Geological Quarterly, 2006, **50** (3): 333–344

Late Wenlock biostratigraphy and the *Pristiograptus virbalensis* group (Graptolithina) in Lithuania and the Holy Cross Mountains

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Radzevičius S. (2006) — Late Wenlock biostratigraphy and the *Pristiograptus virbalensis* group (Graptolithina) in Lithuania and the Holy Cross Mountains. Geol. Quart., **50** (3): 333–344. Warszawa.

Graptolites from Lithuania and the Holy Cross Mountains comprise a succession of the *lundgreni*, *parvus* (except for the Holy Cross Mts.), *nassa*, *praedeubeli*, *deubeli* and *ludensis* biozones of the upper Wenlock, the *parvus*, *praedeubeli* and *deubeli* biozones being recognized for the first time in Lithuania, where a graptolite-free interval may also be distinguished. *P. virbalensis* Paškevičius, 1974 and the *virbalensis* group are not widely known, and are discussed here. Analysis of *P. virbalensis* shows this to be an independent taxon, closely related to *P. auctus*. There are three species — *P. virbalensis*, *P. jaegeri* and *P. auctus* — in the *virbalensis* group.

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Key words: Lithuania, Holy Cross Mts., Silurian, upper Wenlock, biostratigraphy, Graptolithina.

INTRODUCTION

The graptolite genus *Pristiograptus* has been recorded from the *Coronograptus cyphus* to the *Neocolonograptus parultimus–Neocolonograptus ultimus* biozones in the Baltic States. The highest diversity of pristiograptids occurs in the late Wenlock *Pristiograptus parvus–Pristiograptus ludensis* biozones (Fig. 1) in Lithuania (Radzevičius and Paškevičius, 2000). Only pristiograptids and retiolitids have been recorded throughout this interval, other characteristic Wenlock graptolite species having become extinct by the end of the *Cyrtograptus lundgreni* Biozone. Consequently, only pristiograptids and retiolitids can be effectively used in the detailed graptolite biostratigraphy of the *parvus–ludensis* interval. Ulst (Gailite *et al*., 1967; Ulst, 1974; Gailite *et al*., 1987) investigated the *Pristiograptus* species of the Wenlock-Ludlow boundary interval in the Baltic Syneclise. Ulst revealed the detailed distribution pattern of graptolites from the upper part of the *Monograptus testis* (=*lundgreni*) Biozone up to the lower part of the *Neodiversograptus nilssoni* Biozone. Ulst (1974) described a local *parvus–Pristiograptus piltenensis* (=*Gothograptus nassa*) biozone for the first time in Latvia. Paškevičius (1974, 1997) improved the graptolite biozonation and described the distribution of graptolites in the *testis–nilssoni* interval.

Tomczyk (1962), Jaworowski (1965), Teller (1972, 1997) and Szymański and Teller (1998) investigated graptolites from the upper Wenlock of Poland. Koren' and Urbanek (1994*a*) investigated monograptid evolution in the late Wenlock. The upper Wenlock retiolitids, monograptids and biostratigraphy were investigated by Kozłowska-Dawidziuk (1990, 1997, 1999) Porębska (1998) and Porębska *et al*. (2004).

This paper provides a revised graptolite biozonation of the upper Wenlock of Lithuania and the Holy Cross Mts. (Poland). The *lundgreni*, *parvus* (with a graptolite-free interval), *nassa*, *Pristiograptus praedeubeli*, *Pristiograptus deubeli* and *ludensis* biozones may be distinguished in Lithuania. In the Holy Cross Mts. the *lundgreni*, *nassa*, *praedeubeli*, *deubeli*, *ludensis* biozones may be distinguished. The little known pristiograptids of the *Pristiograptus virbalensis* group are discussed in the context of related taxa.

MATERIAL

New palaeontological material of late Homerian (*lundgreni–ludensis* biozones) age (Fig. 1) has been recovered from Lithuania (west part of the East European Platform or Baltica) and the Holy Cross Mts. (Małopolska Block, Kielce Unit). In Silurian time the Małopolska Block was near Baltica

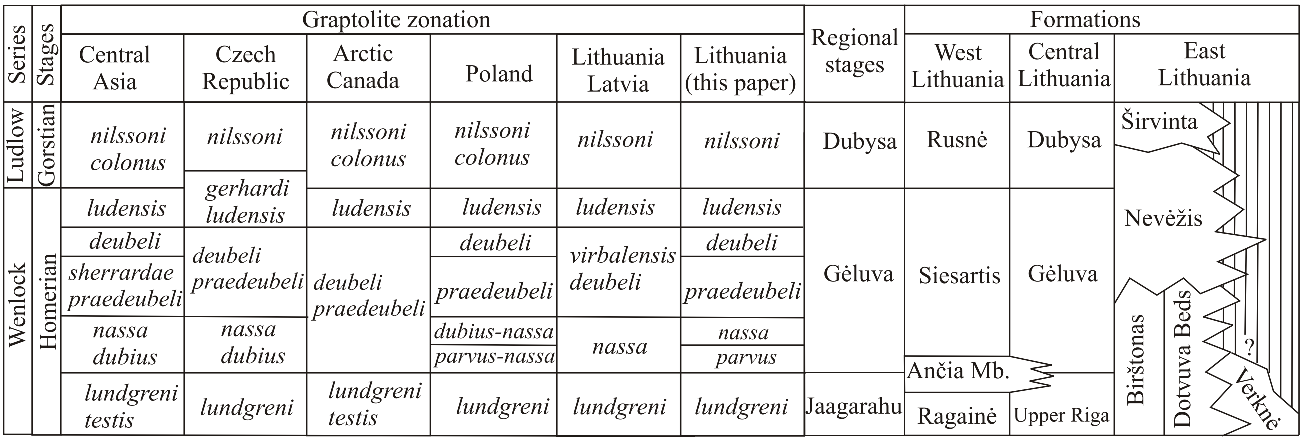

Fig. 1. Correlation of the revised Lithuanian upper Wenlock graptolite biozonation with those of Central Asia (Koren' and Suyarkova, 1994); the Czech Republic (the *gerhardi-ludensis* zonal boundary is higher because *C. gerhardi* disappears in the lower Ludlow — Kozłowska-Dawidziuk *et al.*, 1998); Arctic Canada (Lenz and Kozłowska-Dawidziuk, 2002); Poland (Szymański and Teller, 1998; Lenz and Kozłowska-Dawidziuk, 2002); Lithuania and Latvia (Radzevičius and Paškevičius, 2000; Radzevičius, 2004); and with regional stages and formations

(Nawrocki, 2000); adjacent to the south-west margin of Baltica in the Mid Cambrian (Winchester, 2002; Trela, 2004), by the Late Silurian the Małopolska Block was located at its present position at the south-west margin of Baltica (East European Platform) (Nawrocki, 2000).

The total thickness of the upper Wenlock interval (*parvus–ludensis* biozones) is about 40 m in Lithuania. It comprises (Fig. 1) grey argillite, clayey marl (Western Lithuania), clayey marl, marl, clayey limestone (Central Lithuania), clayey limestone, dolomitic clayey limestone and clayey dolomite (Eastern Lithuania) (Fig. 2B). The new Lithuanian material is from the Vilkaviškis-131 borehole (Fig. 2B) from the 1052–1100 m interval (60 samples) and from the Šiupyliai-69 borehole. Graptolites were studied from the 966–1010 m interval (50 samples) in the Kurtuvėnai-161 borehole and also from the 1274–1330 m interval (45 samples), while the Sutkai-87 borehole 760–805 m interval (25 samples) was also studied. All boreholes are from Northern and Southern Lithuania. In total about 180 samples were collected and investigated.

Rhabdosomes were isolated with HCl or HF from 80 samples of borehole core. About 500 isolated fragments of semi-flattened and 3-dimensionally preserved rhabdosomes were collected, including early astogenetic stages.

In the Holy Cross Mts. the upper Wenlock sequence is well exposed in the Kielce Unit (Fig. 2C) about 2 km to the north from the village of Bardo on the northern side of the Bardo Syncline, especially along the Prągowiec ravine (Fig. 2D). The total thickness of the upper Wenlock and lower Ludlow is about 600 m (Tomczyk, 1962). In this ravine, the upper Wenlock deposits are represented by dark yellow and brown clayey shale in the *lundgreni* Biozone (upper part of the Bardo Beds). The *nassa–Pristiograptus tumescens–Saetograptus leintwardinensis* biozones are represented by dark grey silty shale, locally with concretions of limestone (Prągowiec Beds) and *Bohemograptus bohemicus* Biozone (Fig. 2D) is represented by greywacke (the Niewachlów Greywacke) (Tomczyk, 1962). 100 samples were taken from 9 exposures and 15 samples were taken from screes (Fig. 2D). There are no isolated rhabdosomes in collections from the Holy Cross Mts., because it was impossible to isolate either both with HCI or HF. Samples from the *nassa* (upper part) and *nilssoni* (upper part) — *bohemicus* intervals were not taken, because the ravine in this place is overgrown with vegetation.

Photos of the Lithuanian material were made using the scanning electronic microscope (SEM) in the Laboratory of Materials Research at Tallinn Technical University (Estonia) and in the Institute of Geology, Lund University (Sweden).

The material from both Lithuania and in part from the Holy Cross Mts. is stored at the Department of Geology and Mineralogy of Vilnius University. The material from the Holy Cross Mts. (*lundgreni* Biozone) is stored at the Institute of Geological Sciences, Wrocław University (Poland).

BIOSTRATIGRAPHY

The recent detailed information from the upper Homerian allows distinction of the *lundgreni*, *parvus*, *nassa*, *praedeubeli*, *deubeli* and *ludensis* graptolite biozones in Lithuania and the *lundgreni*, *nassa*, *praedeubeli*, *deubeli* and *ludensis* biozones in the Holy Cross Mts. (Radzevičius, 2003*a*) (Fig. 1).

The *lundgreni* taxon-range Biozone was adapted by Paškevičius (1997) in Lithuania. This interval was formally included in the *testis* Biozone (Paškevičius, 1979, 1991; Brazauskas and Paškevičius, 1981). The upper boundary of this biozone is placed where *Cyrtograptus*, *Monograptus* and *Monoclimacis disappear*. In Lithuania this biozone includes: *Cyrtograptus lundgreni* Tullberg, *Monograptus t. testis* (Barrande), *M. t. inornatus* Elles, *M. f. flemingi* (Salter), *Monoclimacis flumendosae* (Gorthani), *Pristiograptus lodenicensis* Přibyl, *P. pseudodubius* (Bouček) and *Gothograptus* cf. *kozlowskii* Kozłowska-Dawidziuk (Fig. 3). These species do not disappear at the same time. *P. lodenicensis* disappears first, and then *Monograptus testis testis*, *M. t. inornatus* and *M. flumendosae*. The last three species disappear before *C. lundgreni* in boreholes in Lithuania. But *C. lundgreni* disappears earlier than *M. t. testis* (Porębska *et al.*,

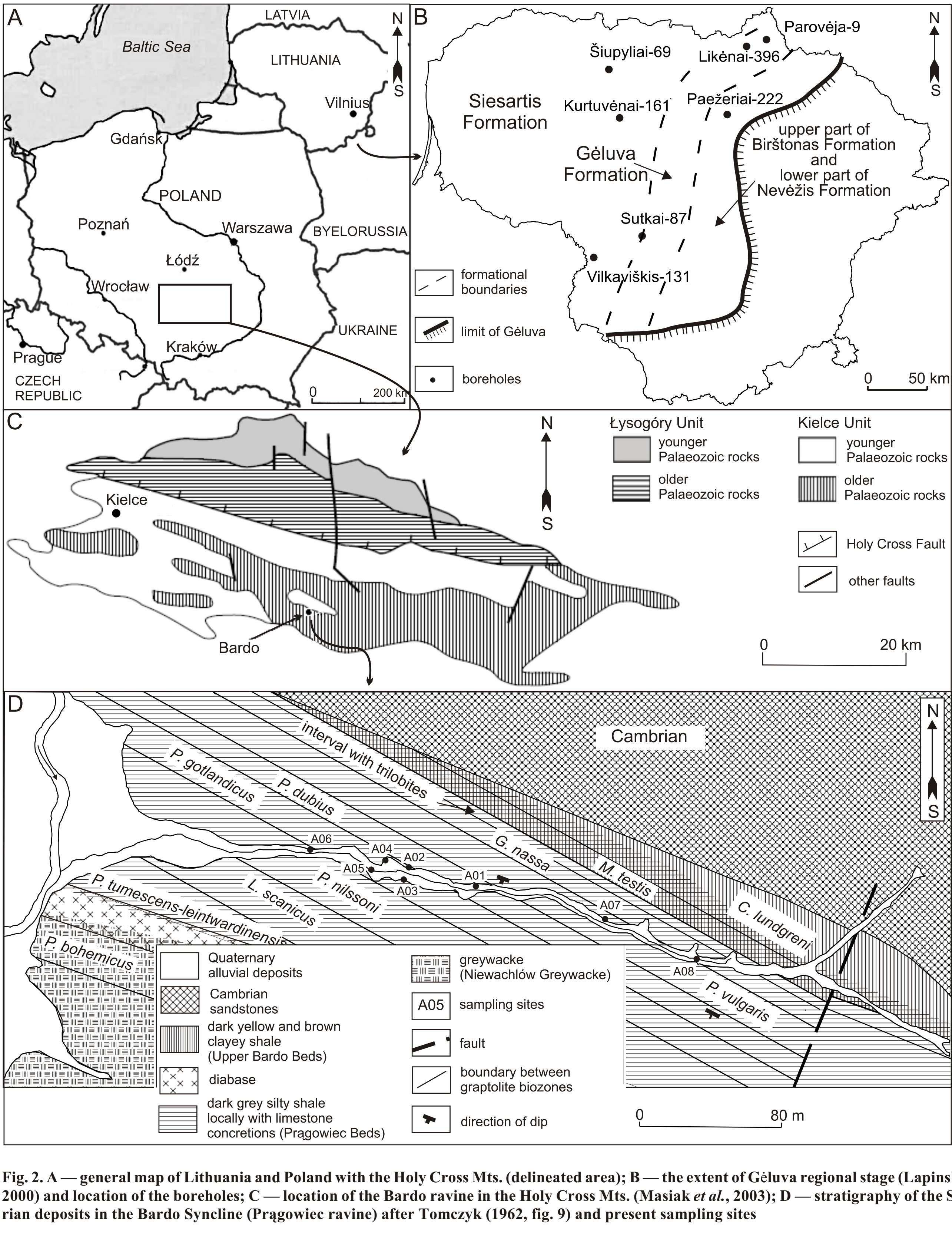

Fig. 2. A — general map of Lithuania and Poland with the Holy Cross Mts. (delineated area); B — the extent of Gėluva regional stage (Lapinskas, 2000) and location of the boreholes; C — location of the Bardo ravine in the Holy Cross Mts. (Masiak *et al.*, 2003); D — stratigraphy of the Silurian deposits in the Bardo Syncline (Prągowiec ravine) after Tomczyk (1962, fig. 9) and present sampling sites

2004) in the Bartoszyce borehole (Poland). *C. lundgreni* disappears together with *M. f. flemingi*, *P. pseudodubius* and *Gothograptus* sp., in the lower part of the Ančia Member.

A graptolite-free interval and the *parvus* concurrent-range Biozone are recognized for the first time in Lithuania (Fig. 3). Previously the *parvus* Biozone interval was attributed to the lower part of the *nassa* Biozone. Ulst (1974) first separated the *P. parvus–P. piltenensis* local Biozone in Latvia, which included the entire interval of the *nassa* Biozone. The lower boundary of this biozone was placed where *C. lundgreni*, *M. t.*

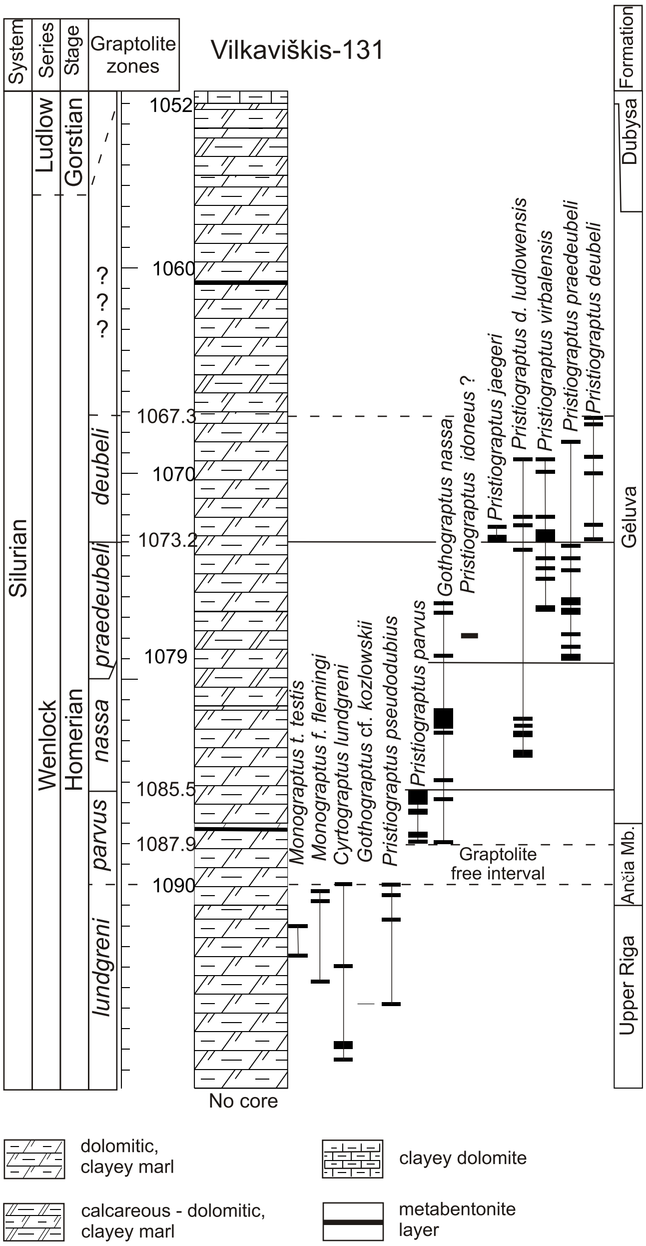

Fig. 3. Distribution of graptolites near the Wenlock-Ludlow boundary in the Vilkaviškis-131 borehole

testis, *M. t. inornatus*, *M. f. flemingi*, *M. flumendosae*, *P. lodenicensis*, *P. pseudodubius* and *G.* cf. *kozlowski* disappear. *P. parvus* Ulst and *G. nassa* (Holm) appear in the upper part of the Ančia Member. Only two species are found in this biozone. Graptolites are absent from the last occurrence of *C. lundgreni* and *P. pseudodubius* to the first appearance of *P. parvus* and *G. nassa* (middle part of the Ančia Member) (Fig. 3). The graptolite-free interval ranges from 0.7 m (Šiupyliai-69) to 2 m (Vilkaviškis-131) in thickness. The upper boundary of the biozone is recognized where *P. parvus* disappears. The vertical extent of *P. parvus* ranges from 5 m in the Kurtuvėnai-161 borehole to 2.4 m in the Vilkaviškis-131 borehole. There is a similar graptolite-free interval in Gotland between the *lundgreni* and *parvus* biozones (Calner and Jeppsson, 2003). This interval represents the Bara Oolite and the lower part of the Mulde Brick-clay Member of the Halla Formation (Calner and Säll, 1999).

Paškevičius (1965) recognized the *nassa* Biozone in Lithuania, which included the interval with *P. parvus*. Later this biozone was divided into two intervals: a lower part with *P. parvus* and an upper part with *P. d. ludlowensis* (Bouček) (Radzevičius, 2004). These two parts are shown as separate biozones in this paper. The lower boundary of the *nassa* Biozone is marked where *P. parvus* disappear and the upper boundary where *P. virbalensis* Paškevičius and *P. praedeubeli* (Jaeger) appear. The *nassa* Biozone, like the *parvus* Biozone, has few species, though these are larger than those in the *parvus* Biozone: they comprise *G. nassa* (Fig. 4) and *P. d. ludlowensis*. The *nassa* Biozone is 6.5 m thick in the Vilkaviškis-131 borehole.

The *praedeubeli* range Biozone is here recognized for the first time in Lithuania. Previously this interval was called the *virbalensis–deubeli* Biozone (Paškevičius, 1997; Radzevičius and Paškevičius, 2000); later, it was referred to as the lower part of the *virbalensis* Biozone with *P. praedeubeli* (Radzevičius and Paškevičius, 2005). The lower boundary is marked where *P. praedeubeli* and *P. virbalensis* appear, while the upper boundary is drawn when *P. deubeli* (Jaeger) appears. This biozone also includes *G. nassa* and *P. d. ludlowensis*. *P. idoneus*? (Koren') has been found in the lower part of the biozone for the first time, while *P. jaegeri* (Holland, Rickards, Warren) occurs in the upper part. The thickness of the *praedeubeli* Biozone is 5.8 m in the Vilkaviškis-131 borehole and 8 m in the Šiupyliai-69 borehole.

The *deubeli* range Biozone is here also recognized for the first time in Lithuania. Previously this interval was called the *virbalensis–deubeli* Biozone (Paškevičius, 1997; Radzevičius and Paškevičius, 2000). The lower boundary is drawn at the first appearance of *P. deubeli*. The upper boundary is drawn where *P. ludensis* appears. The assemblage comprises *P. jaegeri* (in the lower part) *P. deubeli*, *P. praedeubeli*, *P. virbalensis* and *P. d. ludlowensis*. We have been unable to determine the thickness of this biozone in the Vilkaviškis-131 borehole, because the upper part of the Wenlock has yielded no graptolites. The thickness of the *deubeli* Biozone is 5 m in the Šiupyliai-69 borehole.

The *ludensis* range Biozone was recognized by Paškevičius (1979). Previously this biozone encompassed the interval from the *nassa* to the *nilssoni* Biozones (Paškevičius, 1979), while Paškevičius (1997) recognized it in its present meaning. The lower boundary of the biozone is drawn where *P. ludensis* (Murchison) appears, and the upper boundary where *Neodiversograptus nilssoni* (Barrande), *Colonograptus colonus* (Barrande) and *Bohemograptus b. bohemicus* (Barrande) appear. The graptolite assemblage of this biozone includes *P. ludensis*, *P. praedeubeli* and *P. d. ludlowensis*; in the upper part *Colonograptus gerhardi* (Kűhne) appears (Fig. 4), and this taxon is also found in the upper *nilssoni* Biozone.

Tomczyk (1962) recognized the *lundgreni*, *testis*, *nassa*, *Pristiograptus vulgaris*, *P. dubius*, *Spinograptus spinosus–Pristiograptus gotlandicus*, *nilssoni*, *Lobograptus scanicus*, *tumescens–leintwardinensis* and *bohemicus* biozones in the Bardo syneclyse (Holy Cross Mts.) around the Wenlock-Lud-

Fig. 4. Graptolites from the upper Wenlock and lower Ludlow of Lithuania

A — *Monograptus cf. flemingi* (Salter); Parovėja-9 borehole, depth 605.6 m, *lundgreni* Biozone; **B** — *Pristiograptus dubius* var. B, Paežeriai-222 borehole, depth 734.5 m, *lundgreni* Biozone, P.P222-216; **C**–**F** — *Pristiograptus lodenicensis* Přibyl, Parovėja-9 borehole, *lundgreni* Biozone; C — depth 558.3 m, S.P9-211a; D — depth 561.9 m, P.P9-1; E — depth 558.3 m, P.P9-5; F — depth 561.9 m, P.P9-6; **G**–**I** — *Gothograptus* cf. *kozlowskii* Kozłowska-Dawidziusk, Šiupyliai-69 borehole, depth 1010.0 m, *lundgreni* Biozone; G — general view of rhabdosome; H — second theca with hook; I — proximal end of rhabdosome; **J**, **M** — *Colonograptus gerhardi* (Kűhne), Šiupyliai-69 borehole; J — depth 967.4 m, *nilssoni* Biozone, S.Š69-396; M — depth 976.7 m, *ludensis* Biozone, S.Š69-399; **K**, **S**, **T** — *Pristiograptus praedeubeli* (Jaeger); K — Šiupyliai-69 borehole, depth 982.6 m, *deubeli* Biozone, S.Š69-397; S — Sutkai-87 borehole, depth 776.0 m, *praedeubeli* Biozone, P.S87-134; T — Pilviškiai-143 borehole, depth 779.5 m, *praedeubeli* Biozone, S.P143-84; **L**, **R** — *Pristiograptus deubeli* (Jaeger), *deubeli* Biozone; L — Šiupyliai-69 borehole, depth 982.6 m, S.Š69-398; R — Pilviškiai-143 borehole, depth 779.5 m, S.P143-148; **N**–**P** — *Pristiograptus parvus* Ulat, Kybartai-14 borehole, *parvus* Biozone; N, O, — depth 1088.4 m; N — P.K14-109; O — P.K14-115; P — depth 1071.7 m, P.K17-108; **Q** — *Gothograptus nassa* (Holm), Šiupyliai-69 borehole, depth 993.6 m, *nassa* Biozone; **U** — *Colonograptus colonus* (Barrande), Šiupyliai-69 borehole, depth 958.4 m, *progenitor* Biozone; **V** — *Neodiversograptus nilssoni* (Lapworth); Šiupyliai-69 borehole, depth 967.5 m, *nilssoni* Biozone; **W** — *Monograptus* cf. *micropoma* Jaeger, Šiupyliai-69 borehole, depth 971.5 m, *progenitor* Biozone; **X** — *Saetograptus schimaera* (Barrande), Šiupyliai-69 borehole, depth 937.35 m, *progenitor* Biozone; **Y**, **Z** — *Pristiograptus virbalensis* Paškevičius, Sutkai-87 borehole, *praedeubeli* Biozone; Y — depth 768.2 m, P.S87-121b; Z — depth 768.9 m, P.S87-71; **AA** — Dendroidea, Sutkai-87 borehole, depth 787.8 m (interval between *lundgreni*–*praedeubeli* biozones) low boundary (Fig. 5). Tomczyk (1962) also distinguished intervals with trilobites in the lower part of the *nassa* Biozone. Current stratigraphic schemes do not include the *testis*, *vulgaris*, *dubius* and *spinosus-gotlandicus* biozones of the upper Wenlock.

Analysis of the Prągowiec ravine samples allowed separation of the *lundgreni*, *nassa*, *praedeubeli*, *deubeli*, *ludensis* and *nilssoni* biozones. The exact boundaries of these biozones could not be determined because of a lack of material. The oldest graptolite biozone found, the *lundgreni* Biozone, occurs in the upper part of the upper Bardo Beds. The graptolite assemblage from the A09 exposure includes *M. t. testis*, *M. f. flemingi*, *C. lundgreni* and *G.* cf. *kozlowskii*.

The *nassa*, *praedeubeli*, *deubeli*, *ludensis* and *nilssoni* biozones were also recognized in the Prągowiec ravine. Rocks of the *scanicus-bohemicus* interval were not found, because that interval is thickly grown over with bushes and trees. The *parvus* Biozone has also not been found in the Prągoviec ravine, because *P. parvus* has not yet been discovered there. The vertical distribution of *P. parvus* is very narrow in Lithuania. The absence of this species may therefore result from the wide interval of sampling, or *parvus* Biozone may equate to the interval with trilobites that occurs above the *lundgreni* Biozone. The graptolite assemblage of the *nassa* Biozone found in the A08 exposure comprises *G. nassa*, *P. d. ludlowensis*.

The graptolite assemblage of the *praedeubeli* Biozone in the Prągowiec ravine, found in the A07, A01 and A02 exposures is very similar to that of the *praedeubeli* Biozone of Lithuania: *G. nassa*, *P. d. ludlowensis*, *P. virbalensis*, *P. praedeubeli* and *P.* cf. ? *idoneus* (Figs. 6 and 7).

The graptolite assemblage of the *deubeli* Biozone was found in the A01 (lower part), A02 and A04 exposures and it includes *G. nassa* ?, *P. d. ludlowensis*, *P. praedeubeli* and *P. virbalensis*. There is rare *P. praedeubeli* in the *deubeli* Biozone in Lithuania, but this species also occurs in the *deubeli* and *ludensis* biozones of northern Naratau and the Alai Ridge (Central Asia) (Koren' and Suyrkova, 1994*b*) and Arctic Canada (Lenz and Kozłowska-Dawidziuk, 2002).

Series	Stages	Beds	Holy Cross Mountains (Tomczyk, 1962)	Holy Cross Mountains (this paper)	Lithuania (this paper)
Ludlow	Gorstian	Prągowiec	*nilssoni*	*nilssoni*	*nilssoni*
Wenlock	Homerian	Prągowiec	*gotlandicus* *dubius* ? ? *vulgaris*	*ludensis*	*ludensis*
				deubeli	*deubeli*
				praedeubeli	*praedeubeli*
			nassa	*nassa*	*nassa*
					parvus
		Bardo	*lundgreni* *testis*	*lundgreni*	*lundgreni*

Fig. 5. Correlation of the Holy Cross Mts. (Tomczyk, 1962) upper Wenlock graptolite biozonation with those of revised Holy Cross Mts. and Lithuanian biozonations

The graptolite assemblage of the *ludensis* Biozone was found at exposures A03, A04 and A05 and includes *P. d. ludlowensis*, *P. praedeubeli*, *P. deubeli*, *P. virbalensis* and *C. gerhardi* (Fig. 7). *P. virbalensis* does not occur in the *ludensis* Biozone of Lithuania.

It is difficult to correlate the *praedeubeli*, *deubeli* and *ludensis* biozones with the biozones recognized by Tomczyk (1962) from Prągowiec (Fig. 5), because *P. gotlandicus* and *P. vulgaris* are not now recognized as valid taxa. It would be necessary to revise of Tomczyk's collection from the Prągowiec ravine for this correlation to be made.

The graptolite assemblage of the *nilssoni* Biozone, found in the A05 (lower part) and A06 exposures, comprises *C. gerhardi* (Fig. 7), *N. nilssoni* and *Saetograptus* sp.

PRISTIOGRAPTUS VIRBALENSIS GROUP

Four pristiograptid morphological groups are recognized in the upper Wenlock: *dubius*, *lodenicensis*, *deubeli* (*ludensis* or *Ludensograptus*) and *virbalensis* (Radzevičius and Paškevičius, 2000). The first three are widespread and well-known (Přibyl, 1943; Tsegelnjuk, 1988; Radzevičius, 2003*b*; Rickards and Wright, 2003). *P. pseudodubius* does not equate with *P. parvus* (Rickards and Wright, 2003). *P. parvus* is a clearly-marked taxon with a very narrow distribution in time. These two species are similar because they are both of *dubius* type, but *P. parvus* is smaller. The maximum width of the rhabdosome is 1 mm and that of *P. pseudodubius* is 1.5 mm. The first *P. parvus* theca originates are at the sicula aperture or very close to it, while the free part of the *P. pseudodubius* sicula wall is 0.25 mm long.

Our new data helps to constrain the upper limit of *P. lodenicensis*; this species disappears before *M. t. testis* and *C. lundgreni.*

The *virbalensis* group was distinguished by Radzevičius and Paškevičius (2000) for the first time, and it extended through late Wenlock and early Ludlow time. *P. virbalenis* Paškevičius, 1974 (Fig. 8G) is not widely known, and is discussed here. In the new material from Lithuania and the Holy Cross Mts. there is no typical *P. auctus* Rickard, that has a large bulb-like termination to the virgella. A pristiograptid similar to *P. auctus* was find only in the *praedeubeli–ludensis* biozones. The new material from Lithuania and the Holy Cross Mts., enables revision of this group.

The *Pristiograptus* of the *virbalensis* group possesses a massive virgella, and the thecae are inclined at 40–45° to the axis of the rhabdosome. The apertural angle (β) (Fig. 9G) of the thecae is obtuse in the proximal part of the rhabdosome and it is a right angle (90°) in the medial and distal parts. The virgella is obtuse and massive (Figs. 6M, L and 8A, B, D, E, G). There are three species in the virbalensis group: *P. auctus* Rickards (Fig. 8L), *P. jaegeri* (Fig. 8H–K) and *P. virbalensis*. These species are very similar. The main characteristic of *P. auctus*, is "...the presence of a short virgella (0.6 mm) which swells into a bulb-like shape, and has the appearance of a droplet hanging from the proximal end of the rhabdosome.

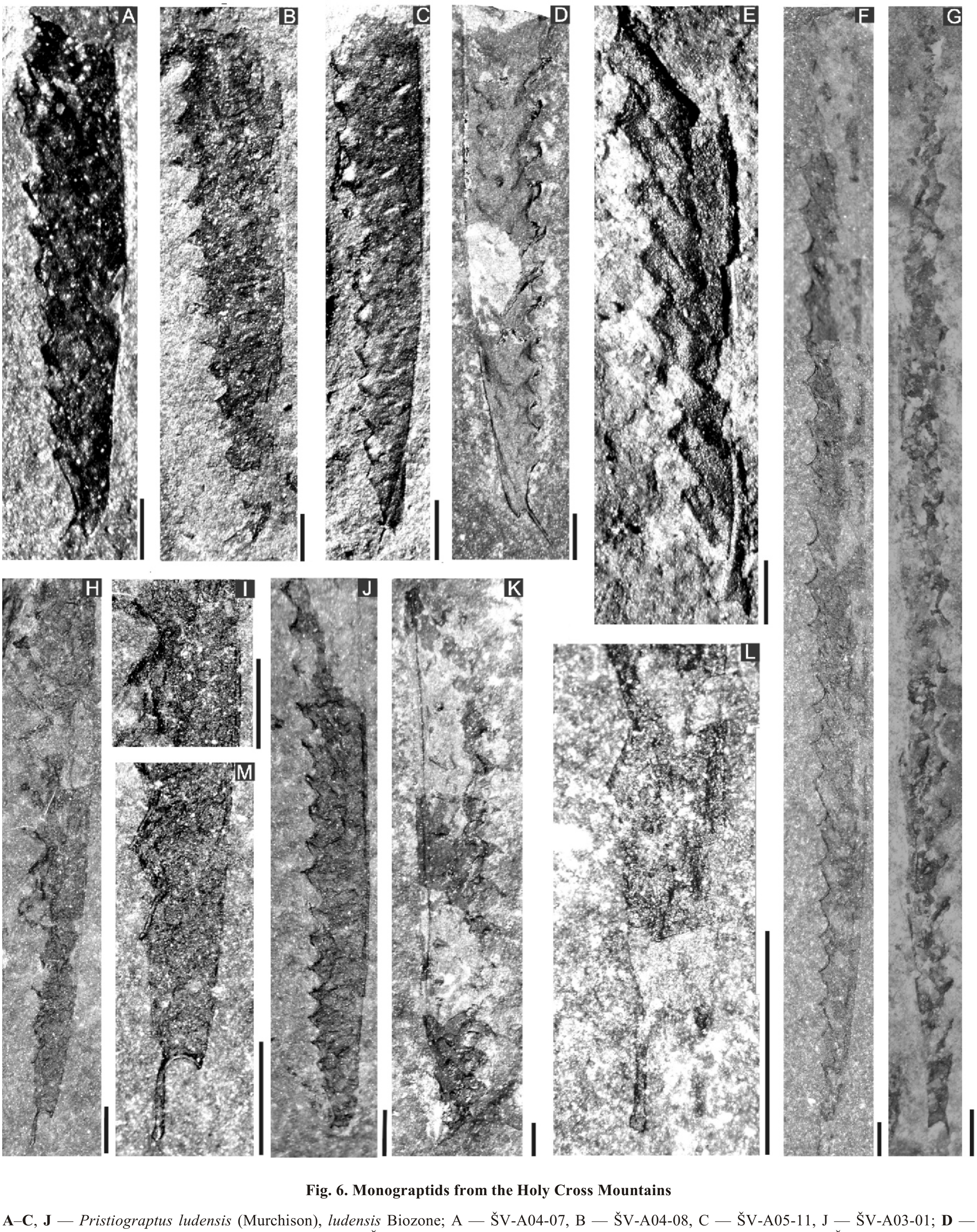

Fig. 6. Monograptids from the Holy Cross Mountains

A–**C**, **J** — *Pristiograptus ludensis* (Murchison), *ludensis* Biozone; A — ŠV-A04-07, B — ŠV-A04-08, C — ŠV-A05-11, J — ŠV-A03-01; **D** — *Pristiograptus praedeubeli* (Jaeger), *deubeli* Biozone, ŠV-A05-05; **E** — *Pristiograptus deubeli* (Jaeger), *deubeli* Biozone, ŠV-A01-10; **F**, **L** — *Pristiograptus virbalensis* Paškevičius, *deubeli* Biozone, ŠV-A04-02, F — general view, L — proximal end of rhabdosome, virgella with virgella nub; **G** — *Pristiograptus* cf. *idoneus* Kpren', *praedeubeli* Biozone, ŠV-A07-01; **H**, **I**, **M** — *Pristiograptus virbalensis* Paškevičius, *praedeubeli* Biozone, ŠV-A02-01, H — general view, I — the sixth theca apertural lip, M — proximal end of rhabdosome virgella with virgella nub; **K** — *Saetograptus* sp., *nilssoni* Biozone, ŠV-A06-05; black bars represent 1 mm

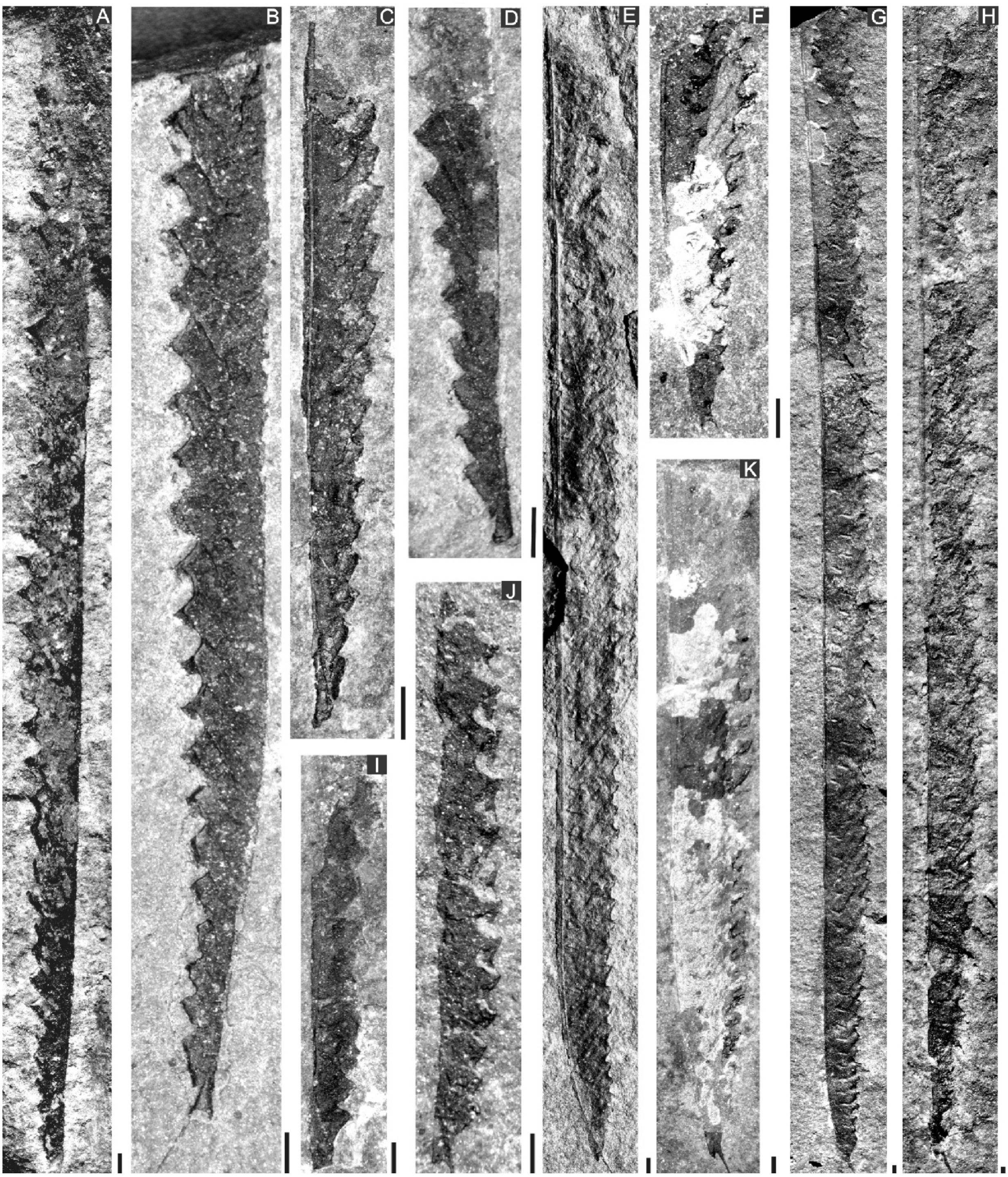

Fig. 7. Monograptids from the Holy Cross Mountains

A–**D**, **I**, **J** — *Pristiograptus deubeli* (Jaeger), *deubeli* Biozone; A — ŠV-A01-02, B — SV-A01-08, C — SV-A02-10, D — ŠV-A01-07, I — ŠV-A019; J — ŠV-A04-23; **E**, **F**, **K** — *Colonograptus gerhardi* (Kűhne), *ludensis* Biozone; E — ŠV-A06-10, F — ŠV-06-01, K — ŠV-A06-02; **G** — *Pristiograptus ludensis* (Murchison), *ludensis* Biozone, ŠV-A05-13; **H** — *Pristiograptus praedeubeli* (Jaeger), *deubeli* Biozone, ŠV-A02-08; black bars represent 1 mm

It's swelling is 0.4–0.5 mm in diameter..." (Rickards, 1965, p. 260). The *P. virbalensis* rhabdosome looks most similar to *P. auctus*. It is straight with a hanging "droplet" on the end of the virgella (Figs. 8D and 9G). In some cases the virgella does not have a droplet but is obtuse (*Pristiograptus* of *dubius* type have a sharply-ended virgella). The droplet is 0.1 mm in diameter and is a little thicker than the virgella itself. The virgella of *P. virbalensis* is twice as long as that of *P. auctus. P*. cf. *auctus* with a very short virgella and with a small "bubble" at its end was found in the Sutkai-87 borehole (Fig. 8C, F); this "bubble" does not exceed 0.2 mm in diameter. The thickness of the virgella is about 0.1 mm, so the thickening to

0.4–0.5 mm is marked. Locally there are degenerate examples of *P. virbalensis* (Fig. 8B, E). They have a thickened virgella end, but the diameter of the droplet does not exceed 0.25 mm. Rickards (1965), described about 40 specimens of *P. auctus*, so it is inconceivable that all these are degenerate. There are *Pristiograptus* with similar virgellae to *P. virbalensis* from the R. Ulst collection (Latvia). Jepsson's graptolite collection from Gotland also includes *P. auctus*, but these do not have a 0.4–0.5 mm thickening at the end of the virgella and so are atypical.

P. virbalensis is also found in the Holy Cross Mountains (Radzevičius, 2003*a*) in the *praedeubeli–ludensis* biozones. It occupies a different stratigraphical position to *P. auctus* and *P. virbalensis*. *P. virbalensis* is found in the *virbalensis–deubeli* (= *praedeubeli–deubeli*) biozones, while *P. auctus* is restricted to the *nilssoni* Biozone. According to Jaeger (1991), *P. auctus* ranges from the upper part of the *praedeubeli* Biozone to the middle of the *vulgaris–gerhardi* (= *ludensis*) interval. Jaeger's *P. auctus* was found in a similar interval to *P. virbalensis*. Therefore it is unlikely that *P. virbalensis* is a subspecies of *P. auctus*, on which more detailed studies are needed.

P. jaegeri is attributed to the *virbalensis* group, as noted above. In *P. jaegeri* the apertural part of the two first thecae with the free part of the neighbouring thecae makes an obtuse angle (Lenz and Kozłowska-Dawidziuk, 2002). This angle in *P. virbalensis* is also obtuse (Radzevičius and Paškevičius, 2000), becoming a right angle in the medial and distal parts. The thecae of *P. jaegeri* are inclined at 40° (Holland *et al*., 1969). Those of *P. jaegeri* from Arctic Canada are inclined at 20° in the proximal, and at 30° in the distal part (Lenz and Kozłowska-Dawidziuk, 2002). The thecae of *P. virbalensis* are

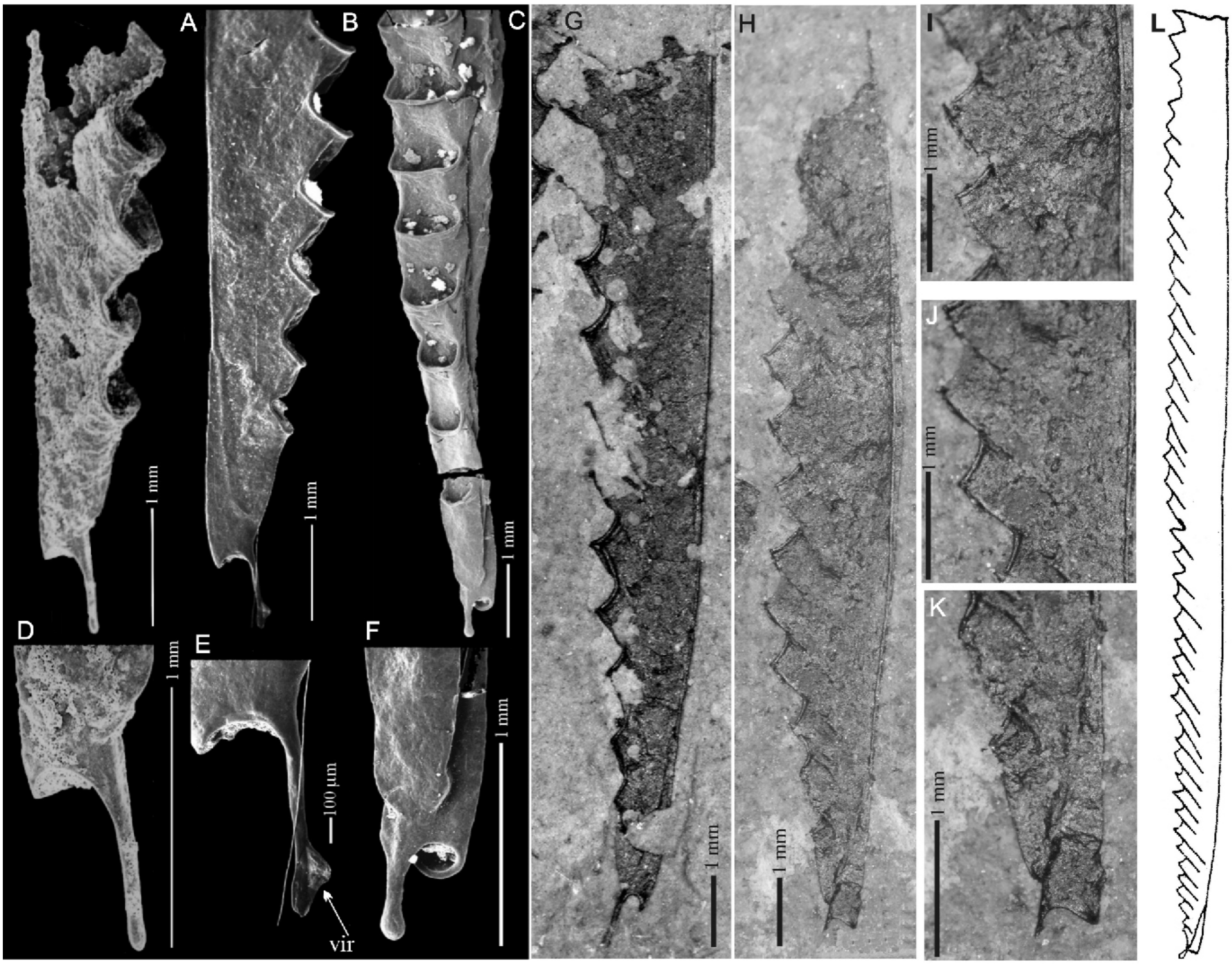

Fig 8. *P. virbalensis* group from Lithuania near the Wenlock-Ludlow boundary

A, **D** — *Pristiograptus virbalensis* Paškevičius; Sutkai-87 borehole, depth 768.2 m, P.S87-121a, *praedeubeli* Biozone, A — general view, D — proximal end of rhabdosome; **B**, **E** — *P. virbalensis*; Sutkai-87 borehole, depth 877 m, P.S87-382, *praedeubeli* Biozone, B — general view, E — mouth of sicula with abnormal virgella (vir); **C**, **F** — *Pristiograptus* cf. *auctus*? Rickards; Sutkai-87 borehole, 768.2 m depth, P.S87-362, *deubeli* Biozone; C — general view, F — proximal end of rhabdosome; **G** — *P. virbalensis*; Virbalis-5 borehole, depth 1026.75 m, holotype, no. 920, *praedeubeli* Biozone; **H**, **I**, **J**, **K** — *P. jaegeri* Holland, Rickards et Warren; Vilkaviškis-131 borehole, depth 1073.2 m, 8004, *deubeli* Biozone; H — general view, I — distal part, J — medial part, K — proximal part; **L** — *P. auctus* Rickards (1965) holotype, HUR./7W/46, text-fig. 2h, *nilssoni–scanicus* Biozone; in the original picture (Rickards, 1965) neither the scale nor the magnification is given

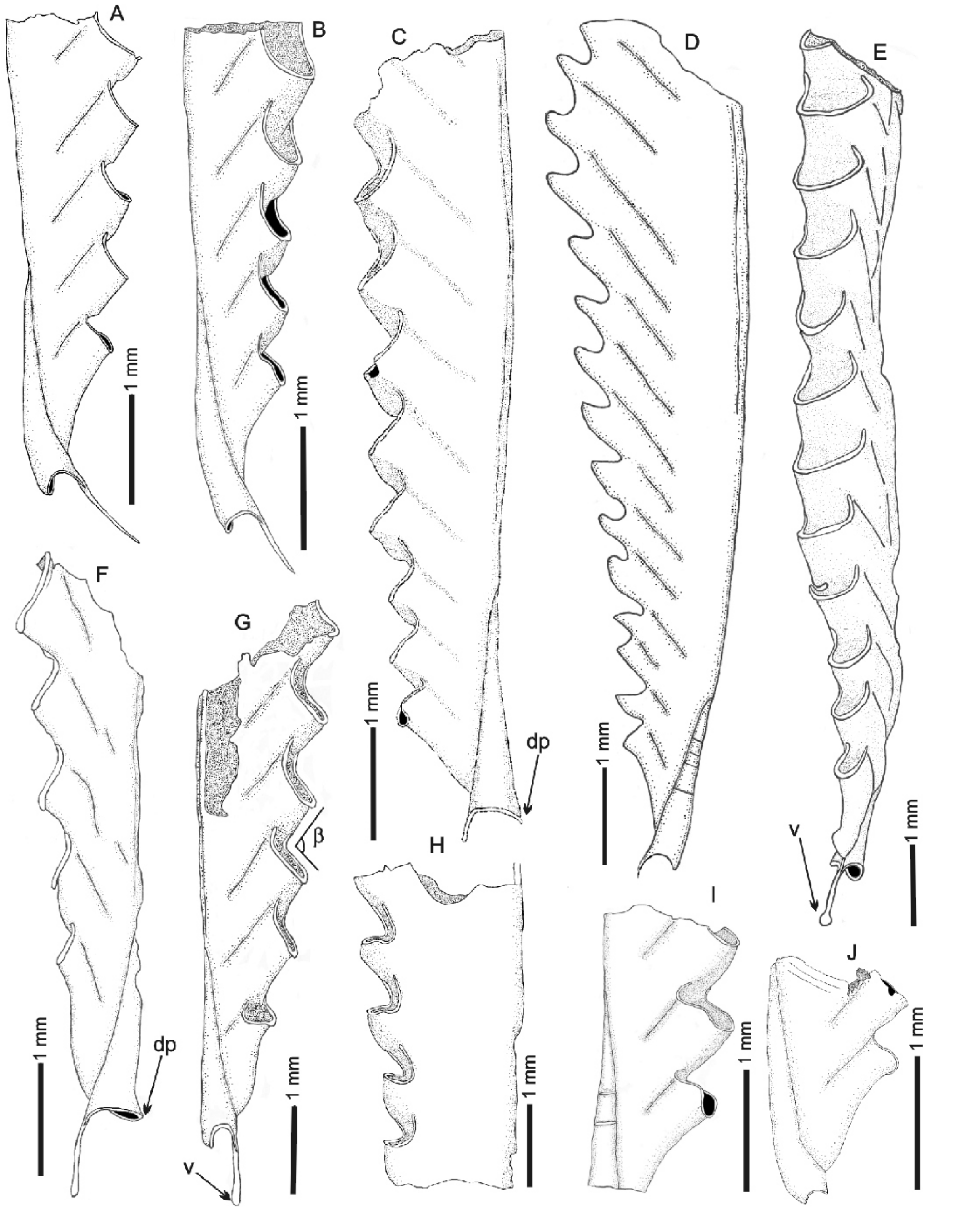

Fig. 9. Drawings of monograptids from Lithuania and the Holy Cross Mts. near the Wenlock-Ludlow boundary

A — *Pristiograptus praedeubeli* (Jaeger); Šiupyliai-69 borehole, 994.1 m depth, *praedeubeli* Biozone, S.S69-34; **B** — *P. praedeubeli*; Šiupyliai-69 borehole, 992 m depth, *praedeubeli* Biozone, S.S69-80; **C** — *P. deubeli* (Jaeger) with distinct dorsal process (dp); Vilkaviškis-131 borehole, 1069.2 m depth, *deubeli* Biozone, S.V131-378; **D** — *Colonograptus gerhardi* Kühne; Holy Cross Mts., outcrop A06, *nilssoni* Biozone, SV-06-2; **E** — *P.* cf. *auctus* Rickards with virgella nub (v); Sutkai-87 borehole, 769.2 m depth, *praedeubeli* Biozone, no P.S87-126; **F** — *P. virbalensis* with distinct dorsal process (dp); Sutkai-87 borehole, 769.2 m depth, *praedeubeli* Biozone, P.S87-125; **G** — *P. virbalensis* with virgella nub (v), apertures angle (β) — the angle between the thecal apertural lip and the succeeding metathecal wall; Pašaltuonis-143 borehole, 765.3 m depth, *praedeubeli* Biozone, S.P143-181; **H** — *C. gerhardi*; Šiupyliai-69 borehole, 976.7 m depth, *ludensis* Biozone, S.S69-285; **I** — *P. deubeli* with broken sicula; Šiupyliai-69 borehole, 982.6 m depth, *deubeli* Biozone, S.S69-348; **J** — *C. gerhardi*, Šiupyliai-69 borehole, 976.7 m depth, *ludensis* Biozone, S.S69-285a

inclined at 30° in the proximal and at 40° in the distal part of rhabdosome (Paškevičius, 1974). The rhabdosome of *P. jaegeri* (found in Lithuania) suddenly widens over the fourth theca (Fig. 8H). The free part of the sixth theca is noticeably smaller than that of the other thecae. *P. jaegeri* from Arctic Canada looks similar to this (Lenz and Kozłowska-Dawidziuk, 2002, pl. 17, fig. 6). The sicula of *P. jaegeri* is similar to the sicula of *Pristiograptus virbalensis* type and is close to the *dubius* type, but not to the *deubeli* (*ludensis*) type. This species differs slightly from other pristiograptids of virbalensis type. The virgella of the *virbalensis* type is obtuse while that of *P. jaegeri* is sharp, but massive. Lenz (Lenz and Kozłowska-

Dawidziuk, 2002) attributes *P. jaegeri* to the group type (*dubius*/*jaegeri*), emphasising that this species is intermediate between *P. dubius* and *P. praedeubeli*. *P. jaegeri* is found in the upper part of the *lundgreni* Biozone to the *nilssoni* Biozone in North Wales (Holland *et al*., 1969). In Arctic Canada this species is found in the *nassa–dubius–ludensis* interval (Lenz and Kozłowska-Dawidziuk, 2002). Ulst (1974) described *Pristiograptus* sp. *A in Latvia and considered it to be P. jaegeri*. The appearance of *P.* sp. A. coincides with the extinction of *G. nassa*. This species (*P.* sp. A) disappeared before the appearance of *N. nilssoni* and *Monograptus uncinatus*. While investigating Ulst's collection of graptolites autor concluded that some *P*. sp. A. specimens are *P. praedeubeli*. In Lithuania *P. jaegeri* is found in the *deubeli* Biozone in the Vilkaviškis-131 borehole.

The pristiograptids of the *virbalensis* group evolved from, those of *dubius* type at the beginning of the *praedeubeli* Biozone. The virgella of dubius type pristiograptids became more massive and thicker at the end of the *nassa* Biozone. The *praedeubeli* Biozone includes *P. virbalensis* possessing an obtuse virgella with a clear drop-shaped thickening at its end, similar to that of *P. auctus*. It is possible that *P. auctus* evolved from *P. virbalensis* at the beginning of Ludlow time. In *deubeli* Biozone some *P. virbalensis* specimens have distinctly wider sicula apertures (Fig. 9F), resembling the funnel shape of *P. deubeli*, but they are smaller. The other morphological features are similar to *P. virbalensis*.

CONCLUSION

The graptolite assemblages around the Wenlock-Ludlow boundary in Lithuania (west part of Baltica) and the Holy Cross Mountains (Małopolska Block, Kielce Unit) are very similar. The following graptolite biozones may be recognized in Lithuania and the Holy Cross Mountains: *lundgreni*, *parvus* (except for the Holy Cross Mts.), *nassa*, *praedeubeli*, *deubeli*, and *ludensis*. The upper boundary of the *lundgreni* Biozone is marked by the extinction of *C. lundgreni*, *P. pseudodubius* and *M. f. flemingi*. *M. t. testis* and *P. lodenicensis* disappear earlier than *C. lundgreni* in Lithuania. There is a graptolite-free interval (attributed to the *parvus* Biozone) about 2 m thick between the last *C. lundgreni* and the first *P. parvus*. We may correlate this graptolite-free interval with the "interval with trilobites" in the Holy Cross Mountains and with the Bara Oolite in Gotland.

The *virbalensis* group of *pristiograptids* is present at the Wenlock-Ludlow boundary in Lithuania and the Holy Cross Mts. Three species of the *virbalensis* group are found in the *nassa–nilssoni* biozones: *P. jaegeri*, *P. virbalensis* and *P. auctus*. *P. virbalensis* may be interpreted either as an independent taxon, or as a subspecies of *P. auctus*. Variations of *P. virbalensis* (sicula with dorsal process, short virgella) are found at the end of the *praedeubeli* Biozone and the *deubeli* Biozone, representing the evolution of short-lived group.

Acknowledgements. Prof. J. Paškevičius (Vilnius University, Lithuania) is thanked for valuable comments during the preparation of the paper. Dr. P. Raczyński (Wrocław University) helped with collecting graptolites in the Holy Cross Mountains; prof. L. Jeppsson (Lund University) shared his collection of graptolites from Gotland; dr. A. Čečys and T. Miyazu (Lund University) helped in photographing graptolites by SEM. J. Stasevičiūtė–Radzevičienė and dr. J. Zalasiewicz (University of Leicester) are acknowledged for improvement of the English of the manuscript. The research was supported by the Estonian Ministry of Education and Research (No. 0182531s03), the Estonian Science Foundation (grant No. 6460) and the Swedish Institute. The efforts of the reviewers of this paper, dr A. Kozłowska (Warszawa) and an anonymous reviewer, are highly appreciated.

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