Journal of Paleontology, 97(2), 2023, p. 395–420

Published by Cambridge University Press
on behalf of The Paleontological Society
0022-3360/23/1937-2337
doi: 10.1017/jpa.2022.94

JOURNAL OF PALEONTOLOGY
A PUBLICATION OF THE Paleontological SOCIETY

Latest Ordovician to earliest Silurian graptolites of northwest Peninsular Malaysia

Muhammad Aqqid Saparin* and Mohd Suhaili Ismail

Geosciences Department, Universiti Teknologi PETRONAS, 32610 Seri Iskandar, Perak Darul Ridzuan, Malaysia
<muhammad_18003032@utp.edu.my>, <suhaili.ismail@utp.edu.my>

Abstract.—Graptolites from the latest Ordovician to the earliest Silurian rocks of northwest Peninsular Malaysia are described and reviewed. The fossils were collected previously by C. R. Jones and presently by the authors inside the black mudstones from the basal section of Tanjung Dendang Formation in Pulau Langgun, Langkawi, which comprises assemblages from the Hirnantian *Metabolograptus extraordinarius* Biozone to the Rhuddanian *Akidograptus ascensus*–*Parakidograptus acuminatus* Biozone. The latest Ordovician strata also include a Hirnantia fauna bed between the *Metabolograptus extraordinarius* and *Metabolograptus persculptus* biozones, in which shelly fossils such as *Mucronaspis* sp. could be recovered. A revised graptolite biozonation is proposed for the latest Ordovician to the earliest Silurian succession of northwest Peninsular Malaysia. This interval is significant for understanding the extent of mass extinction events happening right at the end of the Ordovician period and subsequent faunal change in the region.

Introduction

Graptolites are known to contribute to the establishment of lower Paleozoic terrane in Malaysia, the study of which was pioneered by Clive Roderick Jones together with various other field geologists in the late 1950s and early 1960s. The earliest record of graptolite work was made by Jones (1959) while investigating the geology of northwest Peninsular Malaysia from a band of shales and limestone formations on the Langkawi islands. More graptolite localities were later found in Langkawi as well as in the surrounding area, including the mainland Kedah and Perlis states, which led to the publication of concise graptolite reports by Jones (1973, 1978). Subsequent studies have been done on the stratigraphy of the area by other authors. For example, Cocks et al. (2005) erected a new stratigraphical nomenclature for the successions of the area while Hassan et al. (2013) reviewed a monograptid from the exposures of Devonian black shale in Perlis state. Nevertheless, little study has been done on the systematic paleontology of the Ordovician and Silurian graptolites after Jones's last publication, and the biostratigraphy is lacking in revision for the past 40 years. The latest Ordovician graptolites in particular are of great interest because they mark the earliest graptolite fauna so far recorded from the Malaysian Peninsula. Furthermore, this interval, which is regarded as the Hirnantian, is relatively brief but significant in the geological record for documenting the second largest global extinction bioevent in Earth history. Two pulses of extinction event have been identified, which seem to correspond with the start and end of the Late Ordovician glaciation (Harper et al., 2014). The purpose of this paper is to provide a systematic description of the graptolites from the Ordovician–Silurian boundary of northwest Peninsular Malaysia. Graptolites collected previously by Jones are reexamined and updated herein while new specimens that have been recently recovered are described in detail. A revised graptolite biozonation is also suggested for this interval, which would allow for regional and global correlation.

Geological setting

The Langkawi archipelago is located at the most northwestern edge of Peninsular Malaysia and comprises a collection of 99 islands and islets. The region is part of the northwestern domain of the Peninsular Malaysia Western Belt and is predominantly of Paleozoic rocks (Fig. 1). In Langkawi, the lower Paleozoic graptolites can be found in the Tanjung Dendang Formation (formerly the Lower Detrital Member), which is part of the Setul Group. The name of the formation is taken after Pulau Tanjung Tembus Dendang, an island northeast of Langkawi, but the type section is located on an island west of it, Pulau Langgun, on the south shore of Teluk Mempelam between grid references 6°26′40″N, 99°53′00″E and 6°26′42″N, 99°53′02″E (Jones, 1966).

The Tanjung Dendang Formation in Pulau Langgun is ∼27 m thick overall and consists of well-bedded quartzites through siltstone to dark shales and sometimes includes bedded cherts, which have been recorded to span from the Hirnantian (Late Ordovician) to the top of the Aeronian Stage of the Llandovery Series (lower Silurian). Graptolites are present mainly in the well-bedded, carbonaceous siltstones and shales where the individual bed is generally less than 10 cm in thickness. The Tanjung Dendang Formation overlies the Ordovician Kaki Bukit Limestone Formation (formerly the Lower Setul Limestone), which is a very hard, thickly bedded, gray stylolithic limestone with an abrupt contact (Cocks et al., 2005; Lee,

*Corresponding author.

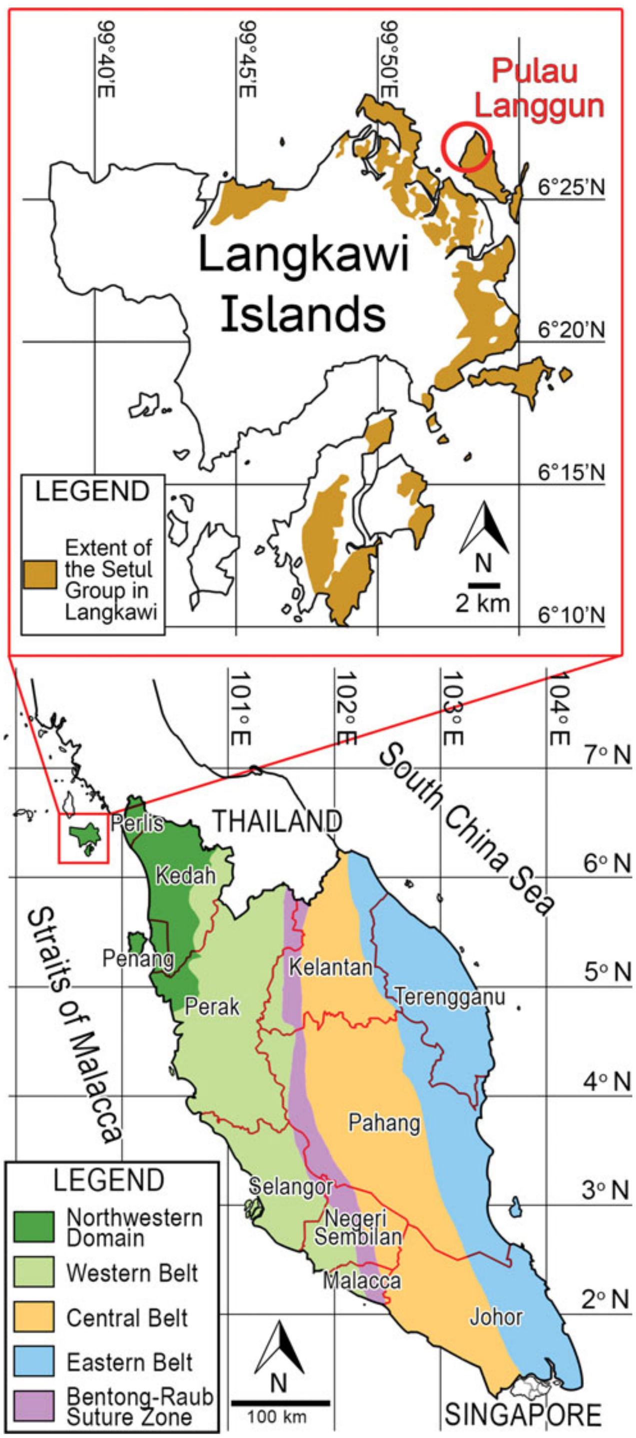


Figure 1. The location of the Langkawi Islands in the northwestern edge of Peninsular Malaysia. The Setul Group in Langkawi is concentrated mostly on the eastern fringe of the island archipelago. The Setul Group is constrained inside the northwestern domain of the peninsula Western Belt, consisting of predominantly Paleozoic rocks.

2009) (Fig. 2.1). The uppermost unit of the Kaki Bukit Limestone has been described to be of late Sandbian–early Katian age using conodont fossils, suggesting the existence of an unconformity with the base of the Tanjung Dendang Formation (Niko et al., 2019). An exposed bed that represents the Hirnantian stage can be found on a vertical rock face near a small cave, away from the coast, and positioned slightly higher than the high tide line (Fig. 2.2). Walking along the shore, the interbedded dark shale and cherty strata are exposed in an almost horizontal succession, dipping to the northeast. A moderate number of graptolite specimens can be recovered on the raised mudstone exposure just after a nearby sandy ditch and can be observed only when the tide is low (Fig. 2.3).

Materials and methods

A total of 26 slabs of graptolite-bearing mudstone collected previously by Jones were obtained from the repository of the Department of Mineral and Geoscience Malaysia in Ipoh, Perak (172F –176F, 178F–183F, 185F–190F, 191-1F, 196F–198F, 200F-1, 200F-2, 202F, 204F, 205F). The materials were recovered from the basal 1.1 m of Tanjung Dendang Formation in Pulau Langgun, Langkawi, which Jones (1973) noted as the lower graptolite beds. At least nine samples recovered more recently from the same interval have been included to supplement the graptolite data. Several shelly specimens from the overlying sandy Hirnantia fauna bed were also retrieved from this succession. Above the Hirnantia fauna bed, we have taken fresh samples at ∼1 m intervals each to recover the smaller number of graptolites that would be present in the mudstone layers. Seventeen specimens have been taken from LG4, nine from LG7, seven from LG8, and four from LG9 and are housed in the Geosciences Department, Universiti Teknologi PETRONAS. Specimens that have been prepared were observed and photographed using an Olympus SZX16 stereomicroscope mounted with a digital camera and Andonstar ADSM302 digital microscope (a smaller, affordable microscope that can be used for working at home). Illustrations of the graptolites were made to highlight the outline and important details such as the proximal astogeny and thecal morphology and for morphometric measurements involving the dorsoventral width (DVW), two-theca repeat distance (2TRD, as defined by Howe, 1983), tubarium length, virgella length, and other quantifiable features. The collected data were later compared with literature, and revisions were made if necessary.

Repositories and institutional abbreviations.—Specimens examined in this study are deposited in the following institutions: Department of Mineral and Geoscience Malaysia (JMG), Perak, Malaysia, or Geosciences Department, Universiti Teknologi PETRONAS (UTP), Perak, Malaysia.

Biostratigraphy

Metabolograptus extraordinarius *Biozone*.—Overlying the thickly bedded stylolithic limestone with an abrupt and possibly unconformable contact, but underlying the Hirnantian shelly sandstone layer, is a 60 cm thick unit of dark, hard, and thinly bedded graptolitic mudstone with discontinuous lamination. Most-abundant graptolites can be recovered in the middle of the section and in some instances cover almost the entire bedding surface. Previously, Jones had identified an indifferently preserved graptolite fauna that included rare *Neodiplograptus modestus* (Lapworth, 1876), abundant *Metabolograptus*

https://doi.org/10.1017/jpa.2022.94 Published online by Cambridge University Press

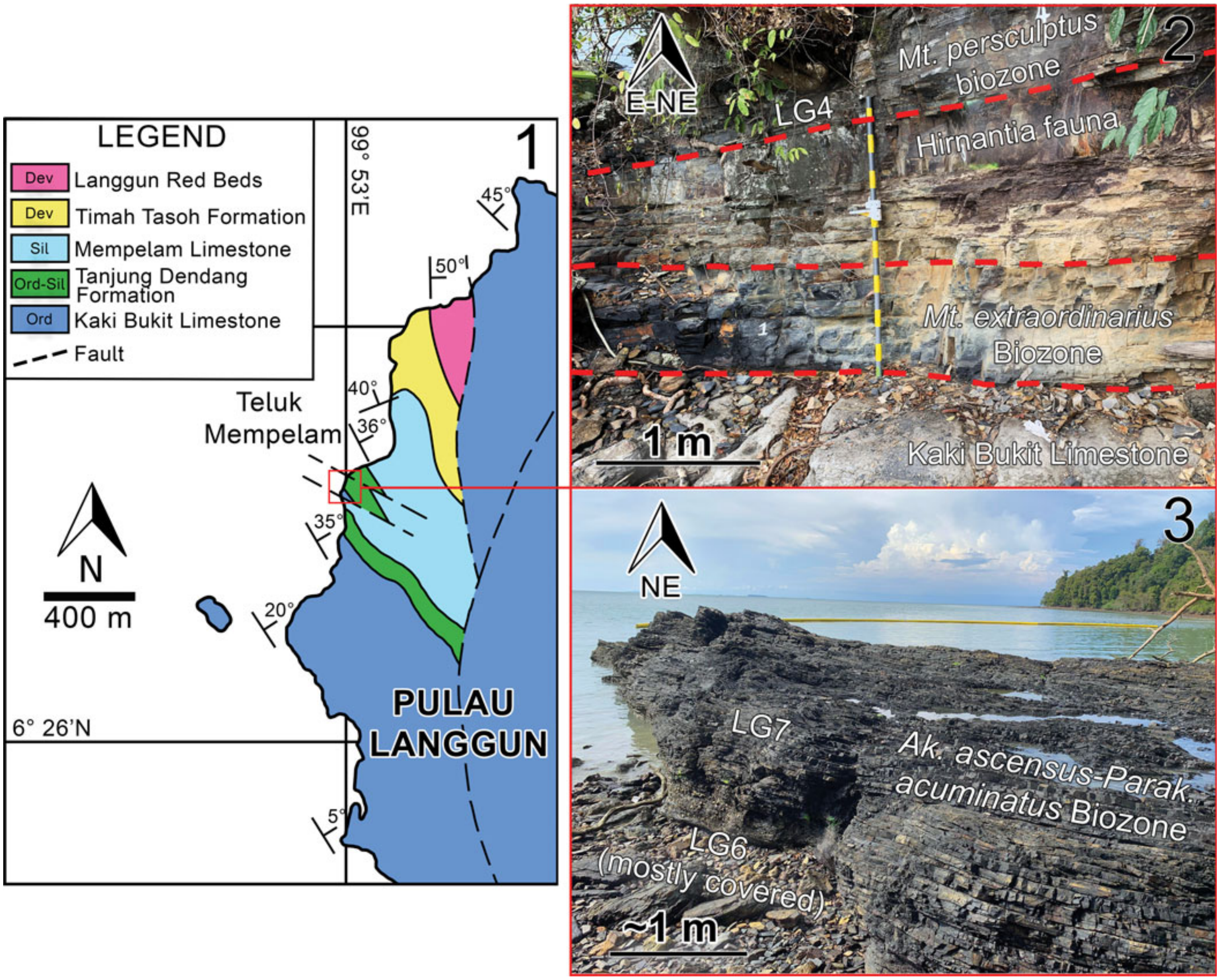


Figure 2. (**1**) The stratigraphy of the northwest coast of Pulau Langgun, Langkawi (modified from Jones, 1978). The graptolites were recovered from the Ordovician–Silurian Tanjung Dendang Formation strata that can be found in Teluk Mempelam area. (**2**) The basal section exposure of the Tanjung Dendang Formation that overlies the Kaki Bukit Limestone where graptolites from the uppermost Ordovician age have been recovered. (**3**) The raised exposure where graptolites of the earliest Silurian age have been recovered. Note that the exposure can be observed only when the tide is at its lowest.

persculptus (Elles and Wood, 1907), and occasionally *Normalograptus temalaensis* (Jones, 1973) (Jones, 1968, 1973, 1978). He then assigned this section and the basal part of the overlying sandstone bed to the *persculptus* Biozone and, thus, assigned the graptolite-bearing succession to the basal Silurian, with the Ordovician–Silurian boundary located at the contact with the limestone unit below, following practice current at the time (Jones, 1973, 1978). It was more than 20 years before Cocks et al. (2005) reviewed the stratigraphy and established the section to be instead of the latest Ordovician (Hirnantian) age. Subsequently, we have taken a chance to reexamine Jones's specimens and, together with our own recently collected specimens, use them to restudy this noteworthy section (Fig. 3). From the result of our research, a more diverse graptolite fauna could be identified, which includes *Anticostia* aff. *A. lata* (Elles and Wood, 1906), *Korenograptus elegantulus* (Mu and Ni, 1983), *Metabolograptus extraordinarius* (Sobolevskaya, 1974), *Metabolograptus ojsuensis* (Koren' and Mikhaylova in Koren et al., 1980), *Neodiplograptus shanchogensis* (Li, 1984) (Li, 1984b), *Normalograptus ajjeri* (Legrand, 1977), *Normalograptus* aff. *N. mirnyensis* (Obut and Sobolevskaya in Obut et al., 1967), and *Normalograptus temalaensis* (Jones, 1973) (Figs. 4, 5). The faunal assemblages suggested an earlier *extraordinarius* Biozone for the section underlying the shelly Hirnantia fauna bed compared with the previously thought *persculptus* Biozone. This finding seems to match well with biostratigraphy schemes in the nearby regions such as in the Mandalay Region in Myanmar (Chen et al., 2020) and South China (Chen et al., 2004), suggesting a close paleogeographical tie, but it seems to differ from that reported in southern Thailand (Wongwanich et al., 1990). In the Mandalay region, graptolites that can be found from the *extraordinarius* Biozone include *Korenograptus acanthus* (Lin in Mu et al., 1993), *Korenograptus selectus* Chen et al., 2020, *Neodiplograptus incommodus* Legrand, 2009, *Normalograptus ajjeri* (Legrand, 1977), *Normalograptus angustus* (Perner, 1895), *Normalograptus pseudovenustus* (Legrand,

https://doi.org/10.1017/jpa.2022.94 Published online by Cambridge University Press

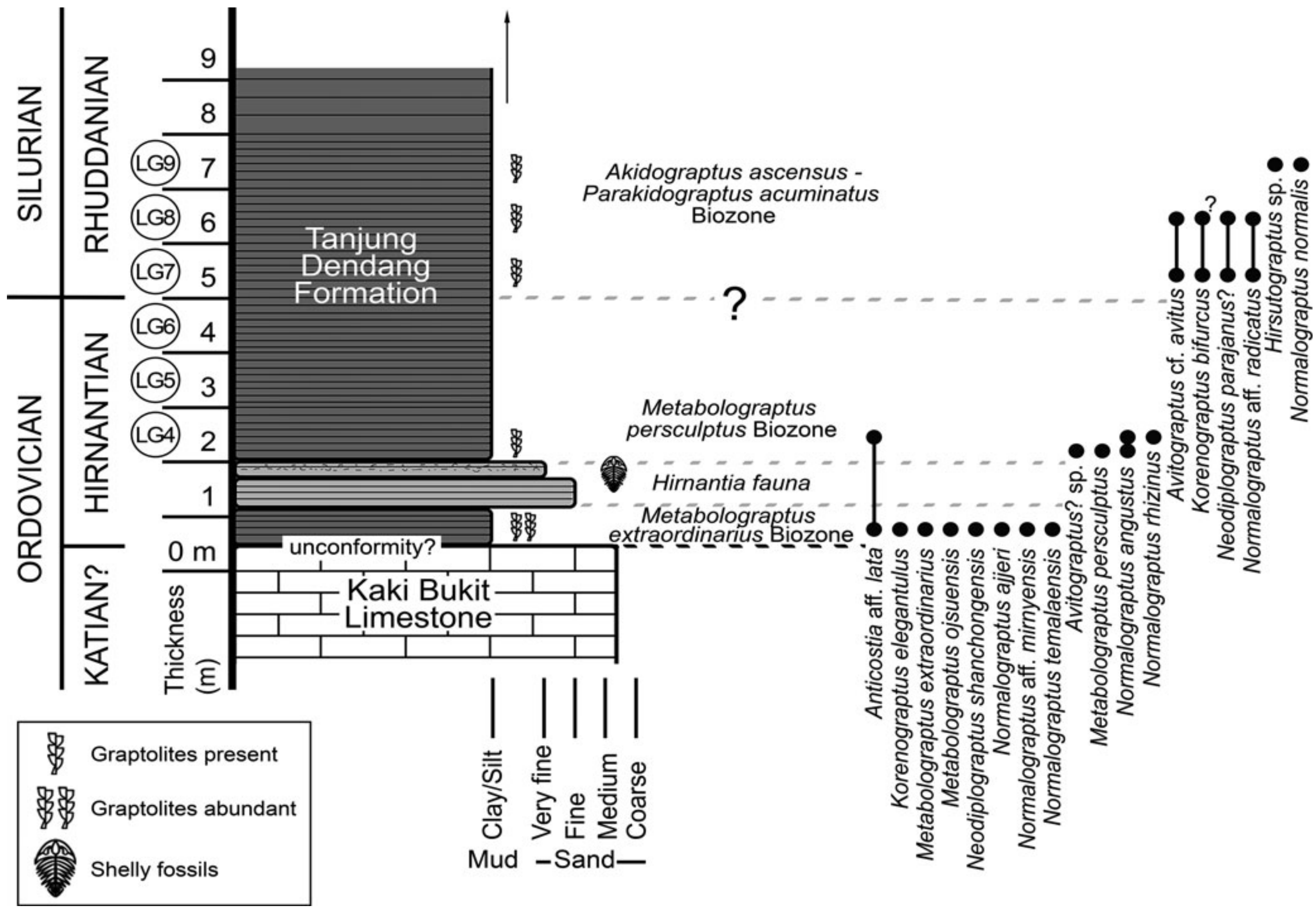


Figure 3. The stratigraphy and occurrence of the graptolites of the uppermost Ordovician to the lowermost Silurian of Tanjung Dendang Formation in Pulau Langgun, Langkawi.

1986), *Metabolograptus ojsuensis* (Koren' and Mikhaylova in Koren et al., 1980), and *Metabolograptus extraordinarius* (Sobolevskaya, 1974) (Chen et al., 2020). The Global Boundary Stratotype Section and Point (GSSP) for the base of the Hirnantian Stage itself was proposed at a point below the base of the Kuanyinchiao Bed in the Wangjiawan North section (Chen et al., 2006) and coincided with the first appearance of *Metabolograptus extraordinarius* (Sobolevskaya, 1974) and a slightly earlier appearance of *Metabolograptus ojsuensis* (Koren' and Mikhaylova in Koren et al., 1980). In the Satun province of southern Thailand, however, the index fossil *Metabolograptus persculptus* (Elles and Wood, 1907) instead was reported from the lower member of Wang Tong Formation, below the Hirnantia fauna bed (Rickards in Wongwanich et al., 1990). The Wang Tong Formation is the stratigraphic equivalent of the Tanjung Dendang Formation (Wongwanich et al., 1990; Cocks et al., 2005), and in theory, they should share the same fauna at this level. However, without any graptolite illustrations to confirm this, it is perhaps more appropriate to restudy the Satun material. At the Vinini Creek section in north central Nevada, the interval defined by the *extraordinarius* Biozone possesses a moderate species diversity that includes the index species *Metabolograptus extraordinarius* (Sobolevskaya, 1974) and *Metabolograptus ojsuensis* (Koren' and Mikhaylova in Koren et al., 1980), which are abundant throughout, while normalograptids such as *Normalograptus ajjeri* (Legrand, 1977), *Normalograptus mirnyensis* (Obut and Sobolevskaya in Obut et al., 1967), and rare *Normalograptus angustus* (Perner, 1895) also make their first appearance in the interval (Štorch et al., 2011). Diplograptina such as *A. lata* (Elles and Wood, 1906) do occur but made their last appearance within the *extraordinarius* Biozone, which coincides with the first appearance of the normalograptids in the Vinini Creek section (Mitchell et al., 2007; Štorch et al., 2011); the same pattern can also be seen in South China (Chen et al., 2005a, b). The dramatic faunal change in this level is attributable to the planktonic graptolite communities under environmental stress due to the climate change leading up to the Late Ordovician mass extinction event (Sheets et al., 2016).

Shelly Hirnantia fauna bed.—The Hirnantia fauna bed is represented by 50 cm of interbedded dark-grey mudstone and fine sandstone at the bottom part and ~30 cm gray, thick-bedded, very fine-grained sandstone at the upper part, in which dark-brown shelly materials are pervasive. Only incomplete specimens of trilobites (most likely *Mucronaspis* sp.) could be recovered from the thickly bedded upper part together with evidence of shelly fauna fragments (Fig. 6). Previously, Jones (1973, 1978) referred to the beds as the *Dalmanitina* siltstone bed (bed 2) and described it as a thickly bedded siltstone and gritty subgraywacke with shelly fossils.

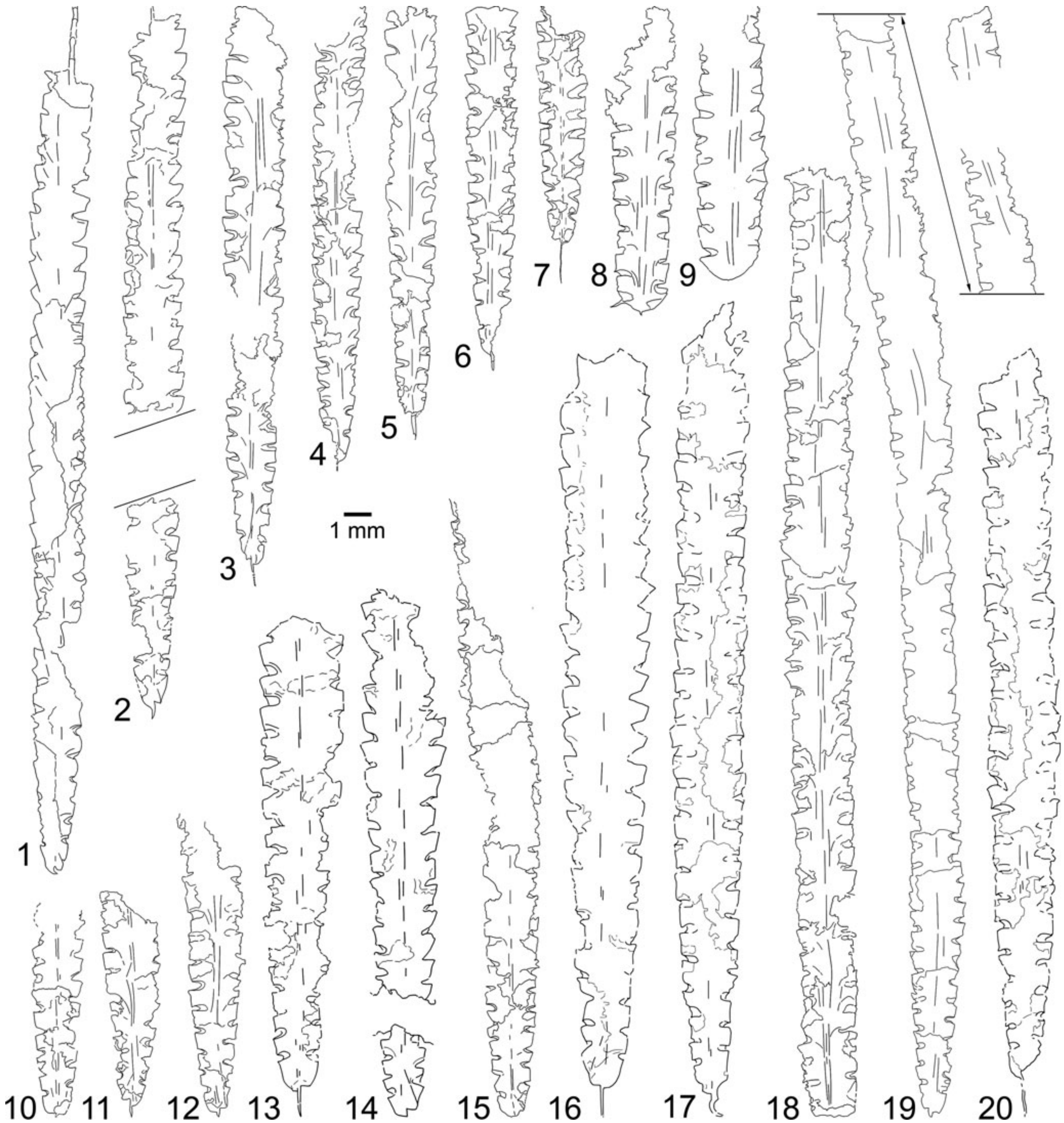


Figure 4. Graptolites of the *Metabolograptus extraordinarius* Biozone in Pulau Langgun, Langkawi. (**1–7**) *Metabolograptus ojsuensis* (Koren' and Mikhaylova in Koren' et al., 1980): (**1**) 191F-1_1; (**2**) 179F_1; (**3**) 175F_3; (**4**) 188F_1; (**5**) 176F_2; (**6**) 173F_1; (**7**) 176F_4. (**8, 9**) *Anticostia* aff. *A. lata* (Elles and Wood, 1906): (**8**) 179F_3; (**9**) 179F_4. (**10–20**) *Metabolograptus extraordinarius* (Sobolevskaya, 1974): (**10**) 190F_6; (**11**) 174F_3; (**12**) 173F_3; (**13**) LG1_01; (**14**) LG1_04-1; (**15**) 174F_2; (**16**) LG1_04-2; (**17**) LG1_02; (**18**) 187F_6; (**19**) 174F_1; (**20**) LG1_03.

Several shelly fossils were recognized, including gastropods (*Megolomphala*? sp., *Lophospira* sp.) and the trilobite *Dalmanitina malayensis* Kobayashi and Hamada, 1964. Subsequently, Cocks et al. (2005) regarded *Dalmanitina malayensis* as a junior synonym of *Mucronaspis mucronata* (Brongniart in Brongniart and Desmarest, 1822). The Hirnantia fauna bed can be recognized by fauna of distinctive brachiopods and trilobites associated with the Late Ordovician Hirnantian glaciation and subsequent drop in sea level occurring in wide ranges of settings (Brenchley, 1988; Harper et al., 2014; Goldman et al., 2020). It is noted to represent the survival fauna of the early part of the Late Ordovician mass extinction and is used as an important tool of correlation worldwide (Harper et al., 2014). Cocks et al. (2005) noted, however, that it is unlikely for the Sibumasu terrane to suffer more than a relatively cool climate during the glaciation

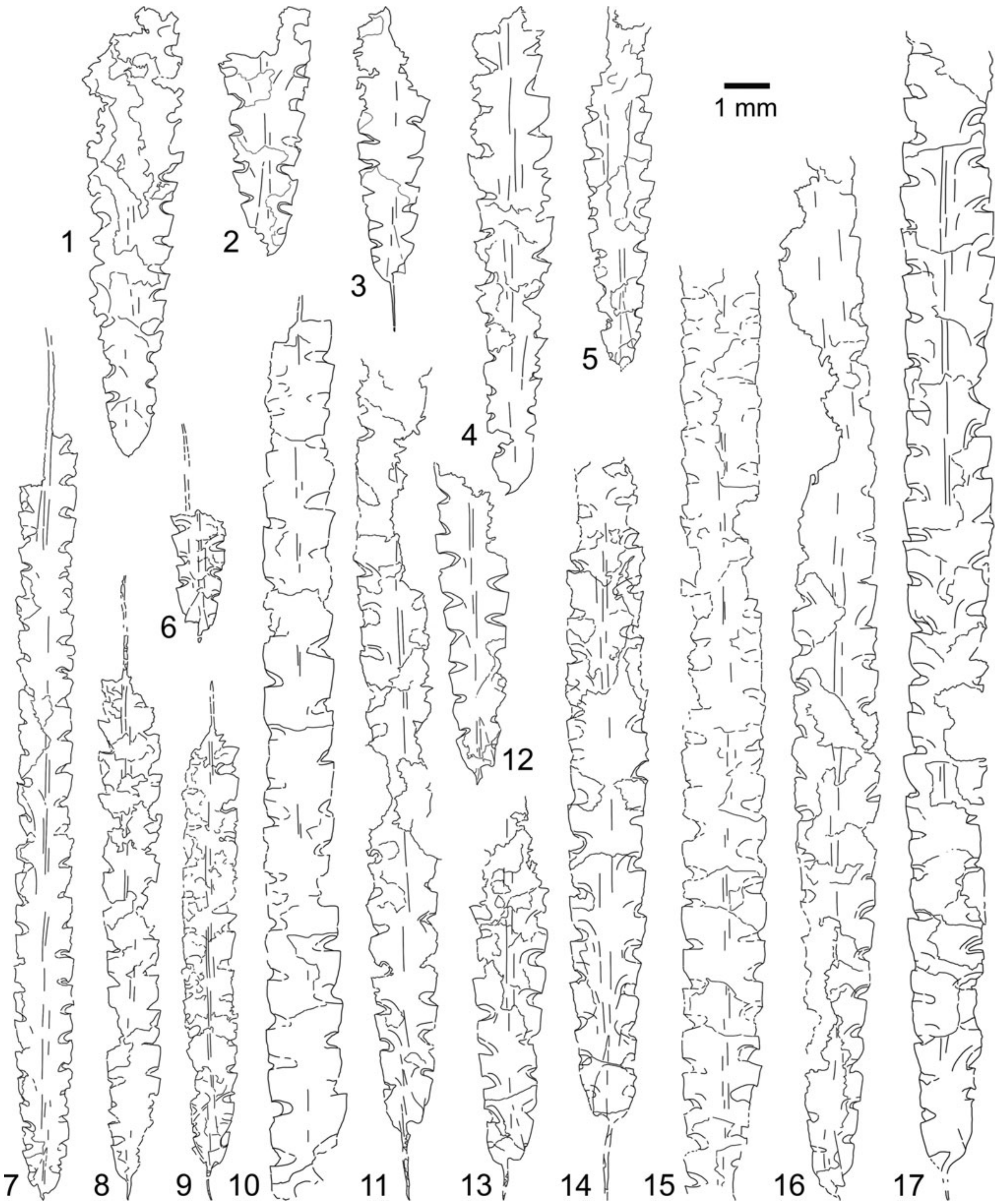


Figure 5. Graptolites of the *Metabolograptus extraordinarius* Biozone in Pulau Langgun, Langkawi. (**1, 2**) *Neodiplograptus shanchongensis* (Li, 1984): (**1**) 180F_3; (**2**) 173F_5. (**3–5**) *Korenograptus elegantulus* (Mu and Ni, 1983): (**3**) 182F_4; (**4**) 183F_3; (**5**) 172F_3. (**6–9**) *Normalograptus* aff. *N. mirnyensis* (Obut and Sobolevskaya in Obut et al., 1967): (**6**) LG1_06-2; (**7**) 185F_5; (**8**) 190F_3; (**9**) LG1_05. (**10–12**) *Normalograptus ajjeri* (Legrand, 1977): (**10**) 180F_1; (**11**) 187F_5; (**12**) 175F_1. (**13–17**) *Normalograptus temalaensis* (Jones, 1973): (**13**) 189F_3; (**14**) 187F_3; (**15**) 172F_2; (**16**) 205F_2; (**17**) 187F_7.

period. A similar occurrence with the section in Langkawi can be observed in the Wangjiawan North section of China, where an interval of argillaceous limestone yielding Hirnantia fauna occurred between the *extraordinarius* and *persculptus* biozones (Chen et al., 2006). While global correlation data suggest the first and last appearance of the shelly Hirnantia

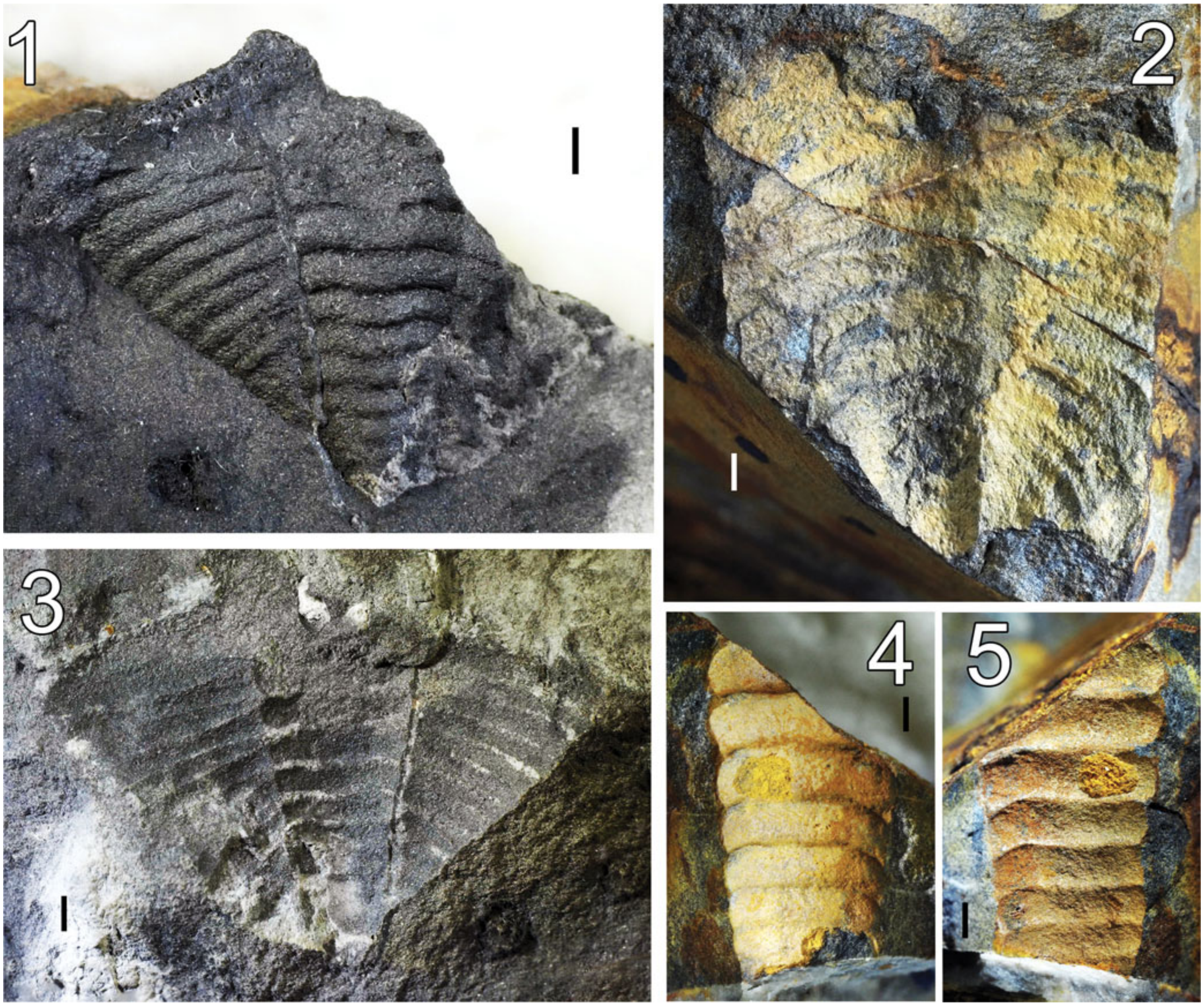


Figure 6. Shelly fossils from the Hirnantia bed in Pulau Langgun, Langkawi. (**1–5**) *Mucronaspis* sp.: (**1**) pygidium; (**2**) incomplete mold with part of the thorax and pygidium; (**3**) counterpart to (**1**); (**4**) thoracic axial lobe; (**5**) counterpart to (**4**). Scale bars = 1 mm.

fauna to be diachronous (Rong et al., 2007, 2020), the majority occurs within the *extraordinarius* Biozone and disappears in the *persculptus* Biozone (= within the lower-middle Hirnantian) (Chen et al., 2006; Rong et al., 2020). Close to the Malaysian border in the Satun Province of Southern Thailand, a correlative Hirnantia fauna bed can be observed from the middle member of the Wang Tong Formation at locality 8 (Cocks and Fortey, 1997). The similar facies change in Thailand is noted to represent the local expression of a global eustatic regression associated with the latest Ordovician glaciation, and the fauna occurring in the section include the trilobite *Mucronaspis mucronata* (Brongniart in Brongniart and Desmarest, 1822) (Cocks and Fortey, 1997; Cocks et al., 2005). The Thailand records, however, differ somewhat from our observation in Langkawi by having the appearance of the shelly Hirnantia fauna within the reported *persculptus* Biozone (Cocks and Fortey, 1997; Wongwanich et al., 2002).

Metabolograptus persculptus *Biozone*.—Directly above the Hirnantia fauna bed lies an interbedded dark-gray mudstone unit. The rocks are much more fissile with continuous lamination and break easily into even layers. It is, overall, less carbonaceous than the mudstone from the *extraordinarius* Biozone. The beddings are distinct at the bottom of this section but become much more deformed going up the succession. The first 1 m of the section has been designated as LG4. Several graptolite fragments have been recovered near the base, which includes *Anticostia* aff. *A. lata* (Elles and Wood, 1906), *Avitograptus*? sp., *Metabolograptus persculptus* (Elles and Wood, 1907), *Normalograptus angustus* (Perner, 1895), and *Normalograptus rhizinus* (Li and Yang in Nanjing Institute of Geology and Mineral Resources, 1983) (Fig. 7). The presence of the index species *Metabolograptus persculptus* (Elles and Wood, 1907) in particular suggests a *persculptus* Biozone assignment for the section above the Hirnantia fauna bed. The graptolites found are relatively scarce and fragmented, likely due to taphonomic processes. Jones previously regarded this section as the lower part of the cherty beds (unit 3), which he described as a closely bedded black quartzite and siltstone without any fossils

https://doi.org/10.1017/jpa.2022.94 Published online by Cambridge University Press

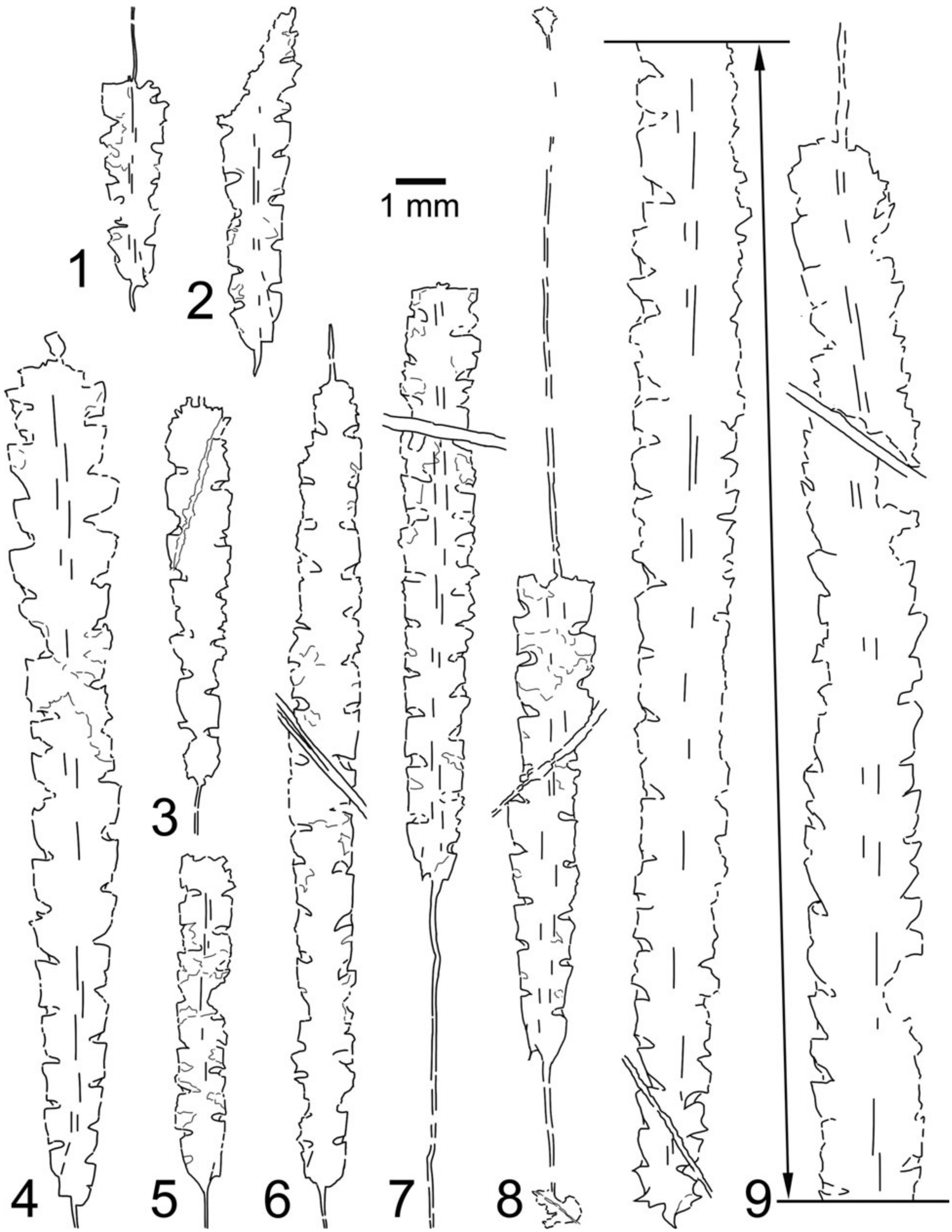


Figure 7. Graptolites of the *Metabolograptus persculptus* Biozone in Pulau Langgun, Langkawi. (**1**) *Avitograptus*? sp., LG4L_05. (**2, 4**) *Metabolograptus persculptus* (Elles and Wood, 1907): (**2**) LG4L_04; (**4**) LG4L_01. (**3, 5, 6**) *Normalograptus angustus* (Perner, 1895): (**3**) LG4M_06; (**5**) LG4L_06; (**6**) LG4L_02. (**7, 8**) *Normalograptus rhizinus* (Li and Yang in Nanjing Institute of Geology and Mineral Resources, 1983): (**7**) LG4M_07-2; (**8**) LG4M_02. (**9**) *Anticostia* aff. *A. lata* (Elles and Wood, 1906), LG4M_07-1.

in it (Jones, 1973, 1978). Although it is true that the majority of this section is indeed unfossiliferous, the presence of fragmentary yet distinct graptolites that are notably different from the previous biozone warrants a proper biozonal assignment for this section. Our observation suggests that the Ordovician–Silurian boundary could occur somewhat higher in the succession above the Hirnantia fauna bed, perhaps within the unfossiliferous interval. In South China, the base of the Lungmachi black shales of the Yangtze Platform also contains a fauna consisting of normalograptids and neodiplograptids, including *Normalograptus angustus* (Perner, 1895), *Normalograptus mirnyensis* (Obut and Sobolevskaya in Obut et al., 1967), *Neodiplograptus shanchongensis* (Li, 1984) (Li, 1984b), and *Neodiplograptus modestus* (Lapworth), which completely replaces the previous diplograptine fauna by the end of the *persculptus* Biozone interval (Chen et al., 2005a; Fan et al., 2011). In the Zhejiang Province, the graptolites recovered from the *persculptus* Biozone of the Anji biota mudstone interval include *Avitograptus acanthocystus* (Fang et al., 1990) and *Avitograptus akidomorphus* Muir et al., 2020, which may represent the morphological intermediates between *Avitograptus avitus* (Davies, 1929) and similar akidograptines (Muir et al., 2020). Elsewhere in China, in the Tielugou section, Shennongjia Anticline, Hubei Province, possible specimens of *Metabolograptus persculptus* (Elles and Wood, 1907) have been recognized from the lowest 1.25 m interval; however, overall faunas are poorly preserved (Maletz et al., 2021b). Common graptolites include *Normalograptus mirnyensis* (Obut and Sobolevskaya in Obut et al., 1967) and *Korenograptus elegantulus* (Mu and Ni, 1983). In the Mandalay region of Myanmar, overlying the Hwe Mawng Purple Shale Member, in which the Hirnantia fauna can be found, is the shale of the Panghsa-pye Formation, where graptolite assemblages include *Normalograptus angustus* (Perner, 1895), *Normalograptus mirnyensis* (Obut and Sobolevskaya in Obut et al., 1967), *Neodiplograptus incommodus* Legrand, 2009, *Neodiplograptus mandalayensis* Chen et al., 2020, and *Avitograptus* cf. *A. avitus* (Davies, 1929), which possibly indicate a *persculptus* Biozone considering that the eponymous index species is absent in the section (Chen et al., 2020). Close by in north of Satun, southern Thailand, abundant graptolites had been reported from the black shales that correlate with the upper member of the Wang Tong Formation (Agematsu et al., 2006). These include *Normalograptus pseudovenustus pseudovenustus* (Legrand, 1986) and *Normalograptus* sp. *Normalograptus pseudovenustus* is noted to be a reliable index species of the Ordovician–Silurian boundary interval. However, the proximal end of the graptolites illustrated does not seem to include the typical pattern H astogeny that can be found in normalograptids; for example, the base of $th1^1$ is at or slightly above the level of the sicular aperture, but further revision could help to corroborate this matter.

Akidograptus ascensus–Parakidograptus acuminatus *Biozone*.—Around 3 m above the base of the *persculptus* Biozone interval is a dark mudstone exposure, just after a nearby sandy ditch. Graptolites have been collected from intervals designated as LG7 to LG9 in this succession. A moderate number of graptolites can be recovered from the thin, fissile mudstone intervals, which are usually sandwiched between thicker, more silicified cherty mudstone layers. Note that the apparent bottom part of the exposure (lower LG7) is usually infested with barnacles and sessile sea life due to the rising sea tide. The graptolites recovered become more fragmented above the LG9 interval as the rocks become much harder and silicified. Jones (1973, 1978) most likely intended to have this whole section as the middle part of the cherty bed (unit 4), which he described as 5.4 m of black, carbonaceous, and silicious mudstone layers with occasional indeterminate graptolite fragments. The result based on our collection identifies a prominent number of graptolites with distinctive elongated proximal ends such as *Avitograptus* cf. *A. avitus* (Davies, 1929). Other graptolites occurring, but usually in lower numbers, include *Hirsutograptus* sp., *Korenograptus bifurcus* (Mu et al. in Nanjing Institute of Geology and Palaeontology, 1974), *Neodiplograptus parajanus*? (Štorch, 1983), *Normalograptus* aff. *N. radicatus* (Chen and Lin, 1978), and *Normalograptus normalis* (Lapworth, 1877) (Fig. 8). The occurrence of *Neodiplograptus parajanus*? (Štorch, 1983) and *Hirsutograptus* sp. are used to indicate the *Akidograptus ascensus–Parakidograptus acuminatus* Biozone, despite the lack of the eponymous index taxa. It should be noted, however, that our specimens of *Neodiplograptus parajanus*? (Štorch, 1983) are admittedly too poorly preserved for confident assignment of the LG7 or LG8 intervals. However, the spine-bearing species of the genus *Hirsutograptus* are only known from the *Akidograptus ascensus–Parakidograptus acuminatus* Biozone; hence, LG9 is definitely within the Silurian. The base of the biozone and hence the base of the Silurian System itself could be lower, but more complete specimens need to be recovered to ascertain this. The GSSP of the Silurian was defined at a point 1.6 m above the base of the Birkhill Shale Formation at Dob's Linn in the southern uplands of Scotland, which is marked by the first appearance of *Akidograptus ascensus* Davies, 1929 and *Parakidograptus praematurus* (Davies) (Zalasiewicz et al., 2009; Melchin et al., 2020). The section can also be further subdivided into a lower *Akidograptus ascensus* Biozone and an upper *Parak acuminatus* Biozone (Melchin and Williams, 2000). Particular taxa that seem to be prevalent in this interval are biserial graptolites with distally forking or branching virgella, including *Korenograptus bifurcus* (Mu et al. in Nanjing Institute of Geology and Palaeontology, 1974), and *Normalograptus* aff. *N. radicatus* (Chen and Lin, 1978) (which Maletz et al., 2021b regarded as the *Normalograptus bifurcus*/*coremus*/*radicatus* group). *Korenograptus bifurcus* (Mu et al. in Nanjing Institute of Geology and Palaeontology, 1974), however, occurs from the *Akidograptus ascensus–Parakidograptus acuminatus* Biozone in China (Chen et al., 2005a), Spain (Štorch et al., 2019), and central Laos (Loydell et al., 2019). Chen et al. (2005a) noted *Normalograptus radicatus* (Chen and Lin, 1978) as a junior synonym of *Normalograptus coremus* (Chen and Lin, 1978); however, we consider them as separate species for now (see the remarks that follow for *Normalograptus* aff. *N. radicatus*). *Neodiplograptus parajanus* (Štorch, 1983) is also one of the key species commonly used to correlate within and between the Gondwanan and peri-Gondwanan regions (Štorch, 1996). Štorch (1996) indicated the range of *Neodiplograptus parajanus* (Štorch, 1983) to be from the middle to upper *Akidograptus ascensus–Parakidograptus acuminatus* Biozone and coincidentally similar findings had been recorded in Jordan (Loydell, 2007) and Saudi Arabia

https://doi.org/10.1017/jpa.2022.94 Published online by Cambridge University Press

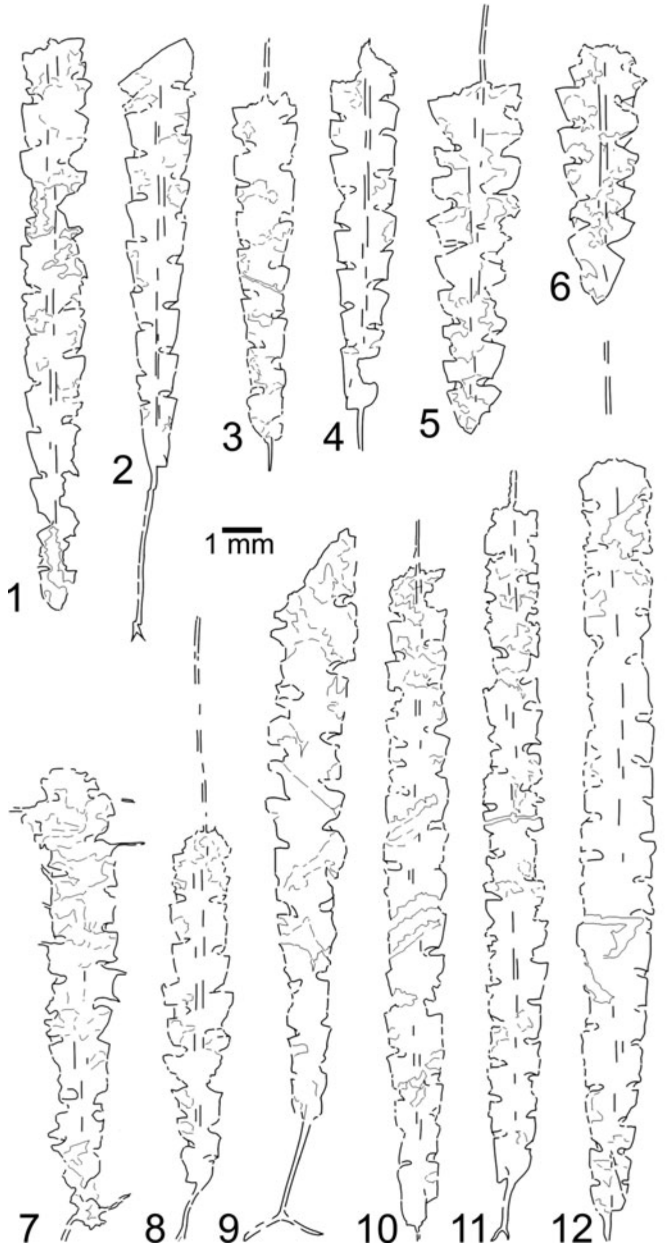


Figure 8. Graptolites of the *Akidograptus ascensus–Parakidograptus acuminatus* Biozone in Pulau Langgun, Langkawi. (**1–4**) *Avitograptus* cf. *A. avitus* (Davies, 1929): (**1**) LG8_06; (**2**) LG8_01-1; (**3**) LG7_06-2; (**4**) LG8_03. (**5, 6**) *Neodiplograptus parajanus*? (Štorch, 1983): (**5**) LG7_08; (**6**) LG8_05. (**7**) *Hirsutograptus* sp., LG9_04-2. (**8?, 9**) *Korenograptus bifurcus* (Mu et al. in Nanjing Institute of Geology and Palaeontology, 1974): (**8**) LG8_01-2; (**9**) LG7_09-1. (**10, 11**) *Normalograptus* aff. *N. radicatus* (Chen and Lin, 1978): (**10**) LG8_07, no virgella preserved; (**11**) LG7_06-1. (**12**) *Normalograptus normalis* (Lapworth, 1877), LG9_02.

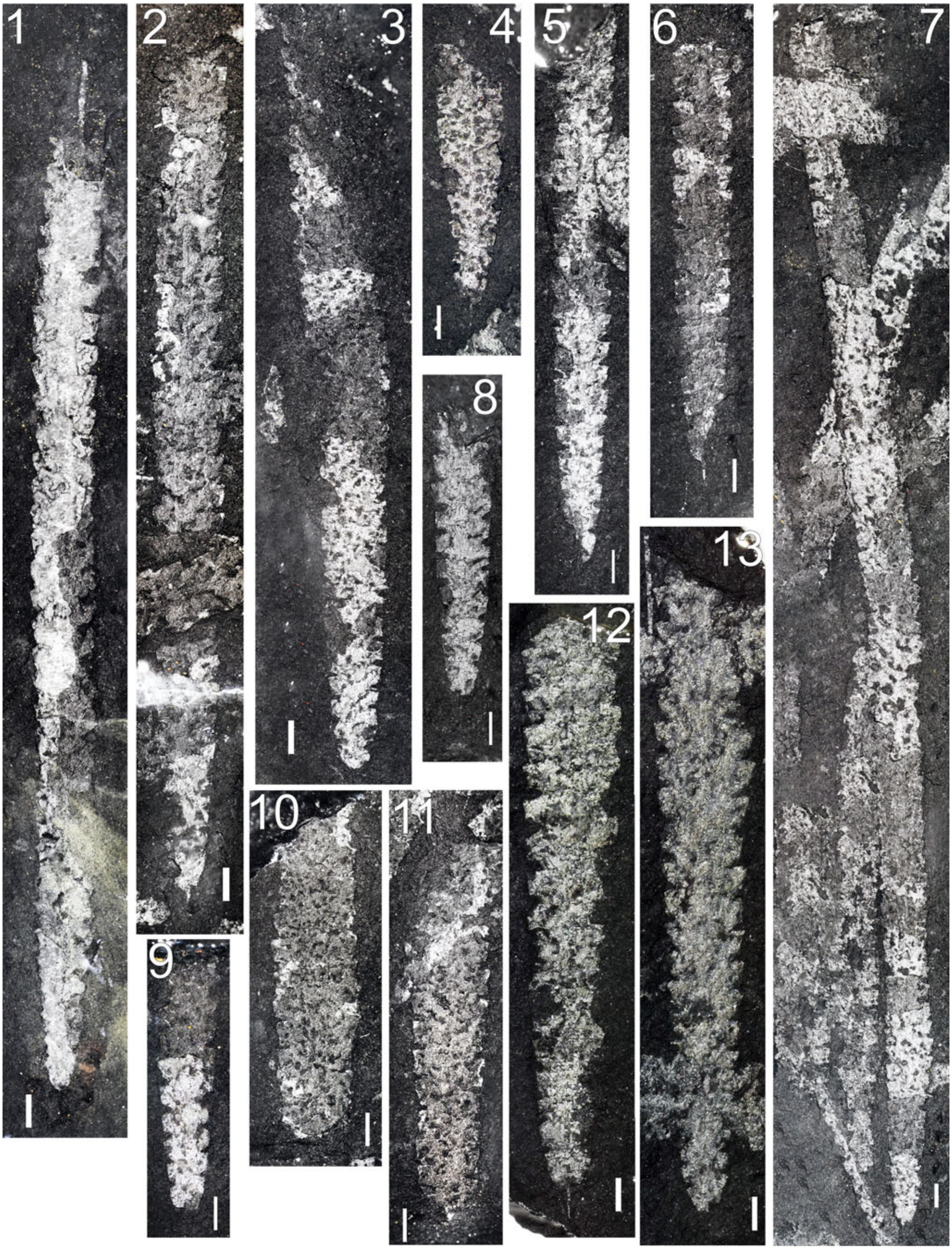
(Williams et al., 2016). As a result, it is possible to further constrain the current Langkawi interval to the middle–upper part of the *Akidograptus ascensus–Parakidograptus acuminatus* Biozone, at least until more specimens are recovered.

Graptolite significance

Chen et al. (2000) noted that *Metabolograptus persculptus* specimens previously reported in the Langkawi Islands had not yet been described in detail and had to assume that the identification of said species is correct when making a correlation between the Ordovician–Silurian succession from the Yangtze region, South China, and the Malay Peninsula. Their analysis suggested that the section bearing the shelly Hirnantia fauna in Langkawi could be correlated with the upper *Metabolograptus persculptus* Biozone or above, which is slightly higher compared with a similar section from the Yangtze region. On restudying the Langkawi specimens, however, we conclude that the hitherto *Metabolograptus persculptus* species instead belong to several different graptolite species from the *Metabolograptus extraordinarius* Biozone, and thus the shelly Hirnantia fauna from the Langkawi Islands demonstrate a much closer association with the South Chinese section in terms of biostratigraphy. A revised graptolite biozonation is thus proposed for the latest Ordovician to the earliest Silurian succession of northwest Peninsular Malaysia (Fig. 9). Other studies had also recognized the similarity between the Sibumasu terrane and South China in the Upper Ordovician based on the fossils and sedimentary facies (Fortey and Cocks, 1998; Rong et al., 2020). In that regard, we believe that new findings or at the very least revision of available graptolite specimens from the Sibumasu terrane (which include those from Peninsular Malaysia, Sumatra, West Thailand, and Myanmar) can be further used for biostratigraphical correlation with other parts of the world. Furthermore, the early Paleozoic is perhaps one of the most critical intervals where evidence of climate shift that lead to a dramatic impact on the biosphere can be observed. Sheets et al. (2016), for example, showed the dramatic changes in the distribution of planktonic graptolites going into the Late Ordovician mass extinction. A more detailed record of graptolite fossils together with high-resolution photographs (Figs. 10–13) could contribute to the paleontological database, which admittedly is rather lacking in the Southeast Asian region. Consequently, the data can be used to promote higher-resolution analysis of the biodiversity patterns and, together with the sedimentological record, give an insight into the marine conditions during the aforementioned period.

System	Stage	The present paper	Cocks *et al.* (2005)	Jones (1973, 1978)
SILURIAN	RHUDDANIAN	*Akidograptus ascensus* - *Parakidograptus acuminatus* Biozone	?	?
ORDOVICIAN	HIRNANTIAN	*Metabolograptus persculptus* Biozone		
		Hirnantia Fauna	'*Dalmanitina* Band'	*Dalmanitina* siltstone
		Metabolograptus extraordinarius Biozone	*Glyptograptus persculptus* Biozone	*Glyptograptus persculptus* Biozone
	KATIAN	? Kaki Bukit Limestone	? Kaki Bukit Limestone	? Lower Setul Limestone

Figure 9. Graptolite biostratigraphy of the Ordovician–Silurian boundary in the northwestern domain of Peninsular Malaysia.



https://doi.org/10.1017/jpa.2022.94 Published online by Cambridge University Press

Figure 10. Photographs of the graptolites from the *Metabolograptus extraordinarius* Biozone in Pulau Langgun, Langkawi. (**1, 2, 5, 6, 8**) *Metabolograptus ojsuensis* (Koren' and Mikhaylova in Koren et al., 1980): (**1**) 191F-1_1; (**2**) 179F_1; (**5**) 188F_1; (**6**) 173F_1; (**8**) 176F_4. (**3, 4, 7, 9, 12, 13**) *Metabolograptus extraordinarius* (Sobolevskaya, 1974): (**3**) 174F_2; (**4**) 174F_3; (**7**) 174F_1; (**9**) 190F_6; (**12**) LG1_01; (**13**) LG1_04-1. (**10, 11**) *Anticostia* aff. *A. lata* (Elles and Wood, 1906): (**10**) 179F_4; (**11**) 179F_3. Scale bars = 1 mm.

Systematic paleontology

Suborder Axonophora Frech, 1897
Infraorder Diplograptina Lapworth, 1880
Family Diplograptidae Lapworth, 1873
Genus *Anticostia* Stewart and Mitchell, 1997, emend. Štorch et al., 2011

Type species.—*Anticostia macgregorae* Stewart and Mitchell (1997, p. 221, pl. 1, figs. 5A–M). From the limestone of the Vauréal Formation, Anticosti Island, Quebec, Canada, by original designation.

Anticostia aff. *A. lata* (Elles and Wood, 1906)
Figures 4.8, 4.9, 7.9, 10.10, 10.11, 12.6, 12.7

aff. *1906 *Climacograptus latus* Elles and Wood, p. 204, pl. 27, fig. 3a–h; text-fig. 135.
aff. 1988 *Amplexograptus latus*; Riva, p. 226, figs. 2a–h, 4.
aff. 2011 *Anticostia lata*; Štorch et al., p. 336, figs. 14G, O, Y, 19H–J, M, O, T, table 9 (see for further synonymy).
aff. 2021a *Anticostia lata*; Maletz et al., p. 170, fig. 5A, J.

Holotype.—Figured by Elles and Wood (1906, pl. 27, fig. 3a) and selected by Riva (1988, fig. 2b), specimen SM A19680. From the upper Hartfell Shale, *Dicellograptus anceps* Biozone, Main Cliff, Dob's Linn, Scotland.

Material.—Two specimens (179F_3 and 179F_4) previously collected by Jones below the shelly Hirnantia fauna bed and one poorly preserved specimen collected by the authors (LG4M_07-1) above the shelly Hirnantia fauna bed of the Tanjung Dendang Formation in Pulau Langgun.

Remarks.—The present specimens have a similar thecal characteristic to *Anticostia lata* (Elles and Wood, 1906) described by Riva (1988) and Štorch et al. (2011); however, it has a bigger overall measurement of DVW and could be instead a closely related species or subspecies of *Anticostia lata* (Elles and Wood, 1906). The DVW is ∼1.2–2.3 mm for the first three thecal pairs and reaches an observed maximum of 2.2–2.6 mm, which it seems to maintain throughout the preserved part of the tubarium. The 2TRD at the proximal section measures 1.4–1.85 mm while for the distal section it is 1.6–1.9 mm. The present specimens displayed a diplograptid-like proximal end furnished with a stout virgella, subapertural spine and anti-virgellar spine, which are the key features for this genus. Previously the species referred to as *Amplexograptus latus* (Riva, 1988) was later redesignated as *Anticostia lata* (Štorch et al., 2011). Riva (1988) also provided a detailed remark on the synonymy of this species when it was described under a different name in other parts of the world. *Anticostia lata* (Elles and Wood, 1906) can be differentiated from the similar-looking *Anticostia tenuissima* (Ross and Berry, 1963) by the former's strong thecal geniculation with thickened rim (Štorch et al., 2011).

Infraorder Neograptina Štorch et al., 2011
Paraphyletic Family Normalograptidae Štorch and Serpagli, 1993, emend. Melchin et al., 2011
Genus *Normalograptus* Legrand, 1987, emend. Melchin et al., 2011

Type species.—*Climacograptus scalaris* var. *normalis* Lapworth (1877, p. 138, pl. 6, fig. 31). From the Llandovery of County Down, Ireland, by original designation.

Normalograptus ajjeri (Legrand, 1977)
Figures 5.10–5.12, 11.9–11.11

*1977 *Climacograptus (Climacograptus) normalis ajjeri* n. ssp., Legrand, p. 171, text-figs. 9A–D, 10A, B.
2007 *Normalograptus ajjeri*; Loydell, p. 29, text-figs. 12G, 15A–F, H, I, O (see for full list of synonymies and discussions).
2011 *Normalograptus ajjeri*; Štorch et al., p. 368, figs. 25B–D, P, V, W, 26L, M, table 21.
2012 *Normalograptus ajjeri*; Štorch and Schönlaub, p. 759, 3A, B, ?D, ?O, 4E, F.
2015 *Normalograptus ajjeri*; Wang et al., p. 532, figs. 4B–D, F, O, 8H.
2020 *Normalograptus ajjeri*; Chen et al., p. 50, figs. 4E–G, J, K, N, 8C, D, J, L, M, S.

Holotype.—Designated by Legrand (1977, p. 171), UL2223 d9. From Oued In Djerane, Algeria.

Material.—Three moderately well-preserved specimens (175F_1, 180F_1, and 187F_5) were chosen for illustration and identification. Recovered below the shelly Hirnantia fauna bed of the Tanjung Dendang Formation in Pulau Langgun.

Remarks.—The dimensions of the present materials match well with the description of *Normalograptus ajjeri* (Legrand, 1977) from Loydell (2007). The DVW at the first thecal pair is 0.9–1.1 mm, at the second thecal pair is 1.1–1.2 mm, at the third thecal pair is 1.4 mm, at the fifth thecal pair is 1.45–1.5 mm, and after the fifth thecal pair reaches a maximum of 1.5–1.7 mm, which it maintains throughout the rest of the tubarium. The 2TRD measures 1.4–1.7 mm at the proximal part and 1.9–2.2 mm at the distal part. Elles and Wood (1906) distinguished *Normalograptus normalis* (Lapworth, 1877) as specimens that have a DVW of no more than 1.5 mm, which has consequently been used repeatedly to diagnose *Normalograptus normalis* (Lapworth, 1877) in much of the

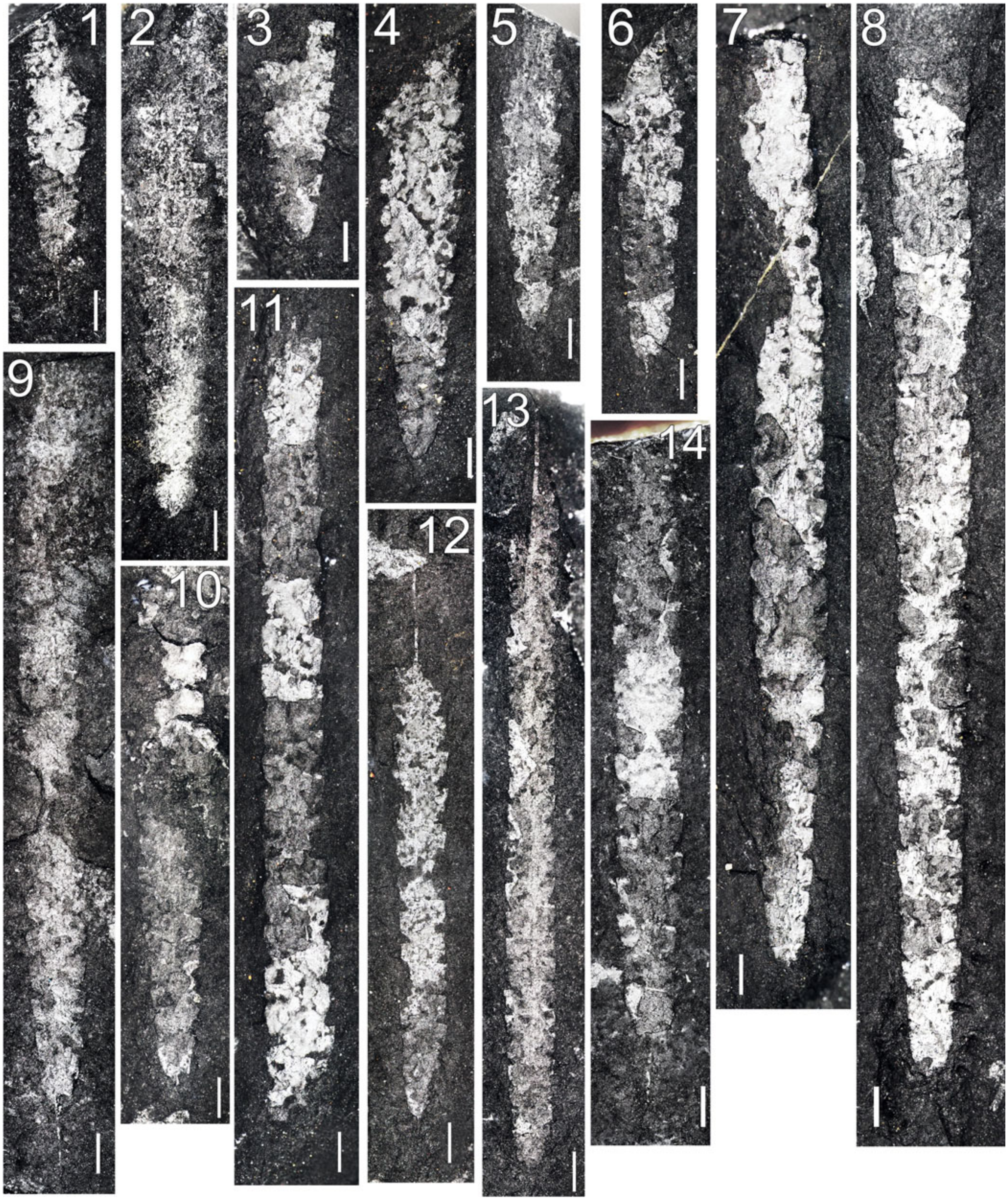


Figure 11. Photographs of the graptolites from the *Metabolograptus extraordinarius* Biozone in Pulau Langgun, Langkawi. (**1, 2, 5**) *Korenograptus elegantulus* (Mu and Ni, 1983): (**1**) 182F_4; (**2**) 183F_3; (**5**) 172F_3. (**3, 4**) *Neodiplograptus shanchongensis* (Li, 1984): (**3**) 173F_5; (**4**) 180F_3. (**6–8, 14**) *Normalograptus temalaensis* (Jones, 1973): (**6**) 189F_3; (**7**) 205F_2; (**8**) 187F_7; (**14**) 187F_3. (**9–11**) *Normalograptus ajjeri* (Legrand, 1977): (**9**) 187F_5; (**10**) 175F_1; (**11**) 180F_1. (**12, 13**) *Normalograptus* aff. *N. mirnyensis* (Obut and Sobolevskaya in Obut et al., 1967): (**12**) 190F_3; (**13**) 185F_5. Scale bars = 1 mm.

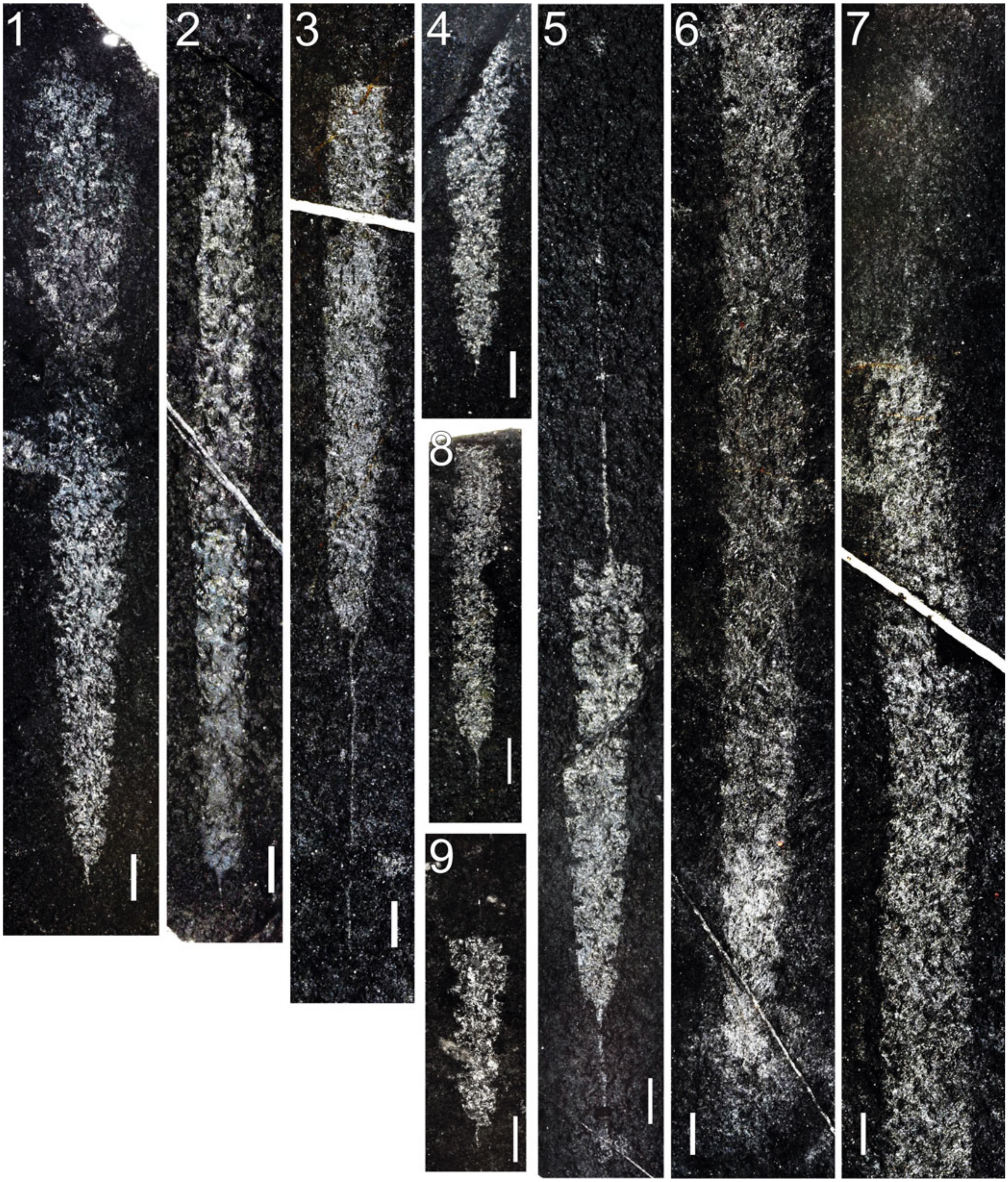


Figure 12. Photographs of the graptolites from the *Metabolograptus persculptus* Biozone in Pulau Langgun, Langkawi. (**1, 4**) *Metabolograptus persculptus* (Elles and Wood, 1907): (**1**) LG4L_01; (**4**) LG4L_04. (**2, 8**) *Normalograptus angustus* (Perner, 1895): (**2**) LG4L_02; (**8**) LG4L_06. (**3, 5**) *Normalograptus rhizinus* (Li and Yang in Nanjing Institute of Geology and Mineral Resources, 1983): (**3**) LG4M_07-2; (**5**) LG4M_02. (**6, 7**) *Anticostia* aff. *A. lata* (Elles and Wood, 1906), LG4M_07-1: (**6**) proximal half; (**7**) distal half. (**9**) *Avitograptus*? sp., LG4L_05. Scale bars = 1 mm.

literature. Loydell (2007), however, restudied the collection of *Normalograptus normalis* (Lapworth, 1877), which had been previously figured by Elles and Wood, and noted that the specimens attained a DVW that is significantly greater than 1.5 mm; the holotype, for example, was recorded to instead be 1.85 mm in DVW. It is then agreed upon that the narrower form of *Normalograptus normalis* (Lapworth, 1877) would henceforth be assigned to *Normalograptus ajjeri* (Legrand, 1977). *Normalograptus ajjeri* (Legrand, 1977) can be further distinguished from other similar normalograptids by having a tubarium that is narrower than that of *Normalograptus medius* (Törnquist, 1897) and less tapering than that of *Normalograptus transgradiens* (Waern in Waern et al., 1948), a more densely spaced thecae compared with *Normalograptus premedius* (Waern in Waern et al., 1948), and a much bigger DVW compared with *Normalograptus angustus* (Perner, 1895) and *Normalograptus mirnyensis* (Obut and Sobolevskaya in Obut et al., 1967) (Štorch and Schönlaub, 2012).

Normalograptus angustus (Perner, 1895)
Figures 7.3, 7.5, 7.6, 12.2, 12.8

*1895 *Diplograptus (Glyptograptus) euglyphus* Lapworth, var. *angustus* mihi Perner, p. 27, pl. 8, figs. 14a, b.
1949 *Climacograptus angustus*; Přibyl, p. 7, pl. 2, figs. 2–9.
1993 *Normalograptus angustus*; Storch and Serpagli, p. 22, pl. 1, figs. 3, 4, ?6, pl. 2, figs. 2, 6, text-figs. 7A?, B, C, E, F.
2000 *Normalograptus angustus*; Koren' and Melchin, p. 1097, figs. 4.8, 4.11–4.13, 5.4.
2005a *Normalograptus angustus*; Chen et. al, p. 252, text-fig. 5D, I, K, Q, DD.
2007 *Normalograptus angustus*; Loydell, p. 30, pl. 1, fig. 3, text-fig. 15L–M (see for further synonymy).
2011 *Normalograptus angustus*; Goldman et al., p. 228, fig. 1K.
2011 *Normalograptus angustus*; Štorch et al., p. 369, figs. 25G, Q, 26H.
2015 *Normalograptus angustus*; Wang et al., p. 534, figs. 3S, 4I, 8G, J.
2020 *Normalograptus angustus*; Chen et al., p. 52, figs. 4A–C, H, I, O, P, 7E, G, 8B, E–H, K, N–Q, 9Q, R.

Holotype.—Figured by Perner (1895, pl. 8, fig. 14a, b), refigured and designated by Přibyl (1949, pl. 2, fig. 8), specimen NM L27552. From the Králův Dvůr Formation, Králův Dvůr Bohemia.

Material.—Three specimens collected by the authors (LG4L_02, LG4L_06 and LG4M_06). Recovered above the shelly Hirnantia fauna bed of the Tanjung Dendang Formation in Pulau Langgun.

Remarks.—The material described agrees well in overall dimension with Ordovician specimens of Perner (1895). DVW at the first thecal pair is 0.8–0.9 mm, at the second thecal pair is 1.0 mm, at the fifth thecal pair is ~1.1–1.2 mm, and subsequently is maintained at less than 1.3 mm throughout the tubarium (note that specimens LG4L_02 and LG4M_06 have a mineral vein running across the tubarium that would make the DVW slightly higher). The overall 2TRD is large, measuring 1.6–2.2 mm. *Normalograptus angustus* (Perner, 1895) can be distinguished by its relatively narrow DVW, parallel-sided climacograptid thecae and a wide 2TRD. Štorch and Serpagli (1993) noted that the Sardinian and Bohemian materials of early Silurian age are narrower compared with the latest Ordovician material of Perner (1895). Riva (1988) and many other authors considered *Normalograptus miserabilis* (Elles and Wood, 1906) to be a junior synonym of *Normalograptus angustus* (Perner, 1895); however, *Normalograptus miserabilis* (Elles and Wood, 1906) was referred to the genus *Styracograptus* after Goldman et al. (2011) restudied specimens of *Normalograptus angustus* (Perner, 1895), including materials from southeast China (Chen et al., 2000, 2005a) along with the type material of *Styracograptus miserabilis* (Elles and Wood) and concluded that they have different internal structures. *Normalograptus angustus* (Perner, 1895) can be differentiated from other similarly parallel-sided normalograptids such as *Normalograptus mirnyensis* (Obut and Sobolevskaya in Obut et al., 1967) by having more widely spaced thecae and from *Normalograptus ajjeri* (Legrand, 1977) by having a much narrower overall DVW (Chen et al., 2000, 2005a; Koren' and Melchin, 2000; Loydell, 2007; Štorch et al., 2011; Wang et al., 2015).

Normalograptus aff. *N. mirnyensis* (Obut and Sobolevskaya in Obut et al., 1967)
Figures 5.6–5.9, 11.12, 11.13

aff. *1967 *Hedrograptus mirnyensis* Obut and Sobolevskaya in Obut et al., p. 47, pl. 1, figs. 4–9.
aff. 2000 *Normalograptus mirnyensis* new combination; Koren' and Melchin, p. 1099, figs. 5.10, 5.17, 7.12, 7.13, 8.1–8.5.
aff. 2005a *Normalograptus mirnyensis*; Chen et al., p. 262, text-fig. 8B, F, G, I, L–N.
aff. 2011 *Normalograptus mirnyensis*; Štorch et al., p. 374, figs. 25E, F, I, J, 26C, F, K, table 24.
aff. 2015 *Normalograptus mirnyensis*; Wang et al., p. 536, figs. 4A, E, G, H, J, L, M, R, X, 7E, G, 8A, C.
aff. 2020 *Normalograptus mirnyensis*; Chen et al., p. 52, figs. 4L, 10M.

Holotype.—Original designation previously figured by Obut et al. (1967, pl. 1, fig.4). From the *Akidograptus ascensus*–*Parakidograptus acuminatus* Biozone of Mirny Creek, northeast Russia.

Material.—Two specimens previously collected by Jones (185F_5 and 190F_3) and two specimens collected by the authors (LG1_05 and LG1_06-2). Recovered below the shelly Hirnantia fauna bed of the Tanjung Dendang Formation in Pulau Langgun.

Remarks.—The present material resembles *Normalograptus mirnyensis* (Obut and Sobolevskaya in Obut et al., 1967) specimens described by Chen et al. (2005a), Štorch et al. (2011), and Wang et al. (2015); however, it possesses a slightly wider DVW and 2TRD overall and might be related to said species. The DVW at the first thecal pair is 0.8–1.0 mm, at the third thecal pair is 1.1 mm, at the fifth thecal pair ~1.15–1.25 mm, and distally reaches an average of less than 1.3 mm, which it maintains throughout the whole tubarium. The 2TRD is relatively dense; at the proximal part it measures 1.1–1.5 mm, and at the distal part it is 1.3–1.7 mm.

Normalograptus mirnyensis (Obut and Sobolevskaya in Obut et al., 1967) is typically characterized by its relatively narrow DVW (normally ∼1.1 mm or less in maximum width), parallel-sided supragenicular walls, and climacograptid thecae with strong geniculation and dense 2TRD. Depending on the preservation, however, the thecae might look slightly glyptograptid. It has a more densely spaced thecae than *Normalograptus angustus* (Perner, 1895) and a markedly narrower tubarium than *Normalograptus ajjeri* (Legrand, 1977) (Chen et al., 2005a, 2020; Štorch et al., 2011; Štorch and Schönlaub, 2012; Wang et al., 2015). It also differs by having no genicular flanges compared with *Normalograptus jideliensis* (Koren' and Mikhaylova in Koren' et al., 1980) and *Normalograptus acceptus* (Koren' and Mikhaylova in Koren' et al., 1980) (Koren' and Melchin, 2000). One specimen (190F_3), which had been described as the juvenile paratype of *Glyptograptus temalaensis* Jones, 1973, was previously recorded with a maximum DVW of 1.6 mm (Jones, 1973, specimen 190F); however, restudy reveals a maximum DVW of 1.3 mm, and it is hereby reassigned to *Normalograptus* aff. *N. mirnyensis* (Obut and Sobolevskaya in Obut et al., 1967).

Normalograptus normalis (Lapworth, 1877)
Figures 8.12, 13.9

*1877 *Climacograptus scalaris* Hisinger (Non. Linnaeus.) Var. *b. normalis* Lapworth, Lapworth, p. 138, pl. 6, fig. 31.
2007 *Normalograptus normalis*; Blackett and Zalasiewicz.
2007 *Normalograptus normalis*; Loydell, p. 38, pl. 1, figs. 4, 7, text-figs. 12E, F, 16C, H, N, 19 (see for full list of synonymies, including specimens formerly assigned to *N. normalis* and further discussions).

Holotype.—Figured by Elles and Wood (1906, pl. 26, fig. 2a), Williams (1983, text-fig. 4a), specimen BU 1136. From the *Parakidograptus acuminatus* s.l. Biozone of Dob's Linn, southern Scotland.

Material.—One specimen collected by the authors (LG9_02). From the LG9 bed (equivalent to Jones's cherty bed) of the Tanjung Dendang Formation in Pulau Langgun.

Remarks.—The present specimen fully agrees with the measurements of the holotype of *Normalograptus normalis* (Lapworth, 1877) refigured in the Atlas of Graptolite Type Specimens Folio 2 (no. 2.61) and restudied by Loydell (2007) together with his Jordanian material. The DVW at the first thecal pair is 1.0 mm, at the second thecal pair is 1.1 mm, at the third thecal pair is 1.3 mm, at the fifth thecal pair is 1.5 mm, and at the tenth thecal pair is 1.9 mm, which is the maximum DVW recorded. The 2TRD measures 1.45–2.00 mm at the proximal part and 1.8–2.3 mm distally. Note that the holotype of *Normalograptus normalis* (Lapworth, 1877) reaches a maximum DVW of 1.85 mm; hence, all instances of *Normalograptus normalis* (Lapworth, 1877) in literature measuring less than 1.5–1.6 mm can instead be assigned to *Normalograptus ajjeri* (Legrand, 1977). Previous

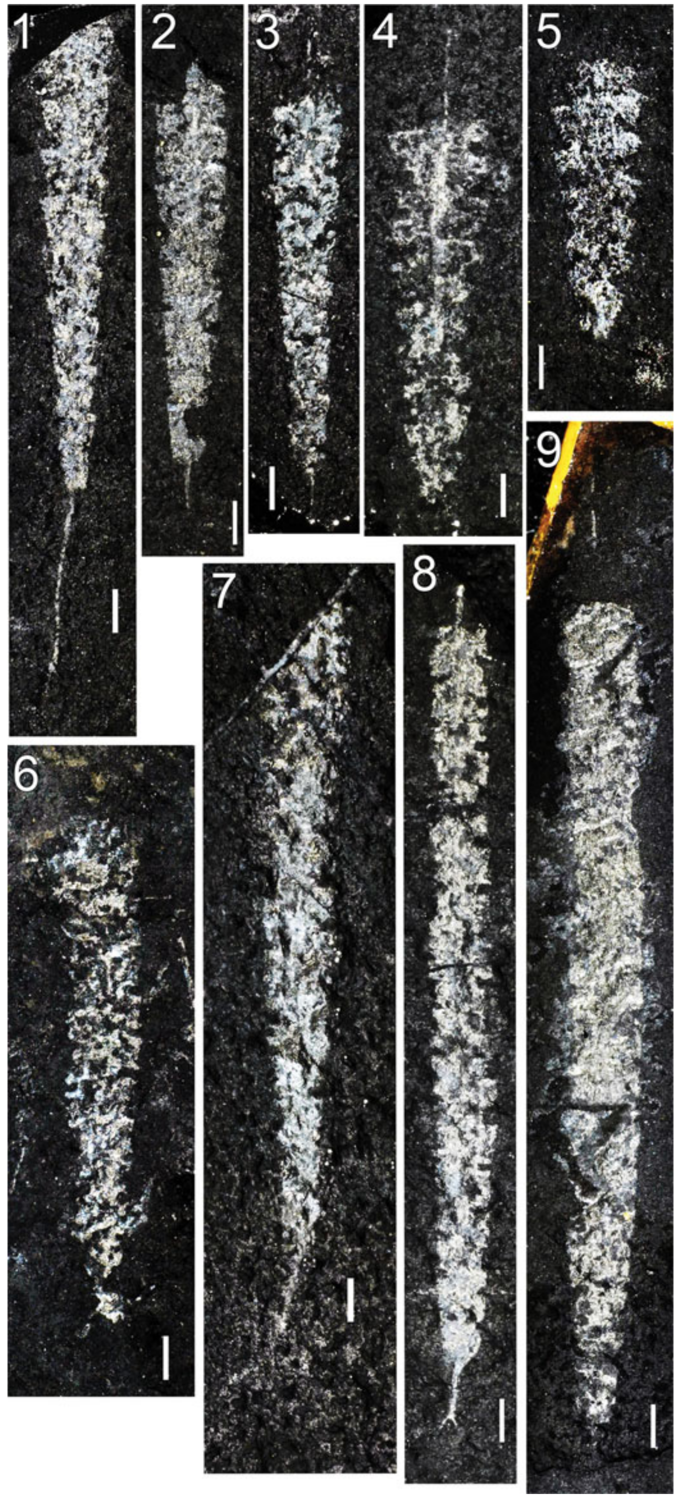


Figure 13. Photographs of the graptolites from the *Akidograptus ascensus*–*Parakidograptus acuminatus* Biozone in Pulau Langgun, Langkawi. (**1–3**) *Avitograptus* cf. *A. avitus* (Davies, 1929): (**1**) LG8_01-1; (**2**) LG8_03; (**3**) LG7_06-2. (**4, 5**) *Neodiplograptus parajanus*? (Štorch, 1983): (**4**) LG7_08; (**5**) LG8_05. (**6**) *Hirsutograptus* sp., LG9_04-2. (**7**) *Korenograptus bifurcus* (Mu et al. in Nanjing Institute of Geology and Palaeontology, 1974), LG7_09-1. (**8**) *Normalograptus* aff. *N. radicatus* (Chen and Lin, 1978), LG7_06-1. (**9**) *Normalograptus normalis* (Lapworth, 1877), LG9_02. Scale bars = 1 mm.

non-synonymies for *Normalograptus normalis* (Lapworth, 1877) are noted by Loydell (2007) for reference. Jones (1968) also described a somewhat narrow form of *Normalograptus normalis* (Lapworth, 1877) from the *Cystograptus vesiculosus* to *Coronograptus cyphus* biozones in Langkawi and from the *Coronograptus cyphus* to *Coronograptus gregarius* biozones in central Kedah, with a DVW measuring 1.0–1.5 mm, which could be instead assigned to *Normalograptus ajjeri* (Legrand, 1977). Do note, however, that one illustrated specimen from Langkawi (Jones, 1968, pl. 7b, specimen 97F) shows a slightly protracted proximal end and is preserved in a somewhat subscalariform view. *Normalograptus normalis* (Lapworth, 1877) can be distinguished from *Normalograptus medius* (Törnquist, 1897) from the latter having a characteristically rounded proximal end while specimens with much narrower thecal apertures can instead be assigned to *Normalograptus scalaris* (Hisinger, 1837) (Loydell, 2007).

Normalograptus aff. *N. radicatus* (Chen and Lin, 1978)
Figures 8.10, 8.11, 13.8

aff. *1978 *Climacograptus radicatus* (Chen and Lin, 1978), p. 31, pl. 5, 12–19.
aff. ?1984 *Climacograptus radicatus*; Chen, p. 253, table A1.
aff. 2017 *Normalograptus*? *radicatus*; Loxton, p. 259, pl. 47.13?, 50.6–50.8, 55.11?; figs. 41.1–41.4.

Holotype.—Chen and Lin (1978, pl. 5.14), specimen number 35960a. From the *Akidograptus ascensus*–*Climacograptus bicaudatus* Biozone of Tongzi, Northern Guizhou.

Material.—Two specimens were collected by the authors (LG7_06-1 and LG8_07). Specimen LG8_07 does not have its virgella preserved. From the LG7 and LG8 bed (equivalent to Jones's cherty bed) of the Tanjung Dendang Formation in Pulau Langgun.

Remarks.—The specimens are most likely related to the *Normalograptus bifurcus*/*coremus*/*radicatus* group, which can be characterized by the distal branching of the virgella (Maletz et al., 2021b). The DVW at the first thecal pair is 1.00–1.05 mm, at the second thecal pair is 1.10–1.15 mm, at the third thecal pair is 1.25–1.30 mm, at the fifth thecal pair is 1.4–1.5 mm, and afterward maintains a DVW of 1.60–1.65 mm throughout the whole tubarium. The 2TRD is large, 1.7–1.9 mm at the proximal part and 1.95–2.40 mm at the distal part. Chen et al. (2005a) regarded *Normalograptus radicatus* (Chen and Lin, 1978) as a junior synonym of *Normalograptus coremus* (Chen and Lin, 1978), suggesting that the differences between the two would be a result of preservation (the former are said to be preserved in a subscalariform to scalariform view). Further inspection of the holotype of *Normalograptus radicatus* (Chen and Lin, 1978) and the best syntype of *Normalograptus coremus* (Chen and Lin, 1978), however, reveals significant differences that present throughout the tubarium: (1) the proximal section of *Normalograptus coremus* (Chen and Lin, 1978) starts relatively narrow (DVW = 0.6 mm) but increases rapidly compared with the blunt end of *Normalograptus radicatus* (Chen and Lin, 1978), which starts with a DVW of 0.95 mm; (2) the maximum distal DVW for *Normalograptus coremus* (Chen and Lin, 1978) is fairly large, reaching ∼2.1 mm, while *Normalograptus radicatus* (Chen and Lin, 1978) reaches a maximum DVW of less than 1.6 mm throughout the tubarium; (3) *Normalograptus radicatus* (Chen and Lin, 1978) maintains climacograptid-like thecae throughout the tubarium while in *Normalograptus coremus* (Chen and Lin, 1978), the thecae become progressively less geniculate distally; (4) 2TRD for *Normalograptus radicatus* (Chen and Lin, 1978) ranged between 1.6 and 1.9 mm while *Normalograptus coremus* (Chen and Lin, 1978) have a consistently higher 2TRD of more than 2.1 mm throughout; (5) the thecae of *Normalograptus radicatus* (Chen and Lin, 1978) alternate for the whole of the tubarium while in *Normalograptus coremus* (Chen and Lin, 1978), the thecae initially alternate in the proximal section but become more opposite to each other in the distal section. In any case, both share a similar long virgella that forked into several branches at ∼2.7 mm down the turning point of the first theca. By comparison, our specimen has a significantly shorter virgella that forked into two after 1 mm down. We would consider these graptolites as a separate species for now; however, more collection and a detailed study would help to further enhance our understanding of this group. Another very similar graptolite is *Normalograptus minor* (Huang, 1982), which also features the same branching virgella. Chen et al. (2005a) described *Normalograptus minor* (Huang, 1982) to have a significantly narrower DVW compared with *Normalograptus radicatus* (Chen and Lin, 1978) and *Normalograptus coremus* (Chen and Lin, 1978), which can also be seen in Loxton (2017), where the maximum DVW measures ∼1.2–1.4 mm. Other authors, however, described *Normalograptus minor* (Huang, 1982) with a maximum DVW of 1.5–1.6 mm such as in Štorch et al. (2019). Loxton (2017) further differentiated *Normalograptus minor* (Huang, 1982) from *Normalograptus radicatus* (Chen and Lin, 1978) on the basis of its smaller proximal 2TRD, which is less than 1.75 mm. *Normalograptus radicatus* (Chen and Lin, 1978) can be distinguished from *Normalograptus rhizinus* (Li and Yang in Nanjing Institute of Geology and Mineral Resources, 1983) from the latter having wider thecal spacing and virgella that tend to expand distally into a vane-like structure (Chen et al., 2005a). The present specimen also resembles very closely *Normalograptus ajjeri* (Legrand, 1977) if the former virgella is not preserved, with both having the same DVW and thecal characteristic; however, our specimen of *Normalograptus* aff. *N. radicatus* (Chen and Lin, 1978) has a slightly bigger 2TRD compared with the Hirnantian *Normalograptus ajjeri* (Legrand, 1977) specimens.

Normalograptus rhizinus (Li and Yang in Nanjing Institute of Geology and Mineral Resources, 1983)
Figures 7.7, 7.8, 12.3, 12.5

*1983 *Climacograptus rhizinus* Li and Yang in Nanjing Institute of Geology and Mineral Resources, p. 454, pl. 162, figs. 13, 14.
1999 *Climacograptus rhizinus*; Li, pl. 4, fig. 8.
2005a *Normalograptus rhizinus*; Chen et al., p. 268, text-fig. 9I, M, P, V–X.
2006 *Normalograptus rhizinus*; Chen et al., p. 191, fig. 9.2.

2017 *Normalograptus? rhizinus*; Loxton, p. 264, pl. 32.1–32.3, 32.6, 32.7, figs. 28.1, 28.2, 28.10, 29.14.
2019 *Normalograptus rhizinus*; Loydell et al., p. 370, fig. 6A.
2019 *Normalograptus rhizinus*; Štorch et al., p. 7, figs. 3n, q, 7b.
2021b *Normalograptus rhizinus*; Maletz et al., fig. 4k.

Holotype.—Designated by Li and Yang in Nanjing Institute of Geology and Mineral Resources (1983, pl. 162. fig. 13), refigured by Li (1999, pl. 4, fig. 8), specimen number 54127. From the *Parakidograptus acuminatus* Biozone of Southern Anhui, China.

Material.—Two specimens collected by the authors (LGM4M_02 and LG4M_07-2). Recovered above the shelly Hirnantia fauna bed of the Tanjung Dendang Formation in Pulau Langgun.

Remarks.—The present specimens are similar to material recorded elsewhere such as in China (Chen et al., 2005a, 2006; Maletz et al., 2021b), Spain (Štorch et al., 2019), and central Laos (Loydell et al., 2019). The DVW at the first thecal pair is 0.95–1.00 mm, at the second thecal pair is 1.15–1.20 mm, at the third thecal pair is 1.20–1.25 mm, and at the fifth thecal pair is ∼1.40–1.45 mm; distally it reaches a maximum of 1.50–1.65 mm. The 2TRD is relatively large, measuring 1.85–2.20 mm. Chen et al. (2005a) noted the distal width variation and suggested that *Normalograptus rhizinus* (Li and Yang in Nanjing Institute of Geology and Mineral Resources, 1983) includes both *Climacograptus rhizinus* and *Climacograptus acus* (Jin et al., 1982). The type specimen of *Climacograptus acus*, which has unfortunately gotten lost, is reported to reach a maximum DVW of 1.7 mm. Specimens illustrated by Chen et al. (2005a) and Loydell et al., (2019, fig. 6A) possess a virgella that either expands abruptly into a broad vane or expands more gradually. The holotype of *Normalograptus rhizinus* (Li and Yang in Nanjing Institute of Geology and Mineral Resources, 1983), for example, has a much more prominent bulb-like vane. The presence of an anti-virgellar spine can be seen in specimens illustrated by Chen et al. (2006, p. 191, fig. 9.2) and Loxton (2017); however, from the latter, several specimens of *Normalograptus? rhizinus* recorded feature multiple spines. *Normalograptus rhizinus* (Li and Yang in Nanjing Institute of Geology and Mineral Resources, 1983) can be differentiated from a very similar *Avitograptus avitus* (Davies, 1929) in the width of the tubarium and in having a long, distally widening virgella. *Avitograptus avitus* (Davies, 1929) is also noted to commonly possess a relatively elongate first thecal pair (Chen et al., 2005a). *Normalograptus rhizinus* (Li and Yang in Nanjing Institute of Geology and Mineral Resources, 1983) are also similar to *Akidograptus ascensus* Davies, 1929 in DVW and general thecal characteristic; however, the genus *Akidograptus* is generally characterized by $th1^1$ that turns up significantly high up the sicular aperture, giving a more protracted proximal end.

Normalograptus temalaensis (Jones, 1973)
Figures 5.13–5.17, 11.6–11.8, 11.14

*1973 *Glyptograptus temalaensis* Jones, p. 18, pl. 1, fig. 3a, c.
?1984a *Glyptograptus temalaensis*; Li, p. 322, pl. 2, figs. 8, ?9–11.
2020 *Diplogarptus temalaensis* (Jones); Zhen et al., p. 384, fig. 12C.

Holotype.—Designated by Jones (1973, pl.1, fig. 3a). The specimen on slab numbered 180F, recovered from Bed 1, equivalent to the *Metabolograptus persculptus* Biozone interval in the Tanjung Dendang Formation in Pulau Langgun, Langkawi. However, the original holotype cannot be identified from the present slab. A new lectotype, specimen 205F_2, as well as two new paratypes, specimens 187F_7 and 189F_3, have been chosen.

Material.—Five specimens previously collected by Jones (172F_2, 187F_3, 187F_7, 189F_3, and 205F_2) were picked for illustration and identification. Originally recorded from the *Metabolograptus persculptus* and *Coronograptus gregarius* biozones of the Tanjung Dendang Formation in Pulau Langgun. However, the record from the latter biozone seems to be ambiguous upon reexamination of Jones's graptolite collection.

Remarks.—The DVW at the first thecal pair is 0.9–1.2 mm, at the second thecal pair is 1.10–1.25 mm, at the third thecal pair is 1.3–1.5 mm, at the fifth thecal pair is 1.4–1.7 mm, at the tenth thecal pair is 1.7–1.8 mm, and after the tenth thecal pair reaches a maximum of 1.80–2.05 mm, which it maintains throughout the rest of the tubarium. The 2TRD increases from 1.5–1.8 mm at the proximal part to 1.7–2.1 mm at the distal part of the tubarium. Jones (1973) noted that the diagnostic features of *Normalograptus temalaensis* (Jones, 1973) are its medium-sized tubarium (maximum DVW ∼1.8–2.0 mm), rather blunt proximal end, and thecae that are widely spaced. In addition, there is a description of how the thecae show a considerable axial torsion, but these features could instead be a preservational artifact, also acknowledged by Štorch et al. (2011). The original holotype (Jones, 1973, pl.1, fig. 3a), which lacked the proximal termination, cannot be identified from Jones's original collection (specimen 180F_1 seems to resemble the holotype but has a different proximal section, smaller length, and slightly smaller DVW). We decided to select a lectotype of *Normalograptus temalaensis* (Jones, 1973), which is specimen 205F_2, for future reference. The paratypes designated by Jones are either missing (for example, specimens that were recorded to be higher in the succession) or reassigned to another species (the smaller paratype regarded as a juvenile specimen, upon reexamination, was assigned to *Normalograptus* aff. *N. mirnyensis* [Obut and Sobolevskaya in Obut et al., 1967]), and consequently, two new paratypes, specimens 187F_7 and 189F_3, are selected. The thecal form of *Normalograptus temalaensis* (Jones, 1973) is somewhere between climacograptid and glyptograptid types and can be further diagnosed from the supragenicular walls that are slightly inclined to no more than 10°, the infragenicular wall that is inclined at a low angle, and the moderately deep excavation overall. Admittedly, *Normalograptus temalaensis* (Jones, 1973) is difficult to distinguish from the similar-looking *Normalograptus normalis* (Lapworth, 1877), *Normalograptus ajjeri* (Legrand, 1977), and *Normalograptus elegantulus* (Mu and Ni, 1983). *Normalograptus temalaensis* (Jones, 1973)

https://doi.org/10.1017/jpa.2022.94 Published online by Cambridge University Press

possesses similar parallel-sided tubarium as *Normalograptus normalis* (Lapworth, 1877) and *Normalograptus ajjeri* (Legrand, 1977); however, *Normalograptus temalaensis* (Jones, 1973) seems to have slightly more inclined supragenicular walls and, overall, a bigger DVW compared with *Normalograptus ajjeri* (Legrand, 1977) (*Normalograptus ajjeri* [Legrand, 1977] usually attain a maximum DVW of significantly less than 1.8 mm). *Normalograptus temalaensis* is somewhat similar to *Normalograptus* ex. gr. *N. normalis* illustrated by Underwood et al. (1998, fig. 5C) and *Normalograptus normalis* (Lapworth, 1877) in Chen et al. (2005a, p. 264) in having a distinct blunt proximal end. Specimens identified as *Normalograptus temalaensis* (Jones, 1973) from South Anhui, China (illustrated by Li, 1984a), had been regarded as a junior synonym of *Normalograptus elegantulus* (Mu and Ni, 1983); however, the latter specimen bears a distinctive glyptograptid thecae with much more inclined supragenicular walls throughout the whole tubarium (Štorch et al., 2011). *Normalograptus temalaensis* (Jones, 1973) also have a smaller maximum DVW compared with *Metabolograptus extraordinarius* (Sobolevskaya, 1974) (which could reach more than 2.5 mm), *Metabolograptus ojsuensis* (Koren' and Mikhaylova in Koren et al., 1980), and *Metabolograptus persculptus* (Elles and Wood, 1907) (where the latter two also have more inclined glyptograptid thecae distally).

Family incertae sedis
Genus *Hirsutograptus* Koren' and Rickards, 1996, emend. Melchin et al., 2011

Type species.—*Hirsutograptus longispinosus* Koren' and Rickards (1996, p. 40, pl. 7, fig.4, text-fig. 8A, F–G) from the Kos-Istek region, western Kazakhstan, by original designation.

Hirsutograptus sp.
Figures 8.7, 13.6

Material.—One poorly preserved specimen collected by the authors (LG9_04-2). From the LG9 bed (equivalent to Jones's cherty bed) of the Tanjung Dendang Formation in Pulau Langgun.

Remarks.—Melchin et al. (2011) in their emended diagnosis described the genus *Hirsutograptus* as having a proximal pattern H astogeny with climacograptid thecae that bear laterally and ventrally directed genicular hoods, genicular spines, or both. The present specimen is too poorly preserved to completely discern its actual species and can be identified only up to the genus level by the presence of the climacograptid thecae with apparent spinosity. The proximal DVW is ∼1.25 mm. Mesially it maintains a DVW of 1.7 mm; however, distally it may reach to a maximum of 2.0 mm depending on preservation. The 2TRD measures ∼1.85–2.40 mm. Similar species include *Hirsutograptus longispinosus* (Koren' and Rickards, 1996, pl. 7, fig. 4; text-fig. 8A, F–G), with the genicula having one mesial spine each and a maximum DVW of 1.7 mm.

Superfamily Monograptoidea Lapworth, 1873, emend. Melchin et al., 2011

Paraphyletic Family Dimorphograptidae Elles and Wood, 1908, emend. Melchin et al., 2011
Genus *Avitograptus* Melchin et al., 2011

Type species.—*Glyptograptus*(?) *avitus* Davies (1929, p. 8, fig. 21). From Dob's Linn, southern Scotland, UK, by original designation.

Avitograptus cf. *A. avitus* (Davies, 1929)
Figures 8.1–8.4, 13.1–13.3

cf. *1929	*Glyptograptus*? *avitus* Davies, p. 8, fig. 21.
1962	*Glyptograptus*? *avitus*; Packham, text-fig. 7a.
cf. 1983	*Glyptograptus*? *avitus*; Williams, p. 625, pl. 66, figs. 8–10; text-figs. 7h–l, 9 a–c, ?d, 10a–c.
non 2005a	*Normalograptus avitus* (Davies, 1929); Chen et al., p. 255, pl. 1, fig. 11; pl. 2, fig. 9; text-fig. 7D, G, J–L.
cf. 2011	*Avitograptus avitus* (Davies, 1929); Melchin et al., p. 292, fig. 6B.
cf. 2017	*Avitograptus avitus* (Davies, 1929); Loxton, pl. 31.25, 32.4, 32.5, 32.8, 32.9, 37.24, 38.1; figs. 27.13, 27.17, 28.7, 29.9, 29.10.
cf. 2020	*Avitograptus avitus* (Davies, 1929); Muir et al., p. 6, figs. 3.2, 4.4.

Holotype.—Figured by Davies (1929) and Packham (1962); later refigured by Williams (1983, text-fig. 7l), specimen SM A10019 stored in the Sedgwick Museum, Cambridge. From the *Parakidograptus acuminatus*? Biozone of the Birkhill Shale, Dob's Linn, Scotland.

Material.—Four specimens were collected by the authors (LG7_06-2, LG8_01-1, LG8_03, and LG8_06). From the LG7 and LG8 beds (equivalent to Jones's cherty bed) of the Tanjung Dendang Formation in Pulau Langgun.

Remarks.—*Avitograptus avitus* (Davies, 1929) is the type species used by Melchin et al. (2011) to describe the genus *Avitograptus*. The diagnosis for the genus includes specimens with pattern J astogeny, with $th1^1$ turning at the level of the sicular aperture, slightly elongated first thecal pair (usually length of $th1^1$ at least 1.4 times the length of the free ventral wall for $th2^1$), geniculate thecae with slight to moderately inclined supragenicular walls and a full median septum (Melchin et al., 2011, p. 295). Note that the point of upturn of $th1^1$ itself seems to vary within the population. Williams (1983) made a detailed redescription of the type species of *Avitograptus avitus* (Davies, 1929) and diagnosed the species as having a maximum DVW of 1.5 mm, straight to sloping supragenicular walls, and virgella commonly bifurcating close to the tubarium. The Langkawi specimens, however, differ in having a bigger DVW compared with the type specimen of *Avitograptus avitus* (Davies, 1929) and as such are referred to *Avitograptus* cf. *A. avitus* (Davies, 1929). The DVW measured at the first thecal pair is 1.0–1.1 mm, at the second thecal pair is 1.05–1.20 mm, at the third thecal pair is 1.10–1.45 mm, at the fifth thecal pair is 1.50–1.55 mm, and distally maintains a maximum of ∼1.7–1.8 mm. The 2TRD is conspicuously

https://doi.org/10.1017/jpa.2022.94 Published online by Cambridge University Press

large, measuring 1.9–2.5 mm. Some authors recorded a maximum DVW higher than the type specimen; for example, Chen et al. (2005a) described *Avitograptus avitus* (Davies, 1929) with a maximum DVW of 1.5–1.8 mm, which Loxton (2017) suggested to be incorrectly assigned due to their great distal width and the lack of protracted proximal thecae. Meanwhile, Wang et al. (2015) described specimens of *Avitograptus* sp. aff. *A. avitus* with a distal maximum width of 1.6–1.7 mm while Chen et al. (2020) described one specimen of *Avitograptus* cf. *A. avitus* (Davies, 1929) that measures 1.8 mm at the ninth thecal pairs (figs. 5G, 9O); however, the proximal section seems to be slightly curved and would be better assigned to *Avitograptus acanthocystus* (Fang et al., 1990). *Avitograptus avitus* (Davies, 1929) can be differentiated from the similar looking *Avitograptus akidomorphus* (Muir et al., 2020) by the latter having more pronounced thecal geniculation and smaller DVW (max DVW = 1.2 mm) overall (Muir et al., 2020). *Normalograptus rhizinus* (Li and Yang in Nanjing Institute of Geology and Mineral Resources, 1983) and *Metabolograptus wangjiawanensis* (Mu and Lin, 1984), however, can be distinguished from *Avitograptus avitus* (Davies, 1929) by its width and its long, spatulate virgella (Chen et al., 2005a).

Avitograptus? sp.
Figures 7.1, 12.9

Material.—One specimen collected by the authors (LG4L_05). Recovered above the shelly Hirnantia fauna bed of the Tanjung Dendang Formation in Pulau Langgun.

Remarks.—This specimen is questionably assigned to the genus *Avitograptus*, which can be identified by the possible pattern J astogeny with the first theca that normally grows down to a point at or above the sicular aperture and then turns upward (Melchin et al., 2011; Muir et al., 2020). The DVW is 0.98 mm at the first pair, 1.07 mm at the second pair, 1.25 mm at the third pair, and 1.35 mm at the fourth pair. The 2TRD measures 1.85–2.00 mm. The current specimen, however, seems to have an abnormal proximal growth, with the sicula on the side of where $th1^1$ grows, resulting in a shorter upward growing portion of $th1^1$. Another possibility is that it could be a transitional species between *Normalograptus* and *Akidograptus* (Melchin et al., 2011), but more specimens need to be collected to ascertain this idea.

Superfamily Retiolitoidea Lapworth, 1873, emend.
Melchin et al., 2011
Paraphyletic Family Neodiplograptidae Melchin et al., 2011
Genus *Korenograptus* Melchin et al., 2011

Type species.—*Glyptograptus gnomus* Churkin and Carter, 1970 (p. 24, pl. 2, fig. 16, text-fig. 11E). From southeastern Alaska, USA, by original designation.

Korenograptus bifurcus (Mu et al. in Nanjing Institute of Geology and Palaeontology, 1974)
Figures 8.8(?), 8.9, 13.7

*1974 *Diplograptus bifurcus* Mu et al. in Nanjing Institute of Geology and Palaeontology, p. 212, pl. 98, fig. 12.
1978 *Diplograptus bifurcus*; Chen and Lin, p. 22, pl. 2.3, 2.4, fig. 4a.
2012 *Rickardsograptus*? *bifurcus* (Ye, 1978); Štorch and Schönlaub, p. 762, figs. 3L–N, 4B–D, K.
2017 *Korenograptus bifurcus* (Ye, 1978); Loxton, p. 311, pl. 45.13; fig. 42.1, 42.8.
2019 *Neodiplograptus bifurcus*; Loydell et al., p. 370, fig. 6B.
2019 *Korenograptus bifurcus* (Mu et al. in Nanjing Institute of Geology and Palaeontology, 1974); Štorch et al., p. 16, figs. 7c, k, 8g, ?j, 10a.

Holotype.—Figured by Mu et al. in Nanjing Institute of Geology and Palaeontology (1974, p. 212, pl. 98, fig. 12) and by Chen and Lin (1978, p. 22, pl. 2.3, 2.4, fig. 4a.), specimen no. 21430.

Material.—Poorly preserved specimens collected by the authors (LG7_09-1, questionably LG8_01-2). From the LG7 and possibly LG8 bed (equivalent to Jones's cherty bed) of the Tanjung Dendang Formation in Pulau Langgun.

Remarks.—*Korenograptus bifurcus* (Mu et al. in Nanjing Institute of Geology and Palaeontology, 1974) can be easily recognized from its long, distally bifurcating virgella that split into two prominent branches. The DVW of the Langkawi specimens is 0.9 mm at the first thecal pair, 1.1 mm at the second thecal pair, and 1.8 mm at the fifth thecal pair; the maximum recorded DVW is ∼2.2 mm at the eighth thecal pair. Most authors recorded a distal DVW of more than 2.0 mm for *Korenograptus bifurcus* (Mu et al. in Nanjing Institute of Geology and Palaeontology, 1974); for example, in specimens studied by Štorch and Schönlaub (2012), a DVW of 2.30–2.55 mm is achieved at the tenth thecal pair, and in Štorch et al. (2019) a DVW of 2.40–2.65 mm is recorded by the tenth–fifteenth thecal pairs. Štorch and Schönlaub (2012) previously differentiated the Ye (1978) species from the species described by Mu et al. in Nanjing Institute of Geology and Palaeontology (1974) by the former having more densely spaced thecae and a more robust proximal end. On further reexamination of the Chinese materials, Štorch et al. (2019) suggested that the Ye (1978) species, along with several other similar taxa, was conspecific with the Mu et al. (in Nanjing Institute of Geology and Palaeontology (1974) species. Štorch and Schönlaub (2012) referred the species to the genus *Rickardsograptus*; however, Loxton (2017) and Štorch et al. (2019) instead assigned it to the genus *Korenograptus*, the former highlighting the lack of tapered proximal end and dramatic change in mesial thecal form, and the latter remarking on the pattern H astogeny and a largely glyptograptid thecae that lack any genicular thickening. Our present specimen unfortunately displays a relatively poorly preserved proximal end. *Korenograptus bifurcus* (Mu et al. in Nanjing Institute of Geology and Palaeontology, 1974) is very similar to *Korenograptus bicaudatus* (Chen and Lin, 1978); however, the latter has a virgella that bifurcates only very slightly below the turning point of the first theca, usually less than 1 mm (Chen and Lin, 1978; Loxton, 2017; Loydell et al., 2019; Štorch et al., 2019).

Korenograptus elegantulus (Mu and Ni, 1983)
Figures 5.3–5.5, 11.1, 11.2, 11.5

https://doi.org/10.1017/jpa.2022.94 Published online by Cambridge University Press

*1983 *Glyptograptus elegantulus* Mu and Ni, 1983, p. 161, pl. 7, fig. 4, pl. 8, figs. 1, 2, 10–13, text-fig. 3b, d.
2011 *Normalograptus elegantulus* (Mu and Ni, 1983); Štorch et al., p. 370, figs. 25K, R, X–Z, 26A, B, D, I, J, 27J–M, table 22.
2021b *Korenograptus elegantulus* (Mu and Ni, 1983); Maletz et al., fig. 5a, c.

Holotype.—Figured by Mu and Ni (1983, pl. 4, fig. 13), specimen no. 67970. Listed to be from the *Diplograptus bohemicus* Biozone, Riajue, Tibet.

Material.—Three moderately preserved specimens (172F_3, 182F_4, and 183F_3) chosen for illustration and identification. Recovered below the shelly Hirnantia fauna bed of the Tanjung Dendang Formation in Pulau Langgun.

Remarks.—The graptolite description matches well with *Korenograptus elegantulus* (Mu and Ni, 1983) (Mu and Ni, 1983; Štorch et al., 2011). The DVW is 0.9–1.0 mm at the first thecal pair, 1.05–1.10 mm at the second thecal part, 1.2–1.3 mm at the third thecal pair, 1.5 mm at the fifth thecal pair, 1.65 mm at the tenth thecal pair, and reaches a maximum of 1.5–1.8 mm (distal part is mostly broken). Compared with *Normalograptus temalaensis* (Jones, 1973), *Korenograptus elegantulus* (Mu and Ni, 1983) are less parallel-sided and possess a much more inclined glyptograptid thecae. *Korenograptus elegantulus* (Mu and Ni, 1983) have a more asymmetrical proximal end, slightly smaller DVW, and wider spaced thecae distally compared with the similar *Normalograptus lungmaensis* (Štorch et al., 2011). *Korenograptus laciniosus* (Churkin and Carter, 1970) is another species that seems to be related to *Korenograptus elegantulus* (Mu and Ni, 1983) but can be differentiated by a shorter sicula, a narrower DVW, and closer spaced thecae (Churkin and Carter, 1970; Chen et al., 2005a; Štorch et al., 2011; Maletz et al., 2021b). Loxton (2017) measured both the specimen of *Korenograptus laciniosus* (Churkin and Carter, 1970) from Blackstone River, Yukon, and South China (as previously described by Chen et al., 2005a) and noted that for most cases, the specimens reach a consistent distal width of or very close to 1.5 mm.

Genus *Metabolograptus* Obut and Sennikov, 1985, emend. Melchin et al., 2011

Type species.—*Diplograptus modestus sibericus* Obut (1955, p. 138). From the Siberian Platform, Russia, by original designation.

Metabolograptus extraordinarius (Sobolevskaya, 1974)
Figures 4.10–4.20, 10.3, 10.4, 10.7, 10.9, 10.12, 10.13

vp1968 *Glyptograptus persculptus* (Salter, 1873); Jones, p. 436 (specimen not figured).
*1974 *Fenhsiangograptus extraordinarius* Sobolevskaya, p. 69, pl. 3, figs. 6, 7, 25A, H, M, N, S–U, 27I, N–R, 28A, B, F, J, K, table 23.
2005a *Normalograptus extraordinarius* (Sobolevskaya, 1974); Chen et al., p. 256, pl. 1, figs. 1, 2; pl. 2, fig. 12; text-figs. 6C, 7H, I, 8W (see for further synonymy).
2011 *Normalograptus extraordinarius* (Sobolevskaya, 1974); Štorch et al., p. 372, figs. 25A, H, M, N, S–U, 27I, N–R, 28A, B, F, J, K, table 23 (see for further synonymy).
2020 *Metabolograptus extraordinarius* (Sobolevskaya, 1974); Chen et al., p. 61, figs. 5Q, 6H, 7I, 9J, T, 11A.

Holotype.—Figured by Sobolevskaya (1974, p1. 3, fig. 6), specimen no. 602x/1, from the Ina River area of the Kolyma Basin, eastern Siberia.

Material.—Eleven specimens figured; six specimens were previously collected by Jones (173F_3, 174F_1, 174F_2, 174F_3, 187F_6, and 190F_6), and five specimens were collected by the authors (LG1_01, LG1_02, LG1_03, LG1_04-1, and LG1_04-2). Recovered below the shelly Hirnantia fauna bed of the Tanjung Dendang Formation in Pulau Langgun. Specimens are preserved in mostly poor to moderately good condition.

Remarks.—One of the most notable characteristics for *Metabolograptus extraordinarius* (Sobolevskaya, 1974) is its significantly wide maximum DVW. The DVW of the Langkawi specimens increases fairly rapidly, from 0.90–1.55 mm at the first thecal pair, to 1.15–1.75 mm at the second thecal pair, to 1.3–1.9 mm at the third thecal pair, to 1.50–2.05 mm at the fifth thecal pair, to a maximum of 2.25–3.20 mm usually attained after the tenth to twentieth thecal pair. Occasional DVW reduction can be observed in the mesial and/or distal section before returning to its maximum. The 2TRD measures ∼1.2–2.2 mm on the proximal part and 1.4–2.4 mm on the distal part of the tubarium. Štorch et al. (2011) noted how papers describing *Metabolograptus extraordinarius* (Sobolevskaya, 1974) from around the world display a degree of morphological variety between and within the population. For example, the maximum DVW of specimens from Vinini Creek, USA, varies from 2.1 to 3.0 mm (Štorch et al., 2011), from the Upper Yangtze region of China it measures 2.9–3.5 mm (Chen et al., 2005a), while in the Mandalay region of Myanmar a maximum of 3.6 mm is recorded (Chen et al., 2020). The DVW of *Metabolograptus extraordinarius* (Sobolevskaya, 1974) from the Langkawi seems to be between the narrower Vinini Creek and the larger Upper Yangtze specimens, but all other parameters seem to match. A very similar graptolite, *Neodiplograptus incommodus* Legrand, 2009, was described to have a maximum DVW between 2.4 and 2.7 (sometimes 2.9 mm), and the thecae tend to become more glyptograptid in the medial and distal parts of the tubarium (Legrand, 2009). We consider that *Neodiplograptus incommodus* Legrand, 2009 might be instead a subspecies or at least the narrow variety of *Metabolograptus extraordinarius* (Sobolevskaya, 1974). So far, the only record of *Neodiplograptus incommodus* Legrand, 2009 is in the Algerian Sahara (Legrand, 2009) and the Mandalay region, Myanmar (Chen et al., 2020), but further examination of the available specimens of *Metabolograptus extraordinarius* (Sobolevskaya, 1974) in other regions could potentially delineate these two graptolites. *Metabolograptus extraordinarius* (Sobolevskaya, 1974) can be distinguished from *Metabolograptus ojsuensis* (Koren' and Mikhaylova in Koren et al., 1980) and *Metabolograptus persculptus* (Elles and Wood, 1907) by having a much wider tubarium overall, less protracted proximal end, and considerably more geniculate and overlapping thecae with relatively smaller apertural excavations and shorter, less inclined supragenicular walls (Štorch et al., 2011).

Metabolograptus ojsuensis (Koren' and Mikhaylova in Koren' et al., 1980)
Figures 4.1–4.7, 10.1, 10.2, 10.5, 10.6, 10.8

- vp1968 *Glyptograptus persculptus* (Salter, 1873); Jones, p. 436, pl. 2, fig. 6a, b.
- *1980 *Glyptograptus? ojsuensis* Koren' and Mikhaylova in Koren' et al., p. 143, pl. 41, figs. 1–8, pl. 42, figs. 1, 2; text-fig. 43.
- 2005a *Normalograptus ojsuensis* (Koren' and Mikhaylova in Koren' et al., 1980); Chen et al., p. 264, pl. 1, figs. 4, 7, pl. 2, fig. 8, text-figs. 9D, K, N, Q, 10I (see for the list of synonymous species *Diplograptus bohemicus* in China).
- 2011 *Normalograptus ojsuensis* (Koren' and Mikhaylova in Koren' et al., 1980); Štorch et al., p. 375, figs. 27A–D, 28G–I, table 25.
- 2020 *Metabolograptus ojsuensis* (Koren' and Mikhaylova in Koren et al., 1980); Chen et al., p. 62, figs. 5K, L, 6G, 7A, C, N, 8A, I, 10I–K, 11C.

Holotype.—Designated and figured by Koren' and Mikhaylova in Koren' et al. (1980, pl. 41, fig. 1), mature specimen 11586/96 housed in the CNIGR Museum, Saint Petersburg, Russia. From Ojsu Spring, Kazakhstan.

Material.—Seven figured specimens (173F_1, 175F_3, 176F_2, 176F_4, 179F_1, 188F_1, and 191F-1_1). Recovered below the shelly Hirnantia fauna bed of the Tanjung Dendang Formation in Pulau Langgun. Specimens are preserved mostly in moderately good condition.

Remarks.—The present material agrees well with specimens of *Metabolograptus ojsuensis* (Koren' and Mikhaylova in Koren et al., 1980) described by several authors such as Chen et al. (2005a, 2020) and Štorch et al. (2011). The DVW of the Langkawi specimens at the first thecal pair is 0.9–1.1 mm, at the second thecal pair is 1.15–1.30 mm, at the third thecal pair is 1.2–1.4 mm, at the fifth thecal pair is 1.3–1.7 mm, at the tenth thecal pair is 1.70–1.85 mm, and mostly after the tenth thecal pair reaches a maximum of 1.85–2.55 mm, which it maintains throughout the rest of the tubarium. The 2TRD measures 1.3–1.7 mm at the proximal part and 1.4–1.9 mm at the distal part of the tubarium. Štorch et al. (2011) distinguished *Metabolograptus ojsuensis* (Koren' and Mikhaylova in Koren et al., 1980) from a very similar *Metabolograptus persculptus* (Elles and Wood, 1907) by the DVW of the proximal end and how fast it reaches the same maximum DVW. *Metabolograptus ojsuensis* (Koren' and Mikhaylova in Koren et al., 1980) is noted to have a narrower proximal end (first thecal pair of 0.9–1.1 mm) and reaches a maximum distal DVW of ∼1.65–2.30 mm well above the tenth thecal pair, compared with *Metabolograptus persculptus* (Elles and Wood, 1907), which has a slightly bigger DVW proximally (first thecal pair of 1.2–1.4 mm) and reaches the same maximum DVW by the sixth to ninth thecal pairs. On the basis of these quantifiable features, we reassigned the specimen of *Metabolograptus persculptus* (Salter, 1865) previously identified by Jones (1968, pl. 2, fig. 6a, b) to *Metabolograptus ojsuensis* (Koren' and Mikhaylova in Koren et al., 1980). Furthermore, *Metabolograptus ojsuensis* (Koren' and Mikhaylova in Koren et al., 1980) is also described as having more strongly geniculate thecae proximally and relatively taller apertural excavations (Štorch et al., 2011). From *Metabolograptus extraordinarius* (Sobolevskaya, 1974), *Metabolograptus ojsuensis* (Koren' and Mikhaylova in Koren et al., 1980) can be differentiated by having a markedly narrower DVW, a more protracted proximal end, and considerably less geniculate and less overlapping thecae with relatively broad excavations and longer, slightly more inclined supragenicular walls (Štorch et al., 2011).

Metabolograptus persculptus (Elles and Wood, 1907)
Figures 7.2, 7.4, 12.1, 12.4

- 1865 *Diplograptus persculptus* (Salter?), Salter, p. 25 (see Strachan, 1971).
- *1907 *Diplograptus* (*Glyptograptus*) *persculptus* Salter; Elles and Wood, p. 257, pl. 31, fig. 7a–c, text-fig. 176a, b.
- 1983 *Glyptograptus persculptus* (Salter, 1865); Williams, p. 622, pl. 66, figs. 1–3.
- 1996 *Normalograptus persculptus* (Elles and Wood); Štorch and Loydell, p. 872, text-figs. 3–5 (see for further synonymy).
- 2005a *Normalograptus persculptus* (Elles and Wood, 1907); Chen et al., p. 266, text-figs. 5B, 9A, F, L (see for further synonymy).
- 2011 *Normalograptus persculptus* (Elles and Wood, 1907); Štorch et al., p. 376, figs. 25L, AA, 27E–H, 28C–E, table 26.

Material.—Two specimens collected by the authors (LG4L_01 and LG4L_04). Recovered above the shelly Hirnantia fauna bed of the Tanjung Dendang Formation in Pulau Langgun.

Remarks.—The current specimens are assigned to *Metabolograptus persculptus* (Elles and Wood, 1907) on the basis of the diagnoses of the species by Williams (1983) and Štorch and Loydell (1996). The measured DVW at the first thecal pair is 0.95–1.05 mm, at the second thecal pair is 1.05–1.10 mm, at the third thecal pair is 1.1–1.2 mm, at the fifth thecal pair is 1.4–1.5 mm, at the tenth thecal pair is ∼1.8 mm, and reaches a maximum of 2.25 mm after the tenth–eleventh thecal pair in a single specimen with preserved distal part. The 2TRD increases from 1.6–2.0 mm at the proximal part of the tubarium to 1.95–2.20 mm at the distal part. *Metabolograptus persculptus* (Elles and Wood, 1907) is very similar to *Metabolograptus ojsuensis* (Koren' and Mikhaylova in Koren' et al., 1980), and it is often difficult to discern these two species. Chen et al. (2005a) recognized that not all specimens in China previously assigned to *Diplograptus bohemicus* (Marek, 1955) are synonymous with *Metabolograptus persculptus* (Elles and Wood, 1907) (Koren et al. in Koren' et al., 1980; Štorch and Loydell, 1996) and instead consider all occurrences of *Diplograptus bohemicus* (Marek, 1955) that either underlie or occur within the strata representing the main phase of glacioeustatic regression to be *Metabolograptus ojsuensis* (Koren' and Mikhaylova in Koren' et al., 1980). The current specimens from Pulau Langgun were found directly above the shelly Hirnantia fauna bed and have a higher 2TRD compared with *Metabolograptus ojsuensis* (Koren' and Mikhaylova in Koren' et al., 1980) specimens found below the shelly bed (*Metabolograptus ojsuensis* identified does not have 2TRD reaching more than 2 mm even in the distal section). The same differences can also be observed for the specimens from the Vinini Creek section (Štorch et al., 2011), where the 2TRD of *Metabolograptus ojsuensis* (Koren' and Mikhaylova in Koren' et al., 1980) very rarely reached more than 2.0 mm except for the very distal thecae, while *Metabolograptus persculptus* (Elles and Wood, 1907) reached the 2TRD of 2.0 mm more consistently even in the proximal section.

Genus *Neodiplograptus* Legrand, 1987, emend. Melchin, 1998

Type species.—*Diplograptus magnus* Lapworth (1900, p. 132, fig. 21a–d). From the Llandovery of central Wales, UK, by original designation.

Neodiplograptus parajanus? (Štorch, 1983)
Figures 8.5, 8.6, 13.4, 13.5

*1983 *Diplograptus parajanus* Štorch, p. 168, pl. 4, figs. 1–3, text-fig. 3A, B.
1993 *Neodiplograptus parajanus*; Štorch and Serpagli, p. 19, pl.3, figs. 1, 5, 6, text-fig. 5A, F, G.
2007 *Neodiplograptus parajanus*; Loydell, p. 24, text-figs. 12C, D, 14A, B, E.

Holotype.—Figured by Štorch (1983, pl. 4, fig. 2, text-fig. 3A), number PŠ 54b. From the *Parakidograptus acuminatus* Biozone of Želkovice Formation, Praha-Řepy, Bohemia.

Material.—Two specimens collected by the authors (LG7_08 and LG8_05). From the LG7 and LG8 bed (equivalent to Jones's cherty bed) of the Tanjung Dendang Formation in Pulau Langgun.

Remarks.—The present specimens are preserved only up to the sixth and eighth thecal pairs. The DVW increases rapidly from 1.3–1.4 mm at the first thecal pair to 1.6–1.7 mm at the second thecal pair and from 1.65 mm at the third thecal pair to 2.0 mm at the fifth thecal pair. A recorded DVW maximum is 2.35 mm. The 2TRD measures 1.7–2.0 mm. The proximal morphologies somewhat agree with *Neodiplograptus parajanus* (Štorch, 1983) specimens described and illustrated by Štorch and Serpagli (1993) and Loydell (2007). Štorch and Serpagli (1993) noted that the proximal thecae in some of their Sardinian specimens are glyptograptid (which can be observed in the Langkawi specimens) while those in the more mature tubarium tend to be more climacograptid in appearance. The distal thecae, however, are glyptograptid to orthograptid. Another discernible difference is that the Langkawi specimens do not have the long virgella that is usually recorded in *Neodiplograptus parajanus* (Štorch, 1983). *Neodiplograptus parajanus* (Štorch, 1983) can be differentiated from other similar Neodiplograptids by its tapering but distinctly wider proximal end and more orthograptid distal thecae (Štorch and Serpagli, 1993). Specimens of *Neodiplograptus lanceolatus* Štorch and Serpagli, 1993, which can occur together with those of *Neodiplograptus parajanus* (Štorch, 1983), have a shallower thecal excavation, a more orthograptid thecal appearance, and a distinct distal narrowing in more mature specimens. Loydell (2007) remarked that some of his Jordanian specimens are similar to *"Orthograptus" regularis* Fang et al., 1990; however, specimens of the latter species differ in having a smaller 2TRD and a broader nema.

Neodiplograptus shanchongensis (Li, 1984)
Figures 5.1, 5.2, 11.3, 11.4

*1984b *Diplograptus shanchongensis* Li, p. 344, pl. 13, figs. 9–11.
2005a *Neodiplograptus shanchongensis*; Chen et al., p. 274, text-fig. 11B–E.
2019 *Neodiplograptus shanchongensis*; Štorch et al., p. 17, figs. 7p, x, 10g, o.

Lectotype.—Not yet designated. Li's (1984b) material from the Kaochiapien Formation, Jiangxian, Anhui, China.

Material.—Two figured specimens previously collected by Jones (173F_5 and 180F_3). Recovered below the shelly Hirnantia fauna bed of the Tanjung Dendang Formation in Pulau Langgun.

Remarks.—Chen et al. (2005a) noted that *Neodiplograptus shanchongensis* (Li, 1984) is distinguished from other Neodiplograptids of the *Neodiplograptus modestus* group by its close thecal spacing and tendency to slightly narrow distally. Jones's specimens are shorter compared with specimens described by Chen et al. (2005a), which grow up to 18 mm long; as such, the distal trend is harder to compare. The DVW increases rapidly from 1.3–1.4 mm at the first thecal pair to 1.6–1.7 mm at the second thecal pair, 1.65 mm at the third pair, and 2.0 mm at the fifth pair to the maximum of 2.35 mm. The 2TRD measures 1.7–2.0 mm. *Neodiplograptus shanchongensis* (Li, 1984) has a smaller tubarium width overall compared with the similarly shaped *Neodiplograptus modestus* (Lapworth), which reaches a maximum of 3.0–3.3 mm at th 10 and is narrower distally with significantly closer thecal spacing compared with *Neodiplograptus charis* (Mu and Ni, 1983) (Chen et al., 2005a). *Neodiplograptus shanchongensis* (Li, 1984) is suggested to be the stratigraphical precursor of the similar *Neodiplograptus lanceolatus* Štorch and Serpagli, 1993 (Štorch et al., 2019). It is described by Štorch and Serpagli (1993) to reach a higher maximum width of commonly 3.0–3.5 mm attained at the level of ninth–eleventh thecal

https://doi.org/10.1017/jpa.2022.94 Published online by Cambridge University Press

pair; in addition, *Neodiplograptus shanchongensis* (Li, 1984) does not seem to form the diagnostic lanceolate shape of *Neodiplograptus lanceolatus* Štorch and Serpagli, 1993 when it narrows distally.

Acknowledgments

This research was made possible thanks to the generous funds provided by the Yayasan UTP (YUTP-FRG) research grant. Special thanks to M. Melchin for providing the camera lucida drawings of the holotype of *Normalograptus radicatus* (Chen and Lin, 1978) and the best syntype of *Normalograptus coremus* (Chen and Lin, 1978). A huge thanks to J. Maletz for his valuable comments on the systematic palaeontology of the graptolites. We would also like to give our utmost thanks to the reviewers including M. Melchin and an anonymous reviewer, and the editorial office of the Journal of Paleontology including E. Currano, P. Štorch and J. Kastigar for their tremendous help and insightful feedback that helped to further improve the manuscript.

Declaration of competing interests

The authors declare none.

References

Agematsu, S., Sashida, K., Salyapongse, S., and Sardsud, A., 2006, Ordovician–Silurian boundary graptolites of the Satun area, southern peninsular Thailand: Palaeontological Research, v. 10, p. 207–214.

Blackett, E., and Zalasiewicz, J.A., 2007, *Normalograptus normalis* (Lapworth, 1877), *in* Zalasiewicz, J.A., and Rushton, A.W.A., eds., Atlas of Graptolite Type Specimens, folio 2.61: London, Palaeontographical Society.

Brenchley, P.J., 1988, Environmental changes close to the Ordovician–Silurian boundary, *in* Cocks, L.R.M., and Rickards, R.B., eds., A Global Analysis of the Ordovician–Silurian Boundary: Bulletin of the British Museum, Natural History (Geology), v. 43, p. 377–385.

Brongniart, A., and Desmarest, A.G., 1822, Histoire naturelle des Crustacés fossiles: les Trilobites: Paris, Chez F.-G. Levrault, 65 p.

Chen, X., and Lin, Y.K., 1978, Lower Silurian graptolites from Tongzi, northern Guizhou: Memoirs of Nanjing Institute of Geology and Palaeontology, Academia Sinica, v. 12, p. 1–106.

Chen, X., 1984, The Silurian graptolite zonation of China: Canadian Journal of Earth Sciences, v. 21, p. 241–257. [in Chinese]

Chen, X., Jiayu, R., Mitchell, C.E., Harper, D.A.T., Junxuan, F., Renbin, Z., Yuandong, Z., Rongyu, L., and Yi, W., 2000, Late Ordovician to earliest Silurian graptolite and brachiopod biozonation from the Yangtze region, South China, with a global correlation: Geological Magazine, v. 137, p. 623–650.

Chen, X., Rong, J.Y., Li, Y., and Boucot, A.J., 2004, Facies patterns and geography of the Yangtze region, South China, through the Ordovician and Silurian transition: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 204, p. 353–372.

Chen, X., Fan, J., Melchin, M.J., and Mitchell, C.E., 2005a, Hirnantian (latest Ordovician) graptolites from the Upper Yangtze region, China: Palaeontology, v. 48, p. 235–280.

Chen, X., Melchin, M.J., Sheets, H.D., Mitchell, C.E., and Fan, J., 2005b, Patterns and processes of latest Ordovician graptolite extinction and recovery based on data from South China: Journal of Paleontology, v. 79, p. 842–861.

Chen, X., Rong, J., Fan, J., Zhan, R., Mitchell, C.E., Harper, D.A.T., Melchin, M.J., Peng, P., Finney, S.C., and Wang, X., 2006, The Global Boundary Stratotype Section and Point (GSSP) for the base of the Hirnantian Stage (the uppermost of the Ordovician System): Episodes, v. 29, p. 183–196.

Chen, X., Chen, Q., Aung, K.P., and Muir, L.A., 2020, Latest Ordovician graptolites from the Mandalay Region, Myanmar: Palaeoworld, v. 29, p. 47–65.

Churkin, M., and Carter, C., 1970, Early Silurian graptolites from southeastern Alaska and their correlation with graptolitic sequences in North America and the Arctic: US Geological Survey Professional Paper No. 653, 51 p.

Cocks, L.R.M., and Fortey, R.A., 1997, A new Hirnantia Fauna from Thailand and the biogeography of the latest Ordovician of South-East Asia: Geobios, v. 20, p. 117–126.

Cocks, L.R.M., Fortey, R.A., and Lee, C.P., 2005, A review of lower and middle Palaeozoic biostratigraphy in west Peninsular Malaysia and southern Thailand in its context within the Sibumasu Terrane: Journal of Asian Earth Sciences, v. 24, p. 703–717.

Davies, K.A., 1929, Notes on the graptolite faunas of the Upper Ordovician and lower Silurian: Geological Magazine, v. 66, p. 1–27.

Elles, G.L., and Wood, E., 1906, A monograph of British graptolites. Part 5: Palaeontographical Society, v. 60, p. 181–216.

Elles, G.L., and Wood, E., 1907, A monograph of British graptolites. Part 6: Palaeontographical Society, v. 61, p. 217–272.

Elles, G.L., and Wood, E., 1908, A monograph of British graptolites. Part 7: Palaeontographical Society, v. 62, p. 273–358.

Fan, J., Melchin, M.J., Chen, X., Wang, Y., Zhang, Y., Chen, Q., Chi, Z., and Chen, F., 2011, Biostratigraphy and geography of the Ordovician–Silurian Lungmachi black shales in South China: Science China Earth Sciences, v. 54, p. 1854–1863.

Fang, Y.T., Liang, S.J., Zhang, D.L., and Yu, J.L., 1990, Stratigraphy and Graptolite Fauna of Lishuwo Formation from Wuning, Jiangxi: Nanjing, Nanjing University Publishing House, 155 p. [in Chinese with English summary]

Fortey, R.A., and Cocks, L.R.M., 1998, Biogeography and palaeogeography of the Sibumasu terrane in the Ordovician: a review *in* Hall, R., and Holloway, J.D., eds., Biogeography and Geological Evolution of SE Asia: Leiden, Backbuys, p. 43–56.

Frech, F., 1897, Lethaea Geognostica, Oder Beschreibung Und Abbildung Für Die Gebirgs-Formationen Bezeichnendsten Versteinerungen: Stuttgart, E. Schweizerbart'sche Verlagshandlung (E. Koch).

Goldman, D., Mitchell, C.E., Melchin, M.J., Fan, J., Wu, S.-Y., and Sheets, H.D., 2011, Biogeography and mass extinction: extirpation and reinvasion of Normalograptus species (Graptolithina) in the Late Ordovician palaeotropics: Proceedings of the Yorkshire Geological Society, v. 58, p. 227–246.

Goldman, D., Sadler, P.M., Leslie, S.A., Melchin, M.J., Agterberg, F.P., and Gradstein, F.M., 2020, The Ordovician Period, *in* Gradstein, F.M., Ogg, J.G., Schmitz, M., and Ogg, G., eds., Geologic Time Scale 2020: Amsterdam, Elsevier, p. 631–694.

Harper, D.A.T., Hammarlund, E.U., and Rasmussen, C.M.Ø., 2014, End Ordovician extinctions: a coincidence of causes: Gondwana Research, v. 25, p. 1294–1307.

Hassan, M.H.A., Erdtmann, B.D., Wang-Xiaofeng, and Peng, L.C., 2013, Early Devonian graptolites and tentaculitids in northwest Peninsular Malaysia and a revision of the Devonian–Carboniferous stratigraphy of the region: Alcheringa, v. 37, p. 49–63.

Hisinger, W., 1837, Lethaea Suecica, seu petrificata Sueciae, iconibus et characteribus illustrata. Supplementum 1: Stockholm, Norstedt, 124 p.

Howe, M.P.A., 1983, Measurement of thecal spacing in graptolites: Geological Magazine, v. 120, p. 635–638.

Huang, Z.G., 1982, Latest Ordovician and earliest Silurian graptolite assemblages of Xainza district, Xizang (Tibet) and Ordovician–Silurian boundary, *in* Editorial Committee of Ministry of Geology and Mineral Resources, ed., Contribution to the Geology of the Qinghai–Xizang (Tibet) Plateau, 7: Beijing, Geological Publishing House, p. 27–52. [in Chinese with English abstract]

Jin, C.T., Ye, S.H., He, Y.X., Wan, Z.Q., Wang, S.B., Zhao, Y.T., Li, S.J., Xu, X.Q., and Zhang, Z.G., 1982, The Silurian Stratigraphy and Paleontology in Guanyinqiao, Qijiang, Sichuan: Chengdu, People's Publishing House of Sichuan, 84 p. [in Chinese with English abstract]

Jones, C.R., 1959, Geology and Palaeontology in Malaya: graptolites recorded from Malaya: Nature, v. 183, p. 231–232.

Jones, C.R., 1966, Pulau Langkawi (Geological map), sheet 150, new series, West Malaysia: Malaysia Geological Survey, scale 1:63,360.

Jones, C.R., 1968, Malayan early to mid-Palaeozoic stratigraphy and the Siluro–Devonian graptolite faunas of the Malay Peninsula [Ph.D. thesis]: Birmingham, University of Birmingham, 777 p.

Jones, C.R., 1973, The Siluro–Devonian graptolite faunas of the Malay Peninsula: Overseas Geology and Mineral Resources, v. 44, p. 1–28.

Jones, C.R., 1978, The geology and mineral resources of Perlis, north Kedah and the Langkawi Islands: Geological Survey Malaysia District Memoir No. 17, 257 p.

Kobayashi, T., and Hamada, T., 1964, On the new Malayan species of Dalmanitina: Japanese Journal of Geology and Geography, v. 35, no. 2–4, p. 101–113.

Koren', T.N., and Melchin, M.J., 2000, Lowermost Silurian graptolites from the Kurama Range, eastern Uzbekistan: Journal of Paleontology, v. 74, p. 1093–1113.

Koren', T.N., and Rickards, R.B., 1996, Taxonomy and evolution of Llandovery biserial graptoloids from the southern Urals, western Kazakhstan: Special Papers in Palaeontology No. 54, 103 p.

Koren', T.N., Mikhaylova, N.F., and Tzai, D.T., 1980, Class Graptolithina (graptolites), *in* Apollonov, M.K., Nikitin, I.F., and Bandaletov, S.M., eds., The Ordovician–Silurian Boundary in Kazakhstan: Alma Ata, Nauka, p. 121–170. [in Russian]

Lapworth, C., 1873, Notes on the British graptolites and their allies. 1. On an improved classification of the Rhabdophora, part 2: Geological Magazine, v. 10, p. 555–560.

Lapworth, C., 1876, On Scottish Monograptidae: Geological Magazine, v. 3, p. 308–321, 350–360, 499–507, 544–552.

Lapworth, C., 1877, On the graptolites of County Down: Proceedings of the Belfast Naturalists' Field Club, v. 1876–7, p. 125–148.

Lapworth, C., 1880, On the geological distribution of the Rhabdophora. Part 3. Results (continued from vol. 5, p. 29): Annals and Magazine of Natural History, ser. 5, v. 6, p. 185–207.

Lapworth, C., 1900, The Silurian Sequence of Rhayader: Quarterly Journal of the Geological Society, v. 56, p. 67–137.

Lee, C.P., 2009, Palaeozoic stratigraphy, *in* Hutchison, C.R., and Tan, D.N., eds., Geology of Peninsular Malaysia: Kuala Lumpur, University of Malaya and Geological Society of Malaysia, p. 55–86.

Legrand, P., 1977, Contribution à l'étude des graptolites du Llandovérien inférieur de l'Oued In Djerane (Tassili N'ajjer oriental, Sahara algérien): Bulletin de La Société d'Histoire Naturelle d'Afrique Du Nord, v. 67, p. 141–196.

Legrand, P., 1986, The lower Silurian graptolites of Oued In Djerane: a study of populations at the Ordovician–Silurian boundary, *in* Hughes, C.P., Rickards, R.B., and Chapman, A.J., eds., Palaeoecology and Biostratigraphy of Graptolites: Geological Society, London, Special Publications, p. 145–153.

Legrand, P., 1987, Modo de desarrollo del Suborden Diplograptina (Graptolithina) en el Ordovícico Superior y en el Silúrico. Implicaciones taxonómicas: Revista Española de Paleontología, v. 2, p. 59–64.

Legrand, P., 2009, Faunal specificity, endemism and paleobiogeography: the post-glacial (Hirnantian–early Rhuddanian) graptolite fauna of the North-African border of Gondwana: a case study: Bulletin de La Societe Geologique de France, v. 180, p. 353–367.

Li, J., 1984a, Graptolites from the Xinling Formation (Upper Ordovician) of South Anhui: Memoirs of Nanjing Institute of Geology and Palaeontology, Academia Sinica, v. 20, p. 145–194. [in Chinese with English summary]

Li, J., 1984b, Graptolites across the Ordovician–Silurian boundary from Jiangxian, Anhui, *in* Nanjing Institute of Geology and Palaeontology, ed., Stratigraphy and Palaeontology of Systemic Boundaries in China, 1. Ordovician–Silurian Boundary: Hefei, Anhui Science and Technology, p. 309–370.

Li, J., 1999, Lower Silurian graptolites from southern Anhui: Bulletin of the Nanjing Institute of Geology and Palaeontology, Academia Sinica, v. 14, p. 70–157. [in Chinese with English summary]

Loxton, J.D., 2017, Graptolite Diversity and Community Changes Surrounding the Late Ordovician Mass Extinction: High Resolution Data from the Blackstone River, Yukon: Halifax, Dalhousie University, 590 p.

Loydell, D.K., 2007, Graptolites from the Upper Ordovician and lower Silurian of Jordan: Special Papers in Palaeontology No. 78, 66 p.

Loydell, D.K., Udchachon, M., and Burrett, C., 2019, Llandovery (lower Silurian) graptolites from the Sepon Mine, Truong Son Terrane, central Laos and their palaeogeographical significance: Journal of Asian Earth Sciences, v. 170, p. 360–374.

Maletz, J., Wang, C., and Wang, X., 2021a, Katian (Ordovician) to Aeronian (Silurian, Llandovery) graptolite biostratigraphy of the YD-1 drill core, Yuanan County, Hubei Province, China: Papers in Palaeontology, v. 7, p. 163–194.

Maletz, J., Wang, C., Kai, W., and Wang, X., 2021b, Upper Ordovician (Hirnantian) to lower Silurian (Telychian, Llandovery) graptolite biostratigraphy of the Tielugou section, Shennongjia anticline, Hubei Province, China: PalZ, v. 95, p. 453–481.

Marek, L., 1955, *Glyptograptus bohemicus* n. sp. z vrstev kosovských (dζ2): Sborník Ústředního ústavu geologického, Oddíl Paleontologický, v. 24, p. 382–384. [in Czech]

Melchin, M.J., 1998, Morphology and phylogeny of some early Silurian diplograptid genera from Cornwallis Island, Arctic Canada: Palaeontology, v. 41, p. 263–315.

Melchin, M.J., and Williams, S.H., 2000, A restudy of the Akidograptine graptolites from Dob's Linn and a proposed redefined zonation of the Silurian stratotype: Palaeontology Down Under 2000, Geological Society of Australia, Abstracts, v. 61, p. 63.

Melchin, M.J., Mitchell, C.E., Naczk-Cameron, A., Fan, J.X., and Loxton, J., 2011, Phylogeny and adaptive radiation of the Neograptina (Graptoloida) during the Hirnantian mass extinction and Silurian recovery: Proceedings of the Yorkshire Geological Society, v. 58, p. 281–309.

Melchin, M.J., Sadler, P.M., and Cramer, B.D., 2020, The Silurian Period, *in* Gradstein, F.M., Ogg, J.G., Schmitz, M., and Ogg, G., eds., Geologic Time Scale 2020: Amsterdam, Elsevier, P. 695–732.

Mitchell, C.E., Sheets, H.D., Belscher, K., Finney, S.C., Holmden, C., Laporte, D.F., Melchin, M.J., and Patterson, W.P., 2007, Species abundance changes during mass extinction and the inverse Signor–Lipps effect: apparently abrupt graptolite mass extinction as an artifact of sampling: Proceedings of the 10th International Symposium on the Ordovician System, Nanjing China., v. 46, p. 340–346.

Mu, E.Z., and Lin, Y.K., 1984, Graptolites from the Ordovician–Silurian boundary sections of Yichang area, W. Hubei, *in* Nanjing Institute of Geology and Palaeontology, Academia Sinica, ed., Stratigraphy and Palaeontology of Systemic Boundaries in China, Ordovician–Silurian Boundary 1: Hefei, Anhui Science and Technology Publishing House, p. 45–82.

Mu, E., and Ni, Y., 1983, Uppermost Ordovician and lowermost Silurian graptolites from the Xainza area of Xizang (Tibet) with discussion on the Ordovician–Silurian boundary: Palaeontologia Cathyana, v. 1, p. 151–179.

Mu, E.Z., Li, J.J., Ge, M.Y., Chen, X., Lin, Y.K., and Ni, Y.N., 1993, Upper Ordovician Graptolites of Central China Region: Palaeontologia Sinica, ser. B, v. 182, 393 p. [in Chinese with English summary]

Muir, L.A., Zhang, Y., Botting, J.P., and Ma, X., 2020, *Avitograptus* species (Graptolithina) from the Hirnantian (uppermost Ordovician) Anji Biota of South China and the evolution of *Akidograptus* and *Parakidograptus*: Journal of Paleontology, v. 94, p. 955–965.

Nanjing Institute of Geology and Mineral Resources, ed., 1983, Palaeontological Atlas of East China: Early Palaeozoic: Beijing, Geological Publishing House, 176 p. [in Chinese]

Nanjing Institute of Geology and Palaeontology, ed., 1974, A Handbook of Stratigraphy and Palaeontology of South-West China: Beijing, Science Press, 454 p. [in Chinese]

Niko, S., Sone, M., and Leman, M.S., 2019, Ordovician Orthocerida and Pseudorthocerida (Cephalopoda: Nautiloidea) from the Lower Setul Limestone of the Langkawi Islands, Malaysia: Journal of Systematic Palaeontology, v. 18, https://doi.org/10.1080/14772019.2019.1608599

Obut, A.M., 1955, Graptolity, *in* Nikiforova, O.I., ed., Polevoy Atlas Ordovikskoy i Silurskoy Fauny Sibirskoy Platformy: Moskva, Gosgeoltechizdat, p. 136–139. [in Russian]

Obut, A.M., and Sennikov, N.V, 1985, Osobennosti llandoveriyskich planktonovich soobchestv Sibirskoy Platformi, *in* Betechtuna, O.A., and Zhuravleva, I.T., eds., Sreda y Zhizn v Geologichechom Proshlom (Paleobasseiny i ich Obitateli), v. 628: Novosibirsk, Trudy Instituta Geologii i Geofiziki, Nauka Publishing House, p. 51–60.

Obut, A.M., Sobolevskaya, R.F., and Nikolaev, A.A., 1967, Graptolites and stratigraphy of the lower Silurian along the margins of the Kolyma massif: Akademiya Nauk SSR, Sibirskoje Otdelenie, Institut Geologii i Geofiziki: Ministerstvo Geologii SSSR, Nauchno-Issledovatel'sky Institut Geologii Arktiki, 164 p. [in Russian]

Packham, G.H., 1962, Some diplograptids from the British lower Silurian: Palaeontology, v. 5, p. 498–526.

Perner, J., 1895, Études Sur Les Graptolites de Bohême. IIIième Partie: Monographie Des Graptolites de L'etage D: Leipzig, Prague, en commission chez Raimund Gerhard, 31 p.

Přibyl, A., 1949, Revision of the Diplograptidae and Glossograptidae of the Ordovician of Bohemia: Bulletin International de l'Académic Tchèque Des Sciences, v. 50, p. 1–51.

Riva, J., 1988, Graptolites at and below the Ordovician–Silurian boundary on Anticosti Island, Canada: Bulletin of the British Museum, Natural History: Geology, v. 43, p. 221–237.

Rong, J., Chen, X., and Harper, D.A.T., 2007, The latest Ordovician Hirnantia Fauna (Brachiopoda) in time and space: Lethaia, v. 35, p. 231–249.

Rong, J., Harper, D.A.T., Huang, B., Li, R., Zhang, X., and Chen, D., 2020, The latest Ordovician Hirnantian brachiopod faunas: new global insights: Earth-Science Reviews, v. 208, n. 103280, https://doi.org/10.1016/j.earscirev.2020.103280

Ross, R.B., and Berry, W.B.N., 1963, Ordovician graptolites of the Basin Ranges in California, Nevada, Utah and Idaho: United States Geological Survey Bulletin, v. 1134, 177 p.

Salter, J.W., 1865, *in* Huxley, T.H., and Etheridge, R., eds., A Catalogue of the Collection of Fossils in the Museum of Practical Geology: London, George E. Eyre and William Spottiswoode, 381 p.

Salter, J.W., 1873, A catalogue of the collection of Cambrian and Silurian fossils in the Geological Museum of the University of Cambridge: Cambridge University Press, 204 p.

Sheets, H.D., Mitchell, C.E., Melchin, M.J., Loxton, J., Štorch, P., Carlucci, K.L., and Hawkins, A.D., 2016, Graptolite community responses to global climate change and the Late Ordovician mass extinction: Proceedings of the National Academy of Sciences of the United States of America, v. 113, p. 8380–8385.

Sobolevskaya, R.F., 1974, New Ashgill graptolites in the middle flow basin of the Kolyma River, *in* Obut, A.M., ed., Graptolites of the USSR: Novosibirsk, Nauka, p. 63–71. [in Russian]

Stewart, S., and Mitchell, C.E., 1997, *Anticostia*, a distinctive new Late Ordovician "glyptograptid" (Diplograptacea, Graptoloidea) based on three-dimensionally preserved specimens from Anticosti Island, Quebec: Canadian Journal of Earth Sciences, v. 34, p. 215–228.

Štorch, P., 1983, The genus *Diplograptus* (Graptolithina) from the lower Silurian of Bohemia: Věstník Ústředního Ústavu Geologického, v. 58, p. 159–170.

Štorch, P., 1996, The basal Silurian *Akidograptus ascensus–Parakidograptus acuminatus* Biozone in peri-Gondwanan Europe: graptolite assemblages, stratigraphical ranges and palaeobiogeography: Věstník Českého Geologického Ústavu, v. 71, p. 177–188.

Štorch, P., and Loydell, D.K., 1996, The Hirnantian graptolites *Normalograptus persculptus* and *"Glyptograptus" bohemicus*: stratigraphical consequences of their synonymy: Palaeontology, v. 39, p. 869–881.

Štorch, P., and Schönlaub, H.P., 2012, Ordovician–Silurian boundary graptolites of the Southern Alps, Austria: Bulletin of Geosciences, v. 87, p. 755–766.

Štorch, P., and Serpagli, E., 1993, Lower Silurian graptolites from southwestern Sardinia: Bollettino della Societa Paleontologica Italiana, v. 32, p. 3–57.

Štorch, P., Mitchell, C.E., Finney, S.C., and Melchin, M.J., 2011, Uppermost Ordovician (upper Katian–Hirnantian) graptolites of north-central Nevada, USA: Bulletin of Geosciences, v. 86, p. 301–386.

Štorch, P., Bernal, J.R., and Gutiérrez-Marco, J.C., 2019, A graptolite-rich Ordovician–Silurian boundary section in the south-central Pyrenees, Spain: stratigraphical and palaeobiogeographical significance: Geological Magazine, v. 156, p. 1069–1091.

Strachan, I., 1971, A Synoptic Supplement to "A Monograph of British Graptolites by Miss GL Elles and Miss EMR Wood": Monograph of the Palaeontographical Society No. 125, 130 p.

Törnquist, S.L., 1897, On the Diplograptidae and Heteroprionidae of the Scanian Rastrites beds: Lunds Universitets Årsskrifter, v. 33, p. 1–24.

Underwood, C.J., Deynoux, M., and Ghienne, J.-F., 1998, High palaeolatitude (Hodh, Mauritania) recovery of graptolite faunas after the Hirnantian (end Ordovician) extinction event: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 142, p. 91–105.

Waern, B., Thorslund, P., Henningsmoen, G., and Säve-Söderbergh, G., 1948, Deep boring through Ordovician and Silurian strata at Kinnekulle, Vestergötland: Bulletin of the Geological Institute, University of Uppsala, v. 32, p. 337–474.

Wang, W., Muir, L.A., Chen, X., and Tang, P., 2015, Earliest Silurian graptolites from Kalpin, western Tarim, Xinjiang, China: Bulletin of Geosciences, v. 90, p. 519–542.

Williams, M., Zalasiewicz, J., Boukhamsin, H., and Cesari, C., 2016, Early Silurian (Llandovery) graptolite assemblages of Saudi Arabia: biozonation, palaeoenvironmental significance and biogeography: Geological Quarterly, v. 60, p. 3–25.

Williams, S.H., 1983, The Ordovician–Silurian boundary graptolite fauna of Dob's Linn, southern Scotland: Palaeontology, v. 26, p. 605–639.

Wongwanich, T., Burrett, C.F., Tansathein, W., and Chaodumrong, P., 1990, Lower to mid Palaeozoic stratigraphy of mainland Satun province, southern Thailand: Journal of Southeast Asian Earth Sciences, v. 4, p. 1–9.

Wongwanich, T., Tansathien, W., Leevongcharoen, S., and Paengkaew, W., 2002, The lower Paleozoic rocks of Thailand, *in* Mantajit, N., Potisat, S., and Wongwanich, T., eds., Proceedings of the Symposium on Geology of Thailand: Bangkok, Department of Mineral Resources, p. 16–21.

Ye, S.H., 1978, Graptolithina, *in* Geological Institute of Southwest China, ed., Palaeontological Atlas of Southwest China, Sichuan. Part 1: Beijing, Fr. Geological Publishing House, p. 431–486. [in Chinese]

Zalasiewicz, J.A., Taylor, L., Rushton, A.W.A., Loydell, D.K., Rickards, R.B., and Williams, M., 2009, Graptolites in British stratigraphy: Geological Magazine, v. 146, p. 785–850.

Zhen, Y.Y., Zhang, Y., Harper, D.A.T., Zhan, R., Fang, X., Wang, Z., Yu, S., and Li, W., 2020, Ordovician successions in southern-central Xizang (Tibet), China—refining the stratigraphy of the Himalayan and Lhasa terranes: Gondwana Research, v. 83, p. 372–389.

Accepted: 12 September 2022