CSIRO Publishing
www.publish.csiro.au/journals/rs

The Royal Society of Victoria, 131, 7–52, 2019
10.1071/RS19008

THE ORDOVICIAN GRAPTOLITE SUBFAMILY KINNEGRAPTINAE IN VICTORIA, AUSTRALIA

A.H.M. VandenBerg

Research Associate, Geoscience, Museums Victoria, GPO Box 666, Melbourne Victoria 3001, Australia

Correspondence: Fons VandenBerg, alfonsvandenberg16@gmail.com

ABSTRACT: Victoria is emerging as the region where members of the Ordovician graptolite subfamily Kinnegraptinae, revised herein, reached its highest diversity, with 16 or 17 species present, grouped in the four genera *Paradelograptus* Erdtmann et al. (1987), *Lignigraptus* n. gen., *Wuninograptus* Ni, 1981 and *Psenograptus* n. gen. The biostratigraphic range of the subfamily extends over much of the Early and Middle Ordovician, from the late Tremadocian *Aorograptus victoriae* Biozone to the late Darriwilian *Archiclimacograptus riddellensis* Biozone. Species described are *Paradelograptus antiquus* (T.S. Hall, 1899a), *P. pritchardi* (T.S. Hall, 1899a), *P. bulmani* (Thomas, 1973), *P. maletzi* n. sp., *P. orthae* n. sp., *P. cayleyi* n. sp., *Lignigraptus chapmani* (Keble & Harris, 1934), *L. sedecimus* (Harris & Thomas, 1938a), *L. ramulosus* (Harris & Thomas, 1938a), *L. erdtmanni* (Rickards & Chapman, 1991), *L. gnomus* n. sp., *L. absidatus* n. sp., *L. daangean* n. sp., *L. diabolus* n. sp., *Wuninograptus quadribrachiatus* Ni, 1981, *Psenograptus costermansi* n. sp., *Psenograptus* sp. A and *Psenograptus* sp. B. The term *glossa* is proposed for the elongate apparatuses that adorn thecal apertures of *Kinnegraptus*, *Lignigraptus* and *Wuninograptus*.

Keywords: Kinnegraptinae Mu, *Paradelograptus*, *Lignigraptus* gen. nov., *Psenograptus* gen. nov., *Wuninograptus*, taxonomy, biostratigraphy, Early Ordovician, Middle Ordovician

The presence of graptolites belonging to the subfamily Kinnegraptinae Mu, 1974 in Victoria was first mentioned in an excursion guide by VandenBerg and Stewart (1983), who listed *Kinnegraptus* sp. from a Floian (Be4–Ch1) fauna from Devilbend Quarry, on the Mornington Peninsula southeast of Melbourne. VandenBerg and Cooper (1992) listed the occurrence of *Kinnegraptus kinnekullensis* at Devilbend Quarry, and further referred *Tetragraptus chapmani* Keble & Harris, 1934 to *Kinnegraptus*. Somewhat earlier, Erdtmann et al. (1987) referred seven Victorian species to their new genus *Paradelograptus*. These were *Leptograptus antiquus* T.S. Hall, 1899a; *Didymograptus pritchardi* T.S. Hall, 1899a; *Clonograptus smithi* Harris & Thomas, 1938a; *Clonograptus ramulosus* Harris & Thomas, 1938a; *Clonograptus tenellus* var. *problematica* Harris & Thomas, 1938a; *Clonograptus rarus* Harris & Thomas, 1938a; and *Dichograptus sedecimus* Harris & Thomas, 1938a. Other Victorian species they thought to be closely related to *Paradelograptus* were *Clonograptus tenellus* sensu lato of Cooper & Stewart 1979, *Tetragraptus chapmani*, *Tetragraptus bulmani* Thomas, 1973 and *Tetragraptus clarkefieldi* Thomas & Keble (in Harris & Thomas, 1938b).

The recognition of *Paradelograptus* as a distinct genus was a considerable advance. Prior to this, generic assignment of some of the species listed by Erdtmann et al. (1987) had proved problematical. Species from the *Aorograptus victoriae* Biozone (La2) had been assigned to several different genera. Cooper (1979a) referred *Leptograptus antiquus* and *Didymograptus pritchardi* to *Adelograptus* Bulman, 1941. *Leptograptus antiquus*, *Didymograptus pritchardi* and *Tetragraptus bulmani* were assigned to *Kiaerograptus* Spjeldnaes, 1963 by other authors, based on the presence of a sicular bitheca.

The recent reviews of the Anisograptidae and Sinograptidae by Maletz et al. (2017, 2018) have further clarified the matter. These authors showed that a sicular bitheca is present in the type species of *Paradelograptus*, *P. onubensis* (Maletz et al. 2018, figs 1.1, 1.2), and also that in *Kiaerograptus*, the apertural part of the sicula is freely pending (Maletz et al. 2017, p. 11) which is not the case in any of the aforementioned La2 species. Erdtmann et al. (1987) considered the degree of symmetry of the two first-order stipes to be one of the prime diagnostic tools to distinguish *Paradelograptus* from *Kinnegraptus*, with *Kinnegraptus* being highly symmetrical and *Paradelograptus* highly asymmetrical (Figure 1). In Victoria, it is possible to discriminate two groups of kinnegraptines: (1) a group whose thecal apertures have simple rutella without projecting apparatuses; and (2) a group whose thecal apertures have long rutella that resemble those of *Kinnegraptus kinnekullensis* Skoglund, 1961. The first group consists of six species that can be readily accommodated in *Paradelograptus*. In the second group, which consists of seven species, two have proximal regions that show no detail of the configuration of the initial growth. Of the remainder, all have the same asymmetric configuration as in *Paradelograptus*. These

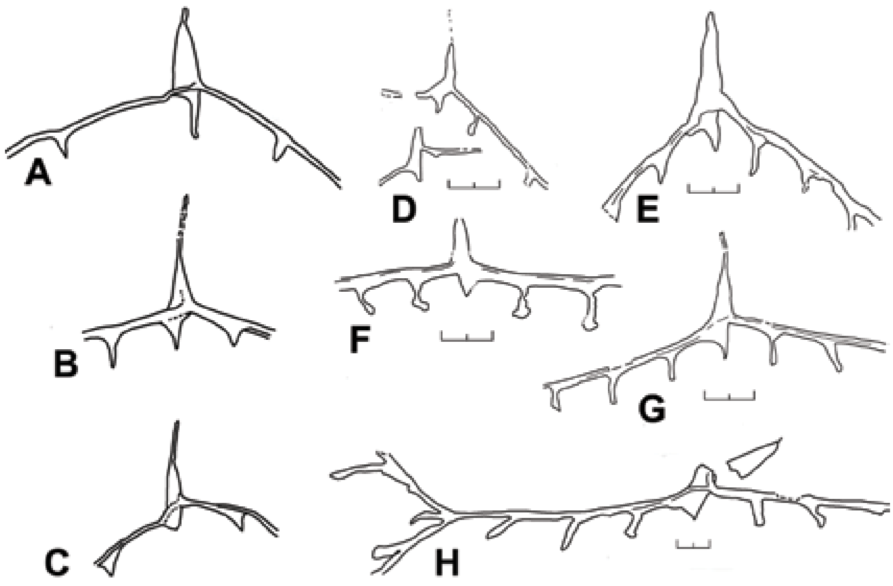


Figure 1: Profiles of proximal regions of kinnegraptines showing differences in symmetry, ranging from essentially symmetrical (**A**) to weakly asymmetrical (**B**, **E**, **F**) to strongly asymmetrical (**C**, **D**, **G**, **H**). **A**: *Kinnegraptus kinnekullensis*; **B**: *Lignigraptus kinnegraptoides*; **C**: *Paradelograptus onubensis*; **D**: *L. gnomus*; **E**: *L. absidatus*; **F**: *L. diabolus*; **G**: *L. daangean*; **H**: *L. chapmani*. **A–C** from Erdtmann et al. (1987, fig. 4, published without scales). Scales 2 mm long.

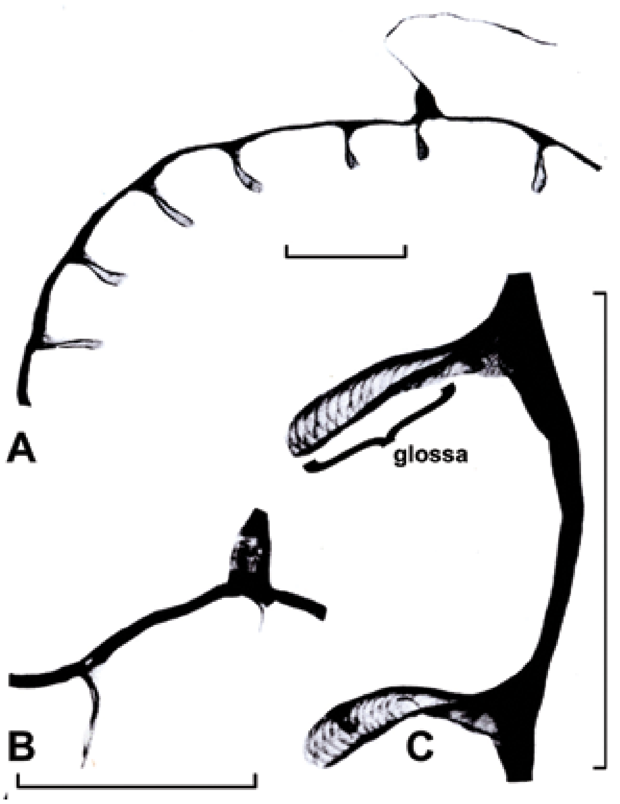


Figure 2: Isolated 3D specimens of *Kinnegraptus kinnekullensis* Skoglund, 1961, from the *Isograptus victoriae lunatus* Biozone of the Cow Head Group, Newfoundland, Canada, from Williams & Stevens (1988, pl. 30 figs 3–5). **A** shows a substantial portion of a tubarium — note the variation in thecal length and the long slender prothecae and very short, strongly flaring metathecae. **B** shows the structure of the sicula; the black portion at the top is the prosicula. **C** shows the fine structure of the spatulate glossae, whose appearance varies with the amount of rotation; viewed from the side, as in **B**, they appear threadlike. Note also the dark rims of the glossae, presumably marking a reinforcing selvage. Scale bars are 1 mm long.

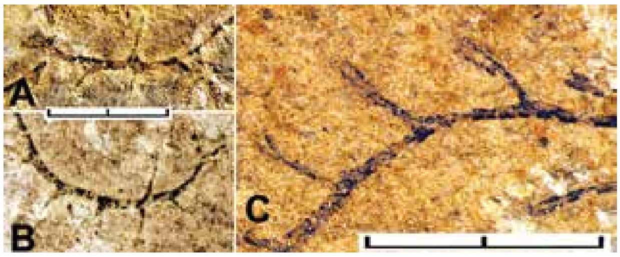


Figure 3: *Wuninograptus quadribrachiatus* Ni, 1981 — details of proximal portions (**A**, **B**) and thecae showing glossae (**C**). **A**: NIGP 54074; **B**, **C**: NIGP 54077; from the upper Darriwilian (*Didymograptus jiangxiensis* Biozone) of Jiangxi Province, China. Photos supplied by Jörg Maletz. Scale bars 2 mm long.

cannot be accommodated in *Kinnegraptus* and comprise a new genus, for which the name *Lignigraptus* is proposed.

The fine structure of the rutellar apparatuses of *Kinnegraptus*, and of species of *Lignigraptus*, did not become clear until 3D tubaria were extracted from limestone (Williams & Stevens 1988). They resemble the scoops of lacrosse sticks, with thickened rims that give them a high preservation potential (Figure 2). This spatulate structure explains why their appearance is variable, sometimes resembling long spines when viewed laterally. They were also quite flexible. I propose the term *glossa* (L: tongue, pl. *glossae*) for these apparatuses. Several specimens of different species of *Lignigraptus* are sufficiently well preserved to show they have the same structure, as do specimens of *Wuninograptus tetrabrachiatus* Ni, 1981 (Figure 3).

As noted by Skoglund (1961) and Erdtmann et al. (1987), the walls of the metathecae in kinnegraptines are generally much thinner than the remainder of the tubarium. In addition, sclerotisation may be complete in all thecae of some tubaria, whereas other tubaria may show only some thecae sclerotised, usually distal ones; in some cases, only the common canals and prothecal portions appear to have been sclerotised. Some large tubaria of multi-stiped taxa have extensive secondary thickening, along the dorsal side of the proximal stipes. This thickening is most prominent in the funicle to the extent that the sicula may be completely obscured.

BIOSTRATIGRAPHIC RANGE

The biostratigraphic appearances of kinnegraptine species in Victoria can only be determined at zonal levels, not within zones, as there are no continuously fossiliferous sequences (VandenBerg & Cooper 1992). The sequence at Hunneberg, Sweden, by contrast, has a continuously fossiliferous succession that shows the first kinnegraptine, *Paradelograptus antiquus*, appearing in the La2 *P. antiquus* Zone of the Töyen Shale, before the appearance of *Paratetragraptus approximatus* (Erdtmann et al. 1987). *Paradelograptus* cf. *onubensis* occurs where *P. approximatus* makes its appearance, marking the base of La3. Two other kinnegraptines occur within La3: *Lignigraptus kinnegraptoides* and *L. chapmani* (recorded as *P. mosseboensis*). In Victoria, by contrast, six kinnegraptine species occur within the La2 *Aorograptus victoriae* Biozone: *Paradelograptus antiquus*, *P. bulmani*, *P. pritchardi*, *P. maletzi*, *P. orthae* and *P. cayleyi*, followed by three in the La3 *P. approximatus* Biozone: *Lignigraptus chapmani*, *L. gnomus* and *Psenograptus* sp. A, with six species making their first appearances in the succeeding Be1 *P. approximatus* + *T. fruticosus* Biozone: *Lignigraptus sedecimus, L. absidatus*, *L. ramulosus*, *L. erdtmanni, Psenograptus costermansi* and *Ps.* sp. B (Table 1). Two more new species, *Lignigraptus daangean* and *L. diabolus,* occur in the next two zones. *Kinnegraptus kinnekullensis*, which was the first kinnegraptine to be described, does not occur in Victoria but occurs in Newfoundland in the Ca1 (= basal Middle Ordovician) *Isograptus lunatus* Biozone (Williams & Stevens 1988). This is a considerable time after the extraordinary diversification of kinnegraptines in the late Tremadocian and early Floian. There is an even longer time gap before the occurrence of the last kinnegraptine, *Wuninograptus quadribrachiatus*, at the end of the Darriwilian (Table 1).

Table 1: Biostratigraphic distribution of taxa discussed in the text. *Kinnegraptus kinnekullensis* does not occur in Australia but is included to show its occurrence well after the burst of radiation of kinnegraptine species in the late Tremadocian and early Floian. Correlation with international stages is based on Loydell (2012). Victorian zone names are as revised by VandenBerg (2017).

		Victorian stages	Symbol	Zone name	Kinnegraptid occurrences
Middle Ordovician	Dapingian	Darriwilian	Da4	*A. riddellensis*	***Wuninograptus** quadribrachiatus*
			Da3	*A. decoratus*	
			Da2	*L.? intersitus*	
			Da1	*L. austrodentatus*	
		Yapeenian	Ya2	*C. morsus*	
			Ya1	*O. upsilon*	
		Castlemainian	Ca4	*I. victoriae maximodivergens*	
			Ca3	*I. victoriae maximus*	
			Ca2	*I. victoriae victoriae*	
Early Ordovician	Floian		Ca1	*I. lunatus*	(***Kinnegraptus** kinnekullensis*)
		Chewtonian	Ch2	*I. primulus*	
			Ch1	*D. kremastus*	***Lignigraptus** daangean*
		Bendigonian	upper	*T. tridens*	***Lignigraptus** diabolus*, ***Psenograptus*** sp. B
			lower	*P. approximatus* + *T. fruticosus*	***Lignigraptus** sedecimus*, *L. absidatus*, *L. ramulosus*, *L. erdtmanni*; ***Psenograptus** costermansi*
		Lancefieldian	La3	*P. approximatus*	***Lignigraptus** chapmani* & *L. gnomus*; ***Psenograptus*** sp. A
	Tremadoc		La2	*A. victoriae*	***Paradelograptus** antiquus*, *P. bulmani*, *P. pritchardi*, *P. maletzi*, *P. orthi*, *P. cayleyi*
			La1b	*Psigraptus*	
			La1a	*R. scitulum* and *Anisograptus*	

Jackson (1974), Jackson and Lenz (2000, 2003) and Jackson and Norford (2004) illustrated various kinnegraptine species, including several new species, from the *A. victoriae* and *T. fruticosus* Biozones in Yukon Territory in Canada. They include *Paradelograptus antiquus*, *P. onubensis*, *P. pritchardi* (as *Didymograptus* (?) *stelcki*), *P. bulmani*, *P. kutchini*, *P. rallus*, *Lignigraptus chapmani*, *L. kinnegraptoides* and *L. reclinatus* — a diversity similar to that in Victoria.

Southern Scandinavia has also yielded a diversity of kinnegraptines from Hunneberg, the Krapperup core and Slemmestad, from the La2–Be1-equivalent interval. Erdtmann et al. (1987) described *Paradelograptus onubensis, Lignigraptus chapmani* (as *Paradelograptus mosseboensis*) and *L. kinnegraptoides*, and Lindholm (1991) described *Paradelograptus* species, including *P. antiquus*, *P. pritchardi*, *P. tenuis* and *P. elongatus* in addition to several unnamed species, and a single unidentified stipe fragment that could belong to *L. chapmani* (Lindholm 1991, text-fig. 16I).

Rushton and co-authors have illustrated the only kinnegraptines found in the UK, from the Ballantrae ophiolite complex in Scotland (Stone & Ruston 1983; Rushton et al. 1986). Originally identified as *Acrograptus*? sp., they include both *Paradelograptus* (Stone & Rushton 1983, figs 3h, 4b–d; Rushton et al. 1986, fig. 3), and a single specimen of *Lignigraptus* sp. (Stone & Rushton 1983, fig. 4a). The *Paradelograptus* differs from named species in having very slender metathecae, akin to those of *P. cayleyi*. Their age is considered to be Chewtonian (Rushton & Stone 1988).

Archer & Fortey (1974) illustrated two stipe fragments questionably referred to *Kinnegraptus* from Spitsbergen. While one of these (their fig. I) has thecae like those of *Kinnegraptus,* they lack glossae so cannot be included.

Carter (1989, fig. 4G) illustrated a fragment of a branching tubarium as ?*Kinnegraptus* from the *Paraglossograptus tentaculatus* Zone (approximately Da1–Da2) of the Metaline Limestone, Washington State, USA. This has the thecal profile of *Kinnegraptus* and also glossae that, while poorly preserved, indicate that it is a kinnegraptine. It resembles *Wuninograptus quadribrachiatus*.

Ganis (2005, figs 3N–Q) referred "*Tetragraptus*" *insuetus* Keble & Benson, 1929 to *Kinnegraptus* but, while the species is clearly a sigmagraptid, its thecae have triangular outlines and seem to lack glossae. VandenBerg (2018) questionably referred it to *Anomalograptus*. The specimens referred to *Wuninograptus* sp. by Ortega and Albanesi (2000, fig. 8a–d), from the *Pterograptus elegans* Zone of the Argentinian Precordillera, belong to *A.*? *insuetus*.

THE BLACKWOOD ANTIMONY MINE, 'GOOD BED' AND LANCEFIELD QUARRY COLLECTIONS

Graptolites from the **Blackwood antimony mine** in the Melbourne Museum were collected by Harry Foster on 9 December 1926, from the 'junction of Brennan's Gully and the Lerderderg River'. It is probably the same as the locality from which the holotype of *Lignigraptus chapmani* (Keble & Harris, 1934) was obtained, which is given as 'gully near junction of Kangaroo Creek and Lerderderg River, 2 miles below Blackwood (right bank)', and has identical lithology and preservation. The locality is shown on the Blackwood geological parish plan (Foster & Knight 1981), located approximately 1 km ESE from Blackwood (approximately 37°28'32.9"S 144°19'40.14"E).

The collection is quite small, a few dozen specimens, the largest of which are approximately A5 sized. Nevertheless, it is surprisingly diverse, mostly graptolites but including a few phyllocarid valves and an unidentified fragment of another crustacean. The graptolite fauna, part of which was described in VandenBerg (2017), comprises more than a dozen species, including *Paratetragraptus approximatus* (Nicholson, 1873); *P. thomassmithi* VandenBerg, 2017; *P. cooperi* VandenBerg, 2017; *P.*? *henrywilliamsi* VandenBerg, 2017; *Tshallograptus cymulus* VandenBerg, 2017; *Pseudobryograptus crassus* (Harris & Thomas, 1938a); *Lignigraptus chapmani*; *L. gnomus* n. sp.; *Psenograptus costermansi* n. sp.; *Loganograptus* sp.; and *Expansograptus* spp. The tubaria are preserved as very pale-grey films of powdery material on dark shale, with no evidence of tectonic deformation. The edges of the fossil material are poorly defined, with whitish material fading into the adjacent matrix.

The '**Good bed**' collection, from the base of the lower Floian *T. fruticosus* Biozone, is the largest graptolite collection in the Melbourne Museum and was begun by Thomas Smith, probably in the 1930s, from loc. **PL 2014** (37°13'57.28"S 144°02'22.80"E; see VandenBerg 2017). The collection is unusually diverse and contains four species of *Lignigraptus*, but preservation is poor, as mostly poorly defined red-brown stains on pale orange shale. The rock has a slaty cleavage but there is no evidence of tectonic distortion.

The **Lancefield Quarry** collection came from a small excavation on the northern side of a small creek, 4.37 km ENE from Lancefield Post Office (37°15'23.37"S 144°46'37.37"E). It is **PL 1144** in the Melbourne Museum's official fossil locality register. It has been collected for many years, and is the source of Victoria's (and probably Australia's) largest graptolite, *Paratemnograptus magnificus* (Pritchard, 1892), measuring 670 x 554 mm, and consisting of 28 separate fragments, embedded in gypsum. The fauna is one of the few in Victoria to have been the subject of a monograph (T.S. Hall, 1899a) on which the La2 graptolite biozone is based. It is also the source of many of the specimens illustrated and described in this paper.

SYSTEMATIC PALAEONTOLOGY

Stipe notation in text and figures follows Cooper and Fortey (1982, fig. 7).

A NOTE ON INTRASPECIFIC VARIATION

One of the familial characters of kinnegraptines is the intraspecific variation of morphological traits on the one hand and the lack of such variation of other traits between species. Characters such as stipe width, length of sicula, and particularly thecal spacing, show little variation between most species. Thecal spacing may differ as much between different stipes of the same specimen as it does across the entire species but in the entire group of kinnegraptines the range of spacing is limited to 4–5½ thecae per 5 mm, both proximally and distally, thus giving no guide for specific assignment. The spacing of dichotomies, by contrast, poses the opposite problem by varying so much that it, too, cannot be used as a diagnostic character. In *Lignigraptus sedecimus*, for instance, the lengths of second-generation stipe segments range from 3.2 mm to 23.5 mm, almost an order of magnitude, measured in four specimens. Stipe width in *Paradelograptus pritchardi* shows limited variation along any particular stipe, but there are narrow-stiped specimens with stipes reaching a width of 0.5 mm, to wide-stiped specimens with a width of 1.45 mm (this does not include the unusually wide specimen shown in Figure 7D). Even the proximal symmetry is not a fail-safe guide to identification, with the proximal configuration of species of both of the main genera of kinnegraptines, *Paradelograptus* and *Lignigraptus*, ranging from near-symmetrical (*P. pritchardi*, *L. diabolus*, *L. daangean*) to highly asymmetrical (*P. onubensis*, *P. orthae*, *L. gnomus*). This variation has made it challenging to firstly determine what are true specific characters, and secondly to define diagnostic features. It has also prevented me from presenting any of the data in tabular form. I have found the tubarium habit, as reconstructed from the flat specimens, to be one of the most useful characters for specific determination.

Suborder SINOGRAPTINA Mu, 1957

Family SIGMAGRAPTIDAE Cooper & Fortey, 1982

Subfamily KINNEGRAPTINAE Mu, 1974

Revised diagnosis. Tubarium multiramous to biramous, reflexed to horizontal to pendent, with or without irregularly spaced delayed dichotomies, nematophorous sicula with or without virgellar process, $th1^1$ diverging at higher level from metasicula than $th1^2$ resulting in variably asymmetrical appearance, with sicula often skewed towards stipe 1; sicula conical; thecae long and slender; metathecal walls often attenuated; sicular bithecae observed in well-preserved specimens.

Erdtmann et al. (1987) placed the genera discussed here in the family Kinnegraptidae Mu, 1974 but Maletz et al. (2018) regarded that name as a junior synonym of Sigmagraptidae. However, I regard the proximal asymmetry of the taxa described here as a sufficiently distinctive character to maintain a super-generic grouping. I therefore propose to retain the kinnegraptine group, but at a subfamily level. In *Kinnegraptus kinnekullensis*, the proximal asymmetry is evident in that $th1^1$ diverges from the sicula at a higher level than $th1^2$, which remains attached to the sicula until it reaches the sicular aperture (e.g. Skoglund 1961, text-fig. 1B). This asymmetry is visible at smaller scale (Skoglund 1961, text-fig. 2A) but the skew towards stipe 1 is much less in *K. kinnekullensis* than in other kinnegraptine genera. Genera included are *Kinnegraptus* Skoglund, *Lignigraptus* gen. nov., *Paradelograptus* Erdtmann et al. and *Psenograptus* gen. nov.

Paradelograptus Erdtmann, Maletz & Gutiérrez-Marco, 1987

Type species. *Paradelograptus onubensis* Erdtmann, Maletz & Gutiérrez Gutierrez-Marco, 1987 (OD).

Diagnosis. Tubarium multiramous to biramous, horizontal to pendent, with or without irregularly spaced delayed dichotomies, nematophorous sicula, $th1^1$ diverging at higher level from metasicula than $th1^2$ resulting in characteristic asymmetrical appearance, with sicula skewed towards stipe 1; thecae long and slender; metathecal walls may be attenuated, thecal apertures simple or with denticulate apertures.

Species included. *Paradelograptus onubensis* Erdtmann et al., 1987; *Leptograptus antiquus* T.S. Hall, 1899a; *Didymograptus pritchardi* T.S. Hall, 1899a; *Tetragraptus bulmani* Thomas, 1973; *Paradelograptus elongatus* Lindholm, 1991; *P. tenuis* Lindholm, 1991; *P. rallus* Jackson & Lenz, 2000; *P. maletzi* n. sp.; *P. orthae* n. sp.; and *P. cayleyi* n. sp.

Paradelograptus antiquus (T.S. Hall, 1899a)
(Figures 4–6A, 8A)

1899a *Leptograptus antiquus*, n. sp.; T.S. Hall, p. 166, pl. 17, figs 5, 6.

1899b *Leptograptus antiquus*, T.S. Hall; Hall, p. 448, pl. 22, figs 3, 4.

1935 *Bryograptus* (?) *antiquus* var. *inusitatus* var. nov.; Benson & Keble, pp. 267–268, pl. 30, figs 17, 18.

pars 1974 *Adelograptus antiquus* (T.S. Hall, 1898); Jackson, pp. 41–42, text-fig. 2D, H (non pl. 5, fig. 3, text-figs 2F, G).

pars 1974 *Kiaerograptus* (?) cf. *pritchardi* (T.S. Hall, 1899); Jackson, p. 51, pl. 5, fig. 3, text-fig. 2D.

pars 1979a *Adelograptus*? *antiquus* T.S. Hall; Cooper, pp. 51, 53–54, text-figs 17a–d, j, pl. 2d.

1979b *Kiaerograptus antiquus* (T.S. Hall); Cooper, fig. 5B.

non 1979 *Kiaerograptus antiquus* (T.S. Hall); Cooper & Stewart, pp. 791–792, text-fig. 8 d, e (= *Paradelograptus pritchardi*).

non 1982 *Kiaerograptus antiquus* (Hall, 1899); Gutiérrez-Marco, text-figs 2a–e (= *P. onubensis*).

1987 *Paradelograptus antiquus* (Hall 1899); Erdtmann et al., pp. 122–123, text-fig. 4, fig. 5G.

1991 *Paradelograptus antiquus* (T.S. Hall); Lindholm, text-fig. 16B.

non 1991 *Adelograptus antiquus* (T.S. Hall, 1899)?; Williams & Stevens, p. 35, text-fig. 12H, I.

pars 2000 *Kiaerograptus onubensis* Erdtmann et al., 1987; Jackson & Lenz, fig. 11A–E.

pars 2000 *Paradelograptus onubensis* Erdtmann et al., 1987; Jackson & Lenz, pp. 1188–1189.

2001 *Paradelograptus antiquus* T.S. Hall; Maletz & Egenhoff, fig. 5K.

pars 2004 *Paradelograptus onubensis* Erdtmann et al., 1987; Jackson & Norford, text-fig. 8F only.

Diagnosis. Slender *Paradelograptus* with two or three stipes, proximal habit horizontal to slightly declined, prosicula mitre-shaped with bluntly conical proximal end and tubular metasicula, with distinct bend towards antirutellar side, aperture slanted with acutely angled rutellum; $th1^1$ short, oriented approximately at right angle to sicula; other thecae long, with long threadlike prothecae and shorter triangular metathecae.

Holotype. NMV P14241, Figure 4B, from PL 1144 (La2), by monotypy.

Material and distribution. Paradelograptus antiquus is quite common in the Bryo Gully Shale near Romsey, and its extension northeast of Lancefield (VandenBerg 1992), although it is generally not well preserved. Poorly preserved specimens also occur with *Hunnegraptus* sp. and *Sagenograptus macgillivrayi* (Hall, 1899a) in grey and pink slate in the Yandoit area near Campbelltown. It is only known from the *Aorograptus victoriae* Biozone (La2; VandenBerg & Cooper 1992). In New Zealand, Benson & Keble (1935) illustrated specimens from Fiordland, and specimens from northwest Nelson were illustrated by Cooper (1979a). Jackson (1974) and Jackson & Norford (2004) illustrated specimens from Yukon Territory in Canada. All are from the *A. victoriae* Biozone or its correlates. Erdtmann et al. (1987) illustrated a specimen from Hunneberg, and Lindholm (1991) illustrated a single specimen from Storeklev, both in southern Scandinavia.

Description. The stipes of *P. antiquus* are very slender, with the threadlike prothecae comprising more than half, often two-thirds, of the free portions of the thecae. Metathecae are triangular, with a maximum width (at the aperture) rarely exceeding 0.35 mm, and straight ventral thecal margins. The sicula and $th1^1$ seem to be disproportionally large. The sicula is curved or bent and tubular for most of its length, which ranges from 0.65 mm to 0.9 mm (but exceptionally, as in the holotype, to 1.25 mm), with a width at the aperture of 0.15–0.25. The very slender nema is short, the longest being 1.33 mm long. The dorsal stipe margin often shows slight bulges at the initial portions of metathecae. Stipes may be quite long, with the longest measured stipe exceeding 49 mm (it runs to the broken edge of the slab). Branching is rare, dichotomous and occurs distally (Figure 6A).

Discussion. *Paradelograptus antiquus* is easily recognised by its slender stipes and the distinction between the very slender prothecae and triangular metathecae. Only the metathecal portion of $th1^1$ is visible, unlike most other species of *Paradelograptus*.

The proximal regions of specimens referred to *P. antiquus* by Williams & Stevens (1991, text-fig. 12 H, I) are quite different from those of *P. antiquus*, having long, slender siculae and $th1^1$.

Paradelograptus pritchardi (T.S. Hall, 1899a)
(Figures 4K2, 6–9)

1899a *Didymograptus pritchardi*, n. sp.; T.S. Hall, p. 167, pl. 17, figs 7 & 9, pl. 19, figs 8 & 10.

1938b *Didymograptus pritchardi* T.S. Hall; Harris & Thomas, pl. 1, fig. 13.

1960 *Didymograptus pritchardi* T.S. Hall; Thomas, pl. 1, fig. 14.

?1962 *Didymograptus tenuiramis* n. sp.; Obut & Sobolevskaya, pp. 84–5, pl. 5, fig. 3.

1966 *Didymograptus pritchardi* T.S. Hall; Berry, pp. 429–430, pl. 45, fig. 1, pl. 46, fig. 1, pl. 47, figs 1 & 2.

1974 *Didymograptus*(?) *stelcki* n. sp.; Jackson, pp. 52–53, pl. 5, figs 5 & 7, text-fig. 1A, B.

non 1974 *Kiaerograptus*(?) cf. *pritchardi* (T.S. Hall); Jackson, p. 51, text-figs 2A– C, pl. 5, fig. 3, text-fig. 2D.

pars 1979a *Adelograptus*? *antiquus* T.S. Hall; Cooper, text-fig. 17g, pl. 2e?.

1979a *Didymograptus pritchardi* T.S. Hall; Cooper, text-fig. 17k.

1979b *Kiaerograptus pritchardi* (T.S. Hall); Cooper, fig. 5A.

Figure 4: *Paradelograptus antiquus* showing variation in tubarium habit and thecal spacing. **A**, **G**: NMV P329462; **B**: proximal portion of the holotype, P14241; the contrast of the remainder of the specimen is too poor for photography. **C1**: P329359; **C2** *Aorograptus victoriae*, not registered. **D**: P329548; **E1**: P329484; **E2**: P329485A; **F**: P329460; **H**: P329351; **J**: P329408; **K1**: P329480; **K2**: P329481, *Paradelograptus pritchardi*; **K3 & K4**: *Aorograptus victoriae*, not registered. All are from PL 1144, *Aorograptus victoriae* Biozone (La2).

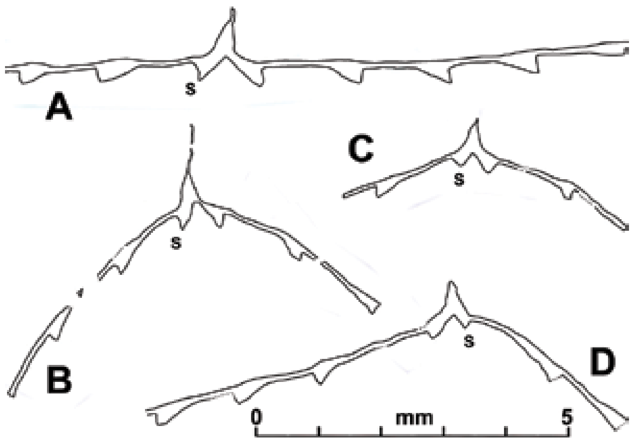


Figure 5: Drawings of the best-preserved proximal portions of *Paradelograptus antiquus*. S = sicula. **A**: NMV P329462; **B**: P329484; **C**: P329485A; **D**: P329408.

1979 *Kiaerograptus antiquus* (T.S. Hall); Cooper & Stewart, pp. 791–792, text-fig. 8 d, e.

non 1982 *Kiaerograptus pritchardi* (T.S. Hall); Gutiérrez-Marco, fig. 2f (= *K. taylori*).

1991 *Paradelograptus pritchardi* (T.S. Hall); Lindholm, text-fig. 16A, D.

non 1991 *Kiaerograptus pritchardi* (T.S. Hall); Williams & Stevens, p. 9, 12–13, pl. 1, fig. 1, text-figs 6A–L.

pars 1991 *Kiaerograptus bulmani* (Thomas); Williams & Stevens, text-fig. 9D only.

2000 *Kiaerograptus pritchardi* (T.S. Hall, 1899); Jackson & Lenz, pp. 1185–1186, fig. 9A–H.

2000 *Paradelograptus*? sp. A; Jackson & Lenz, p. 1191, fig. 13A.

2001 *Adelograptus pritchardi* (T.S. Hall); Maletz & Egenhoff, fig. 5D.

2004 *Kiaerograptus*? *pritchardi* (T.S. Hall, 1899); Jackson & Norford, p. 342, text-fig. 7G.

Diagnosis. Robust *Paradelograptus* with usually 2 but up to 4 stipes, by irregularly spaced dichotomous branching; habit declined, rarely near-horizontal, with straight to gently ventrally curved stipes; prothecae not evident; metathecae with gently curved free ventral walls.

Type material. Lectotype NMV P14238, Figure 7E, paralectotype P14239, designated Berry (1966, p. 429), from PL 1144, La2.

Additional material. Ten measured specimens, all from the same locality.

Geographic and stratigraphic distribution. *Paradelograptus pritchardi* is common in the Bryo Gully Shale and its equivalent horizon at PL 1144 but is restricted to the *Aorograptus victoriae* Biozone. It occurs in equivalent strata in New Zealand (Cooper 1979a), southern Scandinavia (Lindholm 1991) and northwestern Canada (Jackson 1974; Jackson & Lenz 2000; Jackson & Norford 2004).

Description. *P. pritchardi* has the largest and most robust tubarium of any species of *Paradelograptus*. Its maximum size is unknown and in many cases exceeds the slab size — Berry (1966) measured an incomplete stipe of 12 cm long (Figure 6B). Tubaria are declined, with proximal thecae subtending an angle mostly between 115° and 165° (140° is most common). Stipes are gently arcuate to, less commonly, straight. Most tubaria have two stipes (Figures 6B, 7), but both three- and four-stiped tubaria occur (Figure 8). The sicula is large, 1.1–1.55 mm long and slightly conical, with a gentle curvature so that the distal end is curved away from stipe 1. The sicular aperture is slanted, and furnished with a prominent rutellum at the ventral edge. A threadlike nema is usually present, and may be several millimetres long; the longest is 13.6 mm.

Thecae have gently curved free ventral walls that terminate in slightly rounded rutella. The slender prothecae overlap fully with the metathecae of preceding thecae so that the position of the change from protheca to metatheca is not determinable. Apertures are slightly introverted. Stipe width increases slightly in the first three thecae in some specimens, but in most, the stipe width does not widen after th2. In the majority of specimens, stipe width ranges from 0.6 mm to 0.85 mm, with exceptionally slender specimens having stipe widths of 0.45–0.55 mm (e.g. Figures 7A, G, H). The tapering growing tip is 2–6 mm long. Thecal spacing shows no consistent trend — some show a very slight distal increase while others show the reverse. The range, in 5 mm, is between 4 and 5½ thecae.

Most specimens of *P. pritchardi* have two stipes, with stipe 1 leaving the sicula at a high angle, about midway along the ventral side of the sicula. The Museum Victoria collection contains approximately ten three-stiped specimens, and in four of these, branching occurs at the aperture of $th1^1$ (Figures 8B, F; 9F). In one four-stiped specimen, branching is at the apertures of $th1^1$and $th2^1$ (Figures 8G, 9H). Only one specimen has more distal branching, at $th2^2$ (Figures 8E, 9B). Two others are unusual in that branching seems to occur at the sicula. The clearest example is P16239 (Figures 8C, C'; 9C, D), in which the dorsal margin of the lower branch (d in Figure 8C') is clearly separate from the upper stipe and this separation can be traced back to the sicula. P329426 is similar, showing a second stipe originating from the dorsal side of th1 approximately halfway from where th1 diverges from the sicula (Figures 8D, 9C).

Discussion. *P. pritchardi* is easily recognised by its size and, in fully grown specimens, dense sclerotisation throughout, as well as its thecal shape. One of the specimens referred

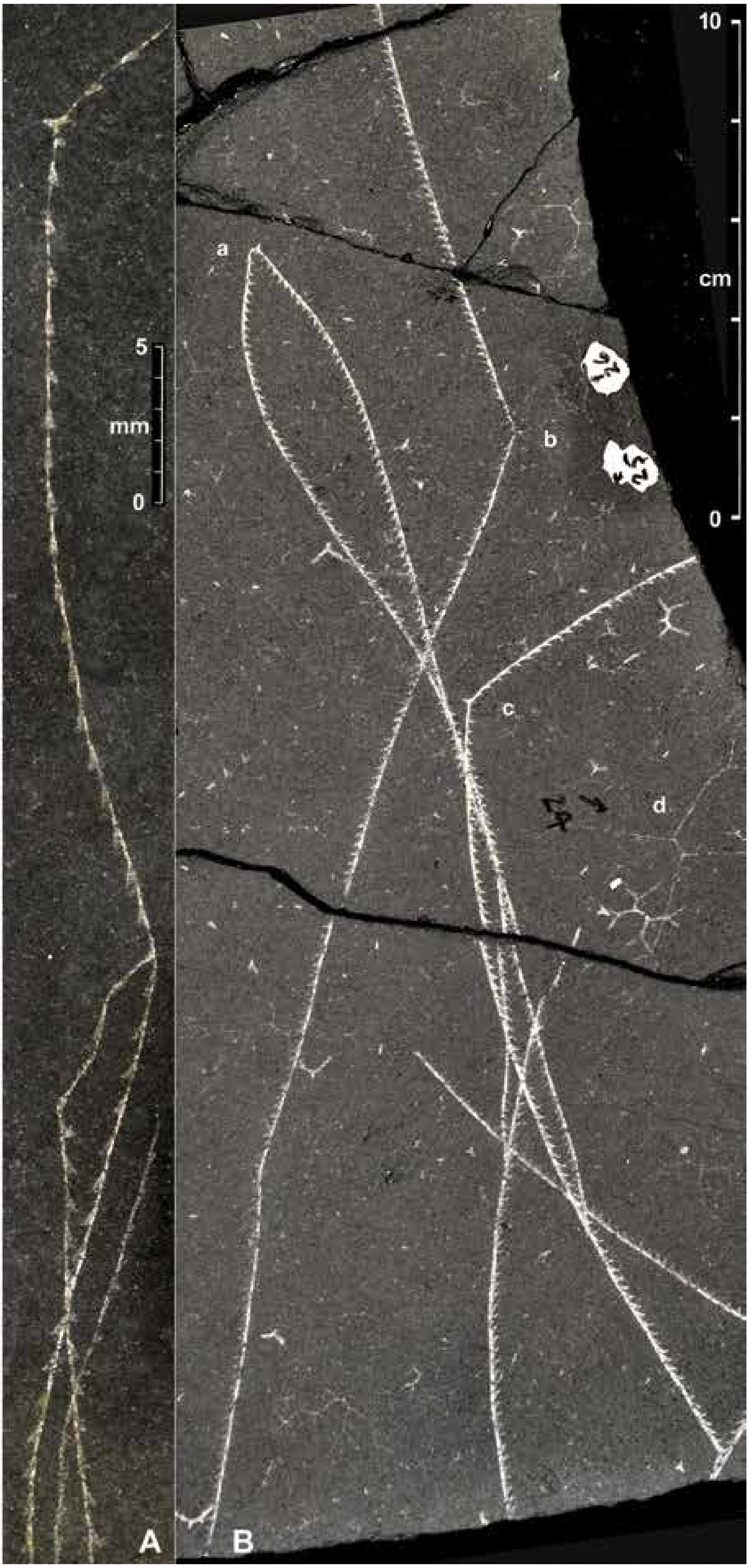


Figure 6: **A**: large tubarium of *Paradelograptus antiquus* showing dichotomous branching; **B**: three large tubaria of *Paradelograptus pritchardi* (**a–c**) and a small tubarium of *Paradelograptus bulmani* (**d**) with distal branching. **A**: NMV P309222; **Ba**: P329528; **Bb**: P329526; **Bc**: P329525; **Bd**: P329524.

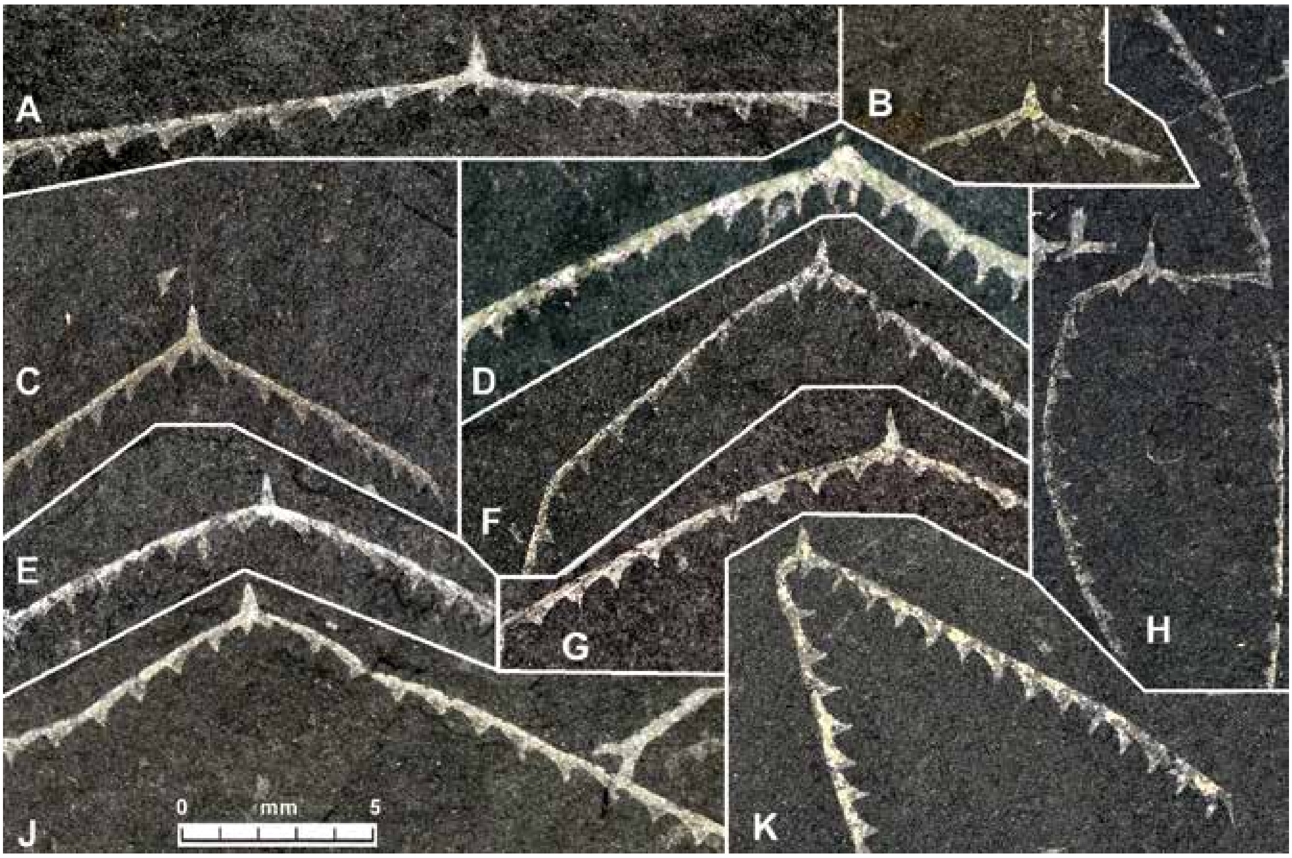


Figure 7: Portions of 2-stiped tubaria of *Paradelograptus pritchardi* showing a range of habits and thecal profiles. **A**: NMV P329391, with a near-horizontal habit; **B**: P329551, a very early growth stage; **C**: P329350 with one of the longest nemas; **D**: P309285A, a pathological tubarium with unusual secondary thickening and elongated rutella; **E**: P14238 (lectotype); **F**: P133819; **G**: P145617; **H**: P318094, with a twisted stipe 2 and bent stipe 1; **J**: P329389, with unusually elongated th2^1 and th3^1; **K**: P329528A with sharply bent stipe 1.

to *Kiaerograptus*(?) cf. *pritchardi* by Jackson (1974) belongs to *Paradelograptus antiquus* (pl. 5, fig. C, text-fig. 2D), while the others (text-figs 2A, C) are very similar to *P. pritchardi* but differ in having siculae that are mitre-shaped rather than conical. None of the specimens from Newfoundland described as *Kiaerograptus pritchardi* (T.S. Hall) by Williams & Stevens (1991) belongs to the species. Their stipes are considerably narrower and mostly straight, and their thecal ventral walls are straight. Their siculae are shorter and straight. It appears to be a new species of *Paradelograptus* or *Kiaerograptus*. The specimen illustrated as *Paradelograptus*? sp. A by Jackson & Lenz (2000, fig. 13A) is very similar to the specimen here shown in Figure 7D, which has unusual secondary thickening.

Paradelograptus bulmani (Thomas, 1973)
(Figures 10, 11)

1971 *Tetragraptus otagoensis* (Benson & Keble); Erdtmann, pp. 25–26, pl. 33, figs 1–3.

1973 *Tetragraptus bulmani* n. sp.; Thomas, pp. 530–531, pl. 2, figs b, c.

1979 *Tetragraptus bulmani* Thomas; Cooper & Stewart, p. 795, text-fig. 8h, k.

pars 1991 *Kiaerograptus bulmani* (Thomas); Williams & Stevens, pp. 17–19, pl. 1, figs 8 & 9, pl. 3, figs 5, 6, 8–14, text-figs 9A–C, E–H, non D.

2003 *Kiaerograptus*? *bulmani* (Thomas, 1973); Jackson & Lenz, pp. 145, 147, figs 8f–k, 9g, h, k.

?2003 *Kiaerograptus*? *kutchini* n. sp.; Jackson & Lenz, p. 147, fig. 8m.

Diagnosis. *Paradelograptus* with short funicle consisting of two horizontal to slightly declined thecae, each of which usually divides into two terminal stipes. Thecae are prominent, with very short prothecal portions and curved free ventral walls.

Holotype. NMV P127296, Figures 10K, 11A, from PL 1171 in the Bryo Gully Shale in Stauro Gully near Romsey, Victoria, *Aorograptus victoriae* Biozone (La2, see Cooper & Stewart 1979; VandenBerg 2018).

Material and distribution. Nine measured specimens and more than a dozen additional specimens, from the stratigraphic equivalent of PL 1171 in PL 1144, the same horizon and localities as the holotype. The species is also known from the Cow Head Group in Newfoundland (Erdtmann 1971; Williams & Stevens 1991).

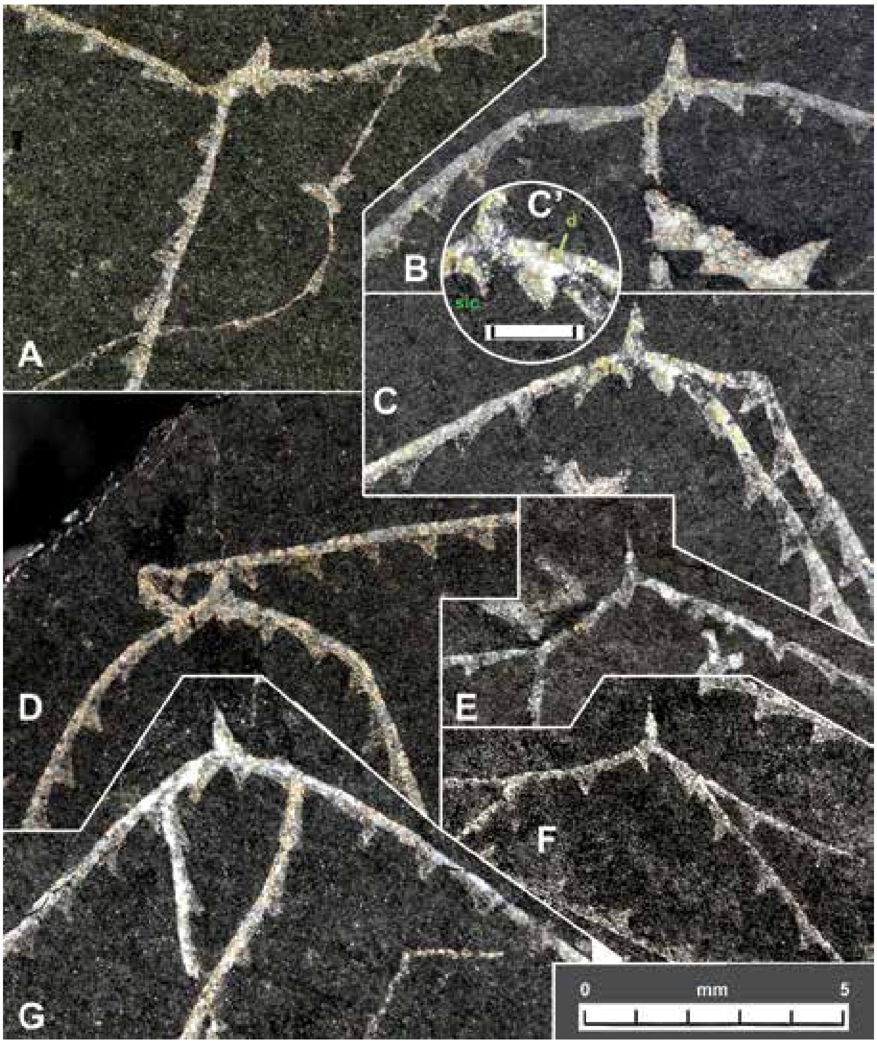


Figure 8: Proximal areas of multistiped tubaria of *Paradelograptus pritchardi* showing the method of branching. 'Normal' branching is shown in **A**, **B**, **F** and **G** where it occurs at the aperture of th1[1]. **G** has an additional stipe originating from th2[1], and **E** has more distal branching, at th2[2]. **C** is unusual in that both branches on the right seem to originate from the sicula (sic in **C'**) — the dorsal margin of the lower branch (d) is clearly separate from the upper stipe and this separation can be traced back to the sicula (see also Figure 9D). In **D**, the upper stipe separates from the lower approximately two-thirds of the distance of the aperture of th1 of the lower branch, suggesting it may also originate from the sicula. Scale in **C'** is 1 mm. **A**: NMV P329480 (with *P. antiquus*, P329481); **B**: P329354A; **C**: P16239; **D**: P329426; **E**: P52778B; **F**: not registered, with P329391; **G**: P309308.

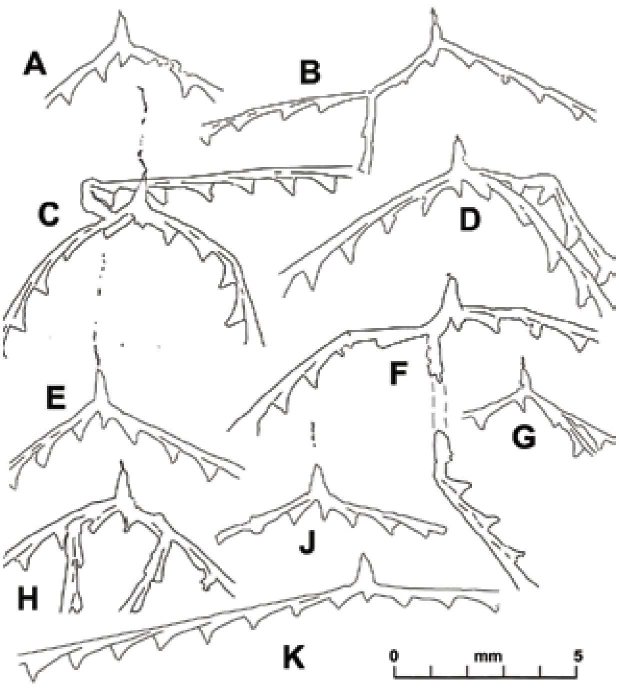


Figure 9: Proximal areas of multistiped tubaria of *Paradelograptus pritchardi* showing the method of branching. **A**: NMV P133819; **B:** P52778B; **C**: P329426; **D**: P16239; **E**: P326350; **F**: P329354A; **G**: not registered, with P329391; **H**: P309308; **J**: P329354B; **K**: P133819.

Description. Most specimens have four terminal, gently curved stipes arranged in an X shape. A single 3-stiped specimen occurs (Figure 10H), and two specimens have delayed third-generation stipe divisions in the two stipes that are unbroken (Figures 10G, 11D). Only one specimen has the sicula preserved in profile view (Figure 10F). It is 1.3 mm long and has a width of 0.3 mm at its aperture. The funicle consists of the two initial thecae and is 2.0–2.6 mm long. Stipes are slender, 0.35–0.65 mm wide proximally and 0.6–0.9 mm distally. Free ventral walls of thecae are gently curved and their length remains constant along the stipe, although in different tubaria it ranges from 0.85 to 1.5 mm. Apertures are slightly inverted and provided with sharply angled rutella. In almost all specimens, the funicle and secondary stipes remain slender throughout but a single specimen shows some secondary thickening (Figure 10J) which has added several tenths of millimetres to the stipe width.

Discussion. Victorian specimens are uninformative about the habit of the tubarium but rare specimens from Newfoundland preserved in lateral view indicate it is

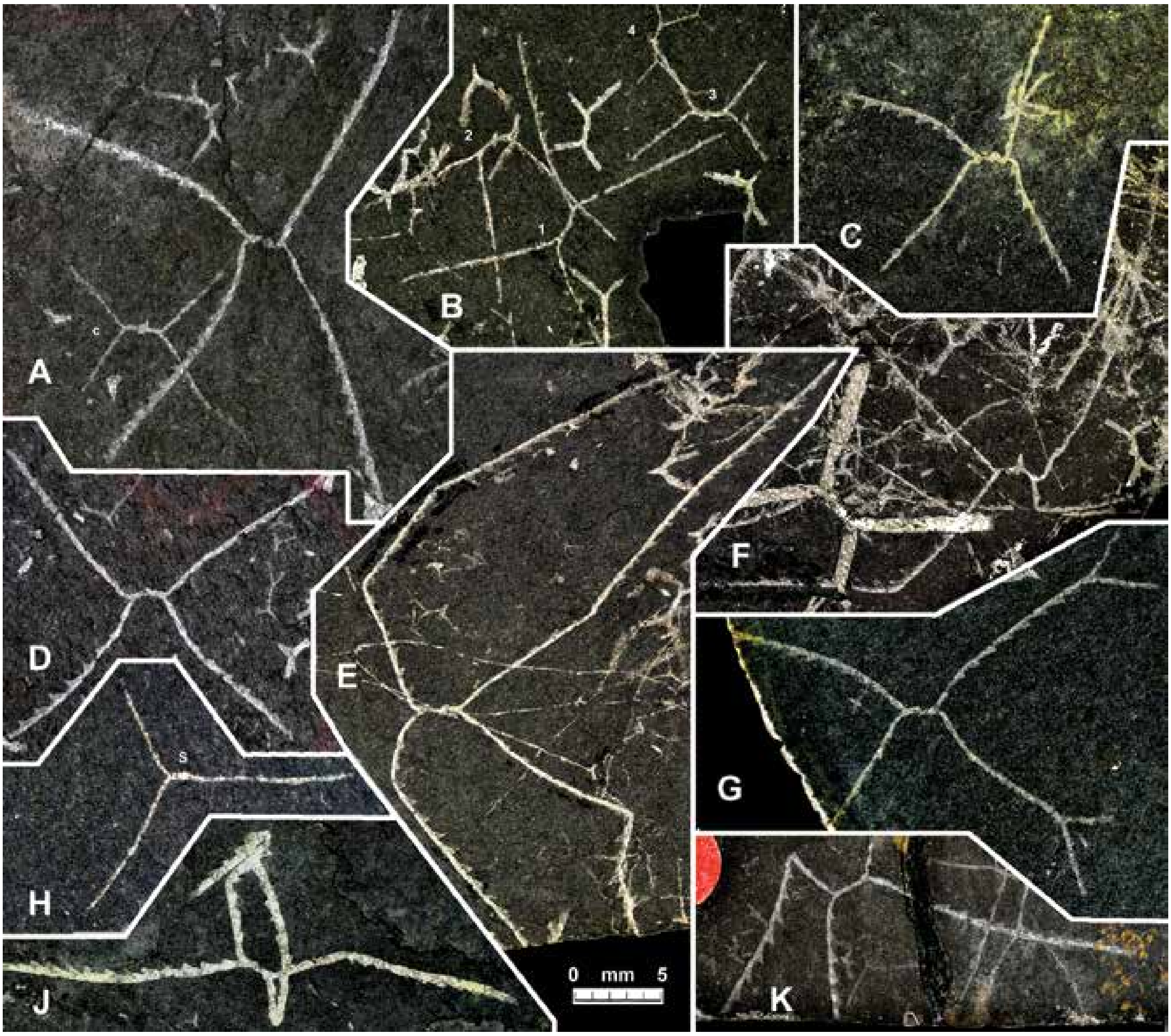


Figure 10: *Paradelograptus bulmani* showing variation in tubarium habit and apparent stipe width. **A**: NMV P47098 (larger tubarium; c = *P. cayleyi*?); **B1**, **B2**: *P. bulmani*; **B3**, **B4**: *P. cayleyi*?; **B1**: P329387; **B2**: P329472; **B3**: P329388; **C**: P329575; **D**: P47090; **E**: P329454, one of the largest specimens; **F**: 328453; **G**: P318193A, a rare 8(?)-stiped tubarium which may belong to *P. kutchini* Jackson & Lenz, 2003; **H**: P329558, the only 3-stiped tubarium (s = sicula); **J**: P329581; **K**: the holotype, P127296. **A–J** are from PL 1144, **K** is from the Bryo Gully Shale in Stauro Gully near Romsey (Loc. 4 in Cooper & Stewart 1979), *Aorograptus victoriae* Biozone (La2, late Tremadocian).

gently declined (Williams & Stevens 1991). These authors also described isolated specimens that show a sicular bitheca. *Kiaerograptus*? *kutchini* Jackson & Lenz, 2003 is somewhat similar to *Paradelograptus bulmani* but has an additional generation of stipes, with second-generation stipe segments of variable length, usually of 5 thecae or fewer. Only one Victorian specimen shows an additional generation of stipes (Figures 10G, 11D) and, given the fluidity of this character in *Paradelograptus*, I regard it as part of the population of *Paradelograptus bulmani.*

Paradelograptus maletzi n. sp.
(Figures 12–15)

1979 *Adelograptus*? sp.; Cooper & Stewart, p. 795, text-fig. 8i.

Diagnosis. Paradelograptus with dome-shaped tubarium, short funicle consisting of usually two thecae; up to five orders of delayed branching, thecae with distinctly concavely curved free ventral walls.

Etymology. Named for Jörg Maletz.

Holotype. NMV P329511 (Figure 13A).

Referred material. Paratypes P329510, P329506, P329496, P329514; all type material is from PL 1144.

Material and distribution. Approximately a dozen additional measured tubaria in various stages of growth, from PL 1144 and PL 1171 (La2 *Aorograptus victorae* Biozone). These are the only known occurrences of the species.

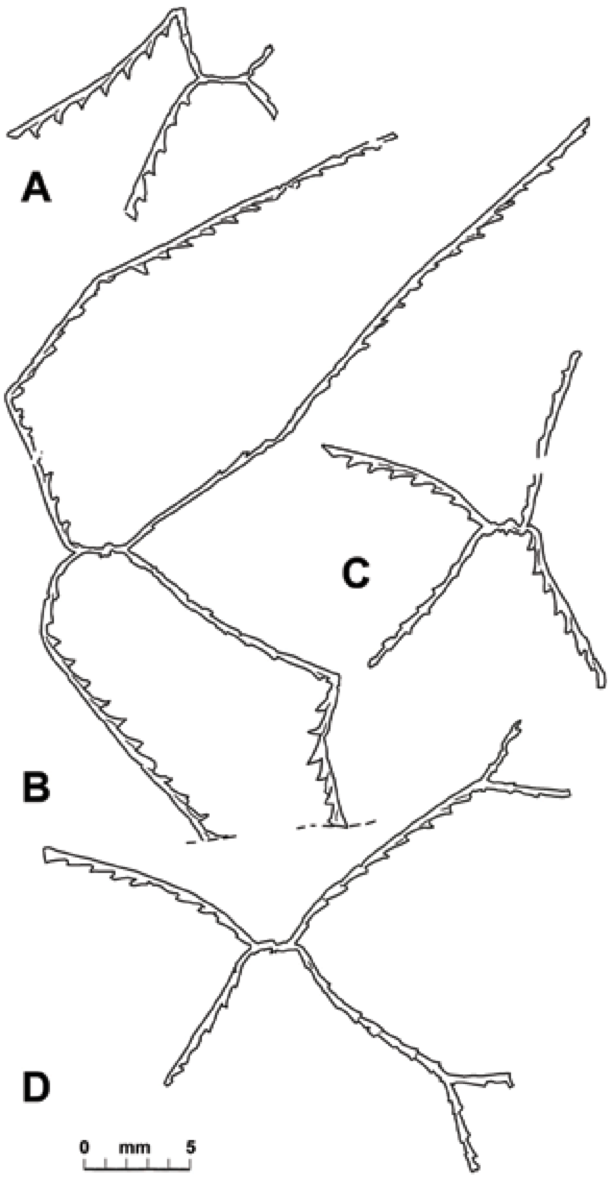


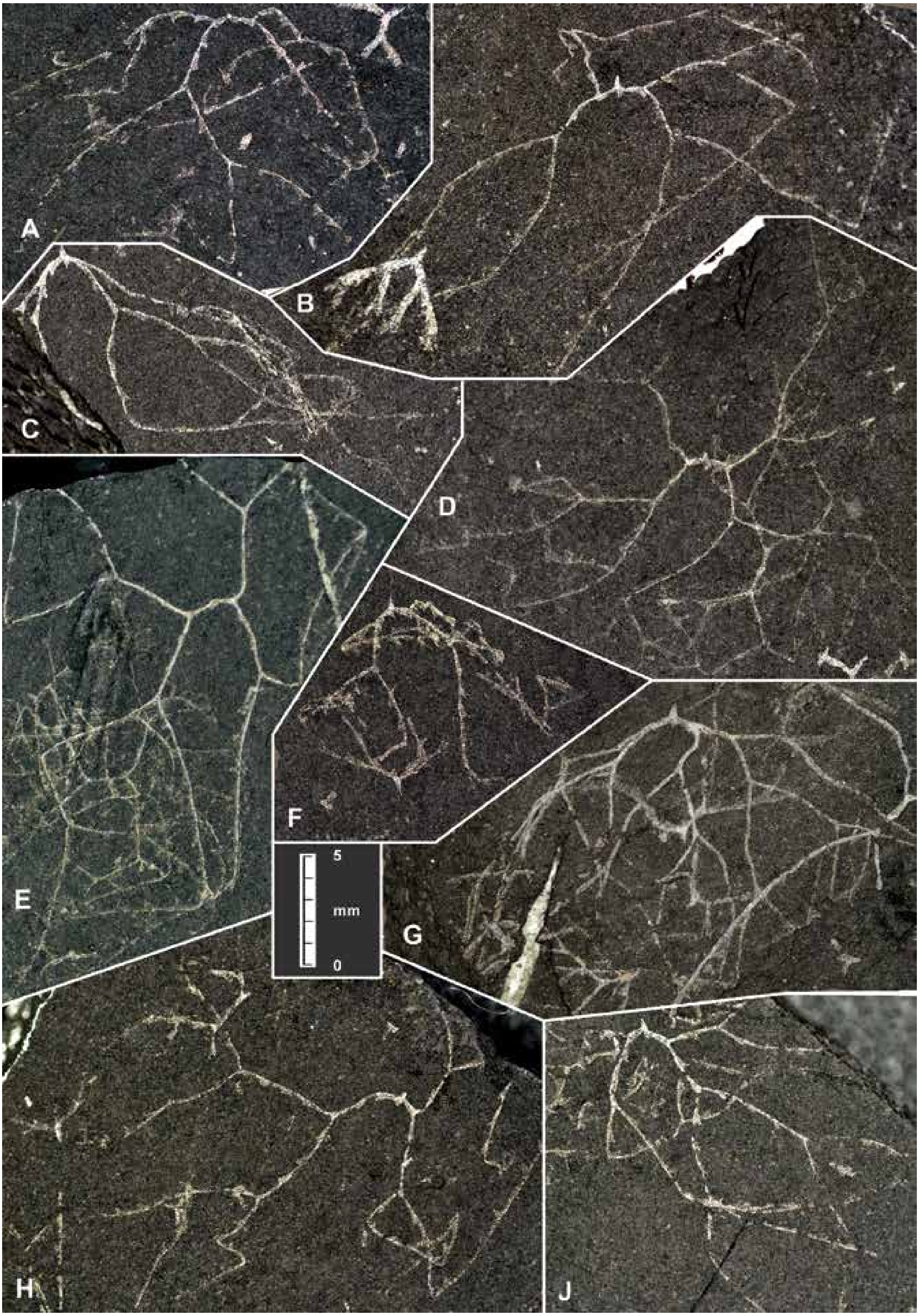
Figure 11: Drawings of selected specimens of *Paradelograptus bulmani*. **A**: the holotype, P127296; **B**: P329454, one of the largest specimens; **C**: P329575; **D**: P318193A, a rare 8(?)-stiped tubarium.

Description. Tubaria preserved in lateral view display a declined habit with an interstipe angle of 95–125°. The funicle usually consists of only the first two thecae, $th1^1$ and $th1^2$, but a few have funicles with 2 thecae on one side. An exceptional case is P319514 (Figures 12H, 14E, 15C) in which stipe 2 consists of 3 thecae but is unusually strongly curved, giving a pendent habit, as though failure to branch has occurred at the more usual position near the aperture of $th1^2$. The sicula is between 1.0 mm and 1.4 mm long and widens to 0.25–0.38 mm wide at the aperture, which is sharply angled, with a pointed rutellum at the ventral edge. A thin, short nema is common, the longest being 1.2 mm long. Almost all specimens have the typical *Paradelograptus* proximal configuration, with $th1^2$ remaining attached to the distal end of the sicula, but there are four exceptions, where $th1^2$ is free from the sicula for a short distance (e.g. Figures 14D, K, M, O, 15F, G). Branching is dichotomous except for the second-generation branching that gives rise to stipes 1a and 2a. Instead of branching occurring at the apertures of $th1^1$ and $th1^2$, as is usual, $th1^{b1}$ and 1^{b2} arise from the dorsal side, a short distance proximal from the apertures of their respective parent thecae (Figures 14A, L, N, 15B, D, H). The branching thecae emerge at a high angle, close to 90°, to the direction of the parent stipe. Thecae are triangular and the transition from protheca to metatheca is imperceptible. Widening is rapid, from a minimum width of 0.12–0.23 mm to a maximum of 0.4–0.55 mm at the apertures, which have sharply pointed rutella and are slightly introverted. Thecal spacing is 4–4⅔ in 5 mm. In many specimens, some or all of the thecae are indistinct, suggesting they were weakly sclerotised. The stipes in these specimens appear smooth-sided (Figures 12G, 14M, Q).

The tubarium is quite small, with a distance from sicula to the end of the terminal stipes of a little over 25 mm in the largest specimens. Stipes are flexuous. Spacing of branching is irregular, with some specimens having longer segments for a particular order of branching than others. Median lengths for segments are: second order from 2.3 mm to 4 mm, third order 3.3 to 9.5 mm and fourth order (one specimen) 4.4 mm. Terminal stipe segments are much longer, with the longest being 15 mm. Terminal segments are flexuous, others are gently curved.

Discussion. *P. maletzi* is similar to *P. tenuis* Lindholm, 1991 but differs in some characters. The sicula in *P. tenuis* is longer and more tubular, and free ventral walls of thecae are less curved. Second-order stipe segments also tend to be shorter (1–2 thecae). *Paradelograptus onubensis* Erdtmann et al., 1987 has a similar number of branching orders but it has clearly differentiated thecae with long prothecal portions (Erdtmann et al. 1987, fig. 5A–F). In addition *P. onubensis* has much looser branching, with at least 2 thecae on each half of the funicle, and second-order stipe segments are more than twice as long (Erdtmann et al. 1987, fig. 7C).

Figure 12 (overleaf): *Paradelograptus maletzi*, fully grown tubaria. **C** and **G** are thought to most closely represent a lateral view of the declined tubarium, while the other shapes show variations in distortion of the tubarium due to how it settled on the sea floor. Note the extent of secondary sclerotisation in **G**, which is probably the largest tubarium in this assortment. **A**: NMV P329506; **B**: P329554 (with early growth stage of *Aorograptus victoriae*); **C**: P329496B; **D**: P329386; **E**: P329476; **F**: P329500B (upper), P329519B; **G**: P309363; **H**: P329514; **J**: P329512. All are from PL 1144.


A
B
C
D
E
F
G
H
J
5
mm
0

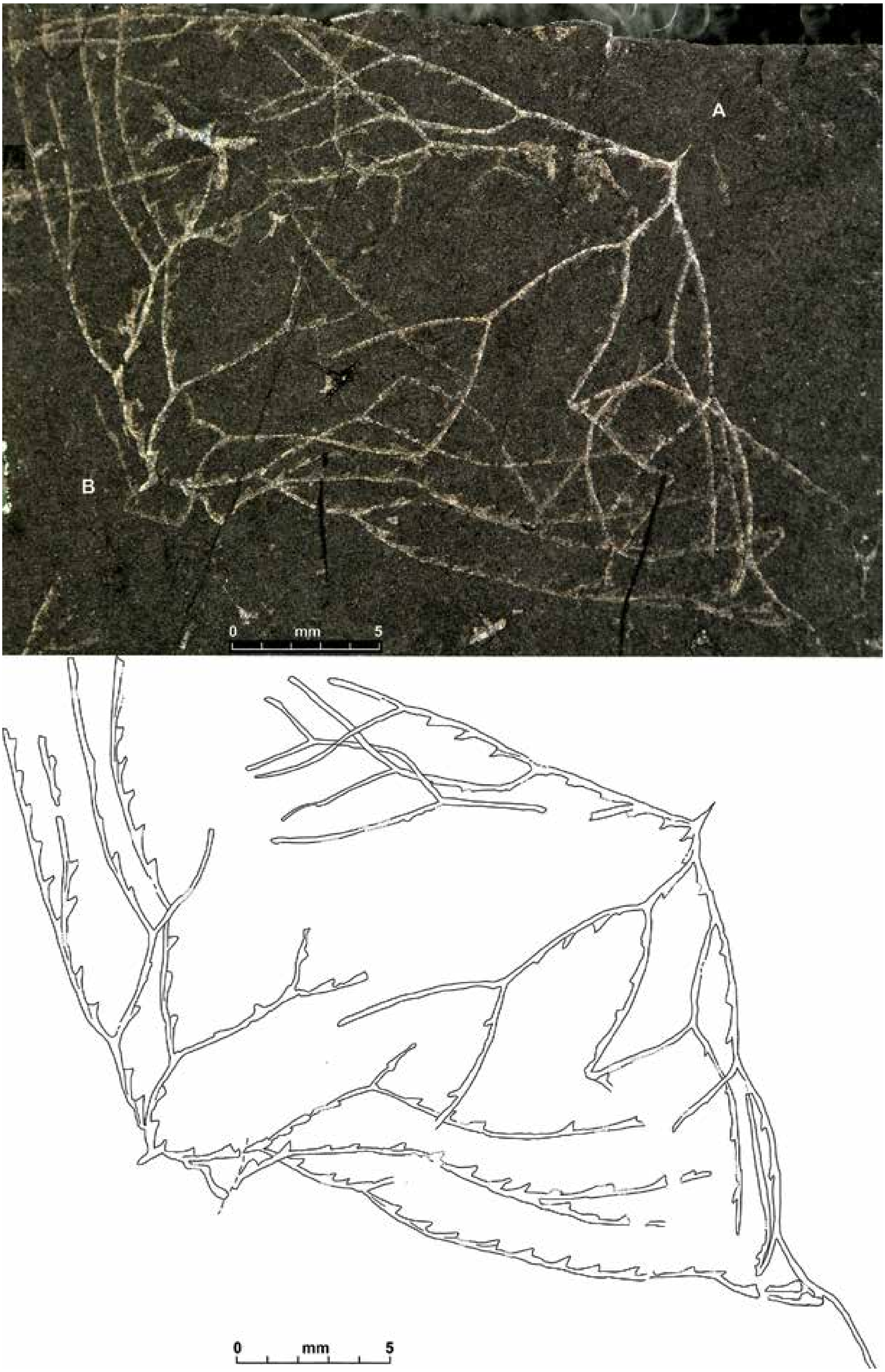


Figure 13: Photo and drawing of the largest tubaria of *Paradelograptus maletzi*. **A**: holotype NMV P329511; **B**: paratype P329510, from PL 1144. These tubaria, if laid flat, would have had a radius of nearly 25 mm.

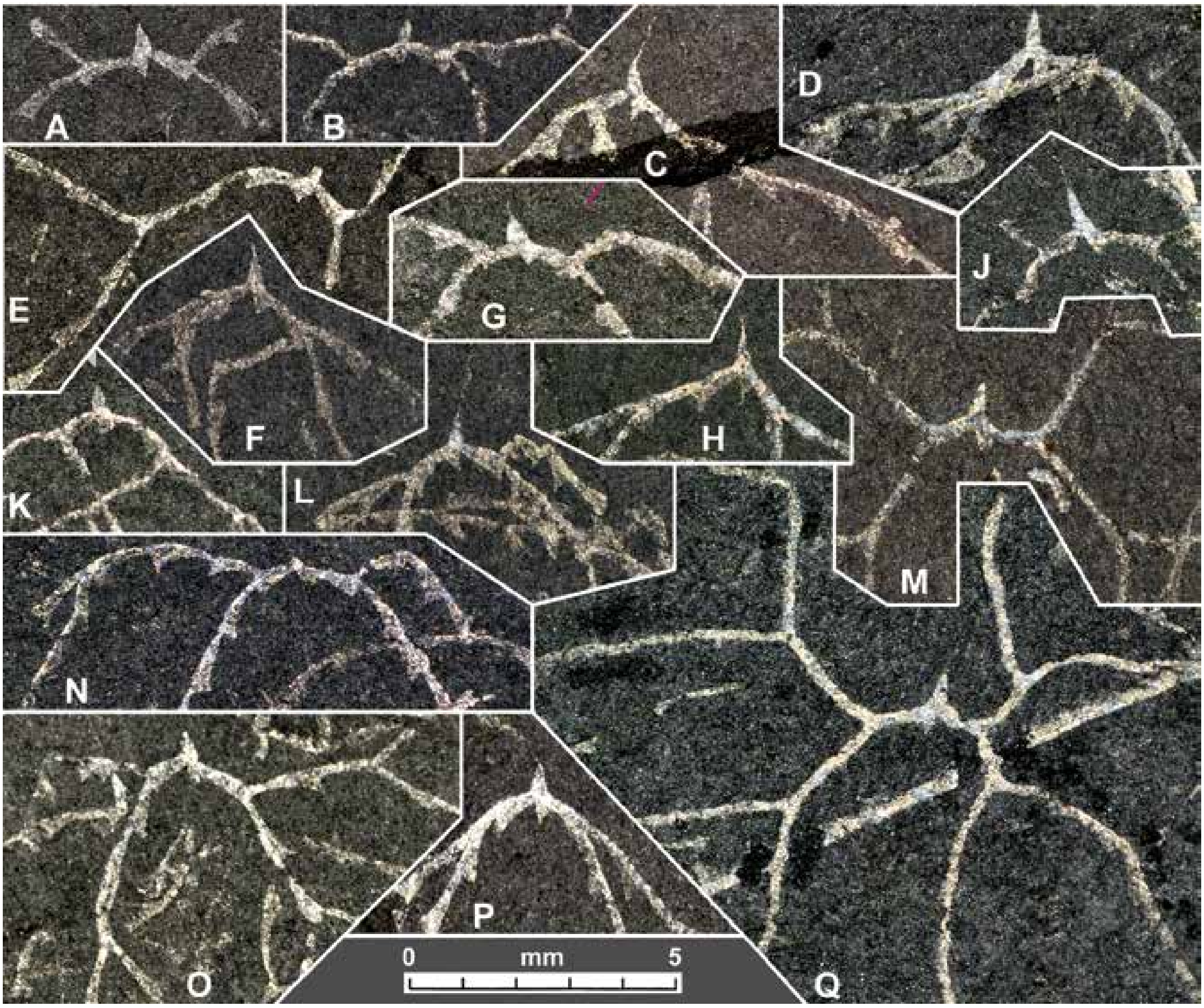


Figure 14: Proximal portions of tubaria of *Paradelograptus maletzi.* Note the variation of the appearance of the siculae, which ranges from long and curved (**C**, **F**, **H**, **J**, **L**, **M**, **P**, **Q**) to very short (**E**, **N**) — reflecting the amount of foreshortening. Siculae with 'free' distal ends are shown in **D**, **K** and **M** (and perhaps **O**). **A**: NMV P329340; **B**: P329394; **C**: P329502; **D**: P329424; **E**: P329514; **F**: P329519B; **G**: P329550; **H**: P329511; **J**: P329361B; **K**: P329563; **L**: P329500B; **M**: P329357B; **N**: P329506; **O**: P329512; **P**: P329496B; **Q**: P329515.

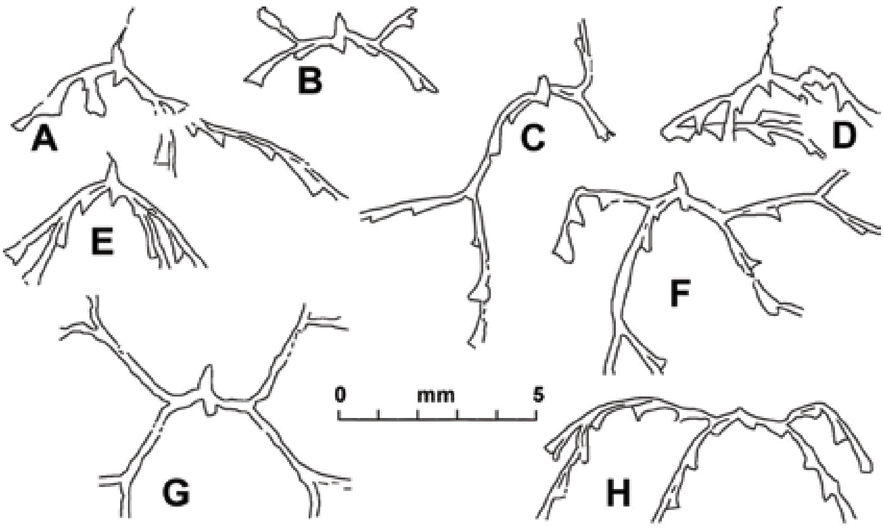


Figure 15: Drawings of proximal portions of tubaria of *Paradelograptus maletzi.* **A**: NMV P329502; **B**: P329340; **C**: P329514; **D**: P329500B; P329424; **E**: P329496B; **F**: P329512; **G**: P329357B; **H**: P329506.

Paradelograptus orthae n. sp.
(Figures 16–18)

1974 *Tetragraptus* (?) sp.; Jackson, pp. 54–55, pl. 5, fig. 8, text-fig. 2I.

Diagnosis. *Paradelograptus* with declined habit, short funicle usually consisting of 2 thecae; up to 3 orders of branching, third order variably delayed; free ventral walls of thecae with short prothecal portions and triangular metathecal portions.

Etymology. Named for Karin Orth, friend and colleague, with whom I celebrated a birthday rafting the Snowy River.
Holotype. NMV P309244, Figures 16A, 17H, from PL 1144.

Referred material. Paratypes P329336, P328385, P329267, P328449, from the same locality.

Material and distribution. Eleven measured specimens, from the same locality. A single specimen figured as *Tetragraptus* (?) sp. by Jackson (1974) from the *Adelograptus* Zone (≡ La2) of the Yukon Territory in Canada is the only other known occurrence.

Description. Almost all specimens have stipes extended in an X-like configuration but the habit is interpreted to be broadly declined as the funicle is declined in most specimens, and the angles between the funicle and the 'upper' stipes (1b and 2b) are more obtuse than those of the 'lower' stipes 1a and 2a. The funicle consists of only the first two thecae, $th1^1$ and $th1^2$. However, an exceptional case is P329267 (Figures 16B, 17E, 18E) in which stipe 2 consists of 5 (?) thecae but is unusually strongly curved, at the aperture of th1, as though failure to branch has occurred at the more usual position near the aperture of $th1^2$ — similar to an example in *P. maletzi* described above. Tubaria show up to three generations of branching but this is variable — some (e.g. the holotype) have no tertiary branches while in others that do, the distance to the final division shows considerable variation. An example is P329267, a six-stiped tubarium, in which the length of the second-generation segments is 16.3 mm (12 thecae) in segment 1a and 7.9 mm (5 thecae) in segment 1b (Figure 16B). Much shorter second-generation segments occur in P309359 (5.6–6.4 mm) and P329534 (5.7–6.4) (Figures 17F, J).

The sicula is 1.2–1.4 mm long and 0.25–0.35 mm wide at the aperture which has a pointed rutellum at the ventral edge. It is gently curved so that the distal end is bent away from stipe 1. Only one specimen has a nema, very short (0.3 mm) and terminating in a poorly defined structure (Figures 17A, 18A). Thecae show marked variation in appearance, probably due to preservation. Those judged to be preserved in full lateral aspect have very short prothecal portions, widening gradually to a rounded ventral margin (e.g. Figures 18C, stipe 1b and F, stipe 2b). Thecal spacing in 5 mm is 3– 4¾ proximally and 3¼ –5 distally.

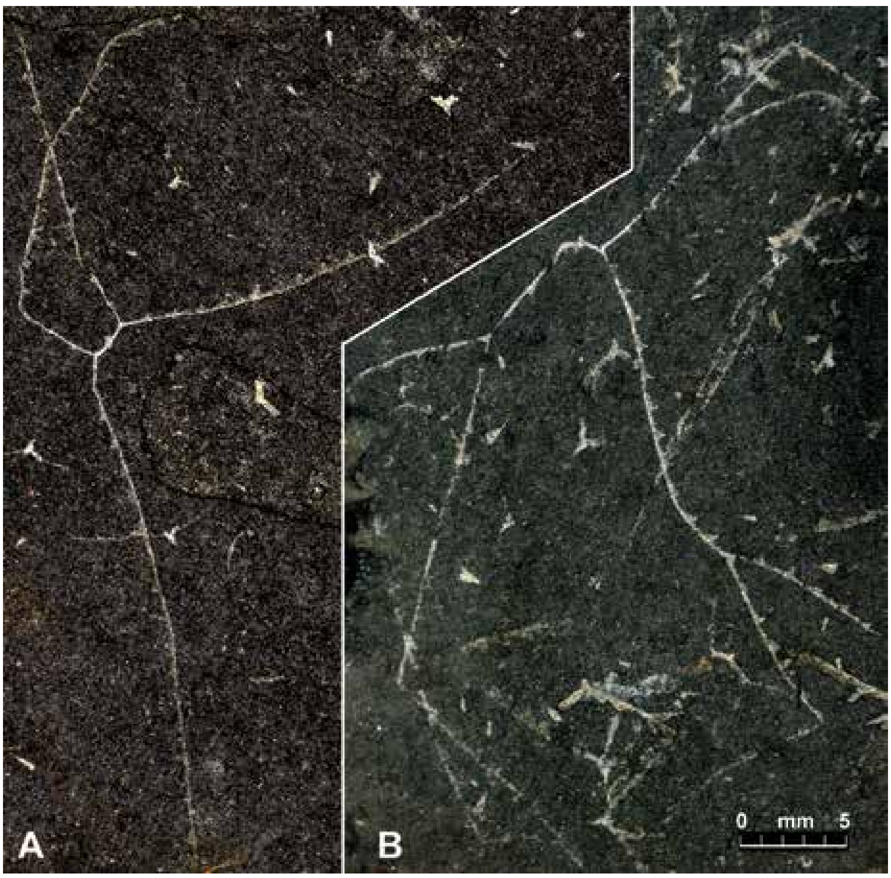


Figure 16: Largest tubaria of *Paradelograptus orthae*. **A**: the holotype, a 4-stiped tubarium, NMV P309244; **B**: a 6-stiped tubarium, paratype P329267, both from PL1144.

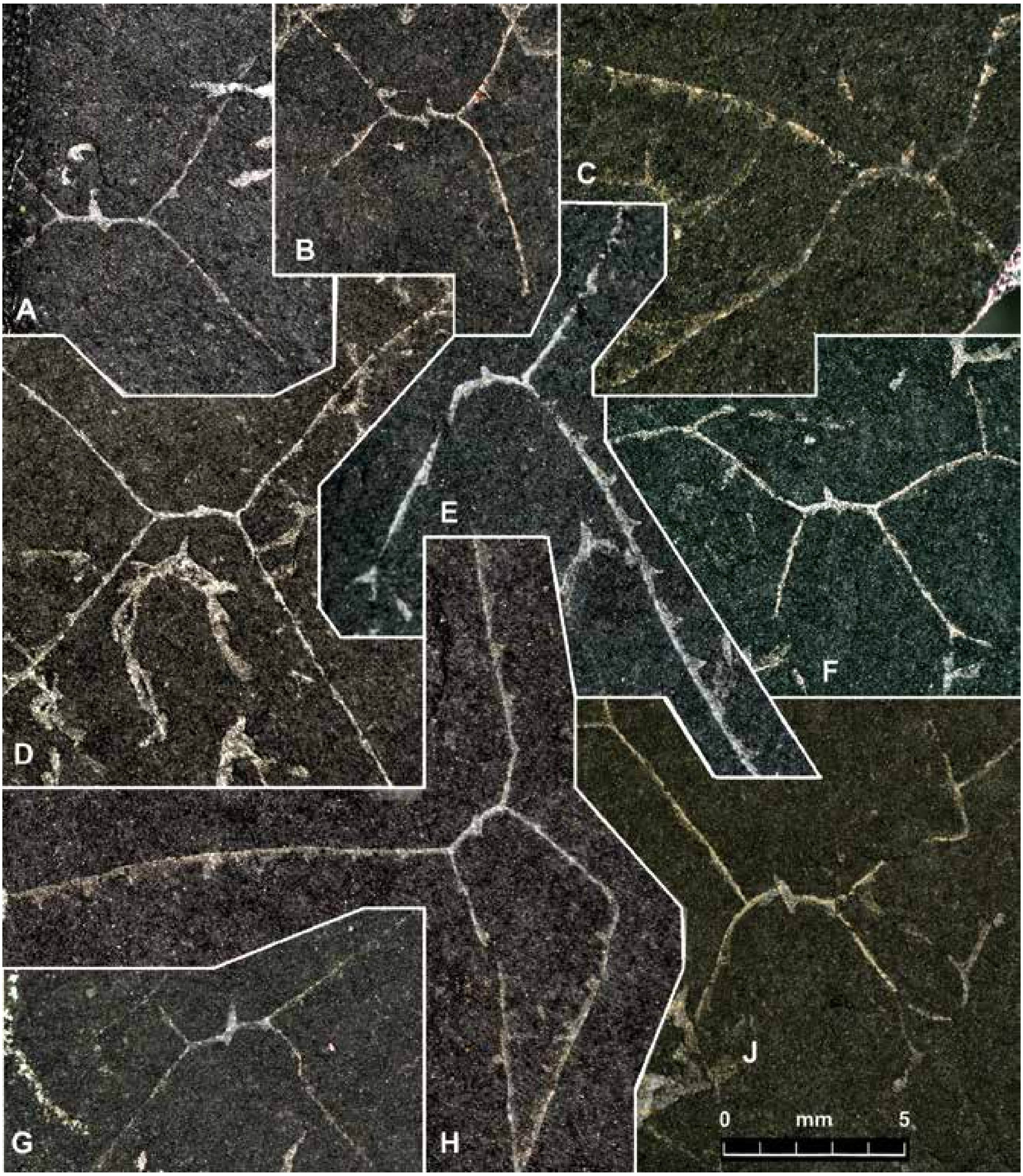


Figure 17: Proximal portions of tubaria of *Paradelograptus orthae* showing the variation in appearance of the sicula, funicle and thecal profiles. **A**: NMV P329336A; **B**: P328385; **C**: P329378; **D**: P329503A; **E**: P329267; **F**: P309359A; **G**: P328449: **H**: P309244; **J**: P329534; all from PL1144.

Discussion. Paradelograptus orthae is similar to *P. maletzi*, but has fewer generations of stipe division, with the third (and final) division generally quite distal. Tubaria also lack secondary thickening, giving them a tenuous, fragile appearance, in contrast to those of *P. maletzi* in which secondary thickening gives them a robust appearance. The specimen illustrated as *Tetragraptus* (?) sp. by Jackson (1974) is very similar to *P. orthae* and occurs with *Paratemnograptus magnificus* (Pritchard, 1892), which is restricted to La2 — it is therefore included in the synonymy and appears to be the only occurrence outside Victoria.

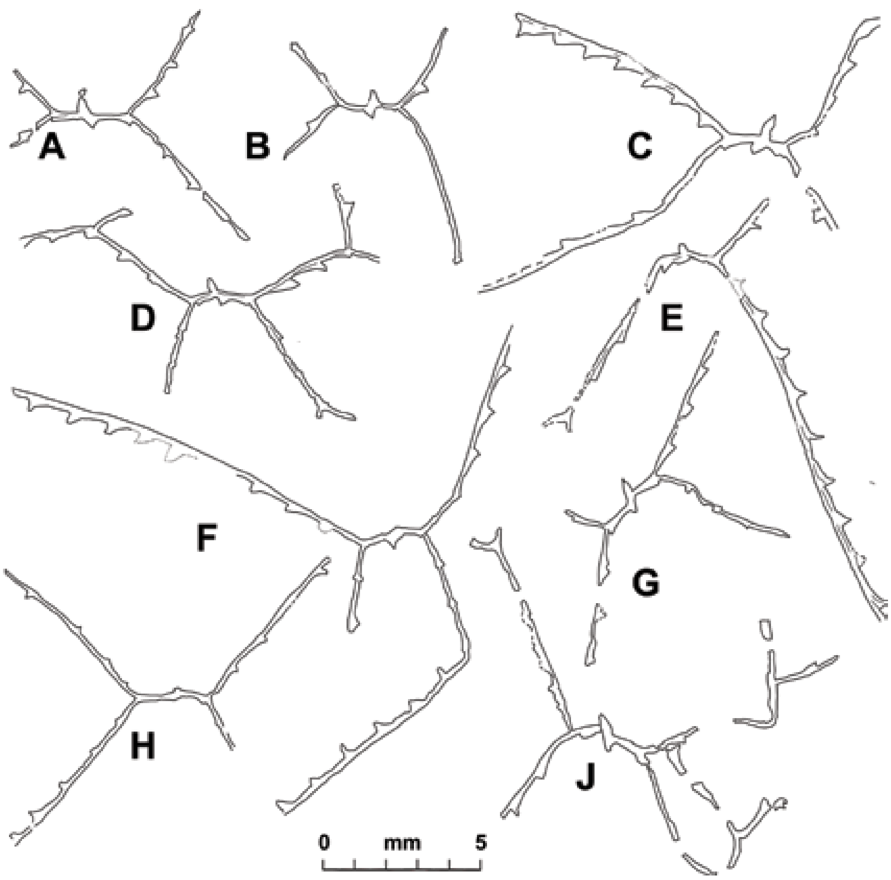


Figure 18: Drawings of proximal portions of tubaria of *Paradelograptus orthae* showing the variation in appearance of the sicula, funicle and thecal profiles. **A**: NMV P329336A; **B**: P328385; **C**: P329378; **D**: P309359A; **E**: P329267; **F**: P309244; **G**: P328449: **H**: 329503A; **J**: P329534; all from PL1144.

Paradelograptus cayleyi n. sp.
(Figures 6Bd, 19–21, ?10A, B)

Diagnosis. Paradelograptus with apparent horizontal habit, funicle consisting of 2 initial thecae, with up to 3 orders of dichotomous branching, third order much delayed; thecae long, with threadlike prothecae and triangular metathecae with maximum width less than 0.4 mm.

Etymology. Named for Ross Cayley, friend and colleague, with whom I mapped the shores of Lake Eildon from a houseboat.

Holotype. NMV P28453, Figures 19B, 20, from PL 1144.

Referred material. Paratypes P328461 and P309355, from same locality.

Material and distribution. P. cayleyi is very rare, with only three specimens identified with confidence. All are from PL 1144, *A. victoriae* Biozone (La2).

Description. The three type specimens are all preserved with stipes arranged in an X-like fashion; the habit is not known. None have a sicula preserved in lateral view; in the holotype, the sicula is obscured by overgrowth of some kind. In paratype P328461, the poorly defined sicula is skewed strongly to the left (stipe 1) (Figure 19B). The funicle consists of the initial 2 thecae and is 2.15–2.5 mm long. Secondary and tertiary stipes are straight to slightly curved and appear threadlike, with faint metatheca on one side. Tertiary divisions are delayed, with secondary stipe segments consisting of 7 or more thecae. Prothecae are very slender and comprise about half of each free theca although the transition from protheca to metatheca is difficult to determine. Metathecae slender, widening gradually to a maximum stipe width of 0.30–0.35 mm at the apertures which are simple — rutella are absent.

Discussion. None of the three type specimens of *P. cayleyi* has a sicula preserved in full lateral view. Nevertheless, generic assignment can be done with confidence on the basis of the asymmetry of the funicle, with the siculae in the two paratypes skewed to one side, and the two primary stipes lying at slightly different positions with respect to the horizontal plane of symmetry of the tubarium. The very slender stipes are distinctive, with free ventral thecal walls almost straight, unlike those of the slender *P. antiquus*.

Lignigraptus n. gen.

Etymology. Contraction from Latin *lignum* = wood, *nigra* = black, for the Parish of Blackwood, source of many of the kinnegraptine species.

Type species. *Lignigraptus chapmani* (Keble & Harris, 1934)

Diagnosis. Kinnegraptines with $th1^1$ diverging at higher level from metasicula than $th1^2$ resulting in characteristic asymmetrical appearance, with sicula skewed towards

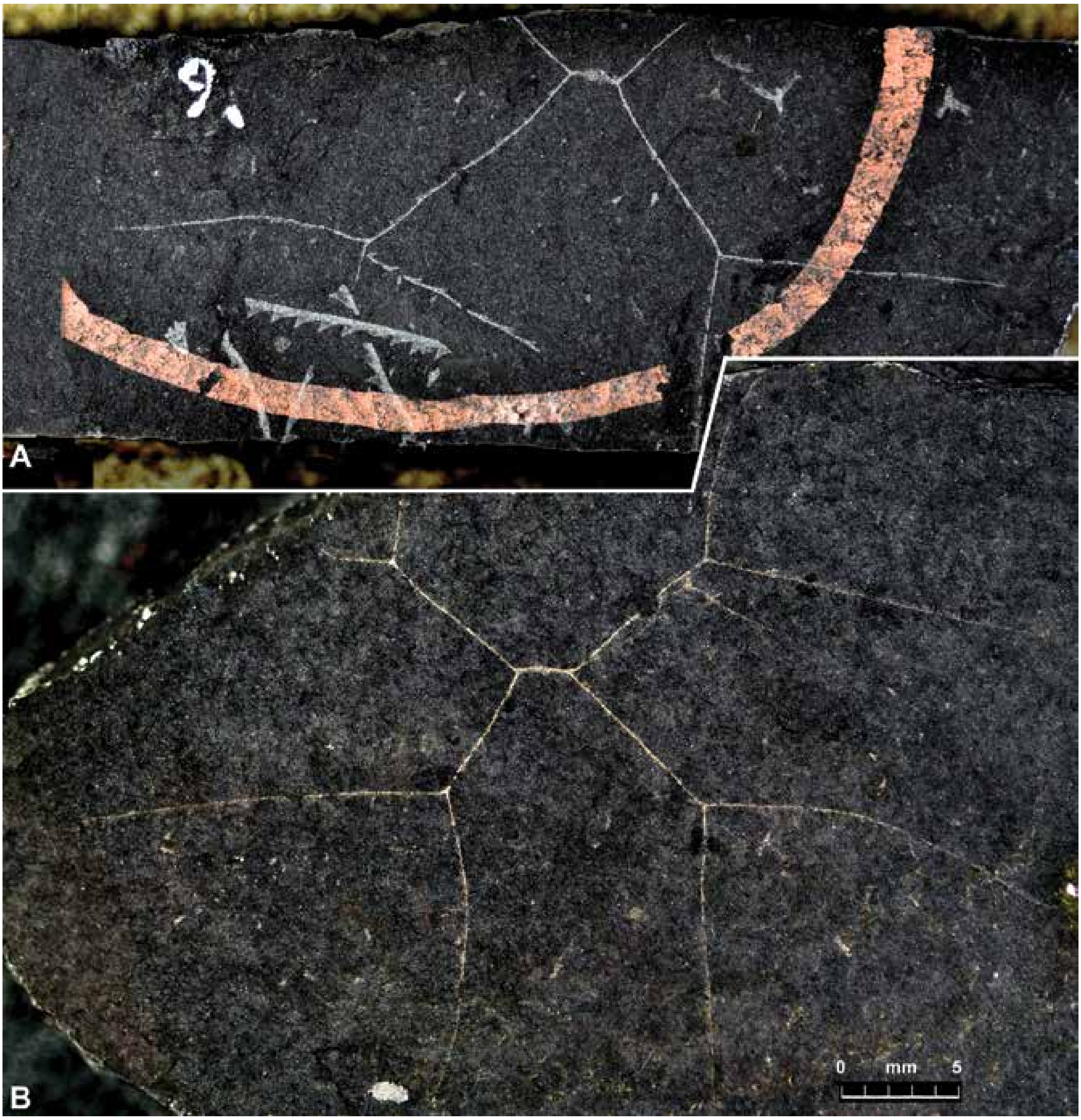


Figure 19: Holotype NMV P28453 (**A**) and paratype P328461 (**B**) of *Paradelograptus cayleyi*. Stipe fragments in lower left of **A** are of *P. antiquus* (top) and *P. pritchardi*. From PL 1144.

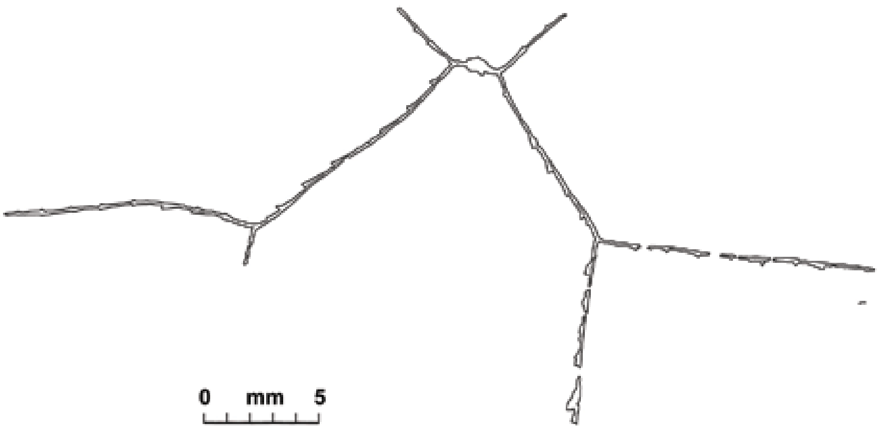


Figure 20: Drawing of the holotype of *Paradelograptus cayleyi*.

Figure 21: Paratype P309355 of *Paradelograptus cayleyi*. From PL 1144.

stipe 1; thecae long and slender; metathecal walls may be attenuated, thecal apertures bearing elongate apertural apparatuses (glossae).

Species included. *Tetragraptus chapmani* Keble & Harris, 1934; *Clonograptus ramulosus* Harris & Thomas, 1938a; *Dichograptus sedecimus* Harris & Thomas, 1938a; *Clonograptus erdtmanni* Rickards & Chapman, 1991; *Paradelograptus kinnegraptoides* Erdtmann *et al*., 1987; *P. mosseboensis* Erdtmann *et al*., 1987 (here regarded as a junior synonym of *L. chapmani*); *Kinnegraptus reclinatus* Jackson & Lenz, 2000; *Lignigraptus daangean* n. sp.; *L. gnomus* n. sp.; *L. absidatus* n. sp.; and *L. diabolus* n. sp.

Lignigraptus chapmani (Keble & Harris, 1934)
(Figures 22–26, 29)

1934 *Tetragraptus chapmani*, n. sp.; Keble & Harris, pp. 169–170, pl. 20, figs 3a, b.
1986 *Tetragraptus* cf. *chapmani*; Lenz & Jackson, fig. 6A.
1986 *Kinnegraptus* sp.; Lenz & Jackson, fig. 6R.
1987 *Paradelograptus mosseboensis* n. sp.; Erdtmann et al., p. 120, figs 5H, I; 10B.
1991 *Tetragraptus (?Tetragraptus) chapmani* Keble and Harris; Rickards & Chapman, pp. 67–68, pl. 20, fig. e, text-figs 97–100.
2000 *Paradelograptus mosseboensis* Erdtmann, Maletz & Gutiérrez-Marco 1987; Jackson & Lenz, p. 1189, figs 12A–E.

Diagnosis. Four-stiped *Lignigraptus* with declined funicle comprising 3–4 thecae on both stipes, secondary stipes long; sicula 1.6–2.1 mm long, provided with a short, sharply pointed rutellum, and a short nema.

Type material. Holotype NMV P14378, Figures 22, 23, 24A, D, from 'gully near junction of Kangaroo Creek and Lerderderg River, 2 miles below Blackwood (right bank)'; paratype P26452 from the Blackwood antimony mine. The holotype slabs contain two additional early growth stages, apparently overlooked by Keble and Harris, P324204 and P324205 (Figures 22, 25A, B).

Material and distribution. The holotype specimen is probably from the same locality as the Blackwood antimony mine from which the other specimens have come. A single early growth stage has also been found in chert in R.A. Keble's loc. F166 on the Mornington Peninsula. All Victorian specimens are of the same age: early Floian, La3, *Paratetragraptus approximatus* Biozone, but in the Yukon Territory, Canada, Jackson and Lenz (2006) have recorded it from both the *P. approximatus* and the succeeding *T. fruticosus* Biozones. *Paradelograptus mosseboensis* is from Hunneberg in southern Sweden, of La3 age (Erdtmann et al. 1987).

Description. Early growth stages of tubaria preserved in profile view have declined funicles, with primary stipes subtending angles of 165–130°. The funicle is quite short, with each primary stipe composed of 2–4 thecae. Stipes of early growth stages are very slender, 0.1–0.2 mm wide, and in most specimens, proximal stipes are straight but in the juvenile specimens on the holotype slabs, stipes are very flexuous, bent at very acute angles (Figure 25B, H). Stipes show progressive widening with age, by addition of cortical material chiefly along the dorsal stipe margins. In the holotype, which is the largest specimen that has a proximal portion, and which shows secondary thickening throughout, stipes of the funicle are 0.3–0.45 mm wide (without glossae, which are not visible); distal stipe widths range from 0.45–0.55 mm without the glossae. Thecal profiles are only visible on a few exceptionally well preserved specimens which show them to be very slender, with long straight prothecal ventral walls ending with a short, curved, more highly inclined metathecal portion (Figure 25).

Glossae are club-shaped in profile, inclined at variable angles to the stipe. They have rounded ends and are approximately 1.3–1.5 mm long. They are considerably fainter than the main portion of the stipe, and have selvages but this is only visible in the best-preserved specimens (Figure 24A). The longest stipe attached to the proximal end in the holotype (stipe 2b) is 97 mm long. This indicates a minimum (flattened) tubarium size of at least 20 cm.

Figure 22: *Lignigraptus chapmani* holotype. The most complete counterpart containing the holotype (**A**, **A'**, **A"**, NMV P14378B). Stipes labelled **A'** can be traced to the funicle **A**, and I regard it likely that a third, labelled P83341, also belongs to the holotype. Whether the stipes labelled **A"** belong to the holotype is less certain. Three other specimens with siculae preserved in profile view are **B** (P83342B), **C–C'** (P324205) and **D–D'** (P324204). Other identifiable tubaria are *Tshallograptus cymulus* VandenBerg, 2017 (**E**) and *Paratetragraptus cooperi* VandenBerg, 2017 (**F**, **G**). From PL 6068, Blackwood (La3).

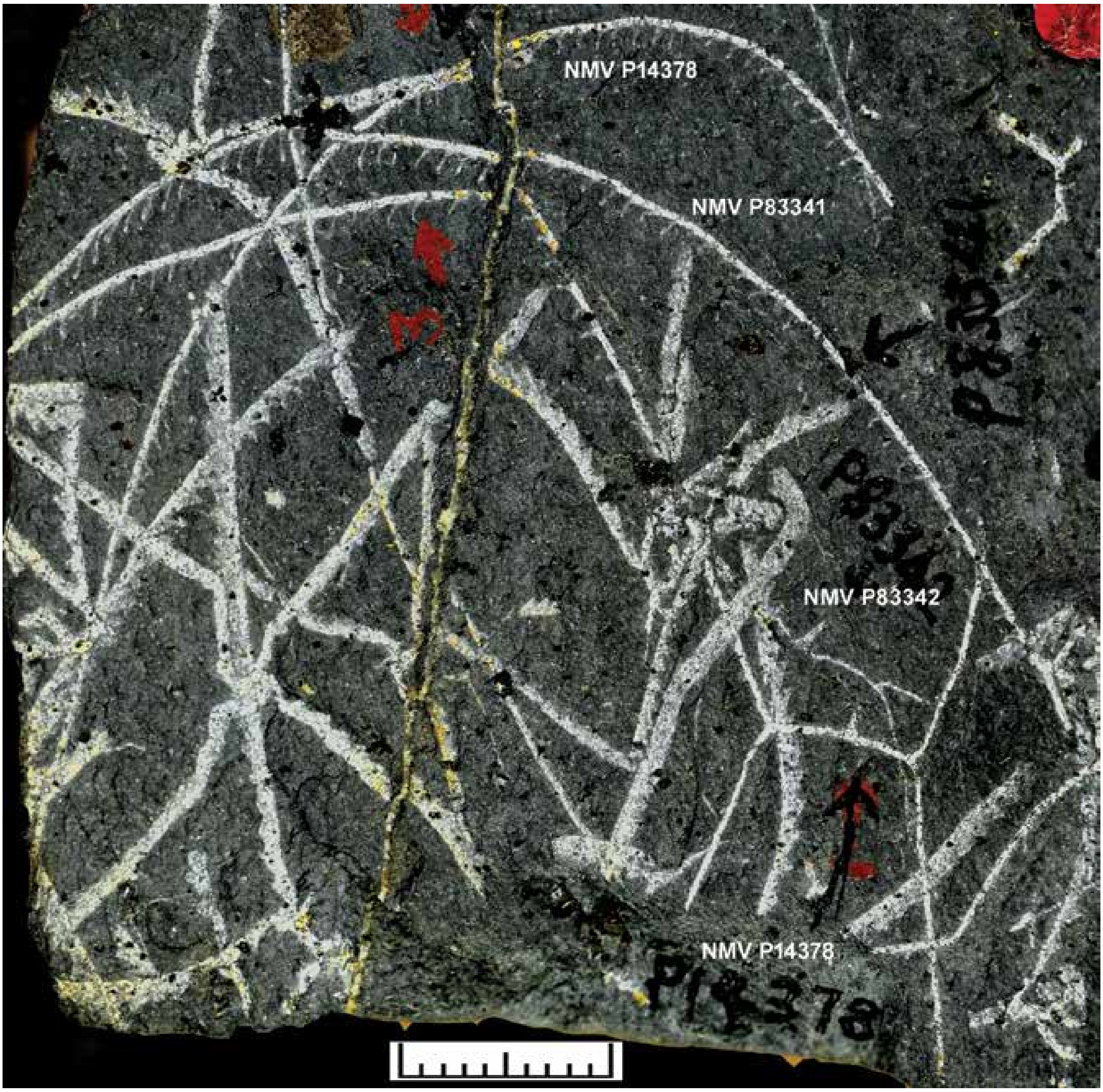


Figure 23: *Lignigraptus chapmani* holotype (continued). In the counterpart of the holotype, P14378A, the funicle and distal stipes, particularly some of the glossae, are slightly better preserved.

Discussion. Specimens illustrated as *Paradelograptus mosseboensis* by Jackson & Lenz, 2000 from Yukon, NW Canada, are much better preserved than Victorian specimens (see also Jackson & Lenz 2006 figs 11s, v) and show an even greater range of funicle length, from 3 to as many as 7 thecae on one of the two primary stipes.

Figure 25 (opposite right): Early growth stages of *Lignigraptus chapmani*. **A** and **B** occur on the same slab as the holotype (and overlap). In most specimens, substantial stipe portions are 'naked', i.e. seem to consist only of common canals that lack thecae. **A**: NMV P324204A, funicle and terminal stipes with thread-like appearance, but with faint glossae visible on the lower right stipe. **B**: P324205B with glossae visible on both the funicle and secondary stipes. The other tubarium is of *Tshallograptus cymulus* VandenBerg, 2017. **C**: P330667; **D**: P330716; **E**: P220668; **F**: P330697; **G**: P330708B; **Ha**: P330731; **Hb**: P330730; **Hc**: P330729; **I**: P330699A. Note that the tops of the siculae in **D** and **Ha** have become detached and are preserved next to the tubaria. All from Blackwood antimony mine.

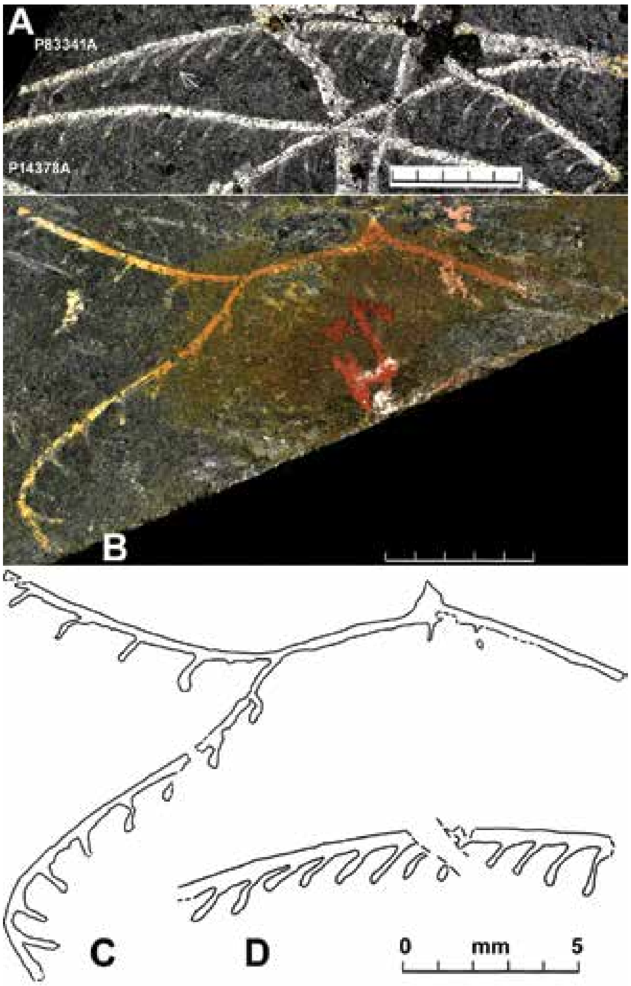
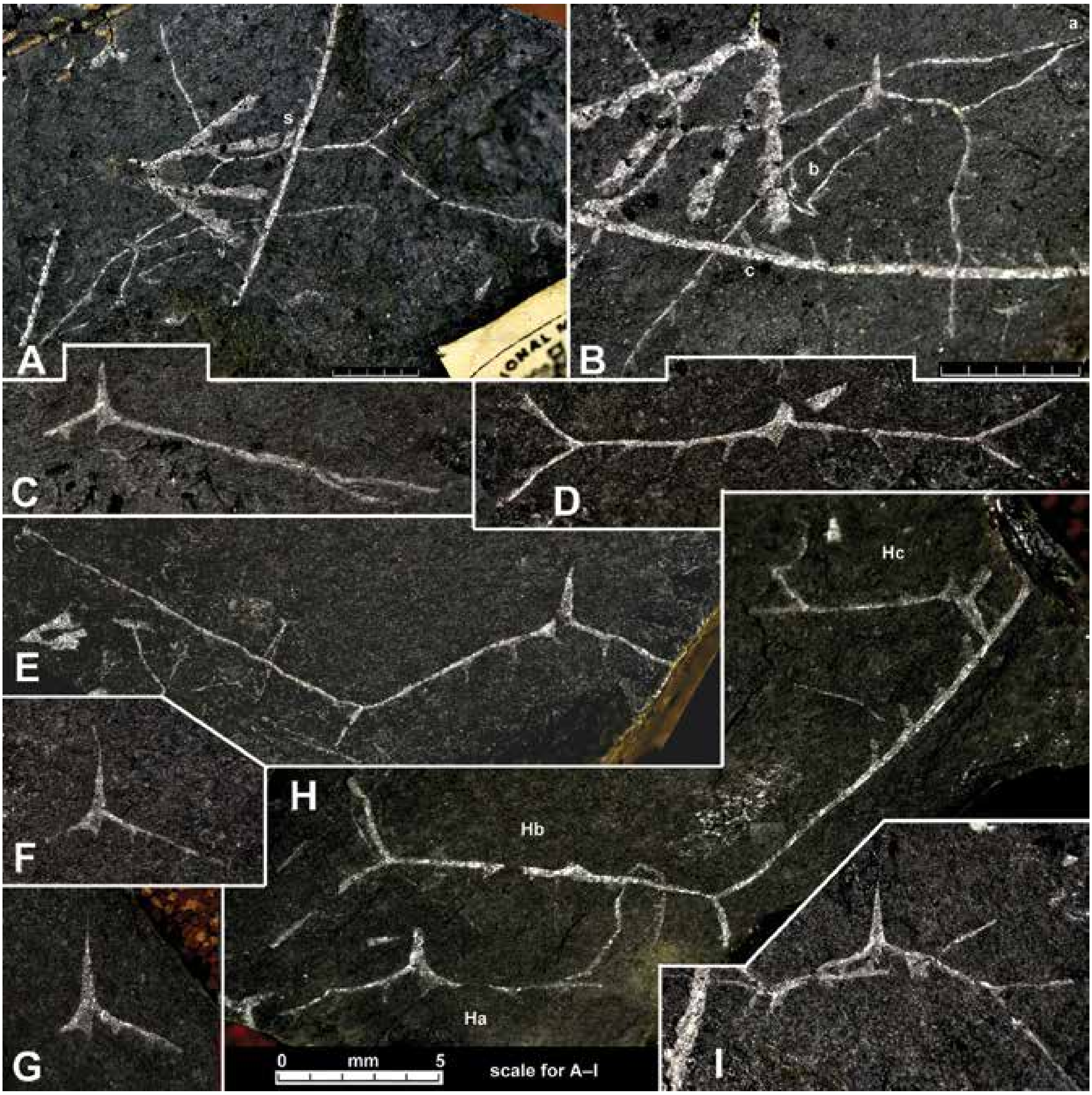
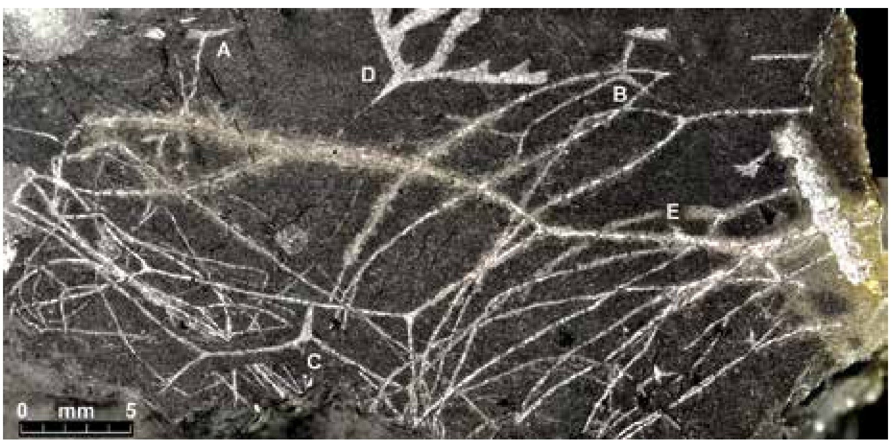


Figure 24: The holotype (**A**, **D**) and paratype (**B**, **C**) of *Lignigraptus chapmani*. The paddle-shaped glossae are well shown in **A**, particularly in the top left (P14378, arrowed), with the loops (selvages) around the edge of the glossae slightly paler (denser) than the interiors (cf. Figure 2C). The details of the proximal structure are impossible to determine due to the brown stain. **B** is from Blackwood antimony mine. Scales are 5 mm long.

Figure 26 (opposite right): Growth stages of *Lignigraptus chapmani* (**A–C**) showing progressive thickening of stipes. **A** and **B** (siculae are adjacent to the letters) are early growth stages with short secondary stipes in which all stipes are very slender, contrasting with the stipes of C, a later growth stage in which the stipes are about twice as wide. Other identifiable taxa are **D**, *Paratetragraptus cooperi* VandenBerg, 2017 (P330707) and **E**, *Psenograptus* sp. A (P332180). **C** has been retouched to remove most of the clutter of stipes that cross the subject. From Blackwood antimony mine.


A
B
C
D
E
F
G
H
I
s
a
b
c
Hc
Hb
Ha
0 mm 5
scale for A–I


A
D
B
E
C
0 mm 5

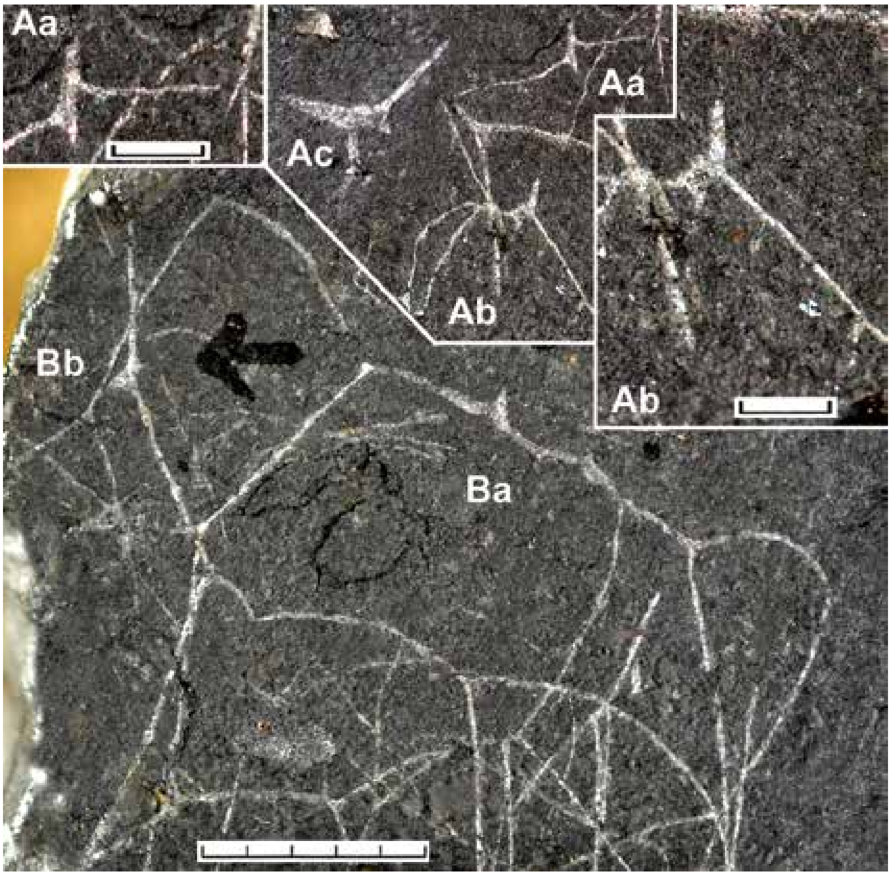


Figure 27: The best-preserved tubaria of *Lignigraptus gnomus*. **Aa**: NMV P340571; **Ab**: P340570; **Ba**: NMV P332176A; **Bb**: 332177A; **Ac**: Sicula and prothecae of *Lignigraptus chapmani*, shown for comparison with the diminutive tubaria of *K. gnomus*. The image has been retouched by moving **Ac** approximately 3 mm closer. In **B**, a few stipe fragments that cross **Ba** and **Bb** have been removed. Scales are 5 mm for the lower and top centre figures, 1 mm for the corner figures.

Figure 29 (opposite right): A confusion of stipes in which tubaria of *Lignigraptus* can be picked out by their distinctive siculae. Few of the stipes show any thecae. **A–C**: *Lignigraptus gnomus*; **D–F**: *L. chapmani*; G: *Paratetragraptus thomassmithi* VandenBerg, 2017 (partly obscured); **H**: *Tshallograptus cymulus* VandenBerg, 2017. Note that, with the exception of **F**, the tubaria of *Lignigraptus* are markedly fainter than those of *P. thomassmithi* and *T. cymulus*, suggesting that they were more weakly sclerotised. **A**: NMV P340572; **B**: P330717; **C**: P340573; **D**: P330719; **E**: P330718; **H**: P330713; Blackwood antimony mine, La3. Scale is 10 mm.

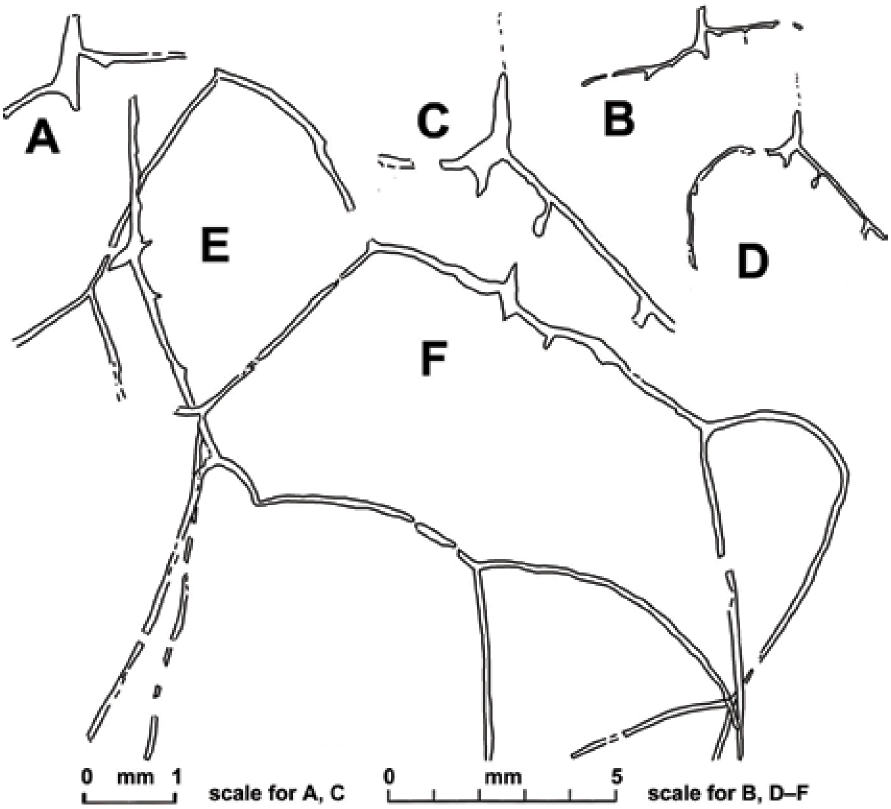


Figure 28: Drawings of the best-preserved tubaria of *Lignigraptus gnomus*. **A**, **B**: NMV P340571; **C**, **D**: P340570; **E**: 332177A; **F**: P332176A.

Lignigraptus gnomus n. sp.
(Figures 27–29)

Diagnosis. *Lignigraptus* with diminutive tubarium with sicula up to 1.3 mm long and at least three orders of irregularly spaced branching.

Etymology. Gnomus = small, a reference to the size of the tubarium and sicula.

Holotype. NMV P340570, Figures 27Ab, 28C, D from the Blackwood antimony mine.

Referred material. Paratypes P340571, 332176, P332177, from the same locality.

Material and distribution. The figured and measured specimens represent a portion of the population of a dozen or so specimens from quite a small collection. Several slabs in the collection have a spaghetti-like confusion of stipes in which a few siculae can be seen but individual tubaria cannot be traced (Figure 29). The collection is of the La3 *Paratretragraptus approximatus* Biozone (VandenBerg 2017). The species is not known from any other locality.

Description. The habit is declined but the interstipe angle is very variable, no doubt at least partly due to the flexibility of the tubarium. The funicle is asymmetric, with both stipes ranging from between 1 and 4 thecae long. Lengths of the second-order segments range from 5.2 to 6.9 mm. P332176 has a third-order segment (1b1) that is 6.1 mm long before dividing again; others have longer second-order segments that do not divide.

The sicula appears disproportionally large but this is due mainly to the very slender appearance of the stipes — it seems that only the common canal is preserved in most tubaria, with thecae only visible in exceptional examples (Figures 27Ab, 28C). The sicula is 1.15–1.25 mm long and 0.3–0.4 mm wide at the aperture. One specimen has a very thin nema 0.8 mm long. Stipes are approximately 0.1 mm wide in early growth stages, increasing to 0.15 mm at thecal apertures. Several specimens show broader stipes, to 0.35 mm wide, apparently due to secondary thickening. The holotype shows a single theca with an apparently complete glossa, approximately 0.35 mm long (Figure 27Ab). Thecae are so rarely preserved that it is not possible to determine their length and spacing; in the holotype, the inferred spacing is 7 in 5 mm proximally.

Discussion. While the poor preservation of the material makes it difficult to make accurate biometric measurements, the diminutive size of the sicula and slenderness of the stipes sets it apart from all other species of *Lignigraptus*.

Lignigraptus sedecimus (Harris & Thomas, 1938a)
(Figures 30–32)

1938a *Dichograptus sedecimus*, n. sp.; Harris & Thomas, p. 73, pl. 1, fig. 12; pl. 4, fig. 11.

1991 *Dichograptus sedecimus* Harris & Thomas; Rickards & Chapman, p. 42, pl. 9, fig. b; text-figs 49, 54.

Diagnosis. *Lignigraptus* with declined funicle consisting of 3 or 4 thecae on each stipe; 2–3 (rarely 4) orders of branching by delayed dichotomy; proximal configuration asymmetric, with sicula skewed towards stipe 1.

Holotype. NMV P32010 (OD), Figures 30, 31, from PL 2017, parish of Campbelltown, early Floian (Be1), *P. approximatus* + *T. fruticosus* Biozone.

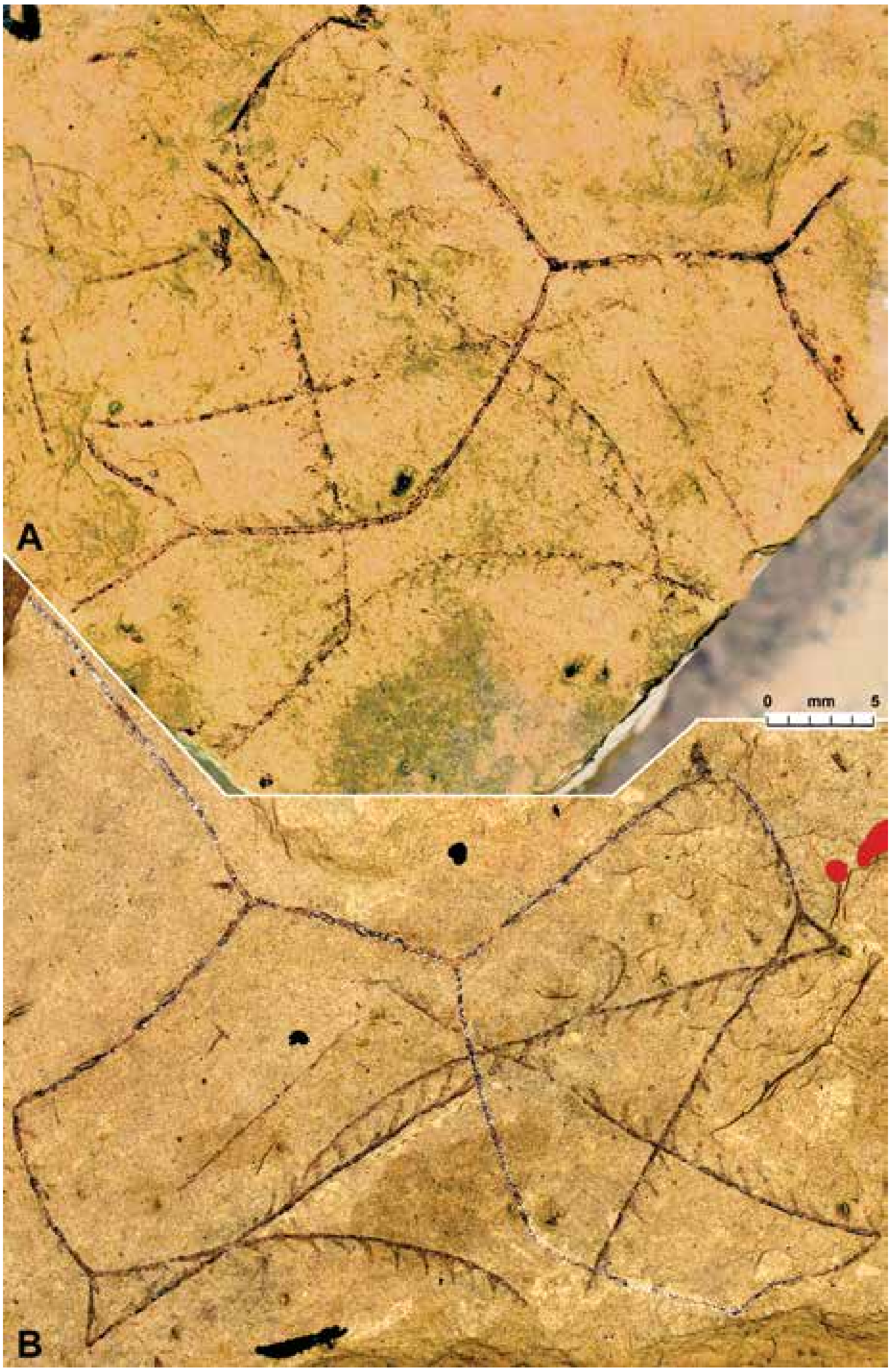


Figure 30: The holotype of *Lignigraptus sedecimus*, NMV P32010B (**A**) and A (**B**), from PL 2014.

Material and distribution. Six measured specimens, all poorly preserved, from PL 2017. The species is rare and not known from outside this locality.

Description. While the funicle is straight in the holotype and several other specimens, these have foreshortened siculae or, as in the case of the holotype, have no visible sicula. In specimens that have the sicula in full profile view, the funicle is declined, with angles of 130–140° between the primary stipes (Figure 32A, B, F). It is assumed that this declined habit reflects the shape in life. The funicle may be symmetrical, composed of 4 thecae on both stipes (4.8–5.5 mm long), or asymmetrical, with only 3 thecae on either stipe (3.9–4.7 mm long). Secondary stipe segments are 23–24 mm long in the holotype but much shorter in other specimens, with the shortest being 5–7 mm long (Figures 32A, F).

The sicula is only measurable in two specimens — one is 1.9 mm long, the other 2 mm but has its apex missing. The holotype is the only specimen that shows sufficient detail of the thecae to make some measurement possible. The thecae show very slight widening towards their apertures, with the most prominent structures being their glossae, whose profile ranges from sharply to bluntly terminated. They are 1.1–1.2 mm long and their spacing ranges from 3⅔– 4⅓ in 5 mm. The glossae are much fainter than the remainder of the tubarium, suggesting they were not sclerotised.

Secondary thickening is evident in some specimens. In some, it is restricted to portions of the funicle (Figure 32A, B) and at stipe dichotomies (Figure 32C). One specimen, P331620, shows unusual thickening in the proximal portions of the funicle, and of selected stipes (Figure 32F).

Discussion. The generic placement of *L. sedecimus* has given previous workers some problems. Harris and Thomas (1938a) discussed the 'artificial nature' of generic placement based largely on branching style, as was the practice then. They referred to the thecae as being 'of the distinctive *Tetragraptus chapmani* type', having 'long rastrites-like projections'. Cooper and Fortey (1982, p. 269) tentatively placed *L. sedecimus* in their new genus *Laxograptus*. They noted the presence of 'denticulate apertural extensions', a character that 'would be expected to carry taxonomic significance at a fairly high level, [but as] this feature is shown by several species of different genera from [PL 2014]', they thought 'it may be environmentally induced and hence of limited taxonomic value'. Rickards and Chapman (1991) placed *L. sedecimus* with *Dichograptus* but did not discuss their reason. However, from the context it is evident that they regarded the number of terminal stipes as the primary criterion.

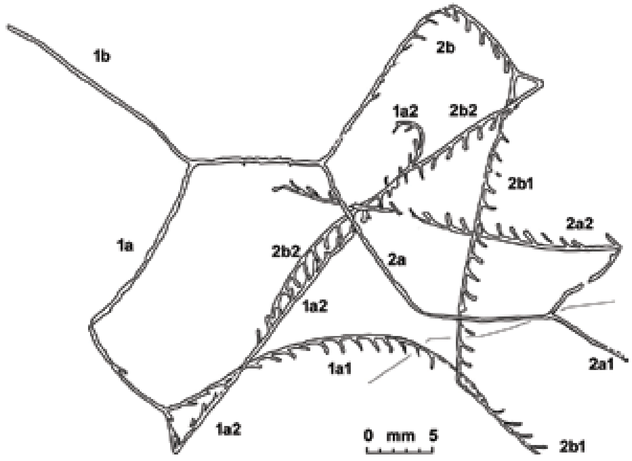


Figure 31: Reconstruction of the holotype of *Lignigraptus sedecimus* from the two counterparts. Note the variation in the appearance of the glossae, from a sharply pointed end (lateral view) to a bluntly rounded end (dorsoventral view). Note also the fortuitous positioning of the five bends in the stipes as they have allowed the preservation of an almost complete tubarium on a small slab. The portion below the grey line is only preserved on P32010B. The stipe notation assumes that stipe 1 is the left portion of the funicle — it has a slightly 'higher' position than the right portion.

Lignigraptus ramulosus (Harris & Thomas, 1938a)
(Figures 33–37)

1938a *Clonograptus ramulosus*, n. sp.; Harris & Thomas, p. 73, pl. 3, fig. 10, pl. 4, fig, 9.

1991 *Clonograptus ramulosus* Harris and Thomas; Rickards & Chapman, p. 29, pl. 1, figs a, b, text-figs 21, 35.

Diagnosis. Lignigraptus with funicle > 15 mm long, stipe segments between dichotomous branching points > 5 mm long, branching to at least fifth order.

Referred material. Holotype NMV P32082 (two counterparts), Figure 34, and paratype P32030 (OD), plus a single additional specimen.

Material and distribution. The holotype and paratype are from the northwest corner of allotment 30A section II, parish of Campbelltown, *Tshallograptus tridens* Biozone. An additional specimen illustrated here (Figure 37) is from loc. S85, Campbelltown and is of the same age.

Description. The holotype is the only reasonably complete specimen. It consists of a horizontal funicle 36 mm long with no sicula or thecae visible. Branching is strongly delayed, with second-order stipe segments ranging from 45 mm to 50.5 mm long, third-order segments between 70 mm and 95 mm long, and the single measurable fourth-order segment of 95 mm long. Higher-order segments are incomplete and at least 80 mm long. Added together, they indicate a total size of more than 650 mm across.

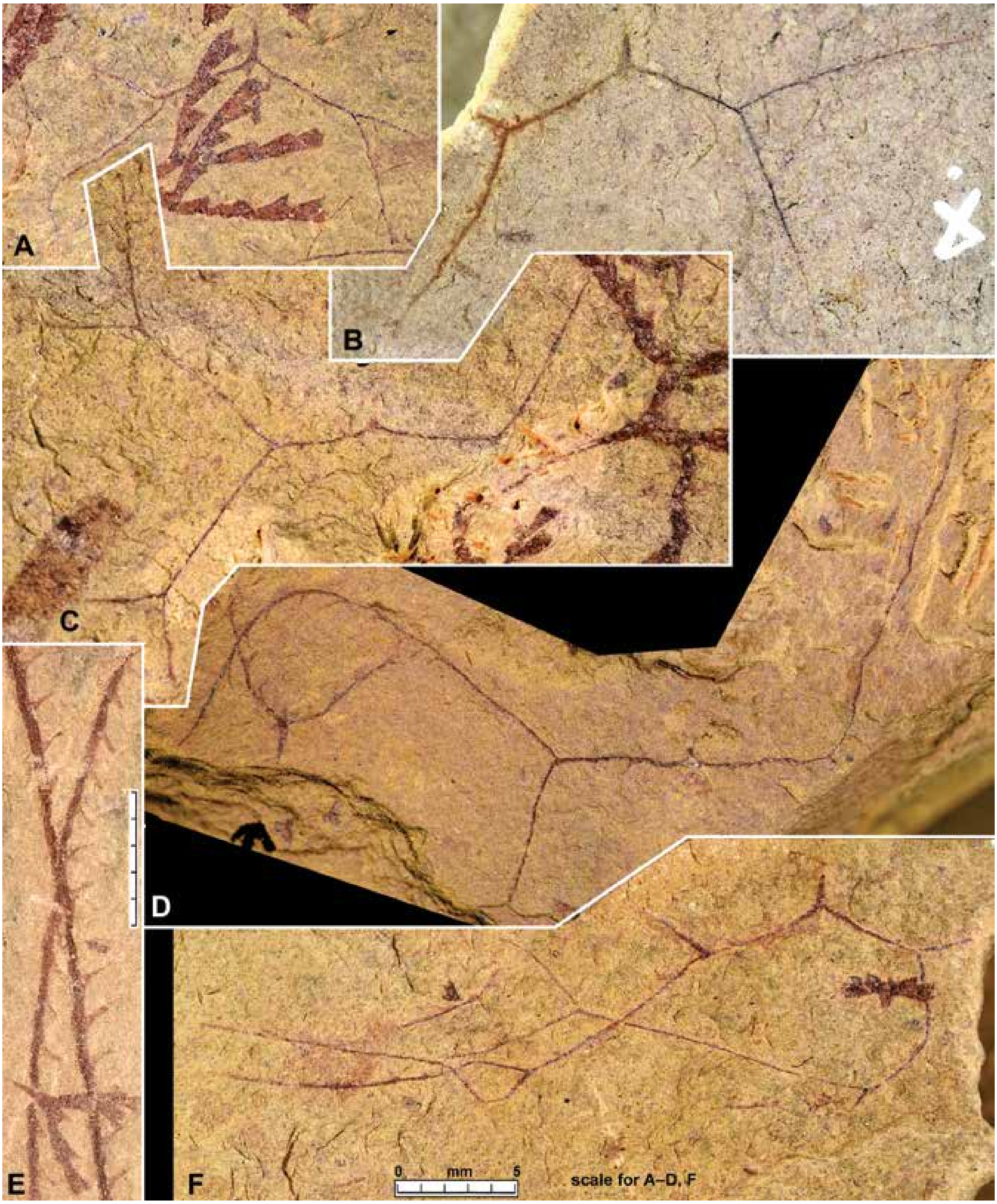


Figure 32: Early growth stages of *Lignigraptus sedecimus*. Note that most of the stipes have a 'skeletal' appearance, with thecae apparent only in short portions. **E** shows distal stipes with variation in profiles of the glossae. **A**: NMV P332402; **B**: P331656; **C**: P332221; **D**: P324119, with *L. absidatus*, P324120; **E**: P324117; **F**: P331620, the only known specimen with 3 orders of branching. All from PL 2017.

Figure 33: Proximal portion of holotype of *Lignigraptus ramulosus* with stipes labelled. **F** is near the mid-point of the funicle — the sicula is not visible.

The only specimen with a sicula preserved is P327864, but its preservation is so poor that the sicular dimensions cannot be measured (Figure 37B). Glossae are visible on the paratype (Figures 35–36) but this shows little detail of the thecae, other than that their inclination is low. All specimens show secondary thickening. The best example is P32030 (Figure 35) which shows thickening gradually decreasing distally.

Discussion. The distinguishing character of this species is the extremely delayed branching, which sets it apart from all other sinograptids. If it were not for the presence of glossae, I would have placed it in *Laxograptus*.

Figure 34: Entire specimen of the holotype of *Lignigraptus ramulosus* (P32082A) with stipes labelled. I have assumed that stipe 2a is bent and branches in a similar fashion to 1b and re-enters the slab at arrowed stipes 2a1 and 2a2.

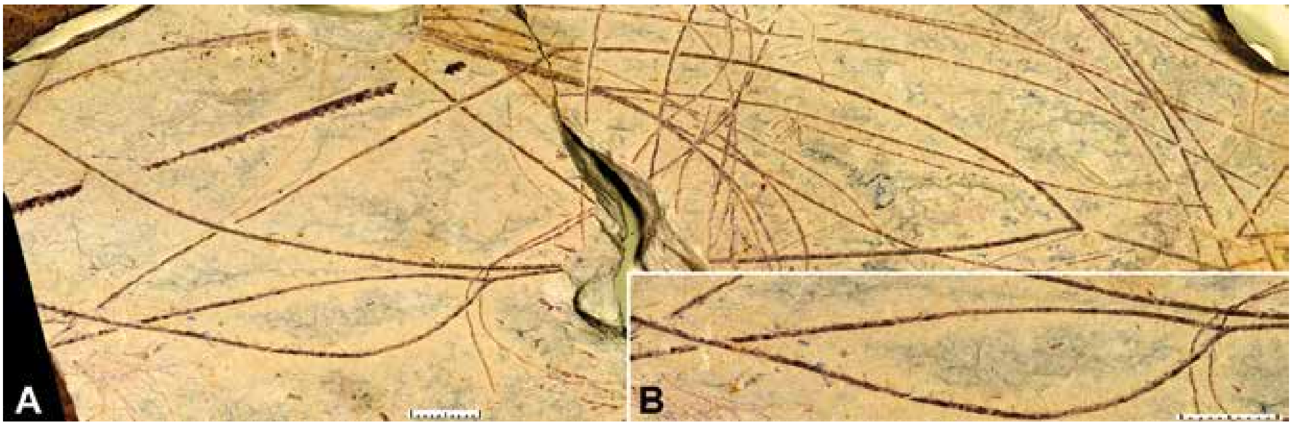


Figure 35: *Lignigraptus ramulosus* paratype P32030. **A**: Entire specimen consisting of a single second-order (?) and higher-order stipes; **B**: Portion of stipes on the lower left showing faint glossae. Scales are 10 mm.

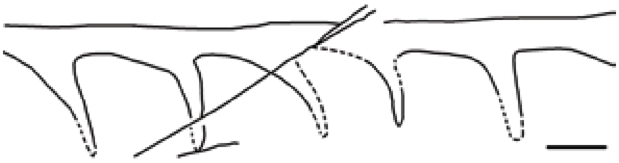


Figure 36: Distal thecae of *Lignigraptus ramulosus* paratype P32030 showing glossae, from Rickards & Chapman (1991, Fig. 35). Scale bar is 1 mm long.

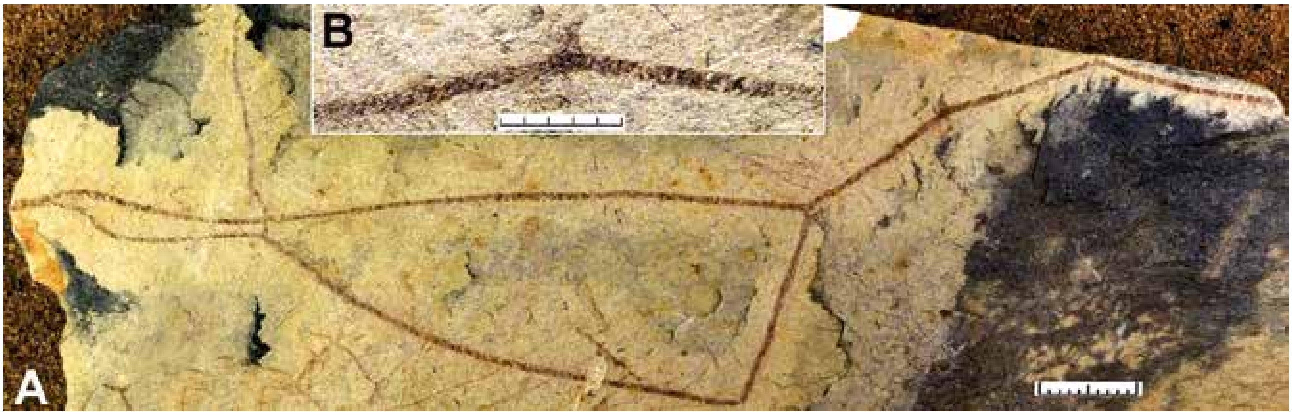


Figure 37: *Lignigraptus ramulosus*, P327864B. The specimen, mentioned but not figured by Harris & Thomas (1938a, p. 73), is the only one with the sicula preserved in profile view. It has the asymmetry characteristic of sigmagraptids, with the first stipe on the right. The slab break coincides with the first dichotomous division (upper right). **A**: entire specimen, scale = 10 mm; **B**: portion of the funicle, scale = 5 mm.

Lignigraptus erdtmanni (Rickards & Chapman, 1991) (Figures 38–40)

pars 1938a *Clonograptus rarus*, n. sp.; Harris & Thomas, p. 73, pl. 1, fig. 8b; pl. 3, fig, 8a.

1991 *Clonograptus erdtmanni* n. sp.; Rickards & Chapman, pp. 31–32, text-figs 22, 34, 40; pl. 3, fig. a.

Diagnosis. *Lignigraptus* with short funicle and declined habit, with delayed dichotomous branching to at least fifth order.

Holotype. NMV P34260 (OD), Figure 38, from PL 2014, Be1 (*P. approximatus* + *T. fruticosus* Biozone).

Material and distribution. The holotype is the only known specimen.

Description. The lack of early growth stages imposes considerable difficulties on our understanding of this species. The habit is declined, with an interstipe angle of 105°. Rickards and Chapman (1991) described the 'sicular region' as 3.2 mm long, but what this means is uncertain — secondary cortical overgrowth obscures all detail in the proximal area (Figure 38B). The funicle is short, with the two primary stipes being approximately 5 and 6 mm long, probably 3 and 4 thecae respectively. Lengths of secondary stipe segments range from 21 mm to 29 mm, and of ternary

Figure 38: *Lignigraptus erdtmanni* holotype. **A**: Entire slab; **B**: Proximal area at higher magnification; **C**: detail of stipes 1b1b1 and 1b1b2 showing glossae; scale = 5 mm.

segments from 20 mm to 62 mm. Stipe width decreases with successive dichotomies, from 1.8 mm at stipe 1 to 0.9 mm to 1.1 mm in fourth order stipes, to 0.6 mm distally (not including the glossae). Proximal stipes are either smooth-sided or show a very slightly stepped thecal profile. Glossae first become visible in fourth-generation segments but are visible only on some stipes, or portions of stipes. They are mostly slender and bluntly rounded, projecting up to 1.4 mm from the ventral stipe margin (Figures 38C, 40). A few show slightly darker edges. Thecal spacing is 3⅔–4½ in 5 mm.

Discussion. With no representatives other than the holotype, which is large, with proximal details obscured by secondary thickening, *Lignigraptus erdtmanni* remains poorly understood. In normal populations, early growth stages are far more numerous than fully grown specimens. Yet in the large collection from PL 2014 (a.k.a. the 'Good bed', the name its discoverer gave to it because of its fossil richness), seems not to have any early growth stages. I consider it possible, however, that *Lignigraptus erdtmanni* represents a 'gerontic' form of *Lignigraptus sedecimus*, in which case the specimen shown in Figure 32F, here

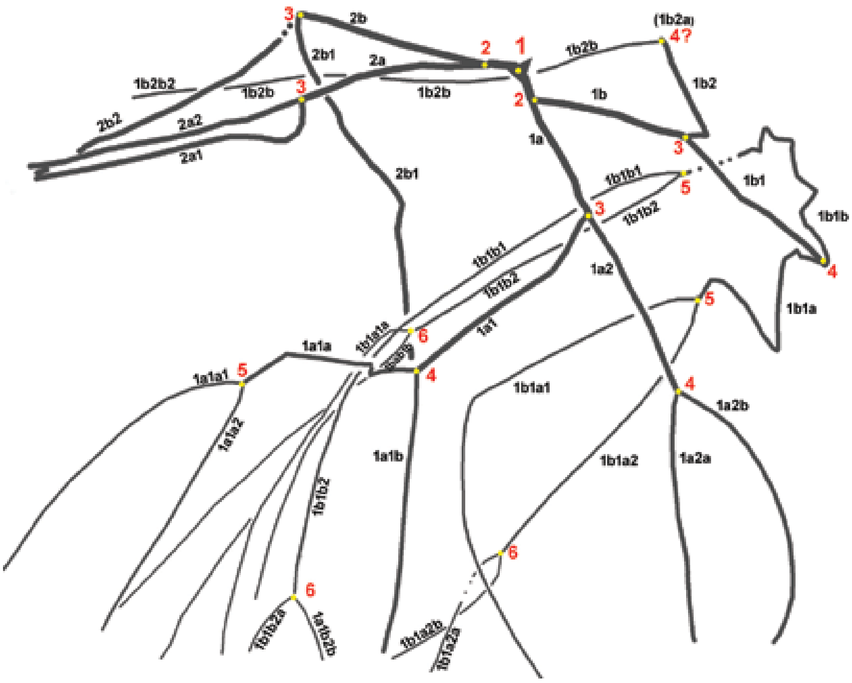


Figure 39: *Lignigraptus erdtmanni* branching diagram. Yellow dots are branching points, sequentially numbered.

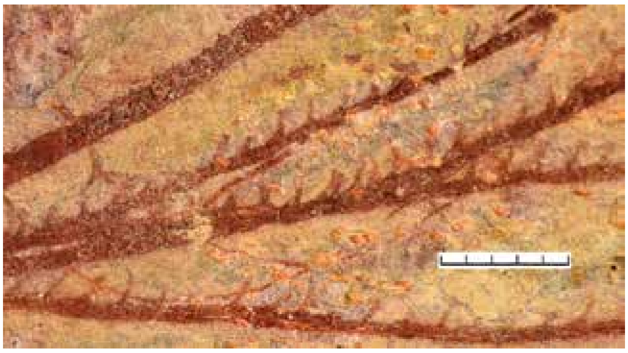


Figure 40: *Lignigraptus erdtmanni* distal stipes showing thecal profiles. Stipes are in area left of 1b1b2. Scale = 5 mm.

included in *L. sedecimus* but with 3 orders of dichotomous division rather than the usual 2, may be a growth stage transitional to that represented by *L. erdtmanni.*

Lignigraptus absidatus n. sp.
(Figures 41, 42)

Etymology. Absidatus (L) = arched, for the funicle shape.

Diagnosis. *Lignigraptus* with 4-stiped pendent tubarium with arch-shaped funicle consisting of 4 or more thecae on both stipes.

Holotype. NMV P331644, Figures 41D, 42A, B, from PL 2014, Be1 (*P. approximatus* + *T. fruticosus* Biozone).

Referred material. Paratypes NMV P331627, P332271 and P324120, all from the same locality.

Material and distribution. Only five specimens are known, all from the same locality. All are poorly preserved as speckled iron oxide films in cleaved shale that shows no evidence of tectonic deformation.

Description. The two most fully grown specimens have four stipes, with an arch-shaped funicle 10.7–11.1 mm long, with primary stipes of nearly equal length, consisting of 4 or 5 thecae (Figure 41A, D). One two-stiped specimen has primary stipes slightly longer, 5.8 mm each. The sicula is 2.30–2.80 mm long, and 0.2–0.4 mm wide at the aperture. A very short nema (longest 0.4 mm) is present in two specimens.

Thecae are of the kinnegraptine type, with the prothecae and metathecae each taking up about half the free ventral wall. The width cannot be measured — total stipe width of the proximal (prothecal) portion is 0.12–0.20 mm, then increasing rapidly, reaching 0.4–0.6 mm at the aperture. Thecal glossae are 0.6–0.85 mm long.

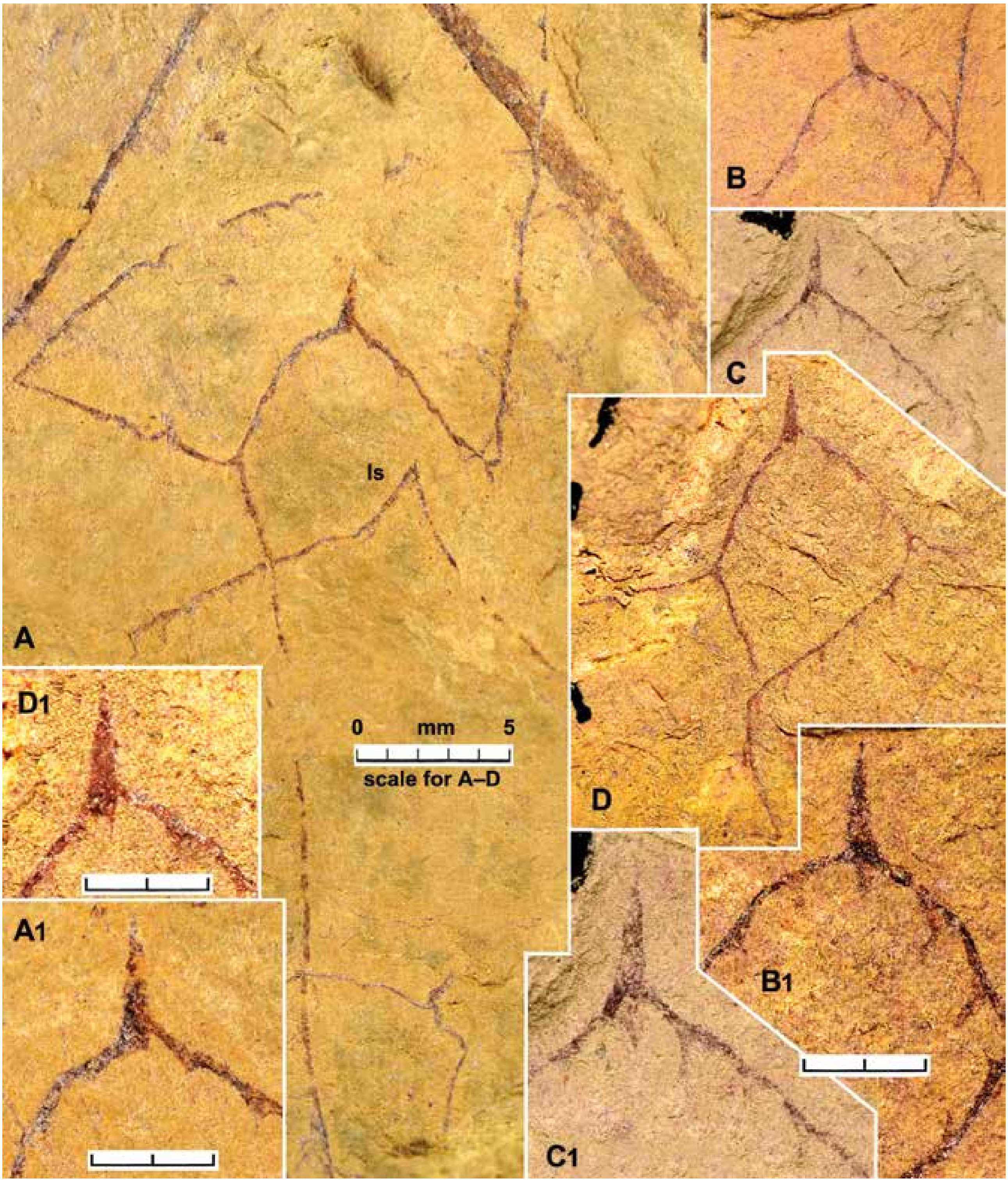


Figure 41: *Lignigraptus absidatus*. **A–D** show entire specimens at magnification shown in centre; **A1–D1** are proximal areas at higher magnification with 2 mm scales. **A**: NMV P332271, with four stipes; ls is a loose stipe that may be the missing portion of stipe 1A—its distal thecae have long glossae that resemble the more poorly preserved glossae on stipe 2B; **B**: P324120; **C**: P331627; **D**: Holotype P331644.

The most fully grown specimen has one secondary stipe 23.8 mm long, suggesting that when complete, a flattened tubarium would have measured approximately 60 mm across. Stipes are slender throughout, lacking any secondary thickening.

Discussion. While *Lignigraptus absidatus* is similar in many respects to *L. chapmani*, its pendent habit is distinctive. It is somewhat similar to *L. kinnegraptoides* (Erdtmann et al., 1987) but in that species, the funicle is shorter and only slightly declined. It also has up to five generations of dichotomous branching.

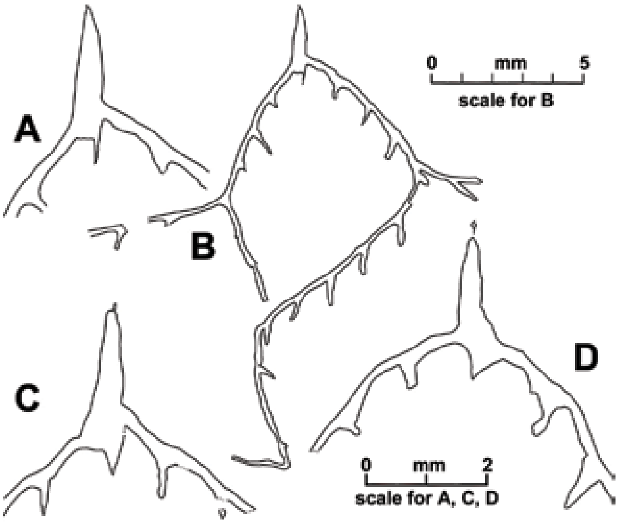


Figure 42: Proximal portions of the best-preserved specimens of *Lignigraptus absidatus*. **A**, **B**: Holotype P331644; **C**: P331627; **D:** P324120.

Lignigraptus daangean n. sp.
(Figures 43, 44)

1983 *Kinnegraptus* sp.; VandenBerg & Stewart, p. 36 (listed only).

Etymology. It is thought that '*Daangean*' is the earliest name given to the locality where the graptolite was found, thought to have been used by the Boon Wurrung people, the first inhabitants of the area.

Diagnosis. Two-stiped *Lignigraptus* with slightly declined stipes and long nema; sicula nearly straight and upright, bearing a small glossa.

Type material. Holotype NMV P76772, Figures 43E, F, 44E, F, paratype P318956.

Material and distribution. The three figured specimens are the only ones thus far identified; all are preserved as pyritised films, from the Devilbend Quarry, Mornington Peninsula, from the Floian *Didymograptellus kremastus* Biozone (Ch1).

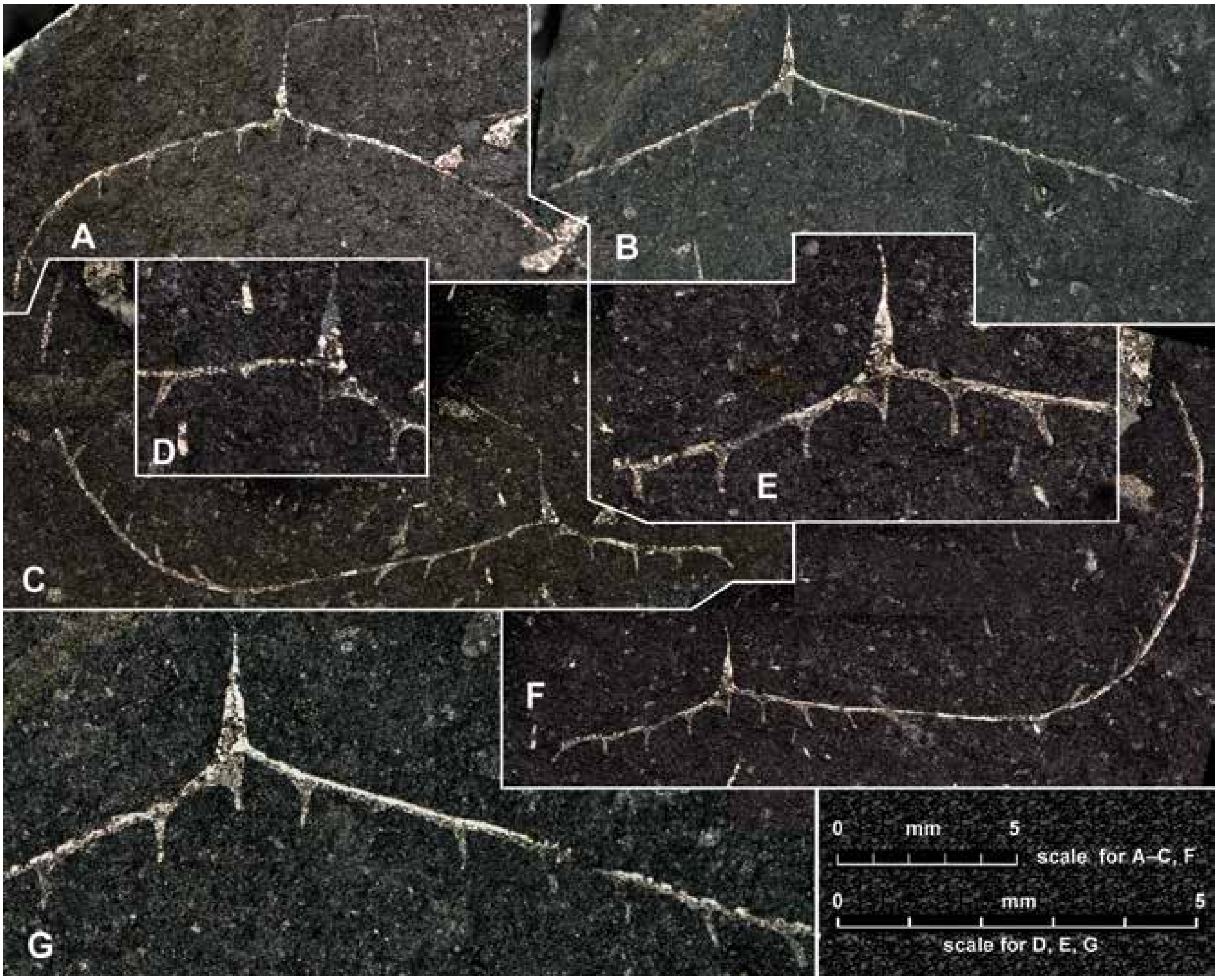


Figure 43: *Lignigraptus daangean*, the only two-stiped species of *Lignigraptus* found in Victoria. **A**: NMV P329779; **B**, **G**: P318956; **C**, **D**: P76772B; **E**, **F**: P76772A. All are from Devilbend Quarry, Mornington Peninsula (Ch1).

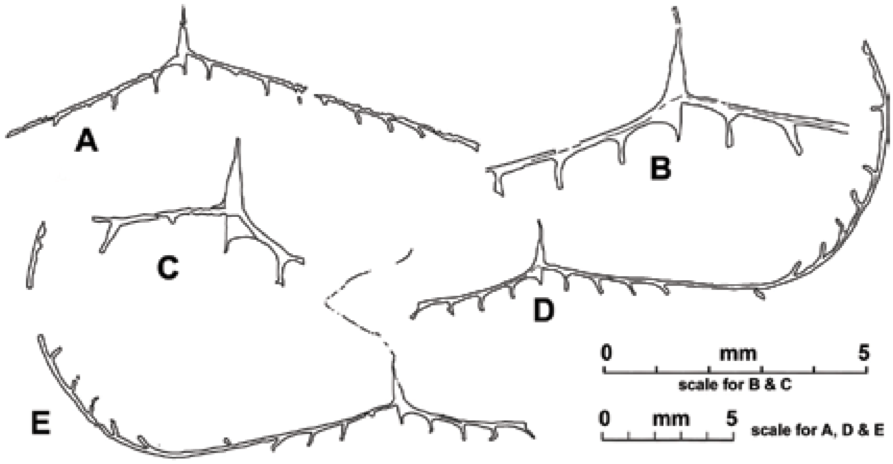


Figure 44: Drawings of *Lignigraptus daangean*. See Figure 43 for registration numbers.

Description. The habit is declined, with interstipe angles ranging from 125–155°. The two stipes are straight to slightly flexuous, showing gently ventral curvature. The holotype is the only specimen in which one of the stipes is 'complete', i.e. not terminated by a slab edge (or by a pathological/post-mortem termination, as in stipe 2 of the holotype). It is 21 mm long, the longest in the three specimens.

The sicula appears disproportionally large but this is due mainly to the slenderness of the stipes. Its length ranges from 1.5 mm to 1.75 mm and its width, at the aperture, is 0.65–0.9 mm. The sicular aperture of P318956 is provided with a ventral glossa 0.25 mm long (Figure 43G). This sicula has a more densely pyritised proximal portion 0.8 mm long that is interpreted to be the prosicula. $Th1^1$ appears to originate from this portion and grows down along the dorsal side of the sicula to approximately 1.3 mm from the tip of the sicula, then makes a sharp dorsal bend that marks the beginning of stipe 1. At the bend, it bifurcates, giving rise to 1^2 which grows towards the ventral apertural margin of the sicula and begins stipe 2. The nema is very slender and unusually long — the longest, in the holotype, is 9.8 mm long.

Thecae are quite long, with irregular spacing ranging from as low as 0.9 mm to as much as 1.5 mm between adjacent thecal apertures, with no consistent trend. Average spacing ranges from 4–4½ in 5 mm. The slender prothecal and rapidly widening metathecal portions of thecae each make up about half the free portions of the ventral walls. Apertural tips carry prominent glossae 0.5–0.7 mm long.

Discussion. *Lignigraptus daangean* is the only known species of *Lignigraptus* that has a sicular glossa, although it is quite short, and in the holotype is visible only in one of the counterparts (Figure 43D). It is very rare, known only from three specimens from a single locality. Its conical sicula is almost straight, and the proximal asymmetry is less pronounced than in other species of *Lignigraptus.*

Lignigraptus diabolus n. sp.
(Figures 45, 46)

Diagnosis. Four-stiped *Lignigraptus* with moderately long funicle and sicula that is at approximately right angles with it.

Etymology. From Latin *diabolus* = devil, named for the type locality, Devilbend Quarry, Mornington Peninsula, Victoria.

Holotype. NMV P318303, Figures 45, 46..

Material and distribution. The holotype is the only specimen. It consists of two counterparts of partly pyritised films, from the Devilbend Quarry, Mornington Peninsula, from the upper Floian *Tshallograptus tridens* Biozone (VandenBerg 2017).

Description. The holotype consists of a moderately long horizontal funicle of which stipe 1 is 12.5 mm long and stipe 2 is 13.0 mm long; both consist of 10 thecae. The only complete secondary stipe, 2a, is 62.3 mm long, from which I infer that the entire tubarium had a radius of approximately 75 mm. The sicula is approximately 1.65 mm long (a tiny portion of the tip seems to be missing) and consists of a conical prosicula and tubular (parallel-sided) metasicula, with a sharply pointed rutellum at the aperture. $Th1^1$ seems to originate in the metasicula and departs from the sicula at a near-orthogonal angle. Stipe 2 leaves the sicula at a slightly lower position than stipe 1, giving the funicle a near-symmetrical appearance.

Free ventral walls of thecae are nearly parallel with the dorsal stipe margin for most of their length, widening slowly from 0.20 to 0.25 mm, then more rapidly to 0.35 mm at the apertural margin. The glossae attached to the margin are very varied in appearance, suggesting they were thin and flexible. In some, the end is bluntly rounded (e.g. in Figure 45B), suggesting a shape similar to the glossae of *Kinnegraptus kinnekullensis* and *L. chapmani*. Thecal

Figure 45: The holotype of *Lignigraptus diabolus.* **A**, **C**: Mosaic of NMV P312303A and enlargement of portion of stipe 2a showing thecal profile and glossae; **B**, **D**: Enlargement of the sicula and the entire funicle of P312303B. Note the entangled tubaria of *Catenagraptus communalis* VandenBerg, 2017. Scales are 5 and 2 mm long.

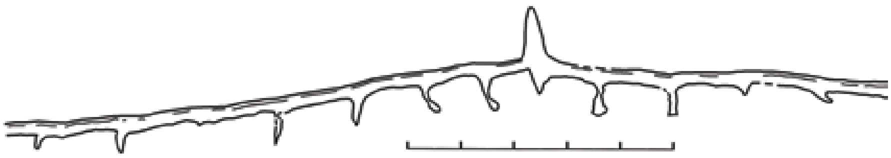


Figure 46: Drawing of portion of the funicle of the holotype of *Lignigraptus diabolus* showing the variation in appearance of the glossae. Scale = 5 mm.

spacing in the funicle decreases from 4⅓–3⅓ per 5 mm and is approximately 3⅓ per 5 mm in the few places where it is measurable along the branches.

Discussion. Lenz & Jackson (1986) illustrated two specimens from the same horizon in the *T. fruticosus* Zone in the Peel River, Yukon, Canada, under the name *Kinnegraptus* sp. One of these, fig. 6K, appears to be *K. kinnekullensis* but the other, fig. 6R, is strikingly similar to *L. diabolus*. A better illustration is needed before this can be verified.

Wuninograptus Ni, 1981

Type species. *Wuninograptus quadribrachiatus* Ni, 1981

Diagnosis. Kinnegraptines with 3–4 reclined stipes; sicula and thecae with long glossae and low thecal overlap; thecal apertures with thickened rims.

Discussion. Maletz et al. (2018) placed the genus *Wuninograptus* in the Thamnograptidae because of the similarity of the development of the thecae. However, this evidence is less convincing than the proximal asymmetry of *Wuninograptus*, which indicates it is best placed in the Sigmagraptidae. Additional evidence is provided by the striking similarity of the glossae of *Wuninograptus* to those of *Kinnegraptus* and *Lignigraptus*, which suggests *Wuninograptus* should be placed in the Kinnegraptinae.

While it is possible that *Wuninograptus* is congeneric with *Lignigraptus* (and therefore its senior synonym), the type specimen is too poorly preserved to show its proximal structure (see Figure 3). *Wuninograptus quadribrachiatus* has a long sicular glossa, a character absent in most *Lignigraptus* species (although *L. daangean* has a very short sicular glossa). In view of the long time gap between the disappearance of *Lignigraptus* and the appearance of *Wuninograptus* (Table 1), I prefer to keep the two separate.

Wuninograptus quadribrachiatus Ni, 1981
(Figures 3, 47)

1933 *Tetragraptus clarkefieldi* (MS.); Thomas & Keble, p. 50 [nom. nud.].

?1979 *Kinnegraptus? gracilis* Chen (n. sp.); Mu et al., pp.

Figure 47: *Wuninograptus quadribrachiatus*, from Jackson's Creek near Clarkefield, Victoria (Da4, *Archiclimacograptus riddellensis* Biozone). Inset shows thecae at lower left at higher magnification. Scales are 5 mm and 2 mm.

114–115, pl. 40, figs 1–4.

1981 *Wuninograptus quadribrachiatus* gen. et n. sp.; Ni, pp. 205, text-figs 2:3, 4, pl. 1:1, 8.

1981 *Wuninograptus erectus* gen. et n. sp.; Ni, pp. 205–206, text-fig. 2:1, pl. 1:7.

1981 *Wuninograptus tribrachiatus* gen. et n. sp.; Ni, pp. 206, text-fig. 2:2, pl. 1:5, 6.

?1989 *Kinnegraptus* ? sp.; Carter, p. B6, fig. 4G.

1991 *Wuninograptus quadribrachiatus* Ni; Ni, pl. 4 fig. 8.

?2002 *Kinnegraptus ? gracilis* Chen; Mu et al., p. 227, pl. 72, fig. 13.

?2016 *Kinnegraptus gracilis* Chen, 1979; Chen et al., pp. 131–132, figs 6-14C, F, J.

2016 *Wuninograptus quadribrachiatus* Ni, 1981; Chen et al., pp. 132–133, figs 6-11D, 6-14A, D–E, H–I.

Diagnosis. *Wuninograptus* with three or four reclined stipes; sicula and thecae with a long glossae and low thecal overlap; thecal glossae with thickened rims (Maletz et al. 2018).

Type material. Holotype NIGP 54074, paratype NIGP 57077 (OD), from the *Didymograptus jiangxiensis* Zone (≡ *D. murchisoni* Biozone), Ningkuo Formation at Xinkaling, Wuning, China.

Material and distribution. The Victorian material consists of a single specimen, with very variable preservation, from Jackson's Creek near Clarkefield, north of Sunbury (loc. 24 in fig. 1, Thomas & Keble 1933), uppermost Darriwilian *Archiclimacograptus riddellensis* Biozone.

Description. Chinese specimens preserved in lateral view indicate a reclined habit, with distal stipes growing vertically upwards (Chen et al. 2016, figs 6-14A, I). The funicle of the Victorian specimen is very slightly curved and very slender, approximately 0.2 mm wide and 2.95 mm long. It is featureless, with no sign of a sicula or thecal apertures. Judging from the thecal spacing on the stipes, it is probably 6 thecae long. The four stipes are flexuous, with proximal dorsal curvature changing distally to ventral curvature. Only two of the stipes are sufficiently well preserved to show thecal profiles. The longest stipe is 19.5 mm long and is cut off at the slab edge.

Thecae are spaced at 5–6 in 5 mm. Thecal inclination is low, approximately 10–15°, and the maximum stipe width is 0.35–0.45 mm. The tip of each aperture is prolonged into a glossa 1.5 mm long that widens from 0.1 mm at the apertural tip to 0.2 mm distally. The rim of the glossa is distinctly more densely sclerotised, giving the appearance of a thread running along the margin. In specimens illustrated by Ni (1981), this thread terminates at the end of the rutellum and does not form a terminal loop but this appears to be a preservational effect — several of the specimens figured by Chen et al. (2016) have glossae with rounded distal ends (e.g. their figs 6–14E and I). In specimens of *Kinnegraptus kinnekullensis* illustrated by Williams and Stevens (1988), some glossae also do not have closed loops (Figure 1B, C).

Discussion. Chen et al. (2016) regarded the three species of *Wuninograptus* described by Ni (1981), all of which are from the same locality, as conspecific. Their age is stated to be *Didymograptus jiangxiensis* Zone (≡ *D. murchisoni* Biozone), approximately equivalent to Da3–Da4. Chen et al. (2016) provided more illustrations, and one of their specimens (fig. 6.14 E, H) is very similar to the Victorian specimen.

Chen (in Mu et al. 1979) illustrated fragments of a branching tubarium as *Kinnegraptus gracilis* Chen, 1979 from the *Didymograptus murchisoni* Biozone of the Saergan Formation, Dawangou, Kalpin, Xinjiang, China, from the same section that contains *Wuninograptus quadribrachiatus* Ni. Although its stipes are more slender than those of *W. quadribrachiatus*, this may be because it lacks secondary thickening. There is therefore a distinct possibility that the two are conspecific, in which case *W. gracilis* is the senior synonym.

Psenograptus n. gen.

Etymology. From *psenos* (G.): smooth, bald, alluding to the absence of visible thecae.

Type species. *Psenograptus costermansi* n. sp.

Diagnosis. Multiramous kinnegraptine with horizontal funicle and no visible thecae.

Psenograptus costermansi n. sp.
(Figures 48–49)

Diagnosis. *Psenograptus* with funicle > 7 mm long and three or more orders of delayed dichotomous branching.

Etymology. Named for Leon Costermans, friend, collaborator and teacher.

Type material. Holotype NMV P327560, Figure 48, and paratype P327612, both from '22B' (= allotment 22B, ph. of Campbelltown; Be1, *P. approximatus* + *T. fruticosus* Biozone).

Material and distribution. The holotype and paratype are preserved as Fe-oxide films on soft, weathered slate that shows evidence of a small amount of tectonic distortion. It is only known from the type locality.

Description. The funicle is declined in the holotype, with an angle of 115° between the primary stipes. It is much less so in the paratype but this has a skewed sicula which suggests that the funicle has been distorted prior to burial. The funicle is asymmetric, with stipe 1 considerably longer (5.3–6.0 mm) than stipe 2 (3.2–4.4 mm). Secondary stipe

Figure 48: Holotype of *Psenograptus costermansi*, with inset showing the funicle at higher magnification. S indicates the sicula, while numerals indicate the position of the three orders of branching. The yellow line is drawn along the trace of the slaty cleavage. Scales are 5 mm long.

Figure 49: Paratype P327612 of *Psenograptus costermansi*. Numerals indicate the positions of the branching points. The red line is drawn along the trace of the slaty cleavage.

segments have lengths ranging from 3.3 to 9.6 mm long, and ternary segments range from 5.2 to 17.7 mm long. All specimens lack any sign of thecae, with stipes being smooth-sided to their distal ends. In the holotype, stipes are slender throughout, approximately 0.08 mm wide, but secondary thickening occurs at all branching points. The paratype show progressive secondary thickening, from a width of 0.18 mm in the primary stipes to approximately 0.02 mm distally where the stipes are not thickened; distal stipe portions are faint and somewhat flexuous. The holotype shows four orders of branching, the paratype shows five.

Discussion. The absence of visible thecae throughout the tubarium, even in the most distal portions, sets *Psenograptus* apart from species in which thecal profiles are obscured by overgrowth, usually in the proximal portions of tubaria.

Psenograptus sp. A
(Figure 10E)

Description. A single specimen of *Psenograptus* (NMV P332180) occurs on a slab from the Blackwood antimony mine, together with several tubaria of *Lignigraptus chapmani.* Its sicula is skewed to the left, from which I infer that it is a kinnegraptine. It shows unusual asymmetry. The funicle, which is straight, has one stipe twice as long as the other (6.0 mm vs 3.2 mm). Stipe 1a is 7.3 mm long, whereas stipe 1b is 12.6 mm long. Stipe 1a2, which is the only ternary stipe that bifurcates, is 12.2 mm long (other stipes extend to the broken edge of the slab).

Psenograptus sp. B
(Figure 50)

Description. A single specimen of *Psenograptus* (NMV P330771) was found in a small collection from loc. ME/B, ph. of Coornnmill (near Blackwood), from the *Tshallograptus tridens* Biozone. In view of the limited material, it seems premature to erect a new species at this stage, even though it is significantly different from *P. costermansi*. Its funicle, which is straight, is somewhat longer and almost symmetrical, with primary stipes 6.2 mm and 6.7 mm long. Secondary segments are longer, 15.3–24 mm long. All stipes are smooth-sided and show secondary thickening; branching points are similarly thickened. The funicle, and stipe segments, are of similar width throughout but become thinner stepwise at each division.

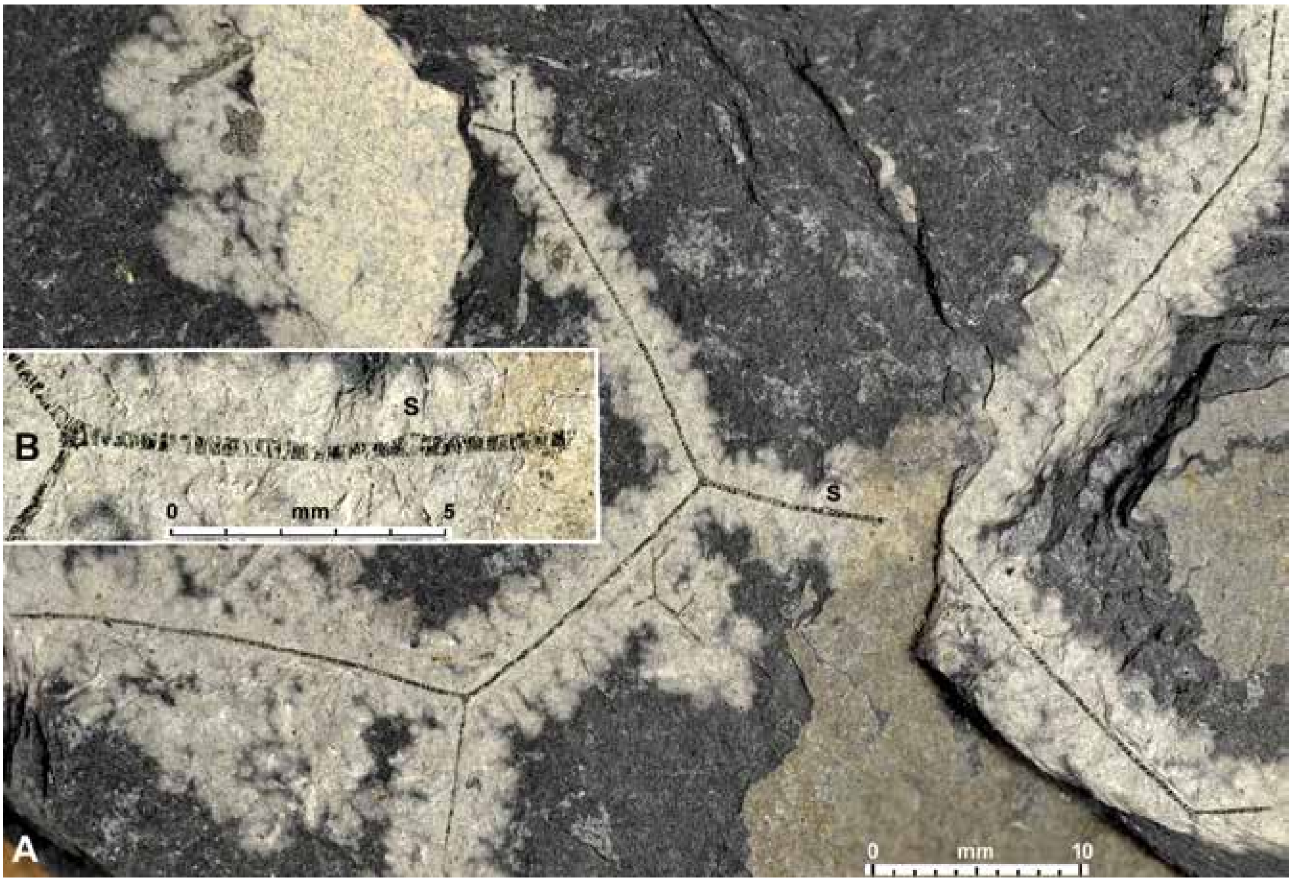


Figure 50: *Psenograptus* n. sp. **B**. The inset shows the funicle at higher magnification; S indicates the position of the sicula. NMV P330771A.

Acknowledgements

I thank Museums Victoria palaeontologists, particularly Rolf Schmidt, David Holloway and Tim Ziegler for access to the collections and help with technical matters, and Leon Costermans for helping me improve my image processing skills. I particularly thank reviewers Adrian Rushton and Gladys Ortega for their patience and thoroughness, which helped make considerable improvements. Jörg Maletz kindly supplied photographs of the type specimens of *Wuninograptus quadribrachiatus.*

References

Archer, J.B. & Fortey, R.A., 1974. Ordovician graptolites from the Valhallfonna Formation, northern Spitsbergen. *Special Papers in Palaeontology* 13: 87–97.

Benson, W.N. & Keble, R.A., 1935. The geology of the regions adjacent to Preservation and Chalky inlets, Fiordland, New Zealand. Part IV. Stratigraphy and palaeontology of the fossiliferous Ordovician rocks. *Transactions of the Royal Society of New Zealand* 65: 244–294, pls 30–33.

Berry, W.B.N., 1966. A discussion of some Victorian Ordovician graptolites. *Proceedings of the Royal Society of Victoria* 79: 415–448.

Bulman, O.M.B., 1941. Some dichograptids from the Tremadocian and Lower Ordovician. *Annals and Magazine of Natural History* 11/7: 100–121.

Carter, C., 1989. Ordovician-Silurian graptolites from the Ledbetter Slate, northeastern Washington State. *U.S. Geological Survey Bulletin* 1860: i–iv, B1–B29, 1 plate.

Chen X., Zhang Y., Goldman, D., Bergstrom, S.M., Fan J., Wang Z., Finney, S.C., Chen Q. & Ma X., 2016. *Darriwilian to Katian (Ordovician) graptolites from Northwest China*. Advanced Topics in Science and Technology in China, Zhejiang University Press/ Elsevier, 354 pp.

Cooper, R.A., 1979a. Ordovician geology and graptolite faunas of the Aorangi Mine area, northwest Nelson, New Zealand. *New Zealand Geological Survey Paleontological Bulletin* 47, 127 pp., 19 pls.

Cooper, R.A., 1979b. Sequence and correlation of Tremadoc graptolite assemblages. *Alcheringa* 3: 7–19.

Cooper, R.A. & Fortey, R.A., 1982. The Ordovician graptolites of Spitsbergen. *Bulletin of the British Museum (Natural History), Geology* 36, pp. 157–302, pls 1–6.

Cooper, R.A. & Stewart, I.R., 1979. The Tremadoc graptolite sequence of Lancefield, Victoria. *Palaeontology* 22: 767–797.

Erdtmann, B.-D., 1971. *Tetragraptus otagoensis* and *Janograptus terranovensis,* n., sp., Ordovician graptolites from western and northern Newfoundland. *Journal of Paleontology* 45: 258–264.

Erdtmann, B.-D., Maletz, J. & Gutiérrez-Marco, J.C., 1987. The new Early Ordovician (Hunneberg Stage) graptolite genus *Paradelograptus* (Fam. Kinnegraptidae), its phylogeny and biostratigraphy. *Paläontologische Zeitschrift* 61: 109–131.

Foster, H. & Knight, J.L., 1981. Blackwood County of Bourke. *Geological parish plan*, Geological Survey of Victoria.

Ganis, G.R., 2005. Darriwilian graptolites of the Hamburg succession (Dauphin Formation), Pennsylvania, and their geologic significance. *Canadian Journal of Earth Science* 42: 791–831.

Gutiérrez-Marco, J.C., 1982. Descubrimiento de nuevos niveles con graptolitos ordovícicos en la unidad "Pizarras con *Didymograptus*" (prov. Huelva, SW de España). *Comunicações dos Serviços Geológicos de Portugal* 8: 241–246.

Hall, T.S., 1899a. Victorian graptolites: Part II. The graptolites of the Lancefield Beds. *Proceedings of the Royal Society of Victoria* 11: 164–178.

Hall, T.S., 1899b. The graptolite-bearing rocks of Victoria, Australia. *Geological Magazine* 4(6), pp. 438–451.

Harris, W.J. & Thomas, D.E., 1938a. Victorian graptolites (new series) — Part V. *Mining and Geological Journal* 1(2): 70–81, Department of Mines, Victoria.

Harris, W.J. & Thomas, D.E., 1938b. A revised classification and correlation of the Ordovician graptolite sequence zones of Victoria. *Mining and Geological Journal* 1(3): 62–72. Department of Mines, Victoria.

Jackson, D.E., 1974. Tremadoc graptolites from Yukon Territory, Canada. In Graptolite studies in honour of O.M.B. Bulman. *Special Papers in Palaeontology* 13: 35–58, R.B. Rickards, D.E. Jackson & C.P. Hughes, eds.

Jackson, D.E. & Lenz, A.C., 2000. Some graptolites from the late Tremadoc and early Arenig of Yukon, Canada. *Canadian Journal of Earth Sciences* 37: 1177–1193.

Jackson, D.E. & Lenz, A.C., 2003. Taxonomic and biostratigraphical significance of the Tremadoc graptolite fauna from northern Yukon Territory, Canada. *Geological Magazine* 140: 131–156.

Jackson, D.E. & Lenz, A.C., 2006. The sequence and correlation of Early Ordovician (Arenig) graptolite faunas in the Richardson Trough and Misty Creek Embayment, Yukon Territory and District of Mackenzie, Canada. *Canadian Journal of Earth Sciences* 43: 1791–1820.

Jackson, D.E. & Norford, B.S., 2004. Biostratigraphical and ecostratigraphical significance of Tremadoc (Ordovician) graptolite faunas from the Misty Creek Embayment and Selwyn Basin in Yukon and Northwest Territories. *Canadian Journal of Earth Sciences* 41: 331–348.

Keble, R.A. & Benson, W.N., 1929. Ordovician graptolites of northwest Nelson. *Transactions of the New Zealand Institute* 59: 840–863.

Keble, R.A. & Harris, W.J., 1934. Graptolites of Victoria: new species and additional records. *Memoirs of the National Museum of Melbourne* 8: 166–183.

Lenz, A.C. & Jackson, D.E., 1986. Arenig and Llanvirn graptolite biostratigraphy, Canadian Cordillera. In *Paleoecology and Biostratigraphy of Graptolites*, C.P. Hughes & R.B. Rickards, eds. *Geological Society Special Publication* 20: 27–45.

Lindholm, K., 1991. Ordovician graptolites from the early Hunneberg of southern Scandinavia. *Palaeontology* 34: 283–327.

Loydell, D.K., 2012. Graptolite biozone correlation charts. *Geological Magazine* 149: 124–132.

Maletz, J. & Egenhoff, S., 2001. Late Tremadoc to early Arenig graptolite faunas of southern Bolivia and their implications for a worldwide biozonation. *Lethaia* 34: 47–62.

Maletz, J., Toro, B.A. & Zhang, Y., 2017. Part V, Second Revision, Chapter 18: Order Graptoloidea and Family Anisograptidae: introduction, morphology, and systematic descriptions. *Treatise Online* 85: 1–14, 9 figs.

Maletz, J., Zhang, Y. & VandenBerg, A.H.M., 2018. Part V, Second Revision, Chapter 19: Suborder Sinograptina: introduction, morphology, and systematic descriptions. *Treatise Online* 107:1–23, 17 figs.

Mu, A.T. 1957. Some new or little known graptolites from the Ningkuo Shale (Lower Ordovician) of Changshan, western Chekiang. *Acta Palaeontologica Sinica* 5: 369–437, 8 pls.

Mu, A.T. 1974. Evolution, classification and distribution of Graptoloidea and graptodendroids. *Scientia Sinica* 17: 227–238.

Mu, E., Ge, M., Chen, X., Ni, Y., & Lin, Y., 1979. Lower Ordovician graptolites of southwest China. *Palaeontologica Sinica* 156, New Series B, 13: 192 pp., 48 pls. (In Chinese, English Abstract pp. 159–164).

Mu Enzhi, Li Jijin, Ke Meiyu, Lin Yaokun & Ni Yunan, 2002. *Fossil Graptolites of China*. Science Press, Beijing, 1025 pp., 256 pl. [in Chinese].

Ni Yu-nan, 1981. Two new graptolite genera from the Ningkuo Formation (Lower Ordovician) of Wuning, North Jiangxi. *Geological Society of America Special Paper* 187: 203–206, pls 1, 2.

Ni Yunan, 1991. Early and Middle Ordovician graptolites from Wuning, northwestern Jiangxi, China. *Palaeontologica Sinica* 181, New Series B, 28: 119–147, 35 pls.

Nicholson, H.A., 1873. On some fossils from the Quebec Group of Point Lévis, Quebec. *Annals and Magazine of Natural History* (Series 4) 2: 133–143.

Obut, A.T. & Sobolevskaya, R.F., 1962. Graptolity rannego ordovika na Taymyre [Lower Ordovician graptolites of Taimyr]. *Akademiya Nauk SSSR*: 65–85 [in Russian].

Ortega, G. & Albanesi, G.L., 2000. Graptolitos de la Formacion Gualcamayo (Ordovicico Medio) en el Cerro Potrerillo, Precordillera Central de San Juan, Argentina. *Boletin de la Academia Nacional de Ciencias* 64: 59 pp. Córdoba, Argentina.

Pritchard, G.B., 1892. On a new species of Graptolitidae (*Temnograptus magnificus*). *Proceedings of the Royal Society of Victoria* 4: 56–58.

Rickards, R.B. & Chapman, A., 1991. Bendigonian graptolites (Hemichordata) of Victoria. *Memoirs of the Museum of Victoria* 52, 135 pp., 35 pls.

Rushton, A.W.A., Stone, P., Smellie, J.L. & Tunnicliff, S.P., 1986. An early Arenig age for the Pinbain sequence of the Ballantrae Complex. *Scottish Journal of Geology* 22: 41–54.

Rushton, A.W.A. & Stone, P., 1988. Graptolite faunas from the Ballantrae Complex. *Scottish Journal of Geology* 24: 93–95.

Skoglund, R., 1961. *Kinnegraptus,* a new graptolite genus from the Lower *Didymograptus* shale of

Västergötland, central Sweden. *Bulletin of the Geological Institute of the University of Uppsala* 40: 389–400.

Spjeldnaes, N., 1963. Some Upper Tremadocian graptolites from Norway. *Palaeontology* 6: 121–131.

Stone, P., & Rushton, A.W.A., 1983. Graptolite faunas from the Ballantrae ophiolite complex and their structural implications. *Scottish Journal of Geology* 19: 297–310.

Thomas, D.E., 1960. The zonal distribution of Australian Graptolites. *Journal and Proceedings of the Royal Society of New South Wales* 94: 1–58.

Thomas, D.E., 1973. Two new graptolites from Victoria, Australia. *Geological Magazine* 109: 529–532.

Thomas, D.E. & Keble, R.A., 1933. The Ordovician and Silurian rocks of the Bulla–Sunbury area, and discussion of the sequence of the Melbourne area. *Proceedings of the Royal Society of Victoria* 45: 33–84.

VandenBerg, A.H.M., 1992. Kilmore 1:50, 000 Map Geological Report. *Geological Survey Report* 91.

VandenBerg, A.H.M., 2017. Revision of zonal and related graptolites of the topmost Lancefieldian and Bendigonian (early Floian) graptolite sequence in Victoria, Australia. *Proceedings of the Royal Society of Victoria* 129: 39–74.

VandenBerg, A.H.M. & Cooper, R.A., 1992. The Ordovician graptolite sequence of Australasia. *Alcheringa* 16: 33–85.

VandenBerg, A.H.M. & Stewart, I.R., 1983. Excursion to Devilbend Quarry and Enoch's Point. *nomen nudum* 12: 35–52.

VandenBerg, F., 2018. *Anomalograptus*? *insuetus* Keble & Benson, 1928. *Atlas of graptolite type specimens,* Folio 3.41.

Williams, S.H. & Stevens, R.K., 1988. Early Ordovician (Arenig) graptolites of the Cow Head Group, western Newfoundland, Canada. *Palaeontographica Canadiana* 5, 167 pp., 34 pls.

Williams, S.H. & Stevens, R.K., 1991. Late Tremadoc graptolites from Newfoundland. *Palaeontology* 34: 1–47.