Late Ordovician Conodonts and Macrofossils from Subsurface Carbonates near Quandialla and Inferred Depositional Age of the Currumburrama Volcanics in South-Central New South Wales

Yong Yi Zhen[1] and Ian G. Percival[1]

[1]Geological Survey of New South Wales, 947–953 Londonderry Road, Londonderry, NSW 2753, Australia

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Late Ordovician conodonts and macrofossils (corals, calcareous algae and bryozoans) were recovered from an unnamed limestone unit within the Currumburrama Volcanics, intersected in drill hole CBMD006 located in the vicinity of Quandialla and Caragabal in south-central New South Wales. The conodont assemblage from the lower part of the limestone unit is characterized by moderately common *Belodina compressa* elements and is assigned to the *B. compressa* Biozone of late Sandbian age, consistent with corals from the upper part of the limestone which suggest a latest Sandbian to earliest Katian age. These fossils support direct correlation with an unnamed carbonate unit within the Lake Cowal Volcanic Complex previously reported near Marsden, about 18 km to the WNW. Together these palaeontological and biostratigraphic studies provide crucial age constraints for the Upper Ordovician volcanic sequences distributed in the southern Junee–Narromine Volcanic Belt (JNVB). Furthermore, they underpin precise correlation with the well-dated marine shelf successions and associated volcanic sequences exposed in the central and northern part of the JNVB, within the Ordovician Macquarie Volcanic Province in central New South Wales.

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INTRODUCTION

Reported herein are conodont and macrofossil assemblages recovered from an unnamed limestone unit within the Currumburrama Volcanics intersected in drill hole CBMD006, located about 20 km NNW of Quandialla and 9 km SW of Caragabal and approximately midway between the major population centres of West Wyalong and Grenfell in south-central New South Wales (Fig. 1). The conodont assemblage from the lower part of the limestone unit is characterized by the common appearance of *Belodina compressa* and is assigned to the *B. compressa* Biozone of late Sandbian (Late Ordovician) age. Together with the previously documented conodont assemblage of a comparable to slightly younger age (*B. compressa* to *Phragmodus undatus-Tasmanognathus careyi* biozones) from an unnamed limestone unit intersected in a drill core section (DDMN 042) within the Marsden prospect about 18 km to the WNW (Percival et al., 2006), they represent the only confirmed conodont data from the area and provide crucial age constraints for the associated Ordovician magmatic rocks (i.e. Currumburrama Volcanics and Lake Cowal Volcanic Complex). These volcanic complexes are widely distributed in this area of the southern Junee–Narromine Volcanic Belt (JNVB) and host world class copper-gold mineralisation (e.g., Lake Cowal Au-Cu deposit). The new data also support correlation with the better-studied shelfal marine successions and associated igneous rocks distributed in the central and northern part of this volcanic belt (Pickett and Percival, 2001; Zhen et al., 2022, 2023).

GEOLOGICAL AND PALAEONTOLOGICAL BACKGROUND

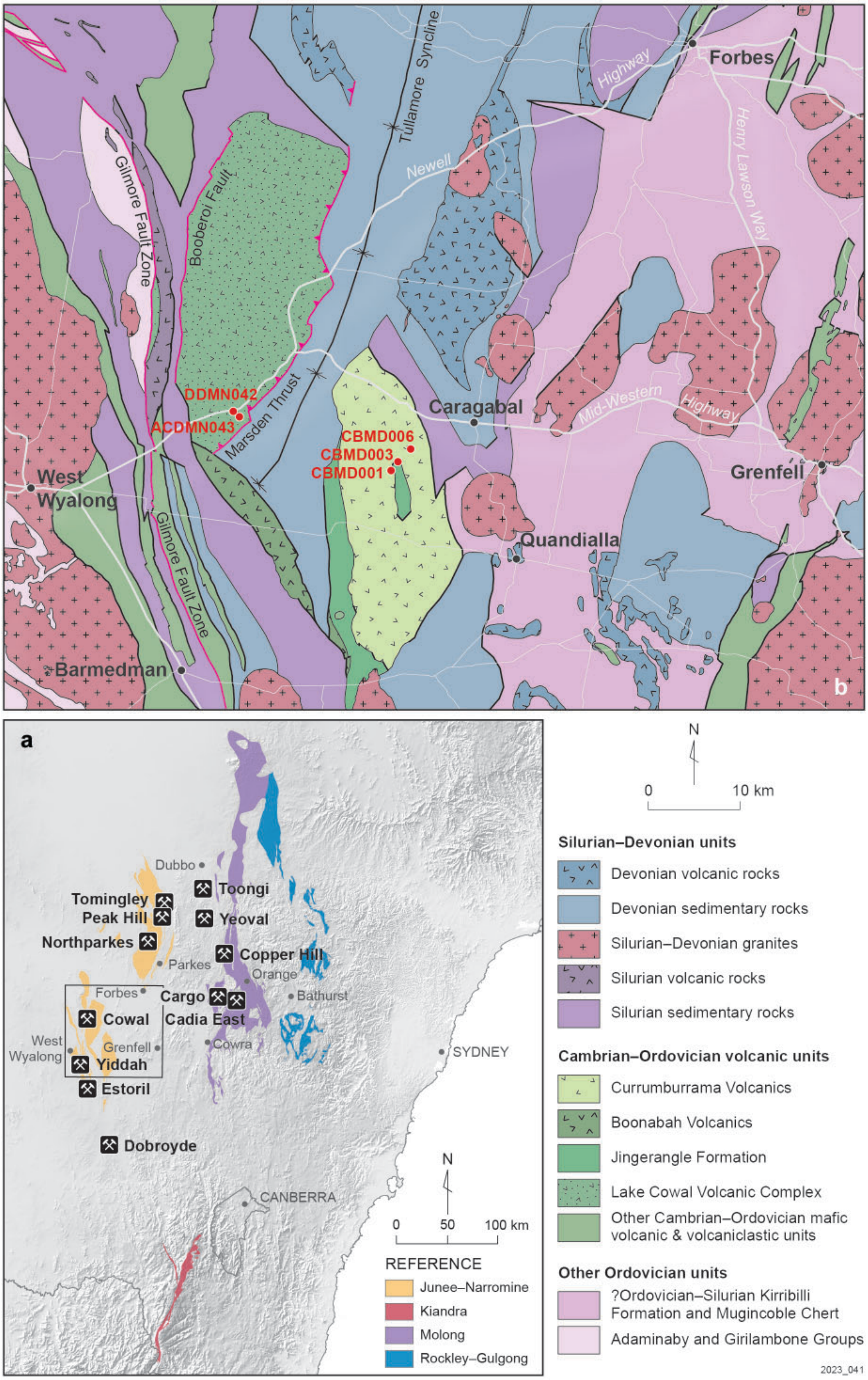
The study area is located tectonically within the southern part of the JNVB, which extends for more than 200 km along the western margin of the mineral-rich Macquarie Volcanic Province in central NSW (Fig. 1). Being mostly covered by alluvium and alluvial floodplain deposits over 100 m in thickness, Ordovician rocks are rarely exposed in the area and interpretation of their temporal and spatial distribution depends largely on data derived from drilling and geophysical (aeromagnetic, gravity and deep seismic) studies (Glen et al., 2007; Percival and Glen, 2007). The Jingerangle Formation, consisting of predominantly thinly bedded siltstones and mudstones, is the only Ordovician sedimentary rock unit exposed in the Quandialla-Marsden district. Fossils from this deep-water siliciclastic unit include siliceous sponges, nautiloids, brachiopods, and graptolites, sampled from two road aggregate quarries in the vicinity of Gibber Trig (Percival et al. 2006). Based on the graptolites from these sites, Percival et al. (2006) assigned an early Bolindian (Bo2) age to the Jingerangle Formation, equivalent to the latest Katian of the international chronostratigraphic scale (Fig. 2).

In the study area Ordovician rocks are primarily represented by two volcanic complexes confined in two fault-bounded blocks flanking the west and east limbs of the Tullamore Syncline consisting of the Upper Devonian Hervey Group. The more westerly Lake Cowal Volcanic Complex comprises volcanic, volcaniclastic and epiclastic rocks with minor polymictic conglomerate, sandstone, and claystone, intruded by granodiorite, diorite and mafic to intermediate sills and dykes of multiple phases (Miles and Brooker, 1998; Crawford et al., 2007). Surface exposures are poor and only known from a small area just west of the West Wyalong–Burcher railway, near Lake Cowal Siding. Based primarily on drill core and aeromagnetic data, distribution of this volcanic complex is confined to a fault-bounded block (40 x15 km) between the Booberoi Shear Zone on the west and the Marsden Thrust on the east (Lyons et al., 2000; Glen et al., 2007). The Muddy Lake Diorite (465 ± 5.2 Ma) is considered to represent the earliest intrusive activity and indicates an early Middle Ordovician age for the initial formation of the Lake Cowal Volcanic Complex, with mineralization associated with subsequent intrusions during Phase 2 (porphyry systems) and Phase 3 (epithermal systems) magmatism of the Macquarie Volcanic Province (Zukowski, 2010; Rush, 2013; Henry et al., 2014; Forster et al., 2015; Leslie et al., 2017).

Peep Männik (pers. comm. 2023) pointed out that some of specimens illustrated by Percival et al. (2006, fig. 4I, K–N) from drill core section ACDMN 043 at the Marsden prospect were misidentified, and actually represent elements of early Silurian conodonts including *Aspelundia* Savage, 1985 and *Oulodus* Branson and Mehl, 1933. Our reexamination of two samples (C2073 and C2074) confirmed the presence of *Oulodus*, *Pseudolonchodina* (according to Simpson and Talent, 1995 and Wang and Aldridge, 2010, *Aspelundia* is a junior synonym of *Pseudolonchodina* Zhou, Zhai, and Xian, 1981) and indeterminate ozarkodinids. Another sample (C2075) has the same early Silurian assemblage mixed with reworked Late Ordovician conodonts represented by *Belodina compressa* and *Tasmanognathus* sp. cf. *T. borealis* (see Percival et al., 2006, fig. 3M, table 1). This reinterpretation has several important ramifications; firstly, it confirms that the Lake Cowal Volcanic Complex extends to the lower Silurian, and secondly, it implies that Ordovician rocks in this region were exposed and eroded over the post-Katian to earliest Silurian interval. Furthermore, it is the first record of lower Silurian limestone from this region, the nearest previously known being from the vicinity of Forbes, 60 km to the NE (Fig. 1).

The Currumburrama Volcanics was introduced by Warren et al. (1995) for subsurface volcanic rocks with an inferred distribution confined to a fault-bounded area between the Tullamore Syncline to its west and Springdale Syncline to its SE, with upper Silurian to lowest Devonian Yiddah Formation (Ootha Group) to the NE (Fig. 1). Because it is only known from subsurface data, the Currumburrama Volcanics remains poorly understood. Numerous exploration and stratigraphic drill holes in the area show that the Currumburrama Volcanics comprises a mixture of volcaniclastic rocks including polymictic volcanic lithic breccias (or conglomerates) and volcaniclastic siltstones, to sandstones of marine shelfal settings, with lesser andesitic intrusives of monzonite, diorite,

(next page) Figure 1. a, map of central NSW showing major and potential mining sites of Ordovician porphyry copper–gold deposits in the Macquarie Volcanic Province and their locations relative to the Ordovician volcanic belts comprising the MVP; and b, geological map of the Quandialla-Marsden district between West Wyalong and Grenfell (modified from Colquhoun et al., 2022), showing the location of three drillholes (CBMD006, CBMD001, and CBMD003) discussed in this study and the Marsden prospect drill sites (DDMN 042 and ACDMN 043) reported by Percival et al. (2006).


Forbes
Highway
Tullamore Syncline
Newell
Henry Lawson Way
Gilmore Fault Zone
Booberoi Fault
Marsden Thrust
DDMN042
ACDMN043
Caragabal
Mid-Western
Highway
CBMD006
CBMD003
CBMD001
Grenfell
West
Wyalong
Quandialla
Barmedman
b
a
Dubbo
Tomingley
Peak Hill
Toongi
Yeoval
Northparkes
Parkes
Copper Hill
Orange
Forbes
Cargo
Cadia East
Bathurst
Cowal
West
Wyalong
Grenfell
Cowra
Yiddah
Estoril
SYDNEY
Dobroyde
CANBERRA
N
0
50
100 km
REFERENCE
Junee–Narromine
Kiandra
Molong
Rockley–Gulgong
N
0
10 km
Silurian–Devonian units
Devonian volcanic rocks
Devonian sedimentary rocks
Silurian–Devonian granites
Silurian volcanic rocks
Silurian sedimentary rocks
Cambrian–Ordovician volcanic units
Currumburrama Volcanics
Boonabah Volcanics
Jingerangle Formation
Lake Cowal Volcanic Complex
Other Cambrian–Ordovician mafic volcanic & volcaniclastic units
Other Ordovician units
?Ordovician–Silurian Kirribilli Formation and Mugincoble Chert
Adaminaby and Girilambone Groups
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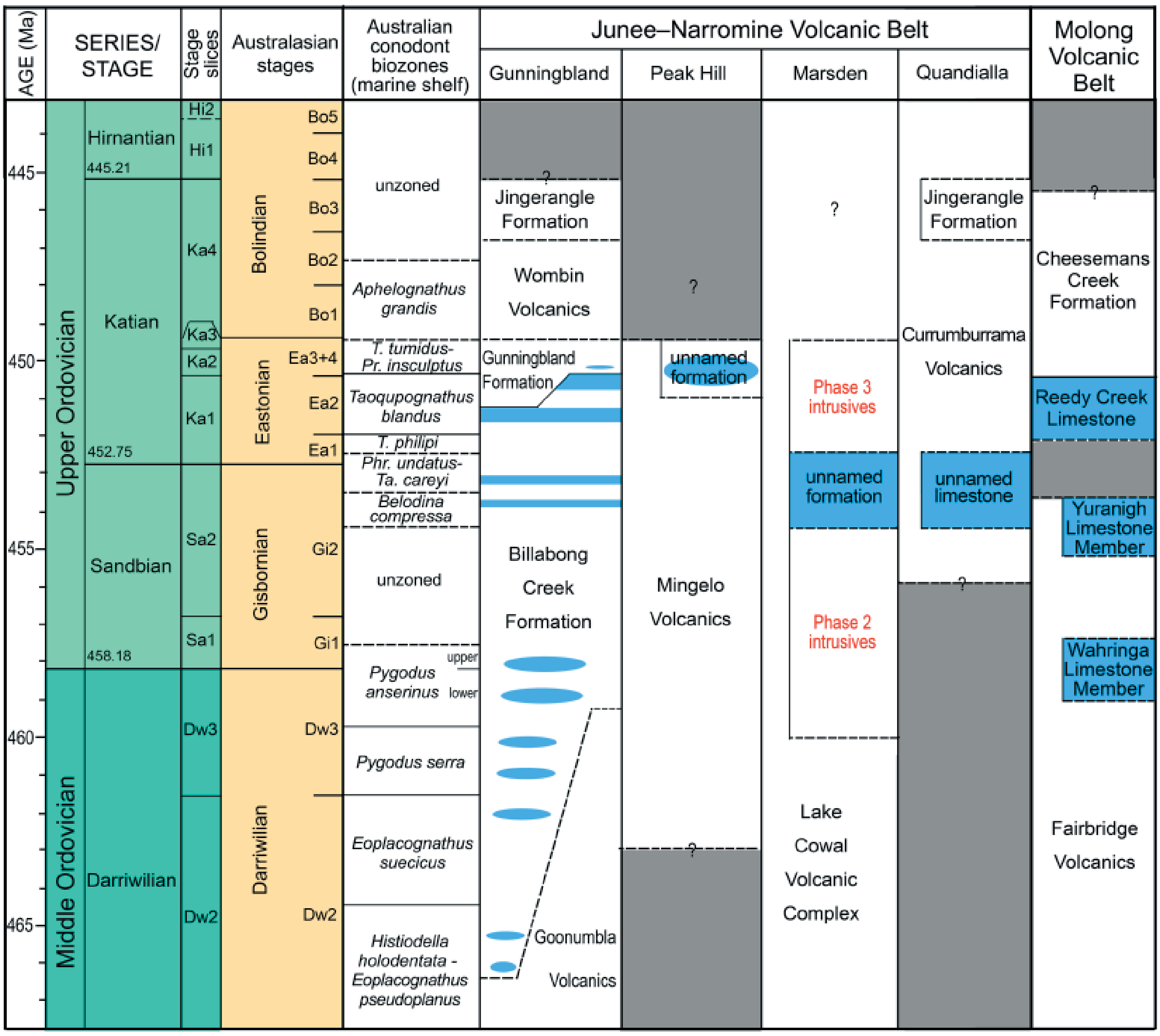

Figure 2. Correlation of the Middle–Upper Ordovician marine shelf carbonate successions from the Junee–Narromine Volcanic Belt and Molong Volcanic Belt in central New South Wales.

monzodiorite and quartz-monzodiorite (Wynne et al., 2013; Hansen and Brookes, 2014; Hansen et al., 2016; Reid and Collier, 2020; Simpson, 2014). As no radiometric age constraints from the Currumburrama Volcanics are available, a broad Late Ordovician to early Silurian age assigned to this unit (Lyons et al., 2000; Downes et al., 2004; Australian Stratigraphic Units Database of Geoscience Australia and Australian Stratigraphy Commission 2022) is mainly based on the occurrence of Late Ordovician graptolites from the Jingerangle Formation exposed in the area and correlation with the Northparkes Group. Simpson (2014) suggested that the Currumburrama Volcanics likely formed during Phase 2 magmatism of the Macquarie Volcanic Province, comparing its volcanic facies and compositional features with the Northparkes Group to the north. Based on the late Sandbian to earliest Katian age of conodonts and corals from the unnamed limestone unit documented in this study, and the late Katian age of the graptolite fauna from the Jingerangle Formation (Percival et al., 2006), a more restricted Late Ordovician age is now inferred for the Currumburrama Volcanics (Fig. 2).

LOCALITIES AND SAMPLES STUDIED

Conodont samples were collected from drill core sections from CBMD006 (Coordinates: -33.876428°, 147.665534°) located in the central northern part of the distribution area of the Currumburrama Volcanics in an area between Quandialla and Caragabal, and

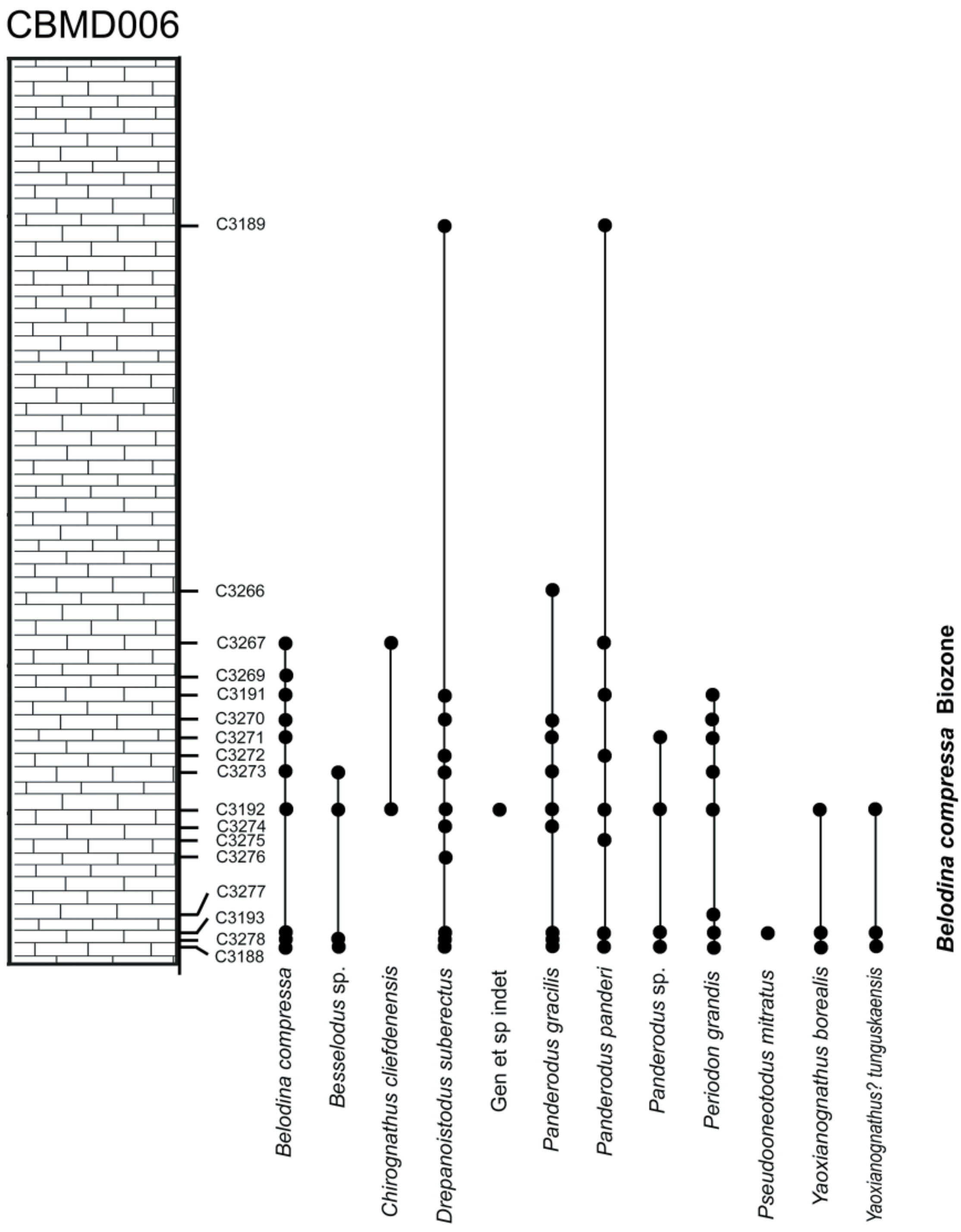

Figure 3. Stratigraphic column of CBMD006 showing horizons sampled for conodonts and species recovered.

CBMD0003 (Coordinates: -33.891825°, 147.650048°) located about 2 km SW from the CBMD006 site and CBMD0001 (Coordinates: -33.902538°, 147.641660°) located about 3.1 km farther SW from CBMD006 (Fig. 1). Only samples from CBMD006 yielded conodonts (Fig. 3). Macrofossils were also collected from CBMD006 and CBMD001 for this study. These three wells were drilled in 2013 by Clancy Exploration Limited as part of its EL6784 Currumburrama Project (from 2007 to 2014) to explore Cu-Au porphyry deposits potentially hosted within the Currumburrama Volcanics (Vassallo, 2012; Vassallo et al., 2013; Dyriw, 2014). Simpson (2014) provided a brief petrographic description of the cores from these three drill core sections, which are currently stored at the GSNSW Core Library at Londonderry. With a total drilled depth of 146 m in CBMD006, conodont samples were collected from the interval 95-146 m, representing a carbonate succession possibly within the Currumburrama Volcanics. The limestones are fractured and stylolitic calcirudites (Fig. 4c, e), pinkish in the upper part (95 to 121 m) and light grey in the lower part (122 to 146 m). Macrofossils including corals, crinoid ossicles (Fig. 4a, b), encrusting (Fig. 4d) or ramose (Fig. 4f) bryozoans, calcareous algae and algal coated clasts (Fig. 4c) are relatively common in the upper part of the limestone in CBMD006, but they are very rare or absent in the lower part (Fig. 5, Table 1).

A conodont fauna comprising 12 identifiable species was recovered from 17 productive samples (among a total of 19) collected from an interval between 104.1 m to 144.5 m in CBMD006 (Fig. 3, Table 1). The conodonts recovered are opaque black with a Colour Alteration Index (CAI) of 5, indicating a burial temperature of over 300°C (Epstein et al., 1977). Figured conodont specimens (Figs 6–8, which appear at the end of this paper) bear the prefix MMMC (MMMC5907 to MMMC5942 inclusive; 36 specimens in total). Macrofossils are represented by seven samples in total, including corals (Fig. 9), calcareous algae (Fig. 10) and bryozoans (Fig. 11) depicted at the end of the paper. They bear the prefix MMF (MMF 33172 to MMF 33178 inclusive). Their distribution is shown in Fig. 5. All the studied samples were processed at the Geological Survey of New South Wales (GSNSW) Palaeontology (conodonts) and petrographic (thin sections) labs and are deposited in the Fossil Collection (GSNSWFC) in the W B Clarke Geoscience Centre at Londonderry, western Sydney.

CONODONT BIOSTRATIGRAPHY AND CORRELATION

The 12 identifiable species recovered from the CBMD006 drill hole (Table 1) include *Belodina compressa* (Branson and Mehl, 1933) (Figs 6a–f, 7a, b), *Besselodus* sp., *Chirognathus cliefdenensis* Zhen and Webby, 1995 (Figs 6n, 7d, e), *Drepanoistodus suberectus* (Branson and Mehl, 1933) (Fig. 6h–l), gen. et sp. indet. (Fig. 6m), *Panderodus gracilis* (Branson and Mehl, 1933) (Fig. 7h–k), *Panderodus panderi* (Stauffer, 1940) (Fig. 8b), *Panderodus* sp. (Figs 7c, 8a), *Periodon grandis* (Ethington, 1959) (Fig. 8c–h), *Pseudooneotodus mitratus* (Moskalenko, 1973) (Fig. 7f), *Yaoxianognathus borealis* (An in An et al., 1985) (Figs 7g, 8j, k) and *Yaoxianognathus*? *tunguskaensis* (Moskalenko, 1973) (Figs 6o, 8i). Among them, occurrence of *B. compressa* is age diagnostic. As the eponymous species of the *B. compressa* Biozone in the upper Sandbian of the North American Mid-continent succession, its First Appearance Datum (FAD) defines the base of the *B. compressa* Biozone. The species range extends through the overlying *Phragmodus undatus* and *Plectodina tenuis* biozones of late Sandbian to earliest Katian age to the base of the succeeding *Belodina confluens* Biozone of early Katian age (Bergström and Sweet, 1966; Sweet in Ziegler, 1981; Sweet, 1984, 1988; Goldman et al., 2020). Lack of any species characteristic of the succeeding *Ph. undatus* to *Belodina confluens* biozones in the samples from the CBMD006 drill core section supports its correlation with the *B. compressa* Biozone recognized in eastern Australia (Zhen and Percival, 2017), and internationally with the same biozone well-established in the North American Mid-continent succession (Bergström and Ferretti, 2017). The *B. compressa* Biozone of late Sandbian age is also recognized in North China (Wang et al., 2018), in the Tarim Terrane of NW China (Zhao et al., 2000; Wang et al., 2017) and possibly in other palaeobiogeographical provinces of the Tropical Domain within the Late Ordovician Shallow-Sea Realm (Zhen and Percival, 2003; Servais et al., 2023). In eastern Australia, a small conodont assemblage from the upper part of the Wahringa Limestone Member within the Fairbridge Volcanics in the Molong Volcanic Belt of central NSW was previously assigned to the *B. compressa* Biozone (Zhen et al., 2004). Recently the *B. compressa* Biozone has also been recognized within the Billabong Creek Formation exposed in the Gunningbland area of the JNVB (Zhen et al., 2023).

Occurrence of *Yaoxianognathus borealis* in the samples studied from the CBMD006 drill core section is also useful for age determination. This species was originally reported from the upper part of the Yaoxian Formation at the Taoqupo section, about 10 km northwest of Yaozhou District (formerly Yaoxian) of Tongchuan City, Shaanxi Province in North China. An et al. (1985) originally described it as a species of *Tasmanognathus* Burrett, 1979. The type species of the latter genus, *Tasmanognathus careyi* Burrett, 1979, was first reported from the Lower Limestone Member of the Benjamin Limestone (the *Phragmodus undatus–Tasmanognathus careyi* Biozone, representing a stratigraphical interval spanning the uppermost Sandbian to lowest Katian;

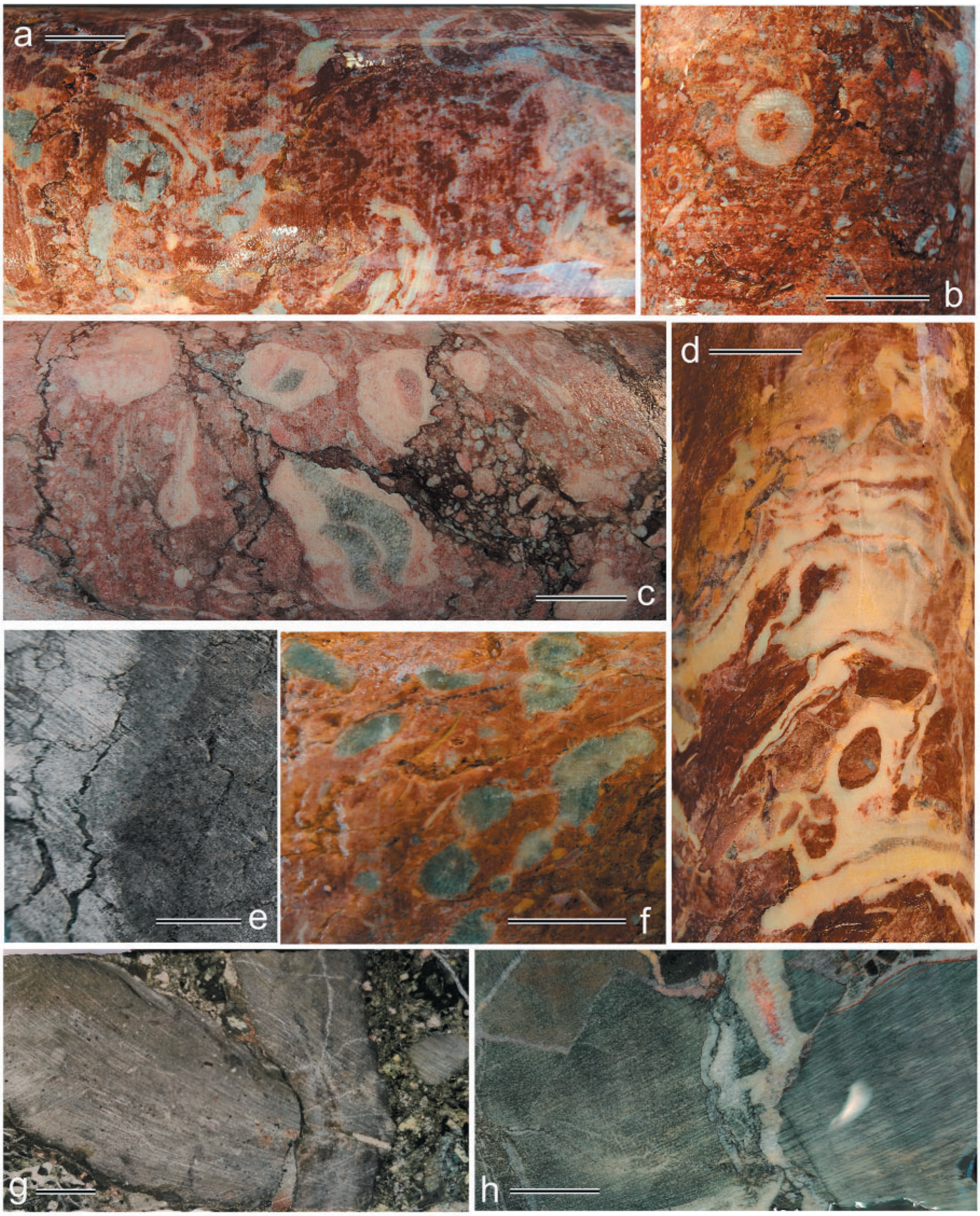

Figure 4. Photos of cores showing the lithology and macrofossils from the CBMD006 drill core section a–f); a, pinkish calcirudite with bioclasts including crinoid ossicles from 99.9 m depth; b, pinkish calcirudite with bioclasts including crinoid ossicles from 99.4 m depth; c, pinkish calcirudite with intraclasts and algal coated bioclasts from 114.4 m depth; d, pinkish limestone with a small domical bryozoan bioherm from 98.8 m depth (MMF 33167a); e, light grey calcirudite with intraclasts and well-developed stylolites from 124.4 m depth; f, pinkish limestone with fossil clasts from depth 98.7 m. g, limestone clasts from 156 m depth of the CBMD001 drill core section; h, limestone clasts from 156 m depth of the CBMD003 drill core section. Scale bars = 1 cm.

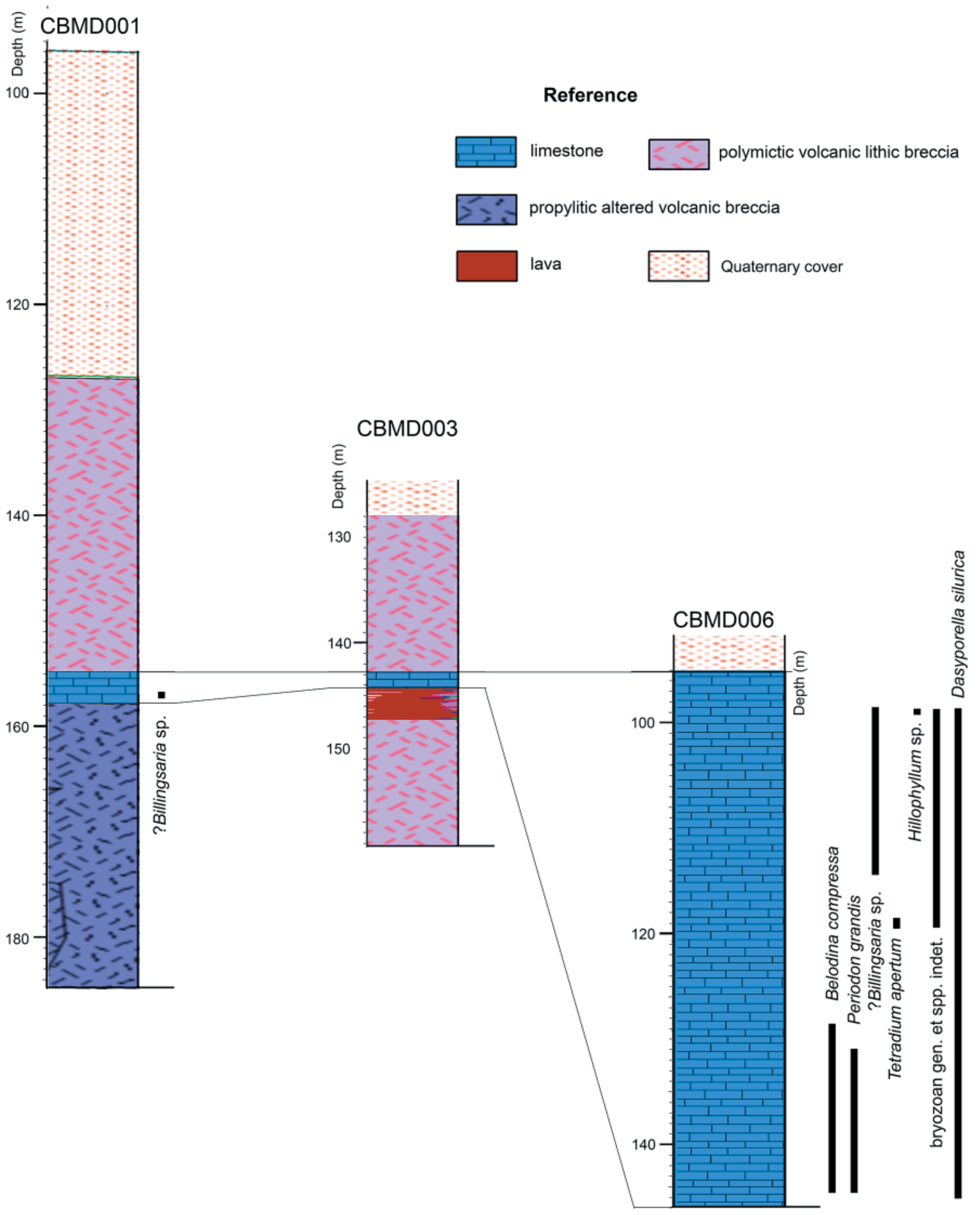

Figure 5. Occurrence of significant conodonts and macrofossils from drill core sections CBMD006 and CBMD001 and inferred correlation of the carbonate intervals intersected in the three drillholes located near Quandialla in south-central New South Wales.

Table 1 (next page). Distribution of conodont species recovered from 17 samples and macrofossils (corals, calcareous algae and bryozoans) from six samples in an unnamed limestone unit within the Curumburrama Volcanics intersected in drillhole CBMD006 near Quandialla in south-central New South Wales.

Sample numbers	MMF 33176	MMF 33174	MMF 33173	MMF 33172	C3189	C3266	C3267	C3269	C3191	C3270	C3271	C3272	C3273	C3192	C3274	C3275	C3276	C3277	C3193	C3278	C3188	MMF 33175	Total
Depth (m)	98.8	119.5	119.4	114.5	104.1-104.7	124.4-124.8	127.0-128.0	129.1-129.6	131.0-131.6	131.6-132.3	132.6-133.1	133.4-134.0	134.5-135.0	136.4-137.0	137.1-138.0	138.5-139.0	139.0-139.7	142.0-143.0	143.4-143.85	143.85-144.0	144.0-144.5	145.5	
Corals																							
Hillophyllum sp.																							
Tetradium apertum		x	x																				
?*Billingsaria* sp.			x	x																			
Calcareous algae																							
Dasyporella silurica	x	x	x	x																		x	
Bryozoans																							
encrusting gen. et sp. indet.	x		x																				
ramose gen. et sp. indet. A																							
ramose gen. et sp. indet. B																							
ramose gen. et sp. indet. C																							
Conodonts																							
Belodina compressa							1	1	2	1	1		3	12					9	2	3		35
Besselodus sp.													1	1						1	1		4
Chirognathus cliefdenensis							1							1									2
Drepanoistodus suberectus					1			1	4	2		1	1	7	1		1		5				24
Gen et sp indet.														1									1
Panderodus gracilis						1				1	6		11	58	5				47	2	6		137
Panderodus panderi					1		2		1			1		4		1			2		1		13
Panderodus sp.											2			3					3		1		9
Periodon grandis									4	1	1		9	13				1	2		1		32
Pseudooneotodus mitratus																			1				1
Yaoxianognathus borealis														4					2		1		7
Yaoxianognathus? tunguskaensis														1					1		1		2
Total					2	1	4	2	11	5	10	2	25	104	6	1	1	1	72	5	15		267

Fig. 2) in central Tasmania. Zhen et al. (2010) suggested that several species of *Tasmanognathus* established in North China were morphologically more closely related to *Yaoxianognathus* and more detailed studies were required to better understand the origination and evolution of the *Yaoxianognathus* species and their inferred ancestral clade represented by the species of *Tasmanognathus*. More recent study of *Tasmanognathus borealis* An in An et al., 1985, based on the material from North China, considered it as representing the earliest known species of *Yaoxianognathus* with a stratigraphic range extending from the *B. compressa* Biozone to *Belodina confluens* Biozone (Yang et al., 2019). In Australia, conodont specimens closely comparable with *Y. borealis* were previously reported from the Fossil Hill Limestone (lower Katian) of the Cliefden Caves Limestone Subgroup, central NSW (Zhen and Webby, 1995, p. 289, pl. 5, fig. 23; referred to as *Tasmanognathus* sp.) and from an unnamed subsurface limestone unit of Late Ordovician (late Sandbian to earliest Katian) age intersected in drillcores in the Marsden Prospect (Percival et al. 2006, fig. 3M; referred to as *Tasmanognathus* sp. cf. *T. borealis*).

The type specimens of *Chirognathus cliefdenensis* were from the Cliefden Caves Limestone Subgroup (Zhen and Webby, 1995). This species with its distinctive morphology was widely recorded from various stratigraphic units of early to middle Katian age in central NSW, including the Bowan Park Limestone Subgroup (Zhen et al., 1999), from allochthonous limestone clasts in the lower part of the Malongulli Formation (Trotter and Webby, 1995), from allochthonous limestone blocks of early to middle Katian age in the upper Silurian Barnby Hills Shale (Zhen et al., 2003), and from allochthonous limestone clasts of early Katian age within the Lower Devonian (Lochkovian) Cuga Burga Volcanics (Zhen, 2018). Its occurrence in the CBMD006 drill core samples of this study confirms that *Ch. cliefdenensis* has a stratigraphic range in central NSW extending from upper Sandbian to middle Katian. Morphologically, *Ch. cliefdenensis* shows some resemblance to *Chirognathus tricostatus* Zhen in Zhen et al., 2010, from the Lower Limestone Member of the Benjamin Limestone of late Sandbian to earliest Katian age (*Phragmodus undatus-Tasmanognathus careyi* Biozone) in central Tasmania. However, the Tasmanian species differs from *Ch. cliefdenensis* in having a distinctive tricostate cusp that is well-developed in its Sb, Sc and Sd elements (Zhen et al., 2010) and has not been reported from outside Tasmania.

CORAL, BRYOZOAN AND CALCIFIED ALGAE ASSEMBLAGES

Macrofossils are common in the upper part of the unnamed limestone unit intersected in the drillhole CBMD006 (Fig. 5). They include the rugose coral *Hillophyllum* sp. (Fig. 9a, b) and tabulate corals *Tetradium apertum* Safford, 1856 (Fig. 9c–e) and ?*Billingsaria* sp. (Fig. 9f–i). This coral association is typical of coral/stromatoporoid Fauna I, which was summarized by Webby et al. (2004, fig. 15.5), or the equivalent *Hillophyllum-Tetradium-Rosenella* coral-stromatoporoid assemblage zone of Pickett and Percival (2001). The occurrence of the corals indicates that the top of this limestone unit may extend to the lowest Katian (Eastonian 1) in the CBMD006 drill core section (Fig. 5). *Hillophyllum* is characterized by having a solitary to fasciculate growth form and exhibiting monacanthine septa and may represent the earliest known rugosan coral; it has only been recorded from Australia. Its type species, *Hillophyllum priscum* Webby, 1971, is an age-diagnostic species of coral/stromatoporoid Fauna I of earliest Katian age in central NSW (Zhen and Webby, 1995). It was reported from the Fossil Hill Limestone, Bowan Park Limestone Subgroup, Regans Creek Limestone, Billabong Creek Formation and Reedy Creek Limestone (Webby, 1971; Webby et al., 2004). Corbett and Banks (1974) reported an occurrence of *Hillophyllum* from the Lower Limestone Member of the Benjamin Limestone in central Tasmania (*Phragmodus undatus-Tasmanognathus careyi* Biozone of late Sandbian to earliest Katian age, see Zhen et al., 2010). *Hillophyllum* is represented only by a fragmentary specimen (Fig. 9a, b) from the very top of the unnamed limestone unit intersected in CBMD006 drillhole (Fig. 5). It shows a narrow peripheral septal stereozone formed by possibly monacanthine and distally free septal spines and complete and slightly domed tabulae spaced 8–10 per 5 mm of vertical distance. Previously reported from the lower part of the Daylesford Limestone (Bowan Park Limestone Subgroup) and from the Billabong Creek Formation, the tabulate coral *Tetradium apertum* (Fig. 9c–e) has a known biostratigraphic distribution in NSW restricted to coral/stromatoporoid Fauna I (Webby and Semeniuk, 1971; Pickett and Percival, 2001). Hemispherical to encrusting cerioid (or ?astreoid) tabulate corals referred to herein as?*Billingsaria* sp. are common in the upper part of the unnamed limestone unit intersected in CBMD006 drillhole, but specimens recovered are too poorly preserved to identify precisely. It is characterized by having a thick wall formed by coarse and dilated septal trabeculae and widely spaced complete and slightly sagging tabulae (Fig. 9f–i). Recovery of ?*Billingsaria* sp. in the much thinner limestone breccia (calcirudite) interval at depth 157.3 m (sample MMF 33178) intersected in CBMD001 suggests a broad correlation with the unnamed limestone unit of CBMD0006 (Fig. 5).

Fossil calcareous green algae represented by fragmentary *Dasyporella* and *Vermiporella* were briefly reported from the upper part of the Daylesford Limestone (early Katian) of the Bowan Park Limestone Subgroup (Semeniuk, 1973; Semeniuk et al., 2019). *Vermiporella* ranges from the Ordovician to Permian and is widely distributed biogeographically. It can be distinguished from *Dasyporella* by having an external lobed form and thin wall (Riding and Fan, 2001). Small sub-cylindrical calcified tubes from limestone unit intersected in CBMD006 drillhole, that are characterized by having a broad central cavity and moderately thick wall pierced at right-angles by narrow closely spaced tubular (acrophorous) pores, are assigned to the calcareous alga *Dasyporella silurica* Stolley, 1893 (Fig. 10a–d). *Dasyporella silurica* was originally documented from Upper Ordovician and lower Silurian rocks of eastern Kazakhstan (Stolley, 1893). This species was also reported from Upper Ordovician strata in the northern part of the Tarim terrane (Riding and Fan, 2001) and from the Middle Ordovician to lower Silurian interval of the Tethys Himalaya, India (Bhargava and Bassi, 1986; Sinha and Trampisch, 2013; Pandey and Parcha, 2018). Its appearance in the limestone intersected in the CBMD006 drillhole represents the first confirmed record of this calcareous alga species from Australia. *Dasyporella silurica* is also palaeobiogeographically significant as its currently known records from Kazakhstan, Tarim, Himalaya and now eastern Australia suggest a distribution likely restricted to eastern Gondwana.

Bryozoans (Fig. 11a–g) are common in the upper part of the unnamed limestone unit intersected in the CBMD006 drillhole and are represented by at least four species. The encrusting form is most common and at 98.8 m depth colonies of this species form a small domical biohermal structure 7 cm in height (Figs 4d, 11a–c). Ramose bryozoans with a slender branching zoarium have only been recovered from the very top (sample MMF 33177, Table 1) of the limestone unit. Ramose gen. et sp. indet. A (Fig. 11d, e) is relatively common, but the other ramose gen. et sp. indet. B (Fig. 11f) and ramose gen. et sp. indet. C (Fig. 11g) are rare. They are represented by only a single specimen each with the former showing the mesothecal region in longitudinal section (Fig. 11f) and the latter showing zooecial orifices and acanthopores in tangential section of the zooecial wall (Fig. 11g). Although bryozoans are common in the Upper Ordovician carbonate succcessions in NSW, this important fossil group has not been taxonomically treated since the documentation of Ross (1961).

BIOFACIES AND INFERRED DEPOSITIONAL SETTINGS

Common appearance of corals (Fig. 9a–i), calcareous alga *Dasyporella silurica* (Fig. 10a–d), small encrusting (Figs 4d, 11a–c) and slender ramose (Figs 4f, 11d–g) bryozoans, and grainstone dominated by algal and cyanobacteria coated bioclasts (Figs 4a–c, f, 10e) at the top of the limestone unit intersected in the CBMD006 drill core section indicates a predominantly shallow water depositional setting. Conodonts are mainly recovered from the middle to lower part of the limestone unit (Fig. 3), which is characterized by extremely rare occurrence or absence of corals, bryozoans and calcareous algae or other encrusting organisms. Hence, we interpret the lower part of the limestone as likely deposited in relatively deeper-water facies of intermediate to distal shelf settings before its subsequent transportation and redeposition in a submarine fan system of slope to basinal settings. Mixture of typical shallow water forms (e.g. *Chirognathus cliefdenensis* and species of *Yaoxianognathus*) and deep-water forms (e.g. *Periodon grandis*) in many of the CBMD006 drill core samples is consistent with the calcirudite lithology of this limestone unit (Fig. 4c, e). Predominance of intraclasts of irregular shapes in the limestone suggests that they were locally sourced, probably from the steep gradient shallow-water carbonate shelf or build-ups fringing volcanic edifices in the region. This unnamed carbonate unit may correlate to the calcirudite interval (Fig. 4g) intersected from depth 150 to 165m in the CBMD0001 drill core section, supported by the appearance of the tabulate coral ?*Billingsaria* sp. in both drillholes (Fig. 5). This carbonate unit is only briefly represented over an interval of 142.80 to 143.35m (Fig. 4h) of limestone clasts in the CBMD0003 drill core section, but no fossils are found (Fig. 5).

CONCLUSIONS

Conodonts and macrofossils (corals, calcareous algae, and bryozoans) recovered from an unnamed carbonate unit intersected in drill hole CBMD006 provide the first definitive age dating for the Currumburrama Volcanics distributed in the southern Junee–Narromine Volcanic Belt (JNVB). These new biostratigraphic data together with faunas previously reported from the Lake Cowal Volcanic Complex of the Marsden prospect and from the Jingerangle Formation exposed in the study area (Percival et al., 2006) support their direct correlation with the well-dated marine shelf successions and associated volcanic sequences exposed in the central and northern sectors of the JNVB within the Ordovician Macquarie Volcanic Province in central New South Wales. Predominance of intraclasts and bioclasts of irregular shapes in the limestone suggests that this unnamed limestone unit within the Currumburrama Volcanics was locally sourced, probably from the steep gradient shallow-water carbonate shelf or build-ups fringing volcanic islands in the region.

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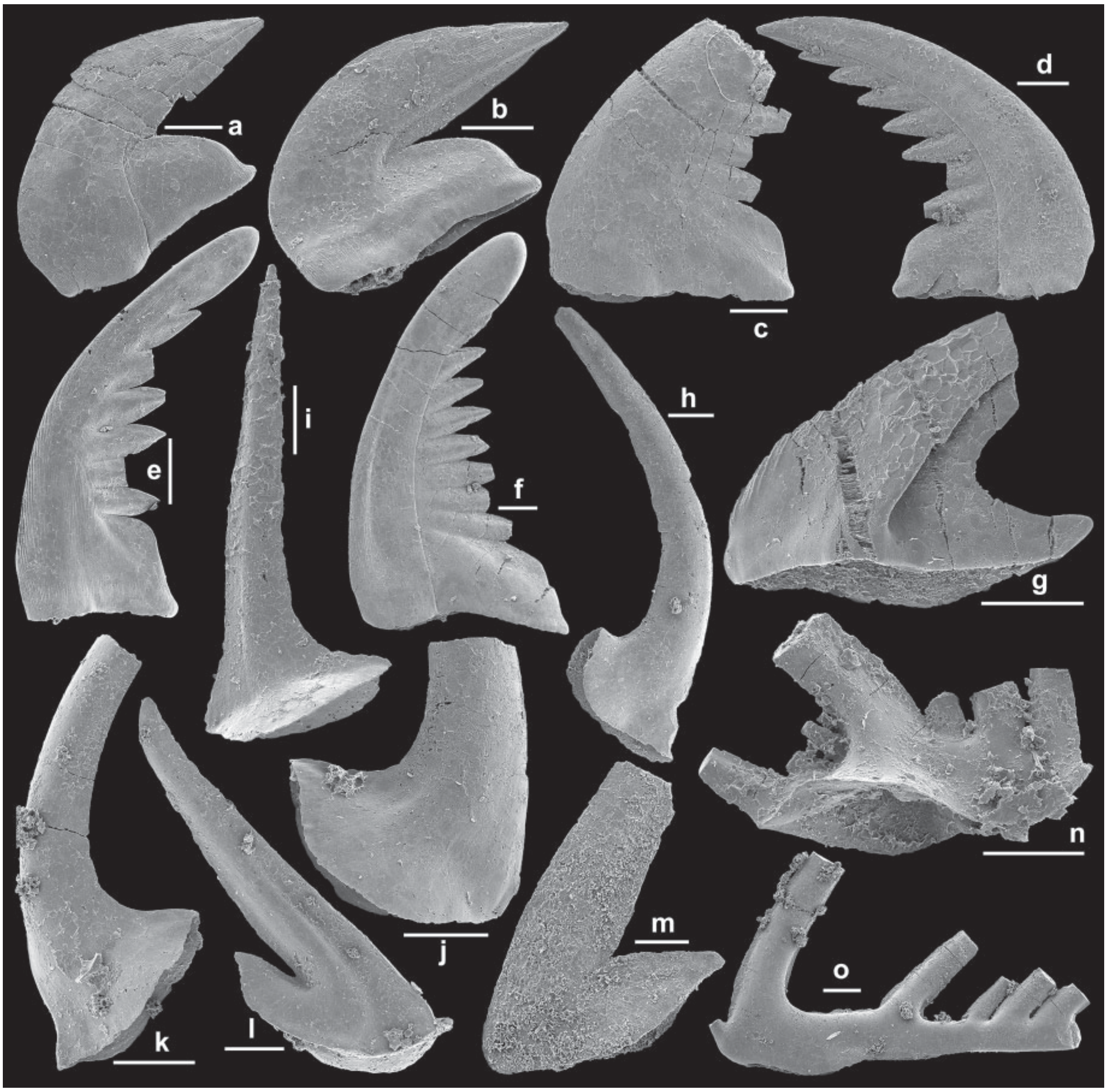

Figure 6. SEM images of conodonts from the CBMD006 drill core section; a–f, *Belodina compressa* (Branson and Mehl, 1933); a, M (eobelodiniform) element, MMMC5907, sample C3188, view of furrowed side (IY415-028); b, M (eobelodiniform) element, MMMC5908, sample C3192, view of unfurrowed side (IY415-009); c, S1 (compressiform) element, MMMC5909, sample C3193, inner-lateral view (IY415-024); d, S1 (compressiform) element, MMMC5910, sample C3192, outer-lateral view (IY415-008); e, S2 (grandiform) element, MMMC5911, sample C3192, inner-lateral view (IY415-007); f, S2 (grandiform) element, MMMC5912, sample C3193, outer-lateral view (IY415-023). g, *Besselodus* sp.; P element, MMMC5913, sample C3188, outer-lateral view (IY415-026). h–l, *Drepanoistodus suberectus* (Branson and Mehl, 1933); h, Pb element, MMMC5914, sample C3192, outer-lateral view (IY415-020); i, Sa element, MMMC5915, sample C3191, lateral view (IY415-027); j, Sc element, MMMC5916, sample C3192, outer-lateral view (IY415-018); k, Pa element, MMMC5917, sample C3192, outer-lateral view (IY415-019); l, M element, MMMC5918, sample C3192, posterior view (IY415-017); m, gen. et sp. indet.; M element, MMMC5919, sample C3192, posterior view (IY415-021); n, *Chirognathus cliefdenensis* Zhen and Webby, 1995; Sc element, MMMC5920, sample C3192, inner-lateral view (IY415-015); o, *Yaoxianognathus*? *tunguskaensis* (Moskalenko, 1973); Sc element, MMMC5921, sample C3192, inner-lateral view (IY415-001). Scale bars = 100 µm.

Figure 7. Focus-stacked black and white images (captured using an Olympus BX53M compound microscope and a DP74 digital camera) of conodonts from the CBMD006 drill core section; a, b, *Belodina compressa* (Branson and Mehl, 1933); a, S1 (compressiform) element, MMMC5922, sample C3192, inner-lateral view; b, S1 (compressiform) element, MMMC5923, sample C3192, outer-lateral view. c, *Panderodus* sp.; MMMC5924, sample C3192, inner-lateral view. d, e, *Chirognathus cliefdenensis* Zhen and Webby, 1995; Sb element; MMMC5925, sample C3267, D, anterior view; E, posterior view. f, *Pseudooneotodus mitratus* (Moskalenko, 1973); MMMC5926, sample C3193, apical view. g, *Yaoxianognathus borealis* (An in An et al., 1985); MMMC5927, sample C3192, outer-lateral view. h–k, *Panderodus gracilis* (Branson and Mehl, 1933); h, arcuatiform element; MMMC5928, sample C3192, outer-lateral view; i, asimiliform element; MMMC5929, sample C3192, outer-lateral view; j, asimiliform element; MMMC5930, sample C3192, outer-lateral view; k, arcuatiform element; MMMC5931, sample C3192, outer-lateral view. Scale bars = 100 µm.

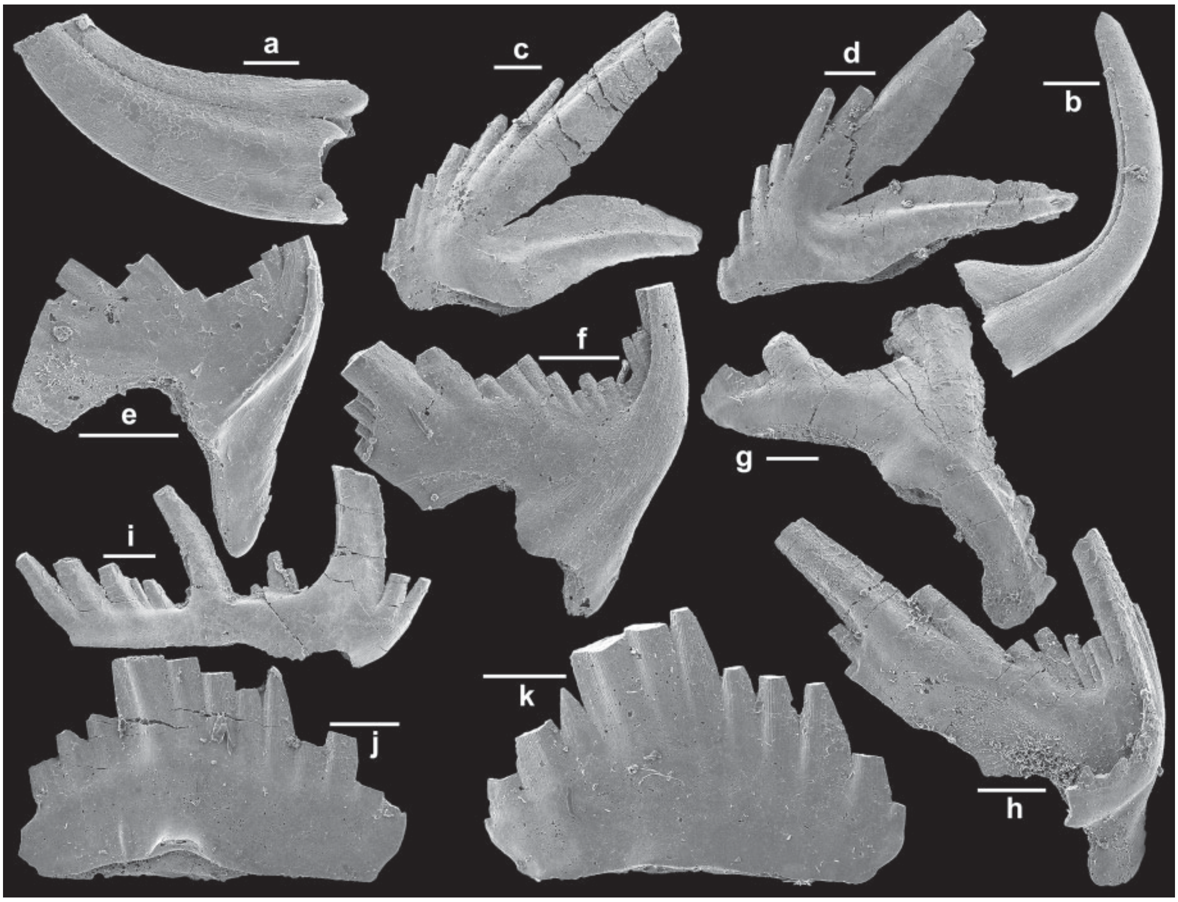

Figure 8. SEM images of conodonts from the CBMD006 drill core section; a, *Panderodus* sp.; MMMC5932, sample C3188, outer-lateral view (IY415-029). b, *Panderodus panderi* (Stauffer, 1940); MMMC5933, sample C3192, outer-lateral view (IY415-022). c–h, *Periodon grandis* (Ethington, 1959); c, M element, MMMC5934, sample C3192, anterior view (IY415-002); d, M element, MMMC5935, sample C3192, posterior view (IY415-003); e, Sb element, MMMC5936, sample C3192, outer-lateral view (IY415-016); f, Sc element, MMMC5937, sample C3192, outer-lateral view (IY415-013); g, Pa element, MMMC5938, sample C3192, outer-lateral view (IY415-014); h, Sb element, MMMC5939, sample C3192, outer-lateral view (IY415-005). i, *Yaoxianognathus*? *tunguskaensis* (Moskalenko, 1973); Sc element, MMMC5940, sample C3193, inner-lateral view (IY415-025). j, k, *Yaoxianognathus borealis* (An in An et al., 1985); Pa element; j, MMMC5941, sample C3192, inner-lateral view (IY415-010); k, MMMC5942, sample C3192, outer-lateral view (IY415-006). Scale bars = 100 µm.

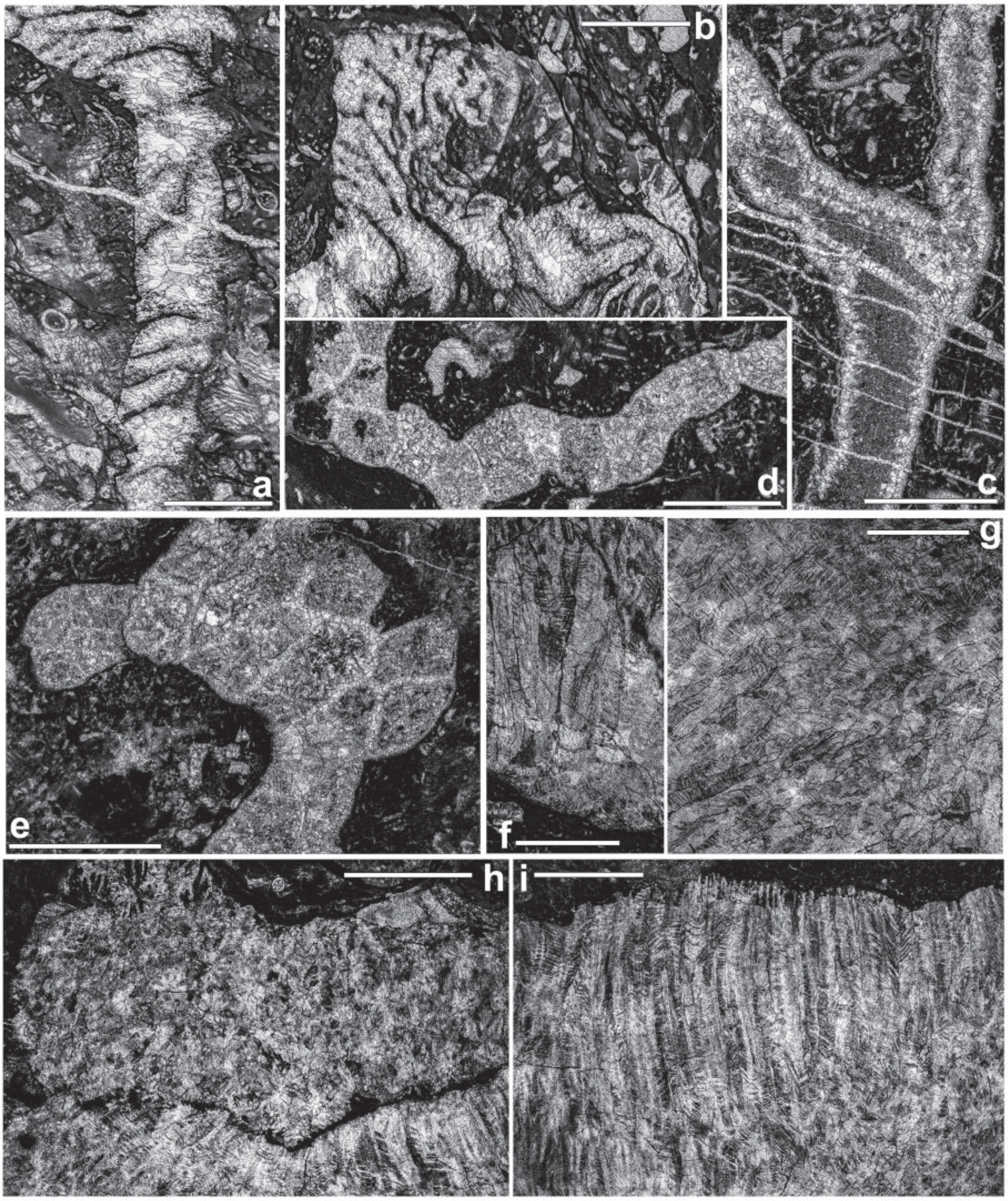

Figure 9. Corals recovered from drill core section CBMD006; a, b, *Hillophyllum* sp.; MMF 33177b-2, a, longitudinal section, b, transverse section. c–e, *Tetradium apertum* Safford, 1856; c, MMF 33174b-1, longitudinal section; d, MMF 33174a-1, transverse section; e, MMF 33174a-2, transverse section. f–i,?*Billingsaria* sp.; f, g, MMF 33177b-1, f, longitudinal section, g, transverse section; h, i, MMF 33172-3, h, transverse section, i, longitudinal section. Scale bars = 2 mm.

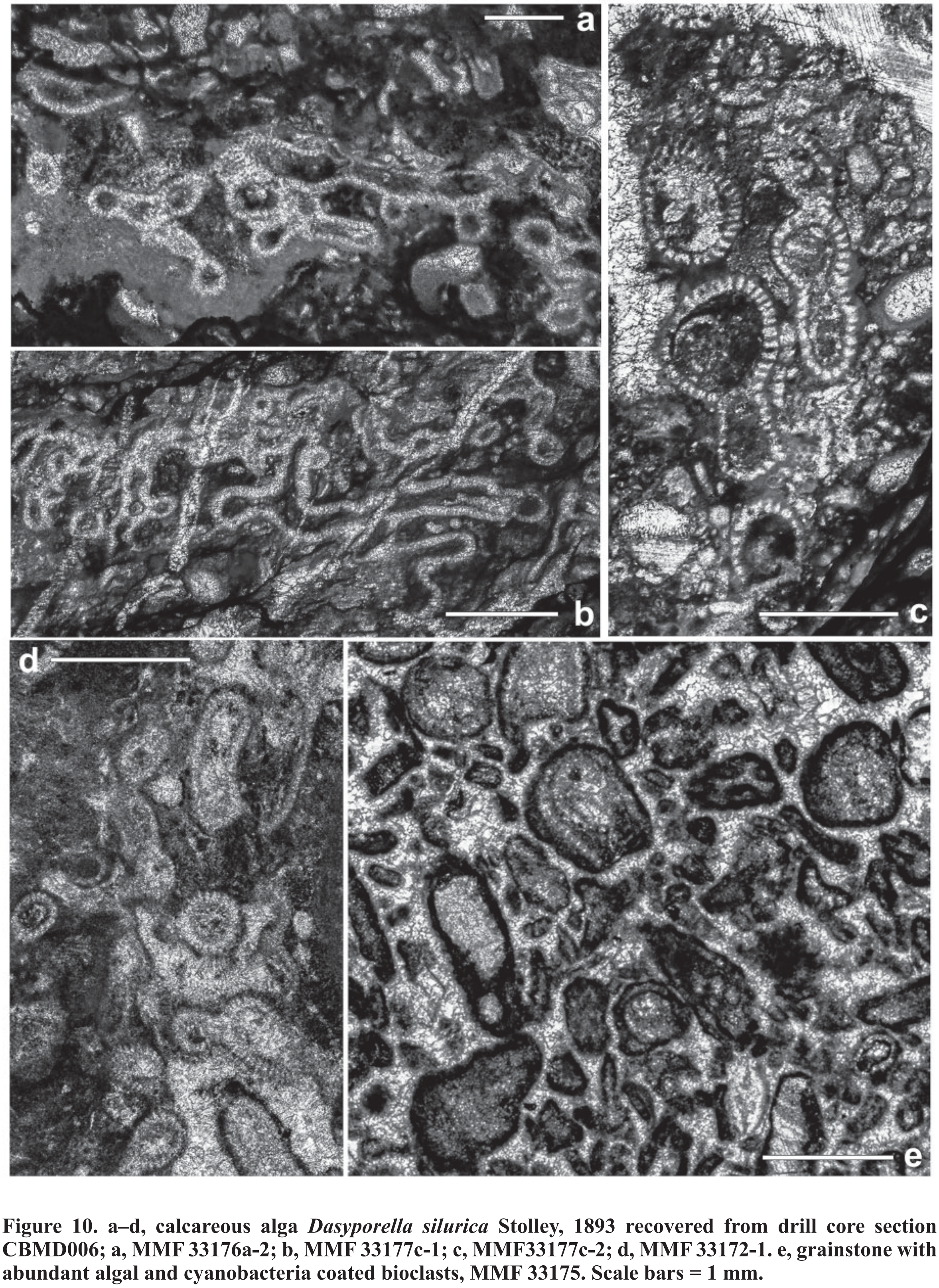

Figure 10. a–d, calcareous alga *Dasyporella silurica* Stolley, 1893 recovered from drill core section CBMD006; a, MMF 33176a-2; b, MMF 33177c-1; c, MMF33177c-2; d, MMF 33172-1. e, grainstone with abundant algal and cyanobacteria coated bioclasts, MMF 33175. Scale bars = 1 mm.

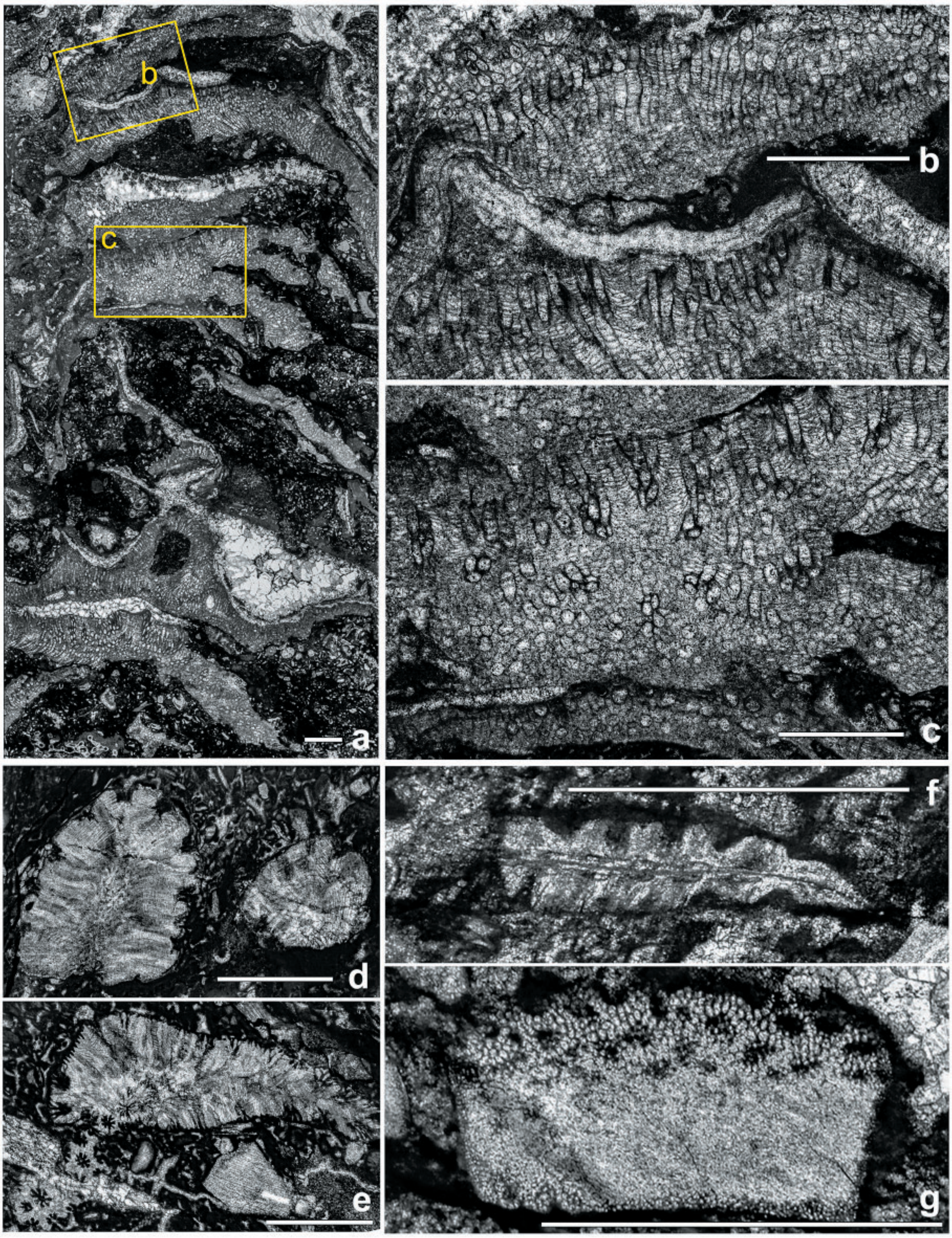

Figure 11. Bryozoans recovered from drill core section CBMD006; a–c, encrusting gen. et sp. indet.; a small domical bioherm structure from 98.8 m depth; MMF 33176a, longitudinal section; a, general view, b, c, close up views. d, e, ramose bryozoans of gen. et sp. indet. A; d, MMF 33177a-1, branch transverse and longitudinal sections; e, MMF 33177a-2, longitudinal section and oblique tangential section showing zooecial orifices. f, ramose bryozoan of gen. et sp. indet. B; MMF 33177b-3, longitudinal section showing the mesothecal region. g, ramose bryozoan of gen. et sp. indet. C; MMF 33177b-4, fragmentary tangential section showing zooecial orifices and acanthopores in the zooecial wall. Scale bars = 1 mm.