C. R. Palevol 13 (2014) 139–146

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General palaeontology, systematics and evolution (Micropalaeontology)

A first report of *Prolinograptus packhami* Rickards and Wright, 1997 from Baltica, Poland

Première découverte de Prolinograptus packhami *Rickards et Wright, 1997 dans la Baltique, Pologne*

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ARTICLE INFO

Article history:
Received 8 February 2013
Accepted after revision 14 May 2013
Available online 25 December 2013

Presented by Philippe Taquet

Keywords:
Silurian
Ludlow
Poland
Graptolithina
Prolinograptus
Plankton

Mots clés :
Silurien
Ludlow
Pologne
Graptolithina
Prolinograptus
Plancton

ABSTRACT

A well-preserved isolated graptolite *Prolinograptus packhami* Rickards and Wright, 1997, well known from Australia, is described for the first time in Europe. The genus has now been recognized in three continents (Australia, Europe and North America). The Australian *P. packhami* occurs in the *Neocucullograptus inexpectatus*/*Neocucullograptus kozlowskii* biozonal interval, while the form from the Mielnik IG-1 core, Poland, appears earlier, in the *Bohemograptus praecornutus* Biozone. *Prolinograptus*, of unclear origin, is one of the least-known genera of the subfamily Linograptinae. *P. packhami*, along with *Neodiversograptus palmeri* and *Prolinograptus orangensis*, form a group of very diminutive specimens, with slender stipes and thecal apertures showing varying degrees of eversion. Scanning electron microscope examination revealed the presence of some micro-ornamentation on the rhabdosome surface of the Polish *Prolinograptus*, similar to that known in retiolitids (Retiolitidae).

RÉSUMÉ

Le matériel bien préservé du graptolite isolé *Prolinograptus packhami* Rickards et Wright, 1997 du forage Mielnik IG-1 (Pologne) représente sa première découverte européenne. Le genre *Prolinograptus* est connu sur trois continents (Australie, Europe et Amérique du Nord). L'espèce australienne *P. packhami* est présente dans l'intervalle comprenant les biozones à *Neocucullograptus inexpectatus* et *Neocucullograptus kozlowskii*, alors que la forme du forage polonais apparaît dans la biozone à *Bohemograptus praecornutus*. *Prolinograptus*, d'origine inconnue, est l'un des genres les moins connus dans la sous-famille des Linograptinae. *P. packhami* forme, avec *Neodiversograptus palmeri* et *Prolinograptus orangensis*, un groupe d'espèces de petite taille, avec des rhabdosomes grêles et des ouvertures des thèques présentant des degrés variables d'éversion. L'examen au microscope à balayage du *Prolinograptus* polonais a montré la présence d'une micro-ornementation sur la surface du rhabdosome similaire à celle connue chez les rétiolites (Retiolitidae).

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http://dx.doi.org/10.1016/j.crpv.2013.05.003

1. Introduction

Prolinograptus is the least-known of the older genera of the subfamily Linograptinae. The type species, *Prolinograptus packhami*, was first described by Rickards and Wright (1997). The type species and *Prolinograptus orangensis* Rickards, Packham, Wright and Williamson 1995 (renamed from *Linograptus orangensis* by Rickards and Wright, 1997) were considered endemic Australian forms, known from New South Wales (Rickards and Wright, 1997, 1999) (Fig. 1). *P. packhami*, described in this paper, is recorded in Baltica (Fig. 1) for the first time. The specimens from the Mielnik IG-1 core are assigned to *P. packhami* on the basis of distinctive features recognized only for this species, such as the remarkably slender rhabdosome and everted, thick-rimmed thecal apertures. At present, it is the second verified occurrence of the species in the world. The current paper presents also for the first time detailed images of *P. packhami* from the scanning electron microscope (SEM).

Specimens similar to the genus *Prolinograptus* were described by Urbanek (1958), from erratic boulders of Poland. The material comes probably from the Lower Ludlow and consists of a few fragmented rhabdosomes with no siculae (Urbanek, 1958, fig. 58). The specimens display straight, long and very thin thecae, as in *P. packhami*, but in contrast to the latter, their rhabdosomes are slightly dorsally curved. Urbanek's material was assigned to the genus *Pristiograptus* Jaekel, 1889. Because the preservation is so poor, a clear identification has been impossible.

In 2004, five incomplete specimens from the Arctic Islands (Canada) (Fig. 1), described by Lenz and Kozłowska-Dawidziuk, were thought to belong to the species *P. packhami*, but because of lack of siculae, the Arctic material was not definitely identified. The authors of the present work suggest a transfer of the material to *P. orangensis*. It is supported by the lack of a thick thecal apertural rim (see Pl. 2: figs. 1–7, p. 53 from Lenz and Kozłowska-Dawidziuk, 2004) and the fact that it was found in the Lower Ludlow.

2. Origin and phylogeny of linograptids

Despite extensive and comprehensive research on the origin, phylogeny and astogeny of the linograptids, mostly by Jaeger (1959, 1960, 1969) and Urbanek (1963, 1970, 1997a,b), the issue of the origin of the linograptids remains unsolved. The ancestor of the Linograptinae probably lived as early as the Late Wenlock (Urbanek, 1970). *Lobograptus? sherrardae* Sherwin, 1974, from the *praedeubeli* Biozone, was proposed as the common ancestral species for the three major Ludlow lineages: the Linograptinae, the Cucullograptinae and the Neocucullograptinae (see Fig. 2, p. 30 from Urbanek and Teller, 1997). Rickards et al. (1995) on the other hand remain sceptical about this idea, because there are too many crucial differences between *L.? sherrardae* and *Neodiversograptus nilssoni* Lapworth, 1876 *sensu* Urbanek, 1954, considered the earliest known representative of the subfamily Linograptinae.

Although the origin of Linograptinae is not clear, the relationships within three older genera of this subfamily (*Neodiversograptus*, *Linograptus* and *Abiesgraptus*) were exhaustively described by Urbanek (1963, 1997a). They were all considered chronospecies (Urbanek, 1997a). Temporal species represented by *Neodiversograptus*, *Linograptus* and *Abiesgraptus* display a transformation of the one-stiped monograptid into a multiramous one and replace each other in time.

Describing the species of the subfamily Linograptinae as chronospecies Urbanek (1997a) did not take *P. orangensis* into consideration. He supposed that the Australian species

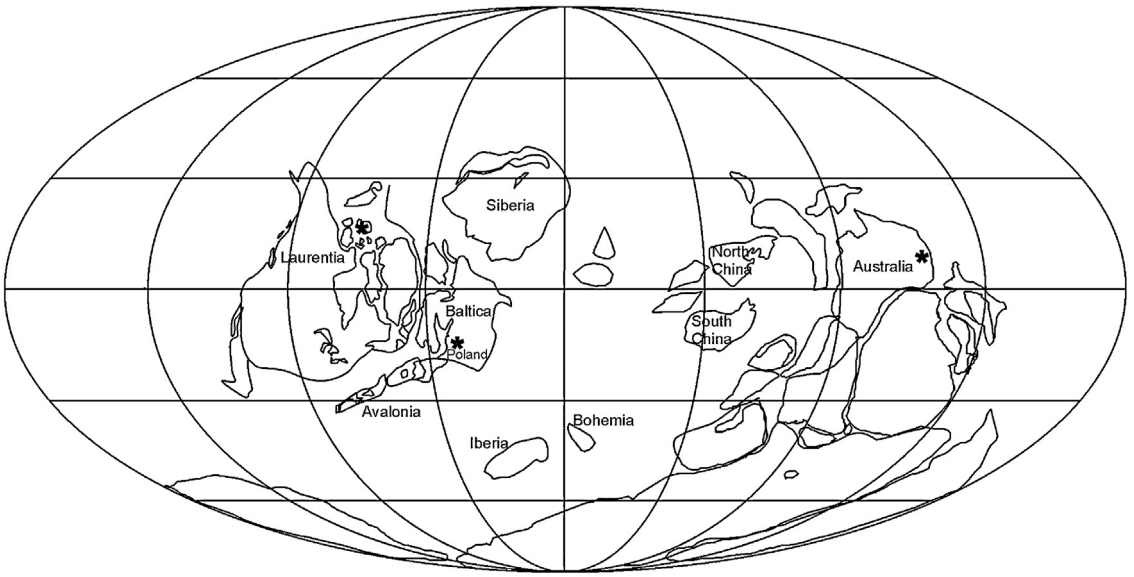

Fig. 1. Locations of *Prolinograptus* species indicated by three stars.
Fig. 1. Localités des espèces de *Prolinograptus* indiquées par de triples astérisques.
Modified after Kozłowska et al., 2009.

came from the border of *nilssoni- progenitor* or bottom of the scanicus Biozone and represents a stage of development comparable to *N. beklemishevi*. Urbanek's paper of 1997 was actually written in 1995 (Urbanek, 1997a, p. 233), before Rickards and Wright (1997) identified *Prolinograptus* and described another species of this genus, the *P. packhami*. Moreover, as shown by Rickards et al. (1995) and Rickards and Wright (1997), *Prolinograptus* overlaps with the range of *Linograptus*, which means they cannot be chronospecies.

Regarding the Australian material, Rickards and Wright (1997) suggested a division of the genus *Linograptus* into two groups, both originating probably from *Neodiversograptus* (Fig. 3). This means that linograptids would not be a single line of ancestral-descendant succession but at least two different directions of evolution. One group is represented by *Linograptus* and *Neodiversograptus* species, except *Neodiversograptus palmeri* Rickards, Packham, Wright and Williamson 1995. This line corresponds to the chronospecies described by Urbanek (1997a).

These forms evolved increasingly introverted thecae, from straight apertures to the rhabdosomal axis as in *N. nilssoni* (Fig. 4), to slightly turned inwards or even strongly introverted thecae as in *Linograptus posthumus introversus* Rickards and Wright, 1997 (Fig. 4A, B). The second line is represented by much less examined species: *N. palmeri*, *P. orangensis* and *P. packhami*. This is a group of very diminutive specimens, with slender stipes and thecal apertures everted to varying degrees (Rickards and Wright, 1997) (Fig. 4E). We agree with Rickards and Wright's (1997) suggestion of the existence of two lineages of linograptids.

Size reduction might have been caused by the continuation of a lilliput effect that followed the *lundgreni* Event (Urbanek, 1993). But in contrast to the most monograptid genera, the *Prolinograptus* retained small and long rhabdosomes. After the crisis it may have had to compete with larger graptolites that spread to more areas. *Prolinograptus* was far less frequent than the other genera of the subfamily Linograptinae. In spite of this, the genus was present in Baltica (Poland), Laurentia (Arctic Canada) and Australia (Fig. 1).

3. Geological setting and material

3.1. Geological setting

Mielnik IG-1, a well-known borehole (Fig. 2) is located on the marginal zone of the Podlasie Depression in eastern Poland. It belongs to the East European Platform, Baltica. The Silurian deposits of this area are recorded in numerous boreholes. Within this marginal zone regular llithological changes are observed in the Silurian deposits. They are composed of calcareous sediments typical of shallow waters and, further to the west (Mielnik IG-1 borehole), acquire a mixed character of marly-calcareous sediments and mudstones (e.g. Tomczyk, 1962; Tomczykowa, 1988; Tomczykowa and Tomczyk, 1979).

The Silurian section of the Mielnik IG-1 core is 536.5 m thick. The Ludlow sequence is dominated by marly claystones and calcareous claystones (Tomczyk, 1962). A very rich and well-preserved graptolite fauna from the

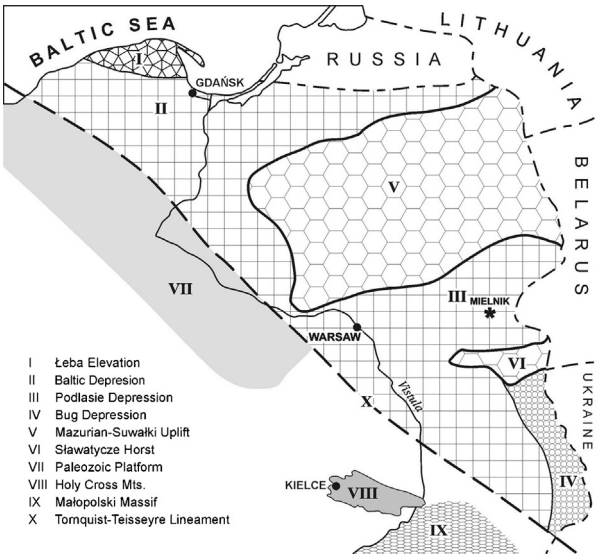

Fig. 2. Structural map of East Poland, the western margin of the East European Platform, with the location of the Mielnik IG-1borehole.
Fig. 2. Carte structurale de l'Est de la Pologne avec la marge occidentale de la plate-forme Est-Européenne et localisation du forage Mielnik IG-1.
Modified after Kozłowska and Urbanek, 2013.

Mielnik IG-1 core has enabled detailed studies not only of stratigraphic occurrence, but also of the morphology, specialization and phylogeny of Silurian graptolites (Kozłowska-Dawidziuk, 1995; Urbanek, 1963; Urbanek, 1966; Urbanek, 1970; Urbanek, 1997a,b; Urbanek and Teller, 1997).

On the basis of graptolites from this core, Urbanek (1966, 1970, 1997a) designated the Ludlow zones. Ludlow biostratigraphic zones of, particularly, the Arctic Canada (Lenz and Kozłowska-Dawidziuk, 2004), the Czech Republic (Štorch, 1995), the Tien Shan region of central Asia (Koren', 1983; Koren' and Suyarkova, 1997), and Ukraine (Tsegelnyuk, 1976), have provided evidence that most of the graptolites from Mielnik IG-1 core are widely distributed.

3.2. Material and methods

The studied material of the *P. packhami* Rickards and Wright, 1997 comes from the Mielnik IG-1 borehole, Poland, Ludlow depth of 915.1 m, *Bohemograptus praecornutus* Biozone. The material consists of about 80 specimens. Investigated material is stored in glycerin in plastic containers, and on SEM stubs in the Institute of Paleobiology of the Polish Academy of Sciences (Warszawa), abbreviated ZPAL G.50/1- ZPAL G.50/13.

The material was isolated from rock following slow dissolution of the host carbonate in 1–10% HCl. A fine hairbrush was used to transfer specimens. The specimens destined for a detailed examination were bleached in a mixture of potassium chlorate, nitric acid and water. After about a 10–15 h bath, the specimens were washed in water to remove the remnants of acid and chlorine. The

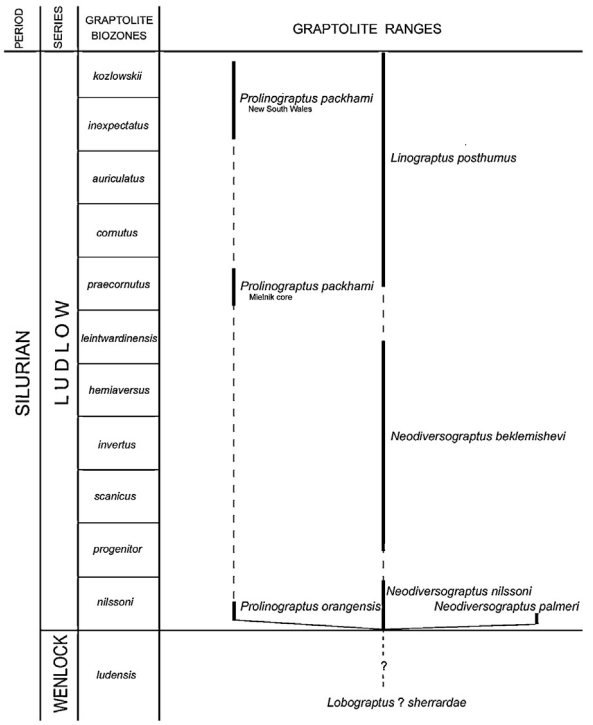

Fig. 3. Evolution of the Linograptinae: chronospecies (middle line) after Urbanek (1997a,b), *Neodiversograptus palmeri* and genus *Prolinograptus* after Rickards et al. (1995). Graptolite biozones after Urbanek and Teller (1997).
Fig. 3. Évolution des Linograptinae : chronoespèces (ligne du milieu) d'après Urbanek (1997a,b), *Neodiversograptus palmeri* et le genre *Prolinograptus* d'après Rickards et al. (1995). Biozones de Graptolites d'après Urbanek et Teller (1997).

isolated specimens were examined under the Philips XL scanning electron microscope (SEM) and the Nikon SMZ 1500 stereomicroscope in the Institute of Paleobiology Polish Academy of Sciences. Photo images of specimens were taken under the Philips XL SEM and with a Nikon D800digital camera.

4. Systematic palaeontology

Order: GRAPTOLOIDEA Lapworth, 1873
Family: MONOGRAPTIDAE Lapworth, 1873
Subfamily: LINOGRAPTINAE Obut, 1957
Genus ***Prolinograptus*** Rickards and Wright, 1997

Type species: *P. packhami* Rickards and Wright, 1997.

Species included: *P. orangensis* Rickards, Packham, Wright and Williamson 1995 and *P. packhami* Rickards and Wright, 1997.

P. packhami Rickards and Wright, 1997
Figs. 5, 6.

1997 *P. packhami* Rickards and Wright; Rickards and Wright, 1997: 226, text-figs. 9K, L, N, O, 10A.

2004 *P. packhami* Rickards and Wright?; Lenz and Kozłowska-Dawidziuk, 2004: 37, pl. 2: 1–7.

Material examined: Three siculae with the first thecae (th^1), well-preserved parts of rhabdosomes: one fragment with six thecae, four fragments with three thecae, 20 fragments with two thecae, and 50 fragments with one theca.

Diagnosis: After Rickards and Wright (1997).

Description: All the studied fragments are very slender and mostly straight; only two of them display a slightly, ventral curvature (Fig. 6D, E). The thecae are 0.15–0.20 mm wide at the aperture and 0.09–0.1 mm at the thinnest portion. Thecae are 1.3–1.5 mm long; the distance between the lips is 1.0–1.2 mm. Thecae number 3.5–4 in 5 mm. Thecal apertures are strongly everted with thick rims (Fig. 5E–G). The shape of thecal apertures is characteristic with its large distal indentations (Figs. 4E, 6C, D). Siculae are straight, 0.9–1.15 mm long, with apices reaching 2/3 along the length of the first theca (th^1). Diameter of the sicular aperture 0.22 mm. One of the siculae has an additional fuselli on the dorsal side of the sicular aperture (Fig. 6A–C). The other two siculae do not have dorsal apertural processes or sicular cladium. Virgella directed proximally. The whole thecae are covered with pustular micro-ornamentation that is densely and irregularly spaced (Fig. 5C–G). One short fragment of the rhabdosome with an unidentified growth about 0.3 mm long perhaps represents some remnant of

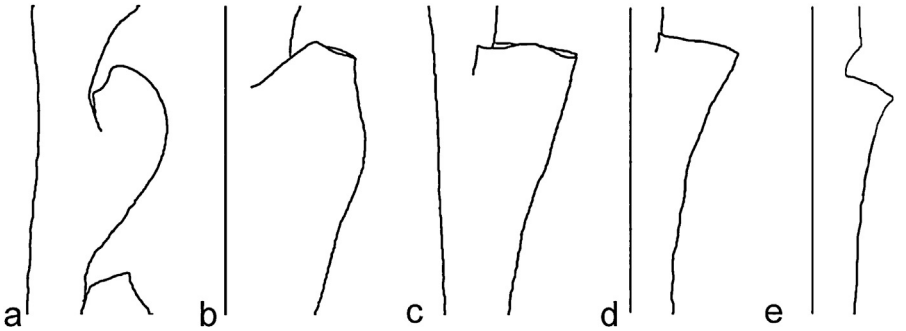

Fig. 4. Shape of thecae and apertures of Linograptinae. **A**, *Linograptus posthumus introversus*, based on Rickards and Wright (1997). **B**, *Linograptus posthumus*, based on Urbanek (1963). **C**, *Neodiversograptus beklemishevi*, based on Urbanek (1963). **D**, *Neodiversograptus nilssoni*, based on Urbanek (1963). **E**, *Prolinograptus orangensis* from Poland, present paper.
Fig. 4. Forme des thèques et ouvertures des Linograptinae. **A**, *Linograptus posthumus introversus*, basé sur Rickards et Wright (1997). **B**, *Linograptus posthumus*, basé sur Urbanek (1963). **C**, *Neodiversograptus beklemishevi*, basé sur Urbanek (1963). **D**, *Neodiversograptus nilssoni*, basé sur Urbanek (1963). **E**, *Prolinograptus orangensis* de Pologne, ce travail.

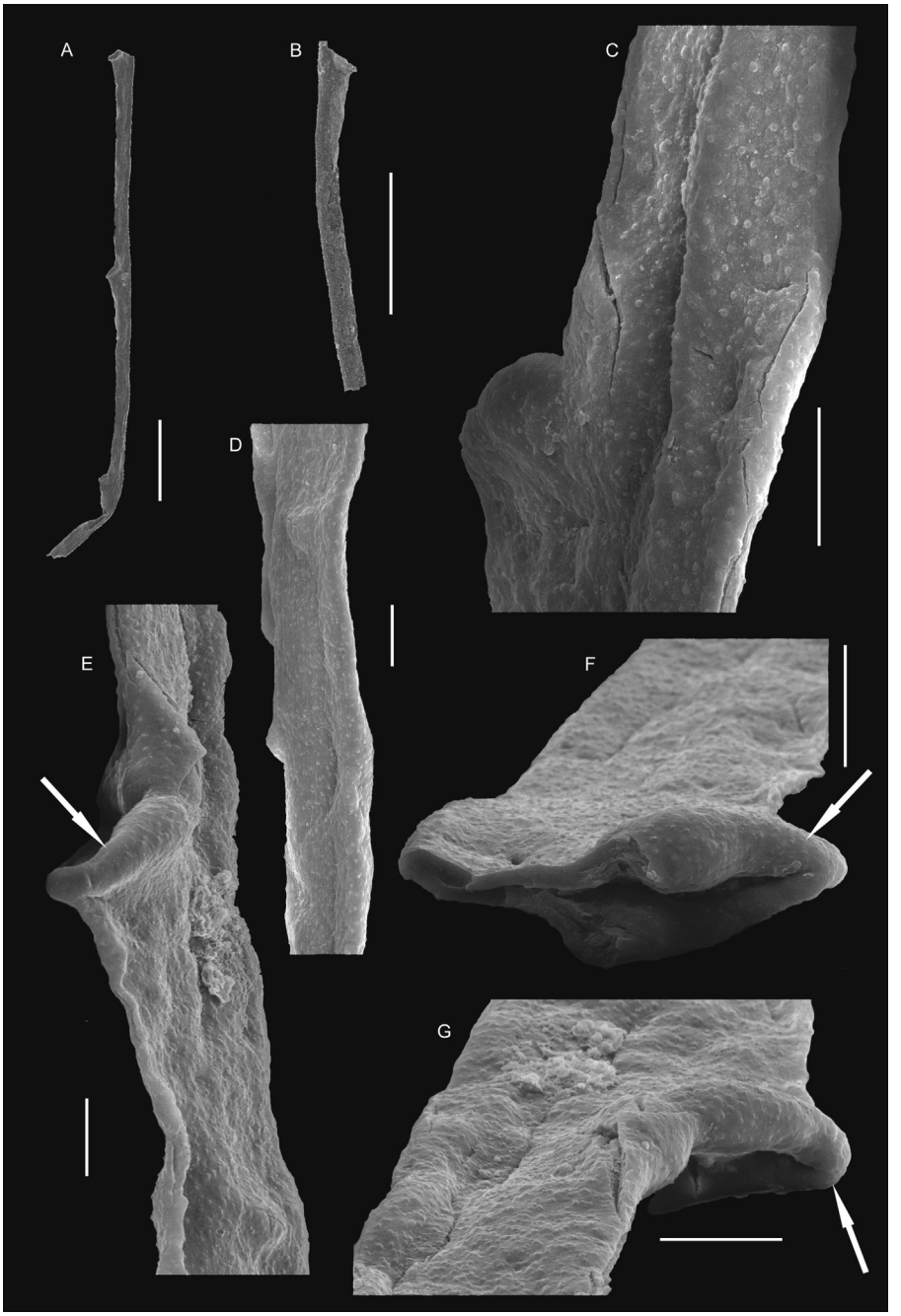

Fig. 5. Scanning electron microscope images of *Prolinograptus packhami* Rickards and Wright, 1997 from the Mielnik IG-1 core, depth of 915.1 m, Poland; **A**, fragment of rhabdosome in lateral view, with two complete thecae, specimen No. ZPAL G.50/1; **B**, most complete thecae in lateral view, specimen No. ZPAL G.50/2; **C**, fragment in dorsal view, showing pustulose surface, specimen No. ZPAL G.50/3; **D**, fragment in dorsal view, showing pustulose surface, specimen No. ZPAL G.50/4; **E**, fragment in ventral view with distinctive thecal apertural rim (arrow), showing pustulose surface, specimen No. ZPAL G.50/5; **F**, broken fragment in distal view with a thecal aperture and thecal apertural rim (arrow), showing pustulose surface, specimen No. ZPAL G.50/6; **G**, fragments in dorso-distal view with a thecal apertural rim (arrow), showing pustulose surface, specimen No. ZPAL G.50/7. Bars **A** and **B** are 500 μm long, **C–G** are 50 μm long.

Fig. 5. Images MEB de *Prolinograptus packhami* Rickards et Wright, 1997 du forage de Mielnik IG-1, profondeur 915,1 m ; **A**, fragment ZPAL G.50/1 du rhabdosome avec deux thèques complètes, vue latérale ; **B**, les thèques les plus complètes en vue latérale, spécimen ZPAL G.50/2 ; **C**, fragment ZPAL G.50/3 montrant la surface pustuleuse en vue dorsale ; **D**, fragment ZPAL G.50/4 montrant la surface pustuleuse en vue dorsale ; **E**, vue ventrale du fragment ZPAL G.50/5 avec le bourrelet apertural d'une thèque (flèche) ; **F**, vue distale du fragment cassé ZPAL G.50/6 avec l'ouverture de la thèque et le bourrelet apertural d'une thèque (flèche), montrant la surface pustuleuse ; **G**, vue dorso-distale de fragments avec un bourrelet apertural d'une thèque (flèche), montrant la surface pustuleuse, spécimen ZPAL G.50/7. Barres d'échelle **A** et **B**, 500 μm, **C–G**, 50 μm.

a parasite or an abnormally developed thecal aperture (Fig. 6G).

Remarks: Compared with the material described by Rickards and Wright (1997) there are differences in stratigraphic occurrence, the size of the sicula, and the large apertural distal indentations (Figs. 4E, 6C, D). The Australian *P. packhami* occurs in the *inexpectus*/*kozlowskii* biozonal interval, while the form from the Mielnik IG-1 core appears earlier, in the *praecornutus* Biozone (Fig. 3). The siculae of the Mielnik IG-1 specimens are bigger than the Australian ones. Their minimum length corresponds to the maximum of the Australian siculae. The apertural

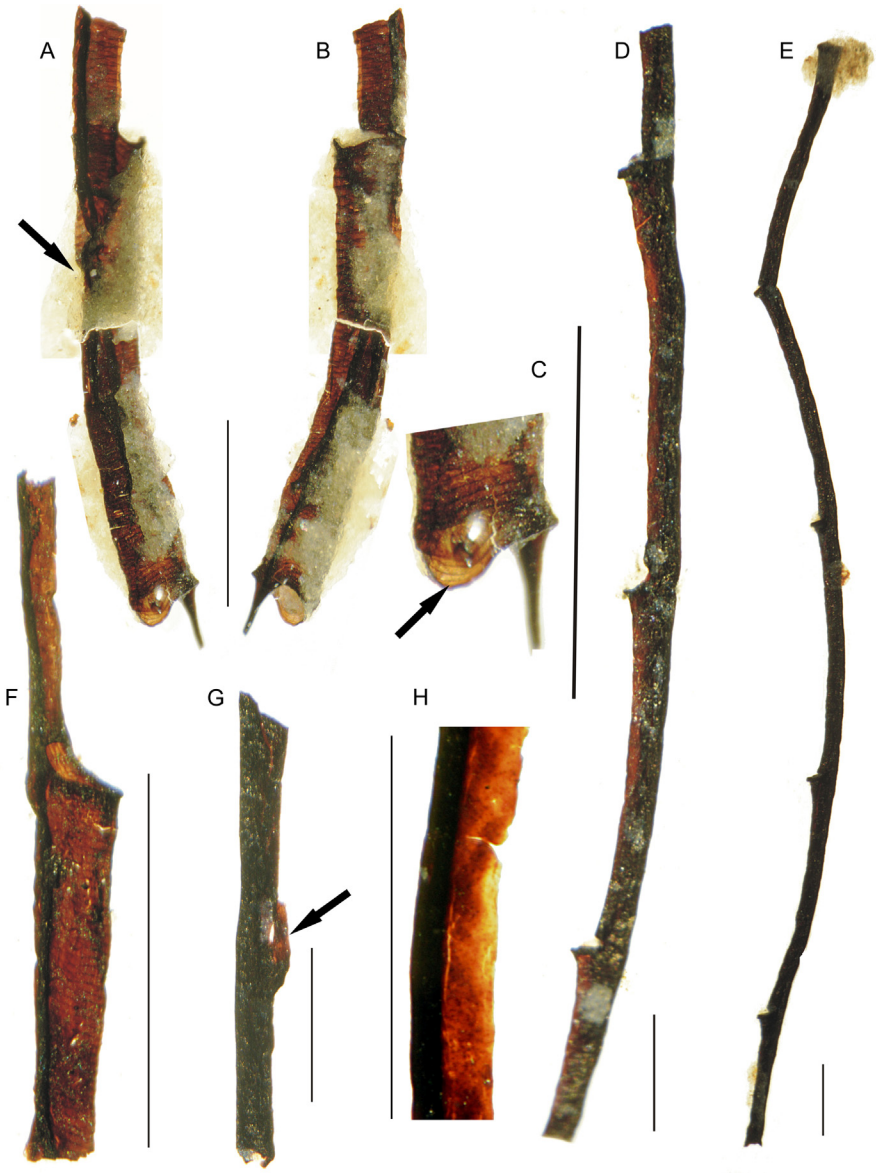

Fig. 6. Light photographs of *Prolinograptus packhami* Rickards and Wright, 1997 from the Mielnik IG-1 core, depth of 915.1 m, Poland, digital camera photos. **A–C**, ZPAL G.50/8 dorsal (**A**) and ventral (**B**) view of sicula with the first thecae, fuselli and apex (arrow) clearly visible, (**C**) an enlargement of additional fuselli on the dorsal side of the sicular aperture (arrow). **D**, ZPAL G.50/9 fragment of rhabdosome in lateral view with clearly visible large apertural distal indentation. **E**, ZPAL G.50/10 fragment of rhabdosome with five thecae. **F**, ZPAL G.50/11 most complete thecae in lateral view with clearly visible fuselli and apertural rim. **G**, ZPAL G.50/12 fragment of rhabdosome in lateral view with an unidentified growth (arrow). **H**, ZPAL G.50/13 fragment showing pustulose surface of the rhabdosome. Bars are 0.5 mm.

Fig. 6. *Prolinograptus packhami* Rickards et Wright, 1997 du forage Mielnik IG-1, profondeur 915,1 m, photos numériques. **A–C**, ZPAL G.50/8 vue dorsale (**A**) et ventrale (**B**) d'une sicule avec les premières thèques, fuselli et apex (flèche du haut) sont bien visibles ; (**C**), agrandissement des fuselli supplémentaires sur le côté dorsal de l'ouverture siculaire (flèche du bas). **D**, vue latérale du fragment d'un rhabdosome ZPAL G.50/9 avec une large indentation aperturale distale bien visible. **E**, fragment du rhabdosome ZPAL G.50/10 avec cinq thèques. **F**, ZPAL G.50/11, thèques les plus complètes en vue latérale avec le bourrelet fusellaire bien visible et le bourrelet apertural. **G**, fragment du rhabdosome ZPAL G.50/12 en vue latérale avec une excroissance non identifiée (flèche). **H**, fragment ZPAL G.50/13 montrant la surface pustuleuse du rhabdosome. Barres d'échelle, 0,5 mm.

Table 1
Comparison of the width of the proximal and distal stipes of the *P. packhami* from Australia (Rickards and Wright, 1997) and from Poland (this paper).
Tableau 1
Comparaison de la largeur des rhabdosomes proximaux et distaux de *P. packhami* d'Australie (Rickards et Wright, 1997) et de Pologne (ce travail).

Origin of specimens	Measurements	
	Minimum width of the proximal stipe in *Prolinograptus packhami* (mm)	Maximum width of the distal stipe in *Prolinograptus packhami* (mm)
New South Wales, Australia	0.15	0.30
Mielnik IG-1 borehole, Poland	0.15	0.20

indentations in *P. packhami* described by Rickards and Wright (1997) are only slight, while the Mielnik IG-1 material displays a very clear one (Fig. 4E). Rickards et al. (1995) described these indentations as "apertures (...) geniculated above thecal aperture". No cladia were found in the Mielnik IG-1 material. The micro-ornamentation on the described specimens is recorded for the first time for the monograptids.

5. Discussion

The sicular cladia are one of the most important diagnostic features of the genus *Prolinograptus* and subfamily Linograptinae (Rickards and Wright, 1997), but not every individual in the population must have them; for example, the specimens of *P. packhami* (Rickards and Wright, 1997, Fig. 9K, O, p. 223) or the specimen of *P. orangensis* described by Rickards et al. (1995, Fig. 35G, p. 60) formed at least 15 thecae and no cladium. Only one of the siculae of *Prolinograptus* from Poland has an additional fuselli that might be the beginning of the first cladium (Fig. 6A–C). The lack of a well-developed cladium in the Mielnik IG-1 specimens does not question its affinity with *Prolinograptus*. The Polish material presents only a portion of a very rare population of this genus, and that might be the reason why no cladium was found.

According to SEM observations the specimens display numerous pustules, irregularly spaced on the surface of the rhabdosome, including the apertural lips (Figs. 5C–G, 6G). This is an extraordinary morphological feature for monograptids, which usually have smooth bandages. Until now a similar micro-ornamentation has been known only in retiolitids (Retiolitidae), but unlike *P. packhami* from Poland, the retiolitids usually display a regular spacing of the ornamentation. Two types of micro-ornamentation have been considered one of the most important characters to distinguish the retiolitids into the two subfamilies Retiolitinae and Plectograptinae (Bates et al., 2005; Lenz and Kozłowska, 2007; Lenz and Melchin, 1987).

Although some of the *P. packhami* described by Rickards and Wright (1997) display a gently ventral curvature (i.e. Rickards and Wright, 1997, Fig. 9N, p. 223), Rickards and Wright (1997) did not say anything about it in the diagnosis of the genus or the species. The Mielnik IG-1 material also contains two slightly, ventrally curved specimens (Fig. 6D, E). But because such forms in the population are few, it probably cannot be a diagnostic feature of the species.

Parasitism on graptolites is a rare phenomenon, but when it happens, it may be manifested as outgrowths of periderm (Bates and Loydell, 2000). Perhaps the growth on one of the examined fragments of *P. packhami* (Fig. 6G) is a blister formed as a result of the activities of some parasite. However, because the specimen is fragmentary, accurate identification is difficult.

As one of the major features of this genus, Rickards and Wright (1997) mentioned little or no increase in dorsoventral width throughout the colony. Our material as well as measurements of specimens from Australia (Rickards and Wright, 1997) do not agree with this view. In extreme cases, differences in the width of the thecae reach up to 100% in the Australian material (Table 1). Fragmentary material from the Mielnik IG-1 core also displays a distinction among the thecae, but the differences are smaller. This may be because only the proximal and medial thecae are present in the examined material.

6. Conclusion

The present study suggests that *P. packhami* Rickards and Wright, 1997, one of the members of the subfamily Linograptinae, was not geographically restricted to Australia as previously thought (Rickards and Wright, 1997, 1999). Apart from Australia the genus *Prolinograptus* appeared in Poland, Baltica as well as in Arctic Canada, Laurentia (Fig. 1).

These are also new data on the stratigraphic occurrence of *P. packhami*, that show it ranged through at least five zones from the *praecornutus* (present paper) to the *inexpectatus- ozlowskii* Biozones (Rickards and Wright, 1997). SEM observations of isolated specimens enabled detailed studies on morphology and description of the micro-ornamentation unprecedented in other monograptids.

Acknowledgement

We are grateful to reviewers Denis Bates from University of Wales and Alfred Lenz from University of Western Ontario who also improved the English in the manuscript. Thanks are given to Andrzej Baliński for taking colour pictures, and Grażyna Matriba for technical assistance in preparation of the material; both are from the Institute of Paleobiology of the Polish Academy of Sciences. The authors greatly appreciate the financial support provided by the Ministry of Science and Higher Education, decision 499/N-NSERC/2009/0.

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