Watsonella was described by Pojeta & Runnegar (1976) as ‘pseudobivalved’, where the presence of a dorsal ridge or groove (Fig. 6f, g, i, k, n) may represent a variably preserved separation between the two ‘pseudovalves’, similar to more derived rostroconchs.

Designation of Watsonella as the ‘oldest known rostroconch’ (Landing et al. 1988, p. 691) deserves reconsideration following new insights into shell microstructures preserved on phosphatic steinkerns. Similarities between shell microstructure textures and their respective spatial distribution on the steinkerns of Anabarella and Watsonella indicate a closer phylogenetic affiliation with bivalves (Kouchinsky, 1999; Carter, 2001). Only a few specimens described herein preserve the characteristic ‘spiny’ microstructure (see Vendrasco, Checa & Kouchinsky, 2011, pl. 6, figs 1–2, pl. 7, fig. 2) near the dorsum and step-like textures (see Vendrasco, Checa & Kouchinsky, 2011, pl. 6, figs 3, 4, pl. 7, fig. 1) on the valves, although polygonal textures are not preserved (Fig. 6h). Comprehensive investigation of the horizontally oriented blades imprinted on the shell surface of Anabarella and Watsonella demonstrate an evolutionary progression towards the laminar structures present in the earliest confirmed bivalves (Pojetaia and Fordilla) (Vendrasco, Checa & Kouchinsky, 2011; Vendrasco et al. 2011). Stratigraphically, there is also a clear discrepancy in timing between the appearance of Watsonella and the earliest undoubted rostroconchs (Vendrasco et al. 2011). In addition, documentation of a bivalved larval shell in a juvenile Watsonella specimen from Tommotian deposits in Yakutia, Siberia (Dzik, 1994, fig. 12g) supports the hypothesis of a closer relationship with bivalves and would serve to separate the genus from the rostroconchs. However, this feature is rarely preserved and undivided or incompletely divided larval shells have also been reported in Watsonella (Vendrasco et al. 2011). Nevertheless, there is now mounting morphological, microstructural and stratigraphic evidence to suggest that Watsonella represents a stem bivalve rather than an early rostroconch.

Watsonella crosbyi Grabau, 1900

1900 Grabau, Watsonella crosbyi; p. 632, pl. 1, fig. 9a–g.
2013 Devaere, Clausen, Steiner, Álvaro & Vachard; Watsonella crosbyi Grabau; p. 37, figs 14.1-33, 15.1-14 (includes full synonymy).

Figured material. Four internal moulds (SAM P53331-53335), with an additional 33 unfigured specimens.

Diagnosis. See Devaere et al. (2013, p. 40).

Description. Univalved (pseudobivalved), bilaterally symmetrical and laterally compressed phosphatic steinkerns; subelliptical in lateral view. Steinkerns range over 0.9–2.7 mm in length, 0.54–1.67 mm in height and 0.29–0.57 mm in width. Lateral surfaces nearly flat, but more strongly convex near dorsum and posterior margin where these surfaces are conjoined. In lateral view dorsum variably convex, tending to be most strongly convex towards posterior. Anterior extremity angular (Fig. 7a), broadly acute; posterior extremity with strongly convex apex overhanging strongly concave subapical field; apertural margin tends to be fairly evenly curved. In dorsal view, steinkerns elongate subelliptical to subrectangular, with maximum width tending to be towards posterior (Fig. 7f, k, l, n).
Figure 7. (a–n) *Watsonella crosbyi* Grabau, 1900, all specimens collected by Brian Daily from the middle member (3) of the Mount Terrible Formation, McGowran Locality, off Old Sellick Hill Road, Sellick Hill, Fleurieu Peninsula. (a–d) SAM P53331: (a) lateral view; (b) ventral view; (c) magnification of apical area; (d) posterior view. (e–i) SAM P53332: (e) lateral view, square shows location of (h); (f) dorsal view, squares show location of (g) and (i); (g) magnification of diverging dorsal median furrow; (h) magnification of lamella-fibrillar micro-ornament. (j–l) SAM P53333: (j) lateral view; (k) posterior view; (l) dorsal view. (m) SAM P53334, posterior view. (n) SAM P53335, dorsal view. (o–x) *Aldanella* sp. cf. *golubevi*, from the upper member of the Mount Terrible Formation. (o) SAM P53336, apertural view; (p) SAM P53337, apertural view. (q–r) SAM P53338: (q) apertural view; (r) spire view. (s, t, x) SAM P53339: (s) spire view; (t) apertural view; (x) magnification of apex. (u) SAM P53340, spire view. (v, w) SAM P53341: (v) spire view; (w) magnification of apex.
Dorsum with narrow median furrow (Fig. 7f, i, n) or very weak ridge (Fig. 7i) along dorsum midline, extending from anterior extremity of shell to just near apex where it sometimes bifurcates (Fig. 7f, g, k). Subapical field very short and poorly preserved in all specimens. Aperture long, slit-like, width similar along entire length (Fig. 7b). In some specimens, what appear to be internal imprints of concentric growth lines are present (Fig. 7a, e). There is also what appears to be an impression of a lamellar texture on the lateral surface of one of the steinkerns (Fig. 7h).

Remarks. Watsonella crosbyi has received thorough taxonomic revision (Parkhaev in Gravestock et al. 2001; Li et al. 2011; Devaere et al. 2013). The material examined here closely resembles specimens described by Parkhaev (in Gravestock et al. 2001, pl. XLII, figs 15, 16) from the Sellick Hill Formation. Parkhaev (in Gravestock et al. 2001, p. 188) distinguished the Sellick Hill Formation specimens from the Siberian species, Watsonella sibirica (= Heraulitia sibirica Missarzhevsky, 1974), based on its comparatively narrow anterior aperture, flattened valves and ‘less risen anterior margin of the aperture’. Jenkins, Cooper & Compston (2002) re-examined material collected by Brian Daily from the Mount Terrible Formation (most likely that documented in this paper), and referred the specimens to W. sibirica. However, W. sibirica is now rightly regarded as a junior synonym of W. crosbyi (Li et al. 2011; Devaere et al. 2013) and the features used to delineate the species used by Parkhaev (in Gravestock et al. 2001) are considered to be within the range of intraspecific variation. Similarly, Yu (2014) described and illustrated specimens of Watsonella yunnanensis (He & Yang, 1982) from the Dahai Member of the Yuhucun Formation, East Yunnan, China, which are also now considered to be synonymous with W. crosbyi (Li et al. 2011; Devaere et al. 2013). Yu (2014) distinguished the Chinese material from the type species based on its smaller size, blunt rounded beak, longer and wider ventral, anterior and posterior gapes, where the latter extends beyond the sub-apical shield and partially along the dorsum (Yu, 2014, fig. 5). However, these characteristics vary within the concept of the species (Li et al. 2011) including the extended posterior gape, which is most likely a feature caused by secondary phosphatization (see Fig. 7d).

Stratigraphic range in South Australia. Middle and top members of the Mount Terrible Formation and Facies Association A to C of the Sellick Hill Formation, Normanville Group, Fleurieu Peninsula, eastern Stansbury Basin. Terreneuvian, Stage 2.

Order HELCIONELLIDA Geyer, 1994
Family ALDANELLIDAE Linsley & Kier, 1984
Genus ALDANELLA Vostokova, 1962

Type species. Aldanella attleborensis (Shaler & Foerste, 1888).

Aldanella sp. cf. golubevi Parkhaev, 2007

Figured material. Seven figured steinkerns (SAM P53336-53341), with an additional seven unfigured specimens.

Description. Asymmetrical, sinistrally coiled low turbinate shell (Fig. 7o–v); up to 1.64 mm in diameter (average 1.42 mm), shell composed of 1.5–1.7 whorls expanding strongly, with last whorl occupying 58% of the maximum shell diameter. Shell height 32% of maximum shell diameter; spire flattened, projecting only slightly; apex rounded (Fig. 7w, x). Aperture ovate, approximately 2.5 times as wide as high; upper margin flattened, lower margin slightly convex (Fig. 7o–q, t), distal margin strongly curved. Umbilicus broadly concave. Faint, shallow furrows, convex towards aperture are present on the upper surface of some specimens (Fig. 7r).

Remarks. Steinkerns of Aldanella from South Australia all exhibit sinistral coiling (Fig. 7r, s, u, v), unlike the dextral coiling that normally characterizes the genus. Whether the shell is a true mirror image of the typical dextral form or whether it is dextrally hyperstrophic is unknown due to the poor preservation of diagnostic shell features, especially muscle scars. A ‘pathological’ sinistrally coiled Aldanella was originally described by Golubev (1976, pl. 3, fig. 13), and an assemblage of sinistrally coiled Aldanella was reported by Parkhaev (2007) from the western Anabar Region of the Siberian Platform. The identification of this particular sinistral assemblage as stratigraphically isolated from other dextral species of Aldanella, in conjunction with it having a unique pointed apex, led Parkhaev (2007) to refer the shells to a new species, A. golubevi. This taxon is known to co-occur with both A. atteboleensis and A. crassa in Fortunian Stage 2 transitional beds of the eastern and western Anabar Region (Golubev, 1976; Parkhaev & Karlova, 2011).

The broad similarities between the South Australian material and Siberian sinistrally coiled A. golubevi are limited to the tight coiling of the whorls, their strong expansion and the low to almost flattened spire. These characteristics further distinguish this taxon from other sinistral taxa attributed to the genera Barskoviola Golubev, 1976 and Nomgoliella Missarzhevsky, 1980, which otherwise possess more oval or rounded apertural cross-sections, respectively. Unfortunately, the diagnostic pointed apex of A. golubevi (Parkhaev, 2007, pl. 2, figs 7, 10b) is not present in our collection (Fig. 7w, x), which consists exclusively of steinkerns. Consequently, the South Australian material is cautiously compared with A. golubevi.

Stratigraphic range in South Australia. Top member, Mount Terrible Formation, Normanville Group, Fleurieu Peninsula. Eastern Stansbury Basin; Terreneuvian, Stage 2.
6. Conclusion

The paucity of cosmopolitan, biostratigraphically significant shelly taxa hinders early Cambrian global correlation. However, the micromollusc _Watsonella crosbyi_ is now known from China, France, Siberia, Mongolia, Avalonia and Australia, and provides a crucial biostratigraphic link between pre-trilobitic strata in disparate palaeocontinents. The revised interpretation of the stratigraphic range of _Watsonella crosbyi_ in South Australia strongly suggests that it is restricted to early Cambrian Stage 2 (Peng, Babcock & Cooper, 2012).

In the Mount Terrible Formation, the first occurrence of _Watsonella crosbyi_ pre-dates the incoming of Diplocraterion piperock in the Wangkonda Formation. Furthermore, the stratigraphic range of _Watsonella crosbyi_ in South Australia pre-dates the local occurrence of _Summanginia imbricata_ in the upper part of the overlying Sellick Hill Formation, which is succeeded by a fauna indicative of the pre-trilobitic _Kalparina rostrata_ Zone (Betts et al. 2016). The stratigraphic range of _Watsonella crosbyi_ in the Normanville Group is estimated as c. 244 m (true thickness; per data in Alexander & Gravestock, 1990; Gravestock et al. 2001; this article). Carbon isotope values through the Facies Association C to E of the Sellick Hill Formation are suggestive of the negative SHICE event, further supporting an early Stage 2 age for _Watsonella crosbyi_ (although additional chemostratigraphic data through the Mount Terrible and Wangkonda formations is required). The new Australian data strengthens the relative value of _Watsonella crosbyi_ as an index fossil to define the base of Cambrian Stage 2.

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Supplementary material

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