Ordovician-Silurian boundary graptolites of the Southern Alps, Austria

PETR ŠTORCH & HANS-PETER SCHÖNLAUB

Seven species of graptoloid graptolites are described from Hirnantian and lower Rhuddanian formations of the Austrian part of the Carnic and western Karavanke Alps. The Plöcken Formation, of latest Ordovician (Hirnantian) age, yields the biozonal index graptolite *Metabolograptus persculptus* in the Cellon Reference Section and, tentatively, the Feistritzgraben Section. A distinctive graptolite assemblage indicating an earliest Silurian (early Rhuddanian) age comes from the Waterfall Section near Zollnersee Hütte. Along with the presence of the biozonal index *Parakidograptus acuminatus* and accompanying taxa, common *Rickardsograptus*? *bifurcus* (Ye) has been recorded – for the first time outside China. The absence of *Neodiplograptus lanceolatus* Štorch & Serpagli, *Normalograptus trifilis* (Manck) and other easily recognizable lowermost Rhuddanian species which are dominant in this level throughout peri-Gondwanan Europe indicates the peculiar character of the *acuminatus* Biozone assemblage encountered in the Carnic Alps. • Key words: graptolite, biostratigraphy, palaeobiogeography, Hirnantian, Rhuddanian, Southern Alps, Austria.

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Petr Štorch, Institute of Geology v.v.i., Academy of Sciences of the Czech Republic, 165 00 Praha 6, Czech Republic; storch@gli.cas.cz • Hans-Peter Schönlaub, Austrian Academy of Science, Center for Geosciences, Dr. Ignaz Seipel-Platz 2, 1010 Vienna (Austria); hp.schoenlaub@aon.at

The Carnic Alps of Southern Austria and Northern Italy (Fig. 1) represent one of the few places in the world where an almost continuous and biostratigraphically well-constrained sequence of Palaeozoic rocks is preserved. Nearly complete successions of Upper Ordovician to Permian marine sedimentary rocks, representing shallow shelf carbonates to deeper-water dark siliceous shales including flysch deposits in the Carboniferous, are exposed in a series of closely spaced thrust sheets. They form part of the Peri-Gondwanide terranes and arcs similar to Avalonia, Armorica-Iberia, Perunica and others which formed originally around the northern margin of Gondwana. The splitting of the latter supercontinent in the Early Ordovician resulted in a rapid northward drift of continental fragments which successively collided and accreted with Laurentia and Baltica, respectively, starting in the Devonian and ending in the Early to Late Carboniferous Variscan Orogeny. Consequently, the microplate named the Apulia Terrane, of which the Southern Alps were a part, has a long-term drifting history from a moderately cold climate of approximately 50° southern latitude in the Ordovician to the equatorial belt in the Permian (Schönlaub 1992).

With regard to Lower Palaeozoic correlation, the Carnic Alps is a key area along the northern margin of Gondwana. For example, the world-famous Cellon Section has been a reference for the Upper Ordovician to Lower Devonian conodont biozonation (*e.g*., Walliser 1964, Kleffner 1995), the occurrence of the late Ordovician Hirnantia fauna (Jaeger *et al*. 1975), evaluation of Silurian global eustatic sea-level changes (Brett *et al*. 2009, Johnson 2010), correlation of Lower Palaeozoic K-bentonites (Histon *et al*. 2007) and isotope chemostratigraphy (Wenzel 1997).

For this paper, the previously scattered records of uppermost Ordovician (Hirnantian) and lowermost Silurian (lower Rhuddanian) graptolites encountered from several sections throughout the Austrian part of the Southern Alps (namely the Carnic and Karavanke Alps) have been revised and supplemented by new data in order to reach higher resolution in local and global biostratigraphical correlation and chronology of past environmental changes. The presence of an exotic graptolite of Chinese provenance and the peculiar composition of the lowermost Rhuddanian faunal assemblage of the Carnic Alps pose new questions that challenge present knowledge of graptolite distribution and palaeobiogeography.

Sections

The Cellon Section (UTM coordinates 33T, E342386, N5163763, GPS coordinates N 46°36´ 32˝, E 12°56´ 30˝)

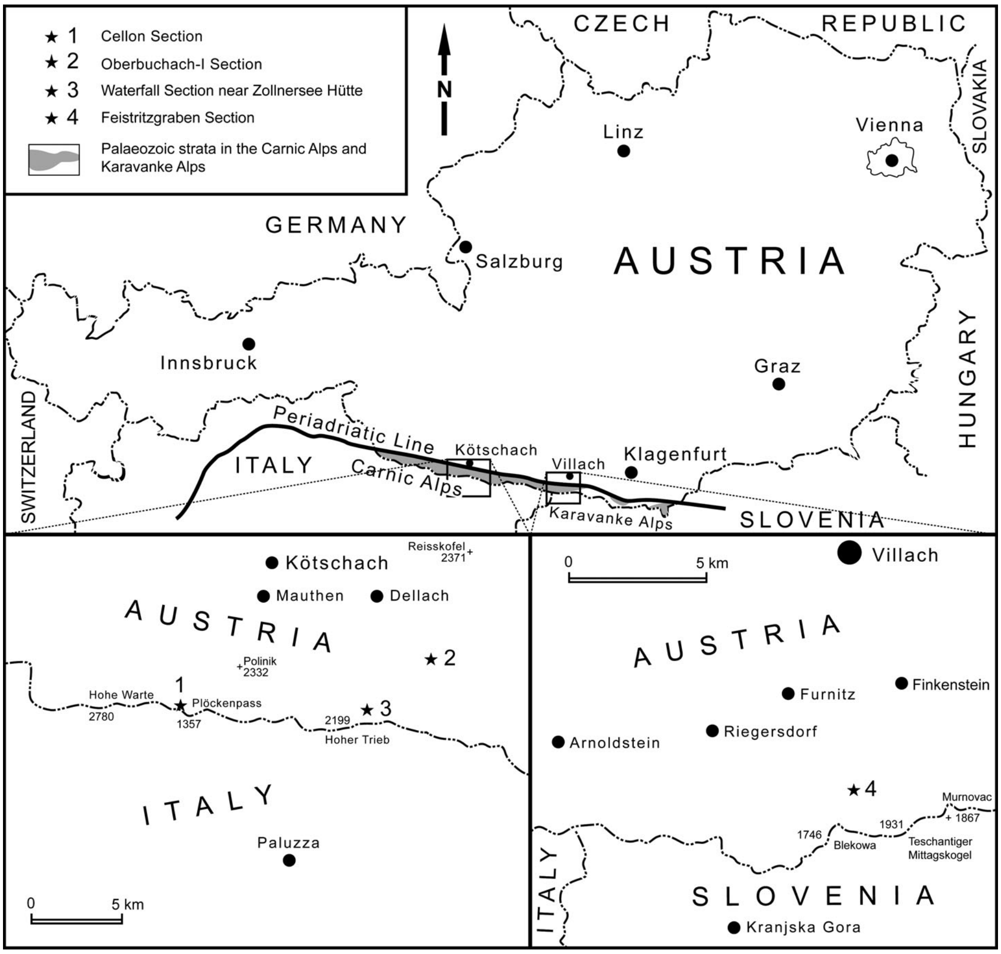


Figure 1. Map showing simplified distribution of Palaeozoic outcrops in the Austrian part of Southern Alps. Note the Periadriatic Line – late Alpine lineament which forms a division between the Adriatic subplate and the European foreland and separates the Carnic Alps and the Karavanke Alps (Southern Alps) from the Eastern Alps in the north. Fossiliferous Ordovician-Silurian boundary sections discussed in this paper are located on two insets.

is located at an altitude between 1480 m and 1560 m on the eastern face of the Cellon mountain in the central Carnic Alps, SSW of the village of Kötschach-Mauthen, close to and accessible from the Austrian/Italian border (Fig. 1) at Plöcken Pass. The section ranging from the Upper Ordovician to the lower Carboniferous is exposed in a narrow avalanche gorge. Previous studies on different faunas and in particular on conodonts (see Schönlaub *et al.* 2011) make it an ideal place for the study of faunal changes across the Ordovician/Silurian boundary and through the Silurian. The bedded argillaceous Uggwa Limestone, 4.11 m thick (Bed Nos 1–4: after Walliser 1964), is overlain by 20 cm of greenish siltstone and 25 cm of marlstone (Bed 4A of Walliser *l.c.*). This is succeeded by 40 cm thickness of greenish siltstone. Schönlaub *et al.* (2011) assigned the whole package to the Uggwa Limestone Formation (Fig. 2). This sequence of strata is separated from the overlying Plöcken Formation by a disconformity. The latter formation begins with a 77 cm thick greyish siltstone that is intercalated with muddy-limestone lenses (Bed No. 5 of Walliser) with a *Hirnantia* brachiopod fauna, the trilobite *Mucronaspis* and rare specimens of the biozonal index graptolite *Metabolograptus persculptus* (Elles & Wood). Higher up, the Plöcken Formation continues with 5.40 m thick pyritiferous limestones and sandstones (Bed Nos 6–8).

The Oberbuchach I-Section (UTM coordinates 33T, E355221, N5165485, GPS coordinates N 46°37´ 38˝, E 013°06´ 32˝) is located at an altitude of 1120 m, south of the village of Gundersheim in the Gail Valley. The section is exposed in the roadcut on the western and southwestern side of small road running from the Gail Valley near Gundersheim to Gundersheim Alm (see also Jaeger & Schönlaub 1980, Schönlaub & Kreutzer 1994). Poorly bedded silty shales and muddy sandstones, 10–11 m thick, are assigned to the Plöcken Formation which terminates with pyrite-bearing sandstones exposed where the road bends. A shaly horizon 50 cm below the top of the Plöcken Formation yields uncommon rhabdosomes of *Normalograptus* cf. *transgrediens* (Waern). The pyrite-bearing sandstone is disconformably overlain by a 0.5 m to 1 m thick bed of quartzite which subsequently passes upwards through laminated dark-grey silty micaceous shale into black graptolitic shale. At the Oberbuchach-I Section we did not find the middle Rhuddanian *Cystograptus vesiculosus* (Nicholson, 1868) reported by Jaeger & Schönlaub (1977) and Schönlaub (1988) from the westward situated

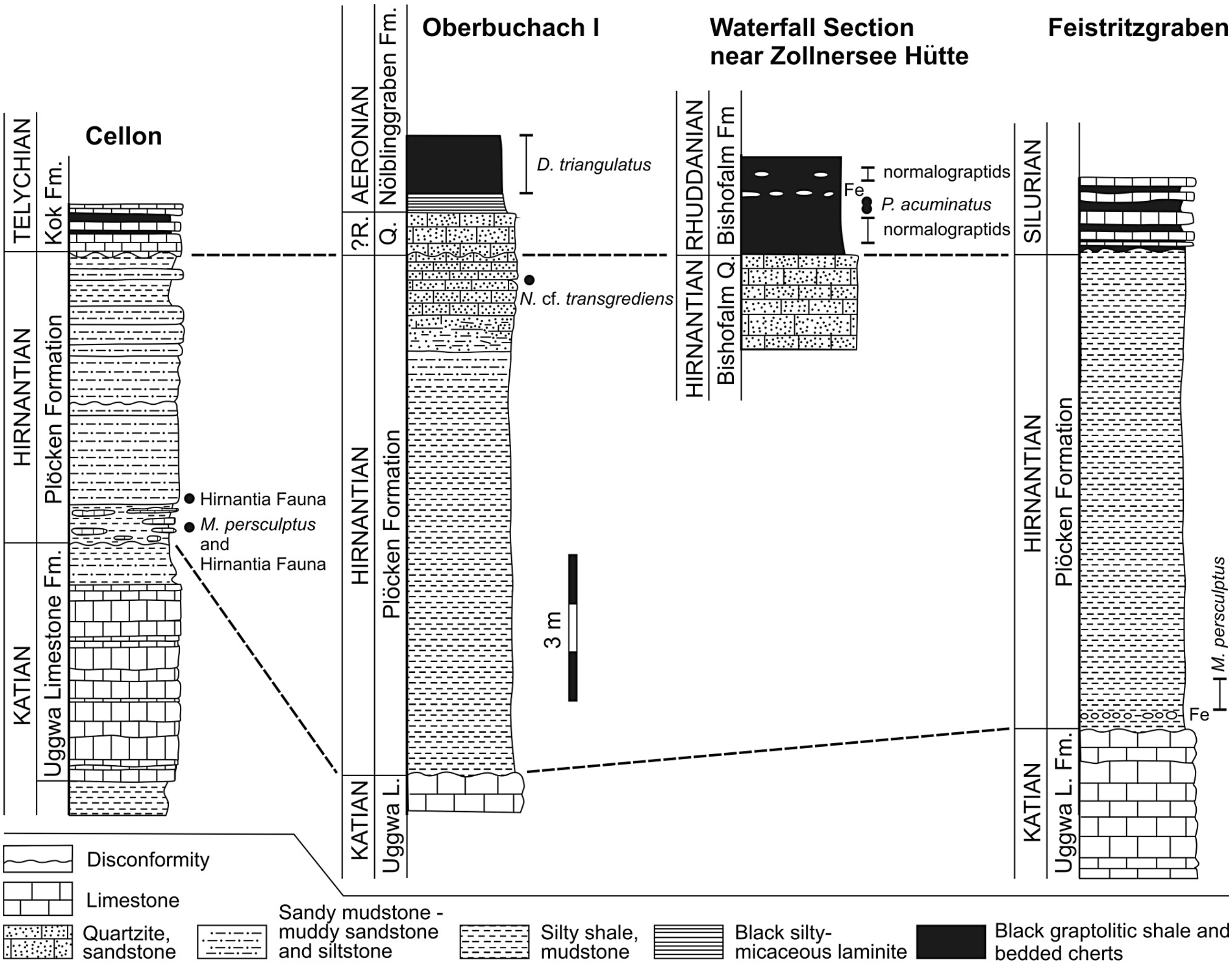


Figure 2. Ordovician-Silurian boundary sections in the Carnic Alps – fossil record and correlation. Abbreviations: Q – basal quartzite at Oberbuchach I, Fe – pyrite nodules and lenticular beds, ?RH – probable Rhuddanian age, D. – *Demirastrites*, M. – *Metabolograptus*, N. – *Normalograptus*, P. – *Parakidograptus*.

Nölblinggraben Section but confirmed the presence of a rich assemblage of the lower *Demirastrites triangulatus* Biozone (lowermost Aeronian) in the black shale succession, *ca* 30 cm above the basal quartzite.

The Feistritzgraben Section (UTM coordinates 33N, E411235, N5153490, GPS coordinates N 46°31´ 40˝, E 013°50´ 36˝) is exposed at an altitude of some 930 m, southwest of the village of Finkenstein on Austrian map sheet No. 201 or UTM sheet No. 3118, respectively. Detailed descriptions are provided by Schönlaub (1971) and Jaeger *et al*. (1975). The section comprises some 3 m of shale (slate) which is overlain by the typical Upper Ordovician Uggwa Limestone reaching a thickness of 6.50 m. It contains a conodont assemblage of the *Amorphognathus ordovicicus* Biozone, widely represented in other coeval strata of the Carnic Alps. This limestone unit is succeeded by *ca* 10 m of black siltstones, calcareous sandstones and laminated arenaceous shales and slates which resemble the Plöcken Formation at the Cellon section. The critical interval immediately above the limestone unit comprises black graphitic slates, sheared and affected by small scale folds, which are rich in deformed graptolite rhabdosomes. Rare brachiopods have been encountered [*Eostropheodonta*? *hirnantensis* (M'Coy)] in addition to a monospecific assemblage of *Metabolograptus persculptus* (Elles & Wood). Globular nodules of pyrite, up to 20 mm in diameter, are common in the slate. This distinct package of rocks is overlain by interbedded black platy limestones and slates which presumably are early Silurian in age although index fossils have not yet been found.

The Waterfall Section near Zollnersee Hütte (UTM coordinates 33N, E352340, N5163175, GPS coordinates N 46°36´ 23˝, E 013°04´ 19˝) is located at an altitude of 1680 m to 1700 m. The exposure is at the base of a 25 m high waterfall below the alpine road from Rösser Hütte to Ochsenalm (Fig. 1). The massive Bischofalm Quartzite crops out at the top of the overturned sequence. The quartzite is succeeded by a succession of layered black cherts with subordinate interbeds of cherty shales; both are rich in pyrite. A lenticular bed of massive pyrite is developed *ca* 130 cm stratigraphically above (actually below in the exposure) the quartzite. Several thin pyrite beds and nodules are scattered throughout the whole thickness of the black cherty succession. Poorly preserved normalograptid rhabdosomes occur in cherts 40–70 cm stratigraphically above (actually below in the exposure) the top of the quartzite. The first determinable graptolites, including *Parakidograptus acuminatus* (Nicholson), came from a cherty shale 92 cm above the quartzite and then, still better preserved, at 100–102 cm (Fig. 2). The graptolites described in this paper came from these two levels. Poorly preserved normalograptids occur also 160 cm stratigraphically above the quartzite. Some bedding planes are covered also by sponge spicules. The further succession is interrupted by a fault *ca* 180 cm above the quartzite and continues with massive black cherts that did not yield any graptolites.

Stratigraphy and correlation

Uppermost Ordovician graptolites were first reported in the Southern Alps by Jaeger *et al*. (1975) from the Feistritzgraben Gorge (see also Schönlaub 1988), from the lowermost Plöcken Fm. just above the Uggwa Limestone. Abundant graptolite rhabdosomes, confined to a black slate rich in globular pyrite and affected by tectonic strain, were tentatively assigned to *Glyptograptus persculptus* (Salter) (= *Metabolograptus persculptus* (Elles & Wood) of present usage). Poorly preserved specimens of the upper Hirnantian biozonal index graptolite *Metabolograptus persculptus*, however, can be easily confused with its likely ancestor *Metabolograptus ojsuensis* (Koren' & Mikhaylova), which is common in the lower Hirnantian *Metabolograptus extraordinarius* Biozone. Hence, the late Hirnantian age of this graptolite occurrence must be considered with some reservation.

Uncommon, but better preserved specimens, assignable with confidence to *Metabolograptus persculptus*, co-occur with the *Hirnantia* fauna in greyish siltstones of the lowermost Plöcken Fm. in the Cellon Section. This association is assignable to the upper Hirnantian *Metabolograptus persculptus* Biozone.

In the Oberbuchach-I Section, a thin silty-shaly intercalation high in the Plöcken Formation yielded several poorly to moderately well preserved rhabdosomes of *Normalograptus* cf. *transgrediens* (Waern). *Normalograptus transgrediens* (Waern) is known from the upper *persculptus* Biozone (Davies 1929), the post-*persculptus* pre-*ascensus* interval (Koren' *et al*. 2003), tentatively from the *acuminatus* Biozone (Davies 1929, Waern 1948, Howe 1982), and also from the *vesiculosus* Biozone (Loydell 2007). The biostratigraphical significance of this monospecific normalograptid assemblage is rather limited although the same species, referred to *Normalograptus* cf. *transgrediens*, is common in the definite *acuminatus* Biozone in the Waterfall Section near Zollnersee Hütte. Similar monospecific normalograptid occurrences are known from shaly interbeds within the post-glacial, late Hirnantian through to Llandovery Los-Puertos Quartzite (Gutiérrez-Marco & Štorch 1998) and Criadero Quartzite (Štorch *et al*. 1998) in Spain. In the Oberbuchach-I Section the Plöcken Formation is topped by an apparent unconformity and succeeded by the so-called 'basal quartzite' which grades into the typical finely laminated graptolitic shale with abundant graptolites of the lowermost Aeronian *Demirastrites triangulatus* Biozone through at least 20 cm of silty-micaceous black shale without determinable graptolites. In the neighbouring Nölblinggraben Section (Jaeger & Schönlaub 1977, Schönlaub *et al*. 2011) the highest quartzite bed in the sequence is overlain by a silty black shale in which H. Jaeger found the middle Rhuddanian biozonal index graptolite *Cystograptus vesiculosus* and also abundant graptolites of the *triangulatus* Biozone (Jaeger & Schönlaub 1977, Schönlaub 1985).

At the Waterfall Section near Zollnersee Hütte a graptolite assemblage of early Rhuddanian (earliest Silurian) age is identified from an apparently overturned succession of black lydites and siliceous shales, *ca* 1 m below the massive Bischofalm Quartzite. Graptolites were first recorded by H. Jaeger (unpublished record noted by Schönlaub 1988). The assemblage includes *Parakidograptus acuminatus* (Nicholson), *Normalograptus ajjeri* (Legrand), *Normalograptus* cf. *transgrediens* (Waern), *Glyptograptus* aff. *tamariscus* (Nicholson), *Rickardsograptus lautus* (Štorch & Feist) and *Rickardsograptus*? *bifurcus* (Ye) and can be assigned with confidence to the *Parakidograptus acuminatus* Biozone. The assemblage, however, is rather peculiar since several abundant and morphologically distinct taxa typical of lower Rhuddanian assemblages in other Peri-Gondwanan sections are missing [*e.g. Neodiplograptus lanceolatus* Štorch & Serpagli, 1993 and *Normalograptus trifilis* (Manck, 1923), see Štorch (1996)] whereas *R.*? *bifurcus*, previously known only from China, is new to Europe.

Systematic palaeontology

All specimens are flattened and more or less deformed by a tectonic strain which is almost negligible at Cellon but strongly affects rhabdosomes from the Feistritzgraben Section. The pyrite-rich black chert and siliceous shale from the Waterfall Section near Zollnersee Hütte may undergo complete decomposition into small sub-millimetre cubes, when kept in wet conditions or photographed in water. This is how we lost rich material collected during a previous field campaign in 2001. Therefore the new material, collected in 2010, was photographed only in alcohol. Specimens prefixed GBA are housed in the Dept of Palaeontology and Collections of the Geologische Bundesanstalt, Vienna. Graptolite genera are used as in the recent phylogenetic analysis by Melchin *et al*. (2011).

Genus *Normalograptus* Legrand, 1987, emend. Melchin *et al*., 2011

Normalograptus ajjeri **(Legrand, 1977)**
Figures 3A, B, ?D, ?O, 4E, F

1977 *Climacograptus* (*Climacograptus*) *normalis ajjeri* nov. subsp.; Legrand, p. 171, text-figs 9A–D, 10A–B.
2007 *Normalograptus ajjeri* (Legrand, 1977). – Loydell, pp. 29, 30, text-figs 12G, 15A–F, H, I, O (see for full list of references and discussion).

Material and stratigraphical range. – 4 flattened rhabdosomes from the *acuminatus* Biozone at the Waterfall Section near Zollnersee Hütte.

Description. – Medium-sized normalograptid, gently widening from 0.8–0.85 mm at the first thecal pair through 1.2–1.3 mm at the fifth thecal pair to the maximum of 1.5–1.6 mm attained at *ca* th10. The median septum of the present specimens is complete, although proximal details are not recognizable due to poor preservation. The rhabdosome is furnished with a thread-like virgella and distally projecting nema. Strongly geniculated thecae exhibit parallel-sided supragenicular walls and thecal apertures opening into prominent semicircular excavations. 2TRD increases from 1.55–1.6 mm at th5 to 1.6–1.8 mm distally.

Discussion. – Several normalograptid rhabdosomes found in the *acuminatus* Biozone of the Waterfall Section agree well with *N. ajjeri* (Legrand) in rhabdosome outline, width and thecal spacing (2TRD). The present specimens are considerably narrower than rhabdosomes of *Normalograptus normalis* (Lapworth, 1877) or *N. medius* (Törnquist, 1897), less tapering than *N. transgrediens* (Waern, 1948), and have thecae more densely spaced than those in *N. premedius* (Waern, 1948). *N. angustus* (Perner, 1895) and *N. mirnyensis* (Obut & Sobolevskaya *in* Obut *et al*., 1967) are narrower; the former can be recognized also by its greater thecal spacing.

Normalograptus **cf. *transgrediens*** **(Waern, 1948)**
Figures 3C, 4L, M, 5E

cf. 1929 *Climacograptus scalaris*-*C. medius* transient; Davies, pp. 8, 22; figs 28, 31.
cf. 1948 *Climacograptus scalaris* His., v. *transgrediens* n. var.; Waern, p. 462, pl. 26, figs 2, 3.
cf. 1982 *Climacograptus transgrediens* Waern. – Howe, pl. 1, figs a, b.
cf. 2003 *Normalograptus transgrediens*. – Koren' *et al*., text-fig. 3, fig. 15.
cf. 2007 *Normalograptus transgrediens* (Waern, 1948). – Loydell, pp. 45, 46, text-fig. 16M.

Material and stratigraphical range. – 15 flattened rhabdosomes from the *acuminatus* Biozone at the Waterfall Section near Zollnersee Hütte, 5 flattened rhabdosomes from silty-shaly intercalations in the upper part of the Plöcken Formation at the Oberbuchach-I Section, either *persculptus* or *acuminatus* Biozone.

Description. – Septate rhabdosome widening gradually from 0.55–0.8 mm at the first thecal pair to 1.0–1.3 mm at the tenth thecal pair. The maximum width is partly influenced by tectonic strain, and ranges from 1.0 mm to 1.5 mm. Sharply geniculated thecae with supragenicular walls parallel or slightly inclined to the rhabdosome axis are densely spaced: 2TRD is 1.5–1.6 mm at th5 and 1.7–1.95 mm distally. Thecal apertures, generally perpendicular to the rhabdosome, open into semicircular excavations.

Discussion. – The most common normalograptid at both the Waterfall Section and Oberbuchach-I Section resembles *Normalograptus transgrediens* (Waern) in having a proximally tapering rhabdosome and closely spaced thecae. In *N. transgrediens*, however, the distal width is still greater and is attained at later thecae. Hence the present, inadequately preserved material has been assigned to *N.* cf. *transgrediens. N. mirnyensis* (Obut & Sobolevskaya *in* Obut *et al*., 1967) and *N. larini* Koren' & Melchin, 2000 can be distinguished by their generally narrower and less tapering rhabdosomes which attain their maximum width at earlier thecae. Their thecae are also more densely spaced (2TRD is 1.2–1.55 mm proximally and 1.35–1.75 mm distally) than those in the present specimens. *N. angustus* (Perner, 1895) can be distinguished by its less tapering, generally narrower rhabdosome and more widely spaced thecae (2TRD *ca* 2.0 mm).

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

Metabolograptus persculptus **(Elles & Wood, 1907)**
Figure 5C, D, ?A, B

1865 *Diplograptus persculptus* (Salter); Salter, p. 25 (see Strachan 1971).

1907 *Diplograptus* (*Glyptograptus*) *persculptus* Salter; Elles & Wood, p. 257, pl. 31, fig. 7a–c; text-fig. 176a, b.

1975 *Glyptograptus* cf. *persculptus* (Salter). – Jaeger *et al*., pp. 281–283, pl. 1, figs 1–6.

1996 *Normalograptus persculptus* (Elles & Wood, 1907). – Štorch & Loydell, pp. 872–875, text-figs 3A–G, 4A–F, 5A–F (see for further references on *N. persculptus*).

2005 *Normalograptus persculptus* (Elles & Wood, 1907). – Chen *et al*., pp. 266–268, text-figs 5B, 9A, F, L (see for further references on *N. persculptus*).

2011 *Normalograptus persculptus* (Elles & Wood, 1907). – Štorch *et al*., pp. 376, 378; figs 25L, AA, 27E–H, 28C–E, tab. 26.

Material and stratigraphical range. – 5 flattened immature rhabdosomes from silty shale with Hirnantia fauna at Cellon Section, 20+ flattened specimens from black, heavily strained black slate at Feistritzgraben Section, both occurrences referred to the *persculptus* Biozone.

Discussion. – Moderately well preserved specimens from Cellon exhibit typical pattern H proximal development with $th1^1$ extending 0.2 mm below the sicular aperture before its abrupt turn upwards. The ascending part of $th1^1$ is 1.0–1.1 mm long. These rhabdosomes are *ca* 1.1 mm wide at the first thecal pair and 1.7 mm wide at the third thecal pair. 2TRD th2 is 1.7 mm. Proximal thecae are glyptograptid with strong genicula. The specimens from Feistritzgraben, although heavily affected by strain (*cf*. Fig. 5A and B), exhibit some characters, such as proximal development and thecal shape, allowing their tentative assignment to *Metabolograptus persculptus* (Elles & Wood) as proposed by Jaeger *et al*. (1975).

Genus *Rickardsograptus* Melchin *et al*., 2011

Rickardsograptus lautus (Štorch & Feist, 2008)

Figures 3P–R, 4H, I

1974 *Diplograptus* aff. *elongatus* Churkin & Carter, 1970. – Hutt, pp. 31, 32, pl. 5, figs 1, 2; text-fig. 9, fig. 12; text-fig. 10, fig. 3.

1983 *Diplograptus elongatus* Churkin & Carter, 1970. – Štorch, p. 168, pl. 3, fig. 6; pl. 4, fig. 5; text-figs 3C, D.

1996 *Neodiplograptus* cf. *elongatus* (Churkin & Carter, 1970). – Štorch, text-fig. 4b.

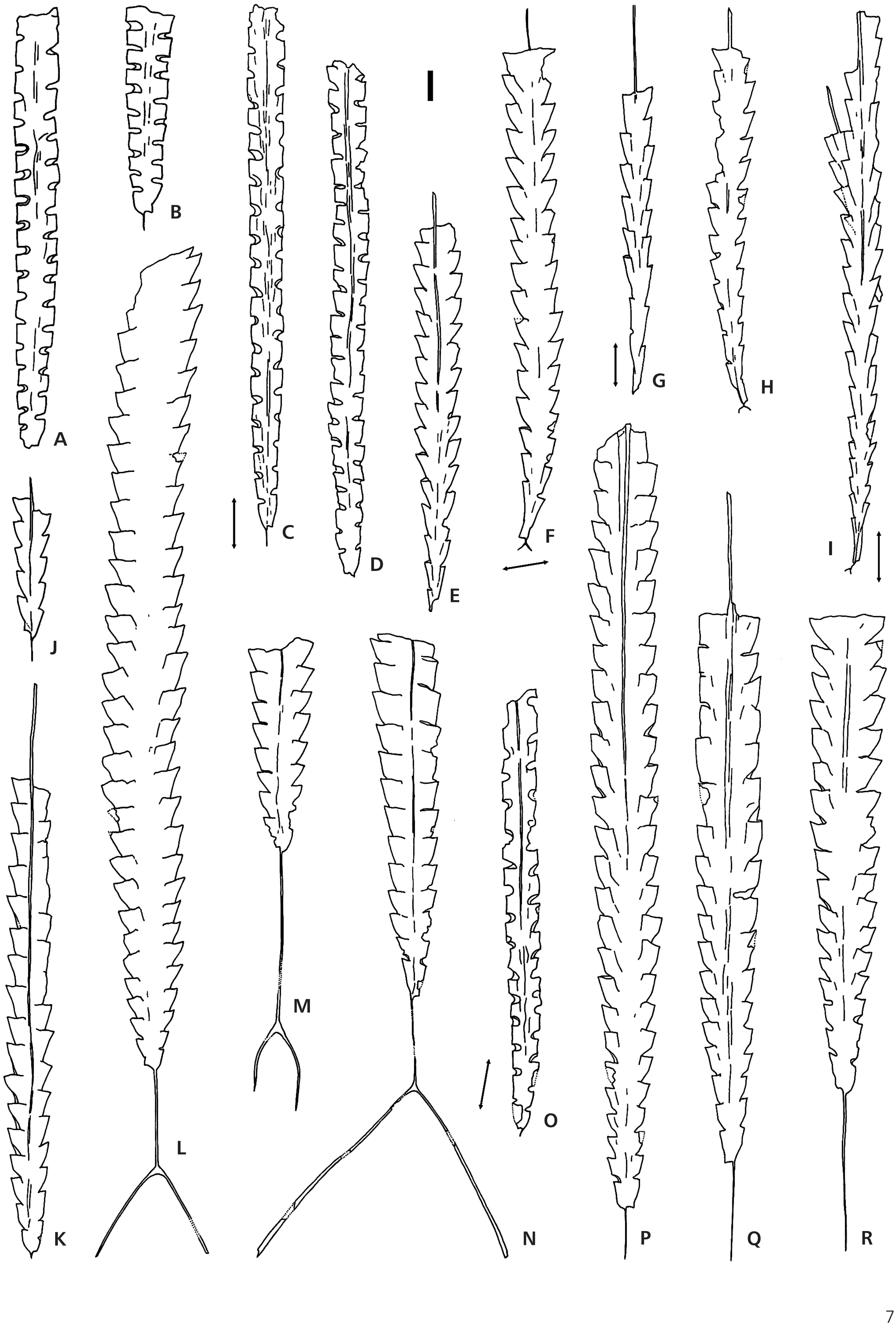
2008 *Neodiplograptus lautus* new species; Štorch & Feist, p. 948, text-fig. 6, figs 3, 6, 8, 9; text-fig. 10, figs 12, 13.

Material and stratigraphical range. – 9 flattened rhabdosomes from the *acuminatus* Biozone at the Waterfall Section near Zollnersee Hütte.

Description. – Rhabdosome up to 45 mm long, septate, widening from 0.9–1.1 mm at the level of the first thecal pair to a distal maximum of 2.3–2.5 mm (2.1–2.7 mm when affected by tectonic strain). DVW varies from 2.0 mm to 2.4 mm at the tenth thecal pair. Proximal astogeny of pattern H, corresponds with other species of *Rickardsograptus*. Thl^1 grows down before it turns up 0.2 mm below the sicular aperture. The upward growing part of thl^1 is *ca* 0.8 mm long. Virgella 1.7–9.5 mm long; robust nema projecting well beyond thecate part of the rhabdosome. Proximal thecae glyptograptid with blunt geniculum. Thecal geniculation weakens through the most rapidly widening mesial part of the rhabdosome; substantially overlapping distal thecae exhibit smooth, weakly expressed genicula. Thecal tube terminates with perpendicular or slightly introverted aperture. 2TRD is 1.3–1.6 mm at the level of the second thecal pair, 1.45–2.1 mm at the fifth thecal pair; distal 2TRD varies from 1.7 mm to 2.4 mm depending on orientation of the rhabdosome relative to the strain.

Discussion. – The maximum width is attained at the 12^{th}–14^{th} thecal pair – more gradually than in most other species referred to *Rickardsograptus* [*e.g. R. tcherskyi* (Obut & Sobolevskaya *in* Obut *et al*., 1967); *R. thuringiacus* (Kirste, 1919) and *R. mucroterminatus* (Churkin & Carter, 1970)] but more abruptly than in *Rickardsograptus elongatus* (Churkin & Carter, 1970) which also exhibits a particularly gradual change from more geniculated proximal to less geniculated distal thecae. The virgella is slender in all of the present specimens of *R. lautus* but its length (when complete) varies from 1.0 mm to 9.5 mm, which is greater variation than observed in topotypical material from Montagne Noire, France.

Figure 3. Lowermost Silurian graptolites from black lydites and siliceous shales of the Bischofalm Formation from the Waterfall Section near Zollnersee Hütte. • A, B, ?D, ?O – *Normalograptus ajjeri* (Legrand, 1977): A – GBA2012/004/0001, B – GBA2012/004/0006, D – GBA2012/004/0006, O – GBA2012/004/0003. • C – *Normalograptus* cf. *transgrediens* (Waern, 1948), GBA2012/004/0004. • E–I – *Parakidograptus acuminatus* (Nicholson, 1867): E – GBA2012/004/0019, F – GBA2012/004/0016, G – GBA2012/004/0005, H – GBA2012/004/0001, I – GBA2012/004/0002. • J, K – *Glyptograptus* aff. *tamariscus* (Nicholson, 1868): J –GBA2012/004/0011, K – GBA2012/004/0007. • L–N –*Rickardsograptus*? *bifurcus* (Ye, 1978): L – GBA2012/004/0013, M – GBA2012/004/0014, N – GBA2012/004/0021. • P–R – *Rickardsograptus lautus* (Štorch & Feist, 2008): P – GBA2012/004/0012, Q – GBA2012/004/0008, R – GBA2012/004/0020. All figures × 6. Thick scale bar represents 1 mm; thin bars with arrows indicate tectonic stretching direction.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***Rickardsograptus*? *bifurcus* (Ye, 1978)**
Figures 3L–N, 4B–D, K

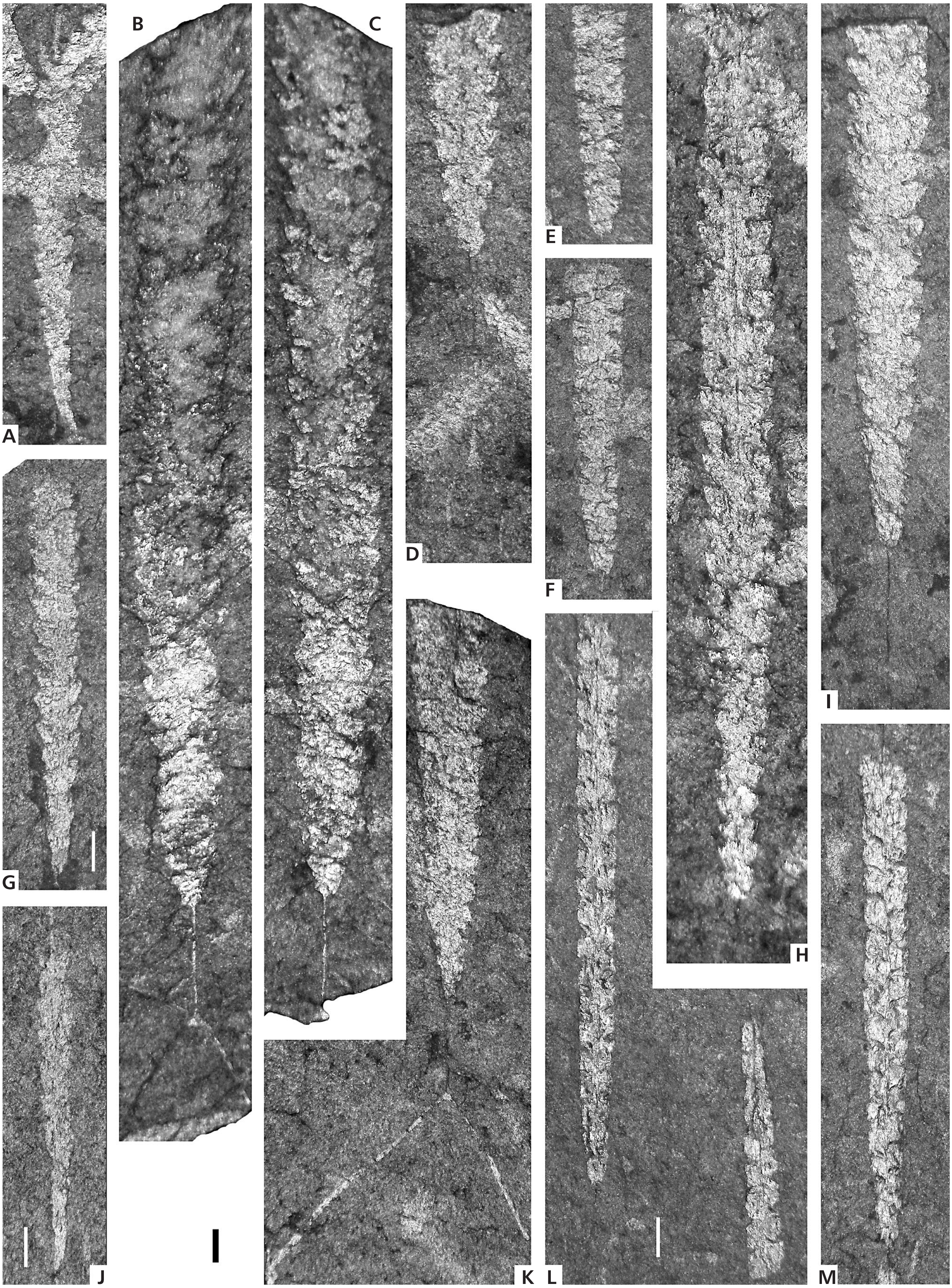
1978 *Glyptograptus bifurcus*; Ye, p. 455, pl. 174, fig. 7.
1990 *Glyptograptus bifurcus* Ye. – Fang *et al*., p. 54, pl. 5, fig. 5; pl. 10, fig. 6.
2002 *Glyptograptus bifurcus* Ye. – Mu *et al*., p. 158, pl. 158, fig. 4.

Material and stratigraphical range. – 12 flattened, mostly complete rhabdosomes from the *acuminatus* Biozone at the Waterfall Section near Zollnersee Hütte.

Description. – Robust septate rhabdosome widens from 0.95–1.2 mm at the first thecal pair, through 1.45–1.8 mm at the third thecal pair, 1.7–2.0 mm at fifth thecal pair and 2.3–2.55 mm at the tenth thecal pair, to the maximum of 2.9–3.5 mm attained distally in the most mature specimens. Proximal end is of pattern H with $th1^1$ growing down the sicular aperture. The upward growing part of $th1^1$ is 0.95 mm long; $th1^2$ is 0.8–0.9 mm long. The metathecae of the first thecal pair are markedly inclined to the rhabdosome axis. Also subsequent proximal thecae, although geniculate, exhibit supragenicular walls inclined to the rhabdosome axis at an angle of *ca* 30°. Thecal geniculation becomes still less recognizable in distal thecae. 2TRD varies, for the most part due to tectonic strain. It is 1.3–1.6 mm at th2, 1.55–1.7 mm at th5, 1.7–2.0 mm at th10 and 1.7–2.0 mm in the most distal thecae. The prominent virgella bifurcates 3.1–5.95 mm from the sicular aperture; the two branches attain a further 15–20 mm in length in mature rhabdosomes. These two branches, which are ribbon-like in the most mature rhabdosomes, diverge from a thickened, broadly triangular junction and form a convex V-shaped arc.

Discussion. – Several species of biserial graptolites furnished with a virgella bifurcating into two prominent branches have been described from China ("*Glyptograptus*" *zhui* Yang, 1964; "*Diplograptus*" *bifurcus* Mu *et. al*. in NIGP, 1974; "*Orthograptus*" *lonchoformis* Chen & Lin, 1978; "*Orthograptus*" *lonchoformis gijiangensis* Ye *in* Jin *et al*., 1982; "*Orthograptus*" *furcatus* Ye *in* Jin *et al*., 1982; "*Glyptograptus*" *bifurcus* Ye, 1978; "*Climacograptus*" *bicaudatus* Chen & Lin, 1978; "*Climacograptus*" *bicaudatus lanceolatus* Li *in* NIGMR, 1983; "*Climacograptus*" *bicaudatus praelongus* Li *in* NIGMR, 1983; "*Climacograptus*" *bifurcatus* Jiao *in* NIGMR, 1983), all of them from the interval corresponding to the *ascensus* and *acuminatus* biozones. Flattened and, in part, slightly deformed rhabdosomes exhibit climacograptid (those in scalariform view), glyptograptid or almost orthograptid thecae. It is beyond the scope of this paper to resolve the whole synonymy of these taxa. Rhabdosomes found at the Waterfall Section have been assigned to *R*.? *bifurcus* because they have 1) a relatively broad proximal end of slightly subtriangular appearance and metathecae of the first thecal pair inclined to the rhabdosome axis, 2) smoothly geniculated proximal thecae and gradual loss of geniculation distally and 3) a prominent virgella which bifurcates 3.1–5.95 mm from the sicular aperture to form a large, convex V-shaped fork. Simply flattened Chinese specimens, without strain effects, widen from 1.0 mm at the first thecal pair to 2.3 mm distally, with thecae overlapping for about half their length (2/5–3/5) and numbering 12 in 10 mm of rhabdosome length. Ye (1978) assigned his new species to *Glyptograptus* which differs, according to current knowledge (summarized by Melchin *et al*. 2011), from *Rickardsograptus* in having proximal astogeny of Pattern I and the nema embedded in or tightly attached to the obverse wall of the rhabdosome. We have assigned this species tentatively to *Rickardsograptus*, which comprises septate neodiplograptids with particularly robust nemata and biform thecae, strongly geniculated in the proximal part and almost orthograptid in the distal part – such as *Rickardsograptus tcherskyi* (Obut & Sobolevskaya), *R. sinuatus* (Nicholson, 1869), *R. elongatus* (Churkin & Carter), *R. thuringiacus* (Kirste), *R. lautus* (Štorch & Feist) and *R*.? *parajanus* (Štorch, 1983). The mesial widening of the rhabdosome is accompanied by retreat of thecal geniculation. *Rickardsograptus*? *bifurcus* is assigned to this group with reservation due to its relatively weakly biform thecae and only slightly geniculated proximal thecae. *R*? *bifurcus* Ye differs from the most similar species – "*Diplograptus*" *bifurcus* Mu *et. al*. – in its more densely spaced thecae (10–12 in 10 mm compared to 8–9 in 10 mm) and more robust proximal end. "*Glyptograptus*" *zhui* Yang, "*Orthograptus*" *lonchoformis* Chen & Lin, "*Orthograptus*" *lonchoformis gijiangensis* Ye, "*Climacograptus*" *bicaudatus* Chen & Lin, "*Climacograptus*" *bicaudatus lanceolatus* Li, "*Climacograptus*" *bicaudatus praelongus* Li, "*Climacograptus*" *bifurcatus*

Figure 4. Graptolites of the *acuminatus* Biozone from the Bishofalm Formation from the Waterfall Section near Zollnersee Hütte, *ca* 1 m above the Bishofalm Quartzite. • A, G, J – *Parakidograptus acuminatus* (Nicholson, 1867): A – GBA2012/004/0001, G – GBA2012/004/0019, J – GBA2012/004/0005. • B–D, K – *Rickardsograptus*? *bifurcus* (Ye, 1978): B – GBA2012/004/0013 (+), C – GBA2012/004/0018 (–), D – GBA2012/004/0014, K – GBA2012/004/0021. • E, F – *Normalograptus ajjeri* (Legrand, 1977): E – GBA2012/004/0006, F – GBA2012/004/0022. • H, I – *Rickardsograptus lautus* (Štorch & Feist, 2008): H – GBA2012/004/0012, I – GBA2012/004/0020. • L, M – *Normalograptus* cf. *transgrediens* (Waern, 1948): L – GBA2012/004/0004, M – GBA2012/004/0020. All figures × 6. Black scale bar represents 1 mm; thin white bars indicate stretching direction.



B
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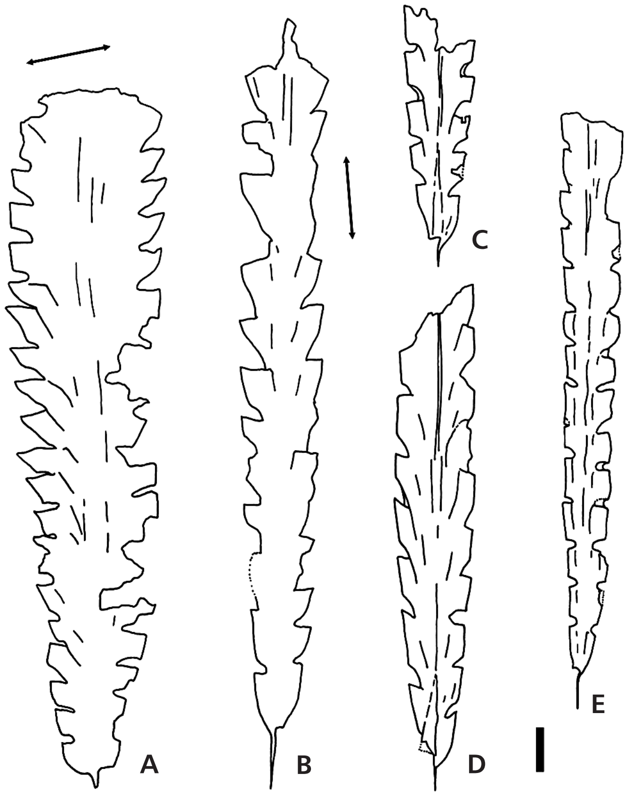

Figure 5. Hirnantian graptolites of the Plöcken Formation. • A, B – *Metabolograptus persculptus* (Elles & Wood, 1907)?: A – GBA2012/004/0030, B – GBA2012/004/0029. • C, D – *Metabolograptus persculptus* (Elles & Wood, 1907): C – GBA2012/004/0024, D – GBA2012/004/0026. • E – *Normalograptus* cf. *transgrediens* (Waern, 1948), GBA2012/004/0028. A, B from Feistritzgraben Section, C, D from Cellon Section, E from Oberbuchach-I Section. All figures × 6. Thick scale bar represents 1 mm; thin bars with arrows indicate tectonic stretching direction.

Jiao and "*Orthograptus*" *furcatus* Ye can be readily differentiated from *R*? *bifurcus* Ye by the early bifurcation of their virgellae (*ca* 1 mm below the sicular aperture) and the straight branches of the V-shaped fork. The extent of true thecal geniculation is hard to reconstruct in many Chinese specimens due to the different modes of their flattening and orientation of thecal profiles to the bedding plane. This is why the original generic assignments have been retained in quotation marks.

Genus *Glyptograptus* Lapworth, 1873, emend. Melchin *et al*., 2011

***Glyptograptus* aff. *tamariscus* (Nicholson, 1868)**
Figure 3J, K

Material and stratigraphical range. – 2 flattened rhabdosomes from the *acuminatus* Biozone at the Waterfall Section near Zollnersee Hütte.

Description. – The rhabdosome of this early member of the aseptate glyptograptids attains a length of 16 mm. It widens from 0.85 mm at the first thecal pair, through 1.2–1.25 mm at the fifth thecal pair to a distal maximum 1.6 mm. The nema appears to be attached to the rhabdosome wall. The asymmetrical proximal end comprises a 1.1 mm long $th1^1$ and 0.95 mm long $th1^2$, which is slightly delayed in origin, leaving a 0.3 mm long part of the ventral side of the sicula exposed. Smoothly geniculate thecae with supragenicular walls markedly inclined to the rhabdosome axis correspond with those of other members of the *tamariscus* group. 2TRD increases from 1.5 mm at th2 to 2.1 mm in the most distal thecae.

Remarks. – Thecal overlap is greater than that in *Glyptograptus dufkai* Štorch, 1992 from the *ascensus* Biozone of Bohemia. The limited material available to date, however, does not allow definitive assignment of this form to one of the several closely morphologically similar species of the *tamariscus* group.

Genus *Parakidograptus* Li & Ge, 1981

***Parakidograptus acuminatus* (Nicholson, 1867)**
Figures 3E–I, 4A, G, J

Material and stratigraphical range. – 25 flattened, mostly complete rhabdosomes from the *acuminatus* Biozone at the Waterfall Section near Zollnersee Hütte.

Discussion. – Typical wedge-shaped, slightly curved, septate biserial rhabdosomes of *Parakidograptus acuminatus* are fairly common in the Waterfall Section. The protracted proximal end is furnished with a short virgella which splits into more than two branches 0.2–0.3 mm below the sicular aperture. Maximum distal width of the rhabdosome attains 1.8–1.9 mm; distal 2TRD is 1.8–2.1 mm. A robust nema projects up to 15 mm beyond the thecate part. Thecae are straight, with apertures normal to the rhabdosome axis, which results in the typical acuminate profile of the thecae. Protraction of the proximal end, when quantified by the distance between sicular aperture and $th1^1$ aperture (1.8–2.2 mm), corresponds with that reported from stratigraphically younger populations of *P. acuminatus* (see Loydell 2007 for instance). However, insufficient preservation and tectonic strain prevent meaningful measurement and stratigraphical interpretation of these figures in a great majority of the present specimens.

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References

Brett, C.E., Ferretti, A., Histon, K. & Schönlaub, H.-P. 2009. Silurian sequence stratigraphy of the Carnic Alps, Austria. *Palaeogeography, Palaeoclimatology, Palaeoecology 279*, 1–28. DOI 10.1016/j.palaeo.2009.04.004

Chen, X., Fan, J.X., Melchin, M.J. & Mitchell, C.E. 2005. Hirnantian (latest Ordovician) graptolites from the Upper Yangtze Region, China. *Palaeontology 48*, 235–280. DOI 10.1111/j.1475-4983.2005.00453.x

Chen, X. & Lin, Y.K. 1978. Lower Silurian graptolites from Tongzi, northern Guizhou. *Memoirs of the Nanjing Institute of Geology and Palaeontology, Academia Sinica 12*, 1–76.

Churkin, M. Jr. & Carter, C. 1970. Early Silurian graptolites from southeastern Alaska and their correlation with graptolite sequences in North America and the Arctic. *United States Geological Survey, Professional Paper 653*, 1–51.

Davies, K.A. 1929. Notes on the graptolite faunas of the Upper Ordovician and Lower Silurian. *Geological Magazine 66*, 1–27. DOI 10.1017/S0016756800099763

Elles, G.L. & Wood, E.M.R. 1907. A monograph of British graptolites. Part 6. *Monograph of the Palaeontographical Society 61(297)*, xcvii–cxx, 217–272.

Fang, Y.T., Liang, S.J., Zhang, D.L. & Yu, J.L. 1990. *Stratigraphy and graptolite fauna of Lishuwo Formation from Wuning, Jiangxi*. 155 pp. Nanjing University Publishing House, Nanjing. [in Chinese with English summary]

Gutiérrez-Marco, J.C. & Štorch, P. 1998. Graptolite biostratigraphy of the Lower Silurian (Llandovery) shelf deposits of the Western Iberian Cordillera, Spain. *Geological Magazine 135*, 71–92. DOI 10.1017/S0016756897007802

Histon, K., Klein, P., Schönlaub, H.-P. & Huff, W.D. 2007. Lower Palaeozoic K-bentonites from the Carnic Alps, Austria. *Austrian Journal of Earth Sciences 100*, 26–42.

Howe, M.P.A. 1982. The lower Silurian graptolites of the Oslo region, 21–23. *In* Worsley, D. (ed.) *IUGS, Subcommission on Silurian Stratigraphy, Field Meeting Oslo region 1982. Palaeontological contributions from the University of Oslo 278*, 1–175.

Hutt, J.E. 1974. The Llandovery graptolites of the English Lake District. Part 1. *Monograph of the Palaeontographical Society 128(540)*, 1–56.

Jaeger, H., Havlíček, V. & Schönlaub, H.-P. 1975. Biostratigraphie der Ordovizium/Silur Grenze in den Südalpen – Ein Beitrag zur Diskussion um die Hirnantia-Fauna. *Verhandlungen der Geologischen Bundesanstalt*, *1975*, 271–289.

Jaeger, H. & Schönlaub, H.-P. 1977. Das Ordoviz/Silur-Profil im Nölblinggraben (Karnische Alpen, Osterreich). *Verhandlungen der Geologischen Bundesanstalt 1977*, 349–359.

Jaeger, H. & Schönlaub, H.-P. 1980. Silur und Devon nördlich der Gundersheimer Alm in den Karnischen Alpen (Österreich). *Carinthia II, 170(90)*, 404–444.

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

Johnson, M.E. 2010. Tracking Silurian eustasy: Alignment of empirical evidence or pursuit of deductive reasoning? *Palaeogeography, Palaeoclimatology, Palaeoecology 296*, 276–284. DOI 10.1016/j.palaeo.2009.11.024

Kirste, E. 1919. Die Graptolithen des Altenburger Ostkreises. *Mitteilungen Osterlände 16*, 60–222.

Kleffner, M.A. 1995. A conodont- and graptolite-based Silurian chronostratigraphy, 159–176. *In* Mann, K. & Lane, H.R. (eds) *Graphic Correlation. SEPM Society for Sedimentary Geology Special Publication 53*. Tulsa, OK.

Koren', T.N., Ahlberg, P. & Nielsen, A.T. 2003. The post-*persculptus* and pre-*ascensus* graptolite fauna in Scania, south-western Sweden: Ordovician or Silurian?, 133–138. *In* Ortega, G. & Aceñolaza, G.F. (eds) *Proceedings of the 7th International Graptolite Conference & Field Meeting of the International Subcommission on Silurian Stratigraphy. Instituto Superior de Correlación Geológica INSUGEO, Serie Correlación Geológica 18*.

Koren', T.N. & Melchin, M.J. 2000. Lowermost Silurian graptolites from the Kurama Range, eastern Uzbekistan. *Journal of Paleontology 74*, 1093–1113. DOI 10.1666/0022-3360(2000)074<1093:LSGFTK>2.0.CO;2

Koren', T.N., Oradovskaya, M.M., Pylma, L.J., Sobolevskaya, R.F. & Chugaeva, M.N. 1983. *The Ordovician and Silurian Boundary in the Northeast of USSR*. 205 pp. Nauka, Leningrad. [in Russian with English abstract]

Lapworth, C. 1873. Notes on the British graptolites and their allies. 1. On an improved classification of the Rhabdophora. *Geological Magazine 1(10)*, 500–504, 555–560. DOI 10.1017/S0016756800469256

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

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

Legrand, P. 1987. Modo de desarrollo del suborden Diplograptina (Graptolithina) en el Ordovício superior y en el Silúrico. Implicaciones taxonómicas. *Revista Española de Paleontologia 2*, 59–64.

Li, J.J. & Ge, M.Y. 1981. Development and systematic position of akidograptids. *Acta Palaeontologica Sinica 20*, 225–234.

Loydell, D.K. 2007. Graptolites from the Upper Ordovician and lower Silurian of Jordan. *Special Papers in Palaeontology 78*, 1–66.

Manck, F. 1923. Untersilurische Graptolithenarten der Zone 10, ferner *Diversograptus* gen. nov., sowie einige neue Arten anderer Gattungen. *Die Natur 14*, 282–289.

Melchin, M.J., Mitchell, C.E., Naczk-Cameron, A., Fan, J.X. & 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 58*, 281–309. DOI 10.1144/pygs.58.4.301

Mu, E.Z., Li, J.J., Ge, M.Y., Lin, Y.K. & Ni, Y.N. 2002. *Graptolites of China*. 1205 pp. Science Press, Beijing.

NANJING INSTITUTE OF GEOLOGY AND PALAEONTOLOGY, ACADEMIA SINICA (ed.) 1974. *Handbook of stratigraphy and palaeontology of southwest China*. 454 pp. Science Press, Beijing. [in Chinese]

NANJING INSTITUTE OF GEOLOGY AND MINERAL RESOURCES (ed.) 1983. *Palaeontological atlas of east China. 1. Early Palaeozoic.* 657 pp. Geological Publishing House, Beijing. [in Chinese]

NICHOLSON, H.A. 1867. On some fossils from the Lower Silurian rocks of the South of Scotland. *Geological Magazine 1(4)*, 107–113. DOI 10.1017/S0016756800205293

NICHOLSON, H.A. 1868. On the graptolites of Coniston Flags; with notes on the British species of the genus *Graptolites*. *Quarterly Journal of the Geological Society of London 24*, 521–545. DOI 10.1144/GSL.JGS.1868.024.01-02.67

NICHOLSON, H.A. 1869. On some new species of graptolites. *Annals and Magazine of Natural History 4*, 231–242. DOI 10.1080/00222936908696041

OBUT, A.M. & SENNIKOV, N.V. 1985. Osobennosti llandoveriyskich planktonovich soobchestv Sibirskoy Platformi, 51–60. *In* BETECHTUNA, O.A. & ZHURAVLEVA, I.T. (eds) *Sreda i zhizn v geologicheskom proshlom (Paleobasseiny i ich obitateli). Trudy Instituta Geologii i Geofiziki 628*. Nauka, Novosibirsk.

OBUT, A.M., SOBOLEVSKAYA, R.F. & NIKOLAEV, A.A. 1967. *Graptolites and stratigraphy of the lower Silurian along the margins of the Kolyma massif*. 164 pp. Akademiya Nauk SSR, Sibirskoe otdelenie, Institut geologii i geofiziki, Ministerstvo geologii SSSR, Nauchno-issledovateľsky institut geologii Arktiky. [in Russian]

PERNER, J. 1895. *Études sur les Graptolites de Bohême. IIième Partie. Monographie des Graptolites de l'Étage D.* 31 pp. Raimond Gerhard, Prague.

SALTER, J.W. 1865. *In* HUXLEY, T.H. & ETHERIDGE, R.A. (eds) *A catalogue of the collection of fossils in the Museum of Practical Geology*. 381 pp. G.E. Eyre & W. Spottiswoode, London.

SCHÖNLAUB, H.-P. 1971. Palaeo-environmental studies at the Ordovician/Silurian boundary in the Carnic Alps. *Mémoires du Bureau de Recherches géologiques et minières 73*, 367–376.

SCHÖNLAUB, H.-P. 1985. Das Paläozoikum der Karnischen Alpen. Exkursion Wolayersee. Arbeitstagung. *Berichte der Geologischen Bundesantalt 1985*, 34–69.

SCHÖNLAUB, H.-P. 1988. The Ordovician-Silurian boundary in the Carnic Alps of Austria, 95–100. *In* COCKS, L.R.M. & RICKARDS, R.B. (eds) *A global analysis of the Ordovician-Silurian boundary*. *Bulletin of the British Museum (Natural History), Geology 43*.

SCHÖNLAUB, H.-P. 1992. Stratigraphy, biogeography and paleoclimatology of the Alpine Palaeozoic and its implications for plate movements. *Jahrbuch der Geologischen Bundesanstalt 135*, 381–418.

SCHÖNLAUB, H.-P., FERRETTI, A., GAGGERO, L., HAMMARLUND, E., HARPER, D.A.T., HISTON, K., PRIEWALDER, H., SPÖTL, C. & ŠTORCH, P. 2011. The Late Ordovician glacial event in the Carnic Alps (Austria), 515–526. *In* GUTIÉRREZ-MARCO, J.C., RÁBANO, I. & GARCÍA-BELLIDO, D. (eds) *Ordovician of the World*. *Cuadernos del Museo Geominero 14*. Instituto Geológico y Minero de España, Madrid.

SCHÖNLAUB, H.-P. & KREUTZER, L.H. (eds) 1994. IUGS Subcommission on Silurian Stratigraphy, Field Meeting Eastern and Southern Alps, Austria 1994 in mem. H. Jaeger. Guidebook and Abstracts. *Bibliothek der Geologische Bundesanstalt Wien 30*, 1–156.

ŠTORCH, P. 1983. The genus *Diplograptus* (Graptolithina) from the lower Silurian of Bohemia. *Věstník Ústředního ústavu geologického 58*, 159–170.

ŠTORCH, P. 1992. Some new and little known graptolites from the Lower Silurian of Bohemia (Prague Basin, Barrandian Area). *Časopis pro mineralogii a geologii 37*, 193–201.

ŠTORCH, P. 1996. The basal Silurian *Akidograptus ascensus-Parakidograptus acuminatus* Biozone in peri-Gondwanan Europe: graptolite assemblages, stratigraphical ranges and palaeobiogeography. *Bulletin of the Czech Geological Survey 71*, 171–178.

ŠTORCH, P. & FEIST, R. 2008. Lowermost Silurian graptolites of Montagne Noire, France. *Journal of Paleontology 82*, 938–956. DOI 10.1666/07-004.1

ŠTORCH, P., GUTIÉRREZ-MARCO, J.C., SARMIENTO, G.N. & RÁBANO, I. 1998. Upper Ordovician and Lower Silurian of Corral de Calatrava, southern part of the Central Iberian Zone, 319–325. *In* GUTIÉRREZ-MARCO, J.C. & RÁBANO, I. (eds) *Proceedings of the Sixth International graptolite Conference of the GWG (IPA) and the SW Iberia Field Meeting 1998 of the International Subcommission on Silurian Stratigraphy (ICS-IUGS). Temas Geológico-Mineros ITGE 23*.

ŠTORCH, P. & LOYDELL, D.K. 1996. The Hirnantian graptolites *Normalograptus persculptus* and "*Glyptograptus*" *bohemicus*: stratigraphical consequences of their synonymy. *Palaeontology 39*, 869–881.

ŠTORCH, P., MITCHELL, C.E., FINNEY, S.C. & MELCHIN, M.J. 2011. Uppermost Ordovician (upper Katian-Hirnantian) graptolites of north-central Nevada, U.S.A. *Bulletin of Geosciences 86(2)*, 301–386. DOI 10.3140/bull.geosci.1264

ŠTORCH, P. & SERPAGLI, E. 1993. Lower Silurian graptolites from Southwestern Sardinia. *Bolletino della Società Paleontologica Italiana 32*, 3–57.

STRACHAN, I. 1971. A synoptic supplement to "A monograph of British graptolites by Miss G.L. Elles and Miss E.M.R. Wood". *Palaeontographical Society Monographs 125(529)*, 1–130.

TÖRNQUIST, S.L. 1897. On the Diplograptidae and Heteroprionidae of the Scanian Rastrites beds. *Acta Universitatis Lundensis 33*, 1–24.

WAERN, B. 1948. The Silurian strata of the Kullatorp core, 337–474. *In* WAERN, B., THORSLUND, P. & HENNINGSMOEN, G. *Deep boring through Ordovician and Silurian strata at Kinnekulle, Vestergötland. Bulletin of the Geological Institute, Uppsala 32*.

WALLISER, O.H. 1964. Conodonten des Silurs. *Abhandlungen des Hessischen Landesamtes für Bodenforschung 41*, 1–106.

WENZEL, B. 1997. Isotopenstratigraphische Untersuchungen an silurischen Abfolgen und deren paläozeanographische Interpretation. *Erlanger geologische Abhandlungen 129*, 1–117.

YANG, D.Q. 1964. Some Lower Silurian graptolites from Anji, Northwestern Zhejiang. *Acta Palaeontologica Sinica 12*, 628–635.

YE, S.H. 1978. Graptolithina, 431–486. *In* GEOLOGICAL INSTITUTE OF SOUTHWEST CHINA (ed.) *Palaeontological Atlas of Southwest China, Sichuan Volume, Part 1, From Sinian to Devonian*. 617 pp. Geological Publishing House, Beijing. [in Chinese]