

MIDDLE LLANDOVERY (AERONIAN) GRAPTOLITES OF THE WESTERN MURZUQ BASIN AND AL QARQAF ARCH REGION, SOUTH-WEST LIBYA

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Abstract: The taxonomy and biostratigraphy of the Aeronian graptoloid graptolites of the Tanezzuft Formation (Murzuq Basin and Al Qarqaf Arch area) is presented and discussed with respect to their palaeoenvironmental setting and palaeobiogeographical links. The *gregarius-libycus*, ‘*leptotheca*’, *convolutus* and *sedgwickii* assemblage biozones and *tenuis* Subzone are recognized and correlated with the generalized zonal scheme and with graptoloid successions in peri-Gondwanan Europe. The Rhuddanian/Aeronian boundary is tentatively placed at the base of the *gregarius-libycus* Biozone. Telychian faunas have not been identified. Fourteen of the 23 species recorded herein belong to the middle Aeronian *convolutus* Biozone assemblage. The overall low diversity may be the result of inhabiting unstable, occasionally

turbulent and/or oxic environments. The lowest diversity, but with abundant graptoloid rhabdosomes, is observed in proximal silty and sandy deposits. The presence of ‘*Paraclimacograptus*’ *libycus* suggests biogeographical links to Aeronian graptolite faunas of Jordan and South America. The *convolutus* Zone assemblage is very similar to the coeval faunas of the Saudi Arabian Qusayba shales. The occurrence of several species endemic to northern and north-western Gondwana and peri-Gondwana provides further evidence for a distinct palaeoclimatic/palaeolatitudinal control on graptolite distribution.

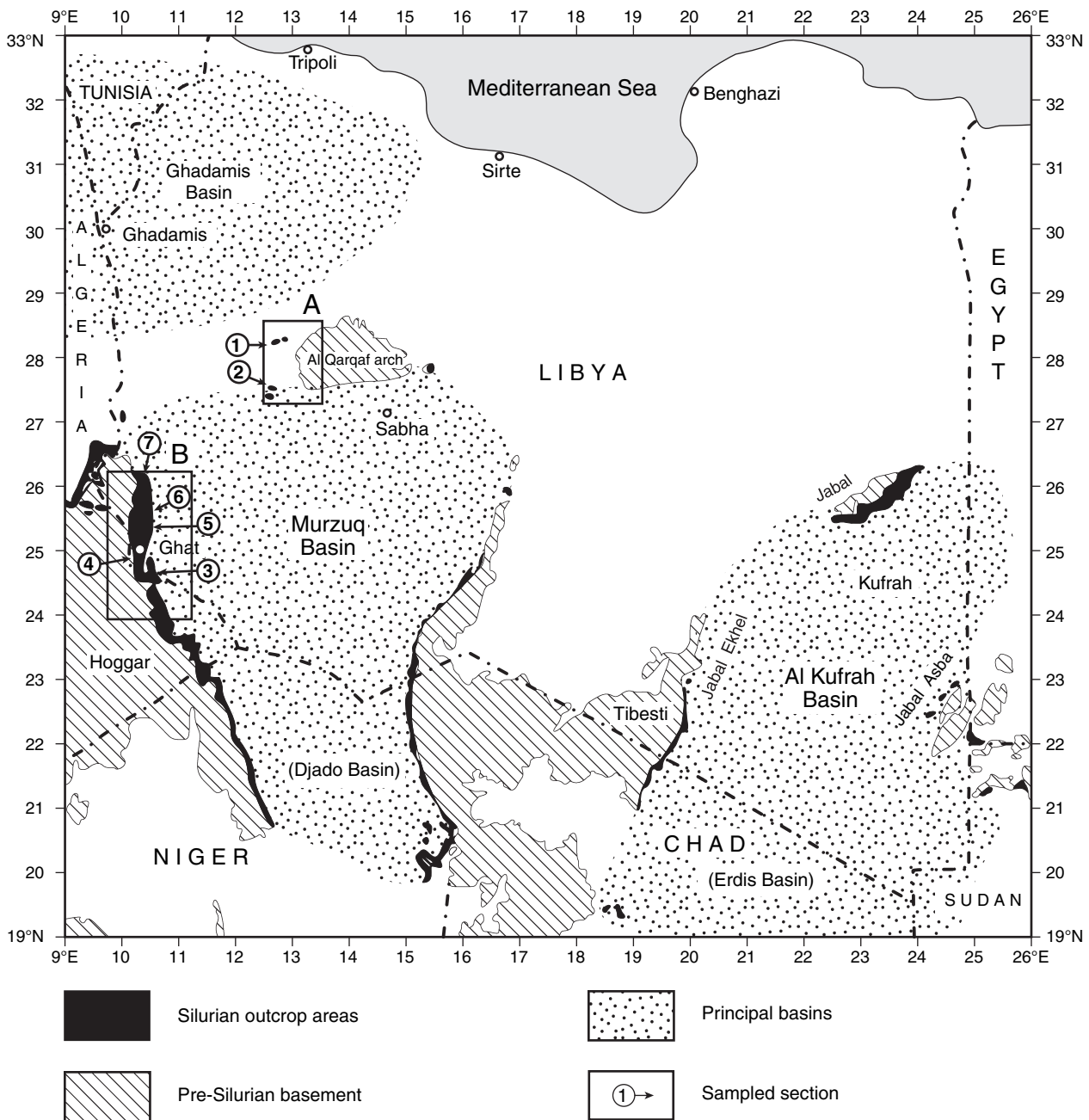
Key words: graptolites, taxonomy, biostratigraphy, palaeobiogeography, Silurian, Libya.

LOWER Silurian dark grey to black (when unweathered) argillaceous rocks are widely distributed across the Palaeozoic Gondwanan shelf of northern and north-western Africa. Lüning *et al.* (2000) estimated that the lowermost, Rhuddanian part of this organic-rich succession is the origin of *c.* 80–90 per cent of Palaeozoic-sourced hydrocarbons in this region. Planktic graptoloid graptolites, which are generally common in Silurian black-shale formations world-wide, have been widely used in the biostratigraphical subdivision, correlation and dating of these hydrocarbon source rocks (Massa and Jaeger 1971; Legrand 1981; Lüning *et al.* 1999, 2000). The graptoloid faunas of the North African shelf exhibit low diversity along with some degree of endemism (Štorch and Massa 2003), which often makes precise biostratigraphical correlation and dating difficult. Some species, however, originally considered to be endemic to North Africa have been identified in peri-Gondwanan Europe. These suggest close palaeobiogeographical links between the two regions and enhance biostratigraphical subdivision and correlation of the North African lower Silurian (Štorch 1998*b*). Close similarity to the Silurian graptoloid assemblages of the Arabian Peninsula is discussed below whilst links with the

equally high-latitude South American graptoloid faunas are in need of further studies.

In south-western and south-eastern Libya, Silurian strata are exposed on the margins of the Murzuq and Kufra basins, respectively (Text-fig. 1). The graptolite-bearing Silurian shales were discovered by Kilian (1928, 1933). The western and northern margins of the Murzuq Basin, with magnificent sections including lower Silurian argillaceous shales with common graptolites, have been studied and described by several workers (Desio 1936; Klitzsch 1965, 1969; Massa and Jaeger 1971; El-Chair *et al.* 1985; Lüning *et al.* 2000) and mapped by Czechoslovak, Yugoslav and Russian geologists (e.g. Pařízek *et al.* 1984; Radulović 1984*a, b*). Very little is known about the eastern margin of the Murzuq Basin (Bellini and Massa 1980; Mamgain 1980). The lower Silurian shales bordering the Kufra Basin have been studied by Bellini and Massa (1980), Turner (1991) and Lüning *et al.* (1999).

At the south-western periphery of the Al Qarqaf Arch Silurian shales with graptolites were found by Lelubre (1946). In 1956 one of us (DM) discovered exposures of graptolite-bearing shales at the north-western periphery of the Al Qarqaf Arch, near Awaynat Wanin (Text-fig. 2).



TEXT-FIG. 1. Sedimentary basins and Silurian outcrops of Libya (after Lüning *et al.* 2000, modified). General location of the surface sections referred to in the text. A, western Al Qarqaf Arch (see Text-fig. 4); B, western Murzuq Basin (see Text-fig. 2); 1, Awaynat Wanin area; 2, B'ir al Qasr area; 3, Wadi Iyadhar; 4, Ghat; 5, Idinene Inaglashem; 6, Tanesfert; 7, Jebel Tdraq.

The latter faunas were assigned to the Middle Llandovery by Massa and Collomb (1960). East of the Al Qarqaf Arch, in Wadi Kneir, an isolated Silurian exposure with graptolites presumed to be of mid-Llandovery age was found by Fürst and Klitzsch (1963).

There are no Silurian exposures north of the Al Qarqaf Arch. In the subsurface, however, Silurian shales are also widespread in the Ghadamis Basin (Massa and Jaeger 1971), Syrte Basin and Cyrenaica region (e.g. well A1-46,

El-Arnauti and Shelmani 1985). A review of the lower Silurian organic-rich graptolite-bearing black shales of the entire North African–Arabian region was presented by Lüning *et al.* (2000).

This paper contains the first systematic description of the Aeronian graptolites of Libya since the pioneering work of Desio (1940) who, however, recorded only a small part of the diversity. The graptolite biostratigraphy of the Tanezzuft Formation is revised and updated herein

and the graptolite fauna is considered from both palaeo-environmental and palaeobiogeographical viewpoints. Our study is based upon material collected by DM at Jebel Tadraq, Tanesfert, Idinene Inaglashem, Wadi Iyadhar, B'ir Al Qasr 1 and Awaynat Wanin, by Czechoslovak mapping geologists at the last two sections, and by PŠ at B'ir Al Qasr 1 and 2 and Magbarat Abu al Hayran. Samples collected by DM and studied by the late H. Jaeger (Massa and Jaeger 1971) have also been re-examined.

Abbreviations

In the text: C., *Coronograptus*; Camp., *Campograptus*; Cl., *Climacograptus*; Clc., *Clinoclimacograptus*; G., *Glyptograptus*; L., *Lituigraptus*; M., *Monograptus*; Met., *Metaclimacograptus*; N., *Normalograptus*; Nd., *Neodiplograptus*; NL., *Neolagarograptus*; P., *Paraclimacograptus*; Pet., *Petalolithus*; Prp., *Parapetalolithus*; Pr., *Pristiograptus*; R., *Rastrites*; S., *Stimulograptus*; T., *Torquigraptus*. 2TRD, two thecae repeat distance.

In Text-figures 4–5: *africanus*, *Neodiplograptus africanus*; cf. *elongatus*, 'Monograptus' cf. *elongatus*; cf. *approximatus*, *Rastrites* cf. *approximatus*; cf. *tariti*, *Normalograptus* cf. *tariti*; *clandestinus*, *Petalolithus clandestinus*; *convolutus*, *Lituigraptus convolutus*; *decipiens*, *Torquigraptus decipiens*; *fezzanensis*, *Neodiplograptus fezzanensis*; *gregarius*, *Coronograptus gregarius*; *helenae*, *Neolagarograptus helenae*; *hughesi*, *Metaclimacograptus hughesi*; *Metacl. sp.*, *Metaclimacograptus sp.*; *libycus*, 'Paraclimacograptus' *libycus*; *limatulus*, *Monograptus limatulus*; *lobiferus*, *Campograptus lobiferus*; *obtusus*, *Campograptus obtusus*; *peregrinus*, *Rastrites peregrinus*; *perlatus*, *Pseudoretiolites* cf. *perlatus*; *regularis*, *Pristiograptus regularis*; cf. *renaudi*, *Pristiograptus* cf. *renaudi*; *Pseudoret. sp.*, *Pseudoretiolites sp.*; *sedgwickii*, *Stimulograptus sedgwickii*; *tenuis*, *Neolagarograptus tenuis*.

GEOLOGICAL AND STRATIGRAPHICAL SETTING

In the Murzuq Basin and Al Qarqaf area the lower Silurian black shales have been formally assigned to the Tanezzuft Formation, first named by Desio (1936) after Wadi Tanezzuft, between Ghat and Al Awaynat (Serdeles). Klitzsch (1965, 1969) considered the section described by Desio (1936) to be unsuitable as a type section because the lower contact is not exposed there. Therefore, he (Klitzsch 1965, 1969, p. 85) proposed and described as type the section at Takarkhouri (Wadi Iyadhar), about 40 km south-east of Ghat. Massa and Jaeger (1971) separated the lower part of the shaly Silurian strata under the name Iyadhar Formation with the younger shales retained in the Tanezzuft Formation. The principal reason for dividing the lower Silurian shales into two formations was the supposed presence of an unconformity between the strata bearing a graptolite fauna referred to the Rhuddanian

cyphus Biozone (Zone 18 *sensu* Elles and Wood 1914 and Massa and Jaeger 1971) and the overlying beds containing *Coronograptus gregarius* and referred to the lower Aeronian. Despite some minor lithological differences (e.g. dolostone intercalations present in the Iyadhar Formation), most authors have not considered the Iyadhar Formation to be a valid lithostratigraphical unit (Pařízek *et al.* 1984; Radulović 1984a, b; Lüning *et al.* 2000).

In the western Murzuq Basin the graptolite-bearing shales of the Tanezzuft Formation rest unconformably upon late Ordovician (Hirnantian) early postglacial (Sutcliffe *et al.* 2000) sandstones of the Memouniat Formation. Graptolite faunas from the lowermost part of the shaly Tanezzuft Formation have been described and discussed by Desio (1940) and Legrand (1976, 1986). Great efforts have been made to indentify the Ordovician/Silurian (O/S) boundary in the sections. Due to the fact, however, that the typical assemblages and biozonal-index taxa (in particular *Akidograptus* and *Parakidograptus*) known from elsewhere are missing in the Saharan basins, the exact position of the boundary is not known. Lüning *et al.* (2003) recorded a *Normalograptus tilokensis* Biozone, of presumably late Hirnantian age, in the E1-NC174 well. By contrast, Legrand (2003, figs 6–7) had assumed that, in the general vicinity of Ghat and Al Awaynat, there are no late Hirnantian and early Rhuddanian strata (including his regional *pseudovenustus*, *pretilokensis-tilokensis*, *kiliani*, *incommodus-saharensis* and *imperfectus* biozones). In our sections, graptolite records suggest that the middle and upper Rhuddanian are present within the lower part of the Tanezzuft Formation (Legrand 1976, 1986; Štorch and Massa 2003) whilst the O/S boundary interval is probably missing due to an unconformity.

Middle Llandovery (Aeronian) graptolites from the Murzuq Basin have remained largely unknown except for 'Paraclimacograptus' *libycus*, described and figured by Desio (1940) and further discussed under the name *Climacograptus innotatus brasiliensis* Ruedemann by Jaeger (1976) and El-Chair *et al.* (1985). Other Aeronian graptolites were listed from the Murzuq Basin and Al Qarqaf Arch by Massa and Jaeger (1971). Several species collected at B'ir al Qasr (Al Qarqaf Arch) were illustrated by Pařízek *et al.* (1984). Both the published and some unpublished Libyan records of Lower Silurian graptolites have been reviewed briefly by Štorch and Massa (2003). There are no published records of late Llandovery (Telychian) graptolites in the Al Qarqaf Arch or south of it. The Telychian, however, is probably represented by the overlying sandstone-dominated deltaic strata of the Acacus Formation.

Considerable caution should be exercised in graptolite-based correlation of north Saharan sections when only lists of graptolites identified are provided because many species have been regularly misidentified. As a result, bio-

stratigraphic interpretations made now might differ significantly from those made some 30 or more years ago (e.g. Berry and Boucot 1973).

Western Murzuq Basin

Large exposures of the early Silurian Tanezzuft Formation are widespread along the Libya-Algeria border, in particular in the vicinity of Ghat (Text-fig. 2). From this area the earliest records of Silurian graptolites in Libya were published by Kilian (1928) and Desio (1936, 1940). The general vicinity of Ghat became a classical area for Silurian strata in this part of the world. The stratigraphy of the Tanezzuft and Acacus formations, based on five sections and their graptolite records, was studied by Massa and Jaeger (1971). Additional data from early Llandovery (Rhuddanian) strata from sections further south, in

Algeria (e.g. Oued In Djerane), were summarized by Legrand (2000). The Middle Llandovery (Aeronian) graptolite records from Jabal Tadraq, Tanesfert, Idinene Inaghlashem, Ghat and Wadi Iyadhar sections, referred to by Massa and Jaeger (1971) and Jaeger (1976), are revised herein allowing more detailed bio- and, consequently, chronostratigraphic assignment and correlation of the Tanezzuft Formation.

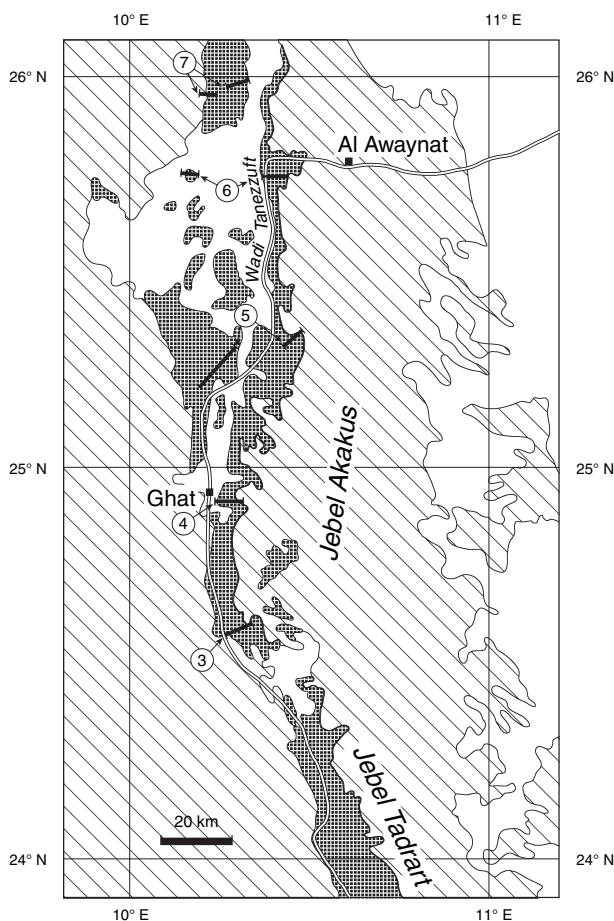
In the Jabal Tadraq section (TR 2, Al Awaynat or northern Tanesfert; Text-fig. 3) the Tanezzuft Formation is c. 100 m thick, and is overlain by the 46-m-thick Acacus Formation. Sandstones with broken graptolite rhabdosomes have been recorded near the top of the Tanezzuft Formation. The graptolite assemblage is assigned to the *sedgwickii* Biozone.

The Tanezzuft Formation is 210 m thick in the Tanesfert section (TR 3, Text-fig. 3) and rests unconformably on latest Ordovician sandstones of the Memouniat Formation. *Neodiplograptus africanus* (Legrand) and *N. fezzanensis* (Desio)? have been recorded within the lowermost 20 m of the Tanezzuft shales. '*Paraclimacograptus*' *libycus* (Desio) occurs from c. 45 m above the base. A few metres higher, *Coronograptus gregarius* makes its first appearance, and it is accompanied by *P. libycus*. The middle part of the Tanezzuft Formation is marked by *Neolagarograptus helenae*, which is accompanied by *Rastrites* sp. (ex gr. *peregrinus*), both indicating a mid Aeronian age. Higher up the section, *Neolagarograptus tenuis*?, *Stimulograptus sedgwickii*, *Pristiograptus regularis* and *Metaclimacograptus hughesi* indicate the presence of the upper Aeronian *sedgwickii* Biozone, including its newly introduced *tenuis* sub-zone.

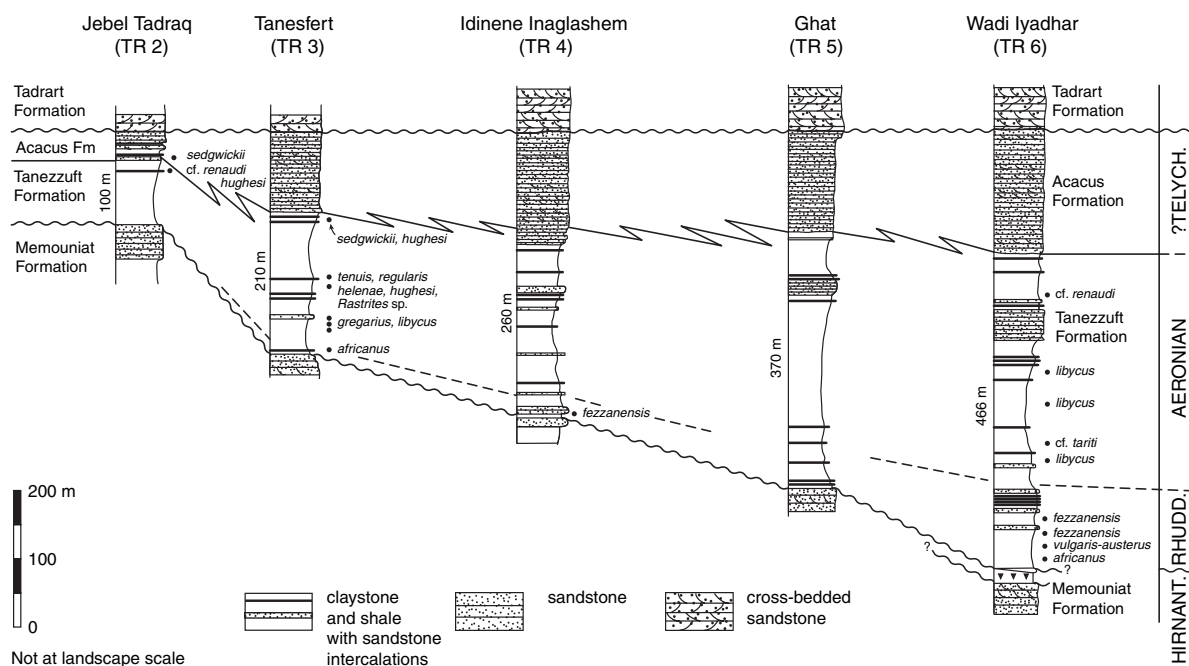
In the Idinene Inaghlashem section (TR 4, Text-fig. 3) the Tanezzuft Formation is 260 m thick and rests unconformably on late Ordovician sandstones of the Memouniat Formation. The uppermost 25 m of the Tanezzuft Formation are represented by intercalated mudstones and sandstones, which coarsen upwards into the sandstones of the 125-m-thick Acacus Formation. *Neodiplograptus fezzanensis* occurs just above the base of the Tanezzuft Formation.

The Tanezzuft Formation thickens towards the south. Thus, in the Ghat Section (TR 5, Text-fig. 3) the unit attains a thickness of 370 m and rests unconformably on top of the Memouniat Formation. The sandstone-dominated Acacus Formation here is 140 m thick.

The Wadi Iyadhar section (TR 6, Text-fig. 3) is the type locality of the Tanezzuft Formation at Takarkhourri described by Klitzsch (1965). Here the Tanezzuft Formation attains its maximum thickness of 466 m, and is overlain conformably by the 162-m-thick Acacus Formation. The Tanezzuft Formation rests, probably unconformably, on barren green mudstones with large rounded quartz clasts (referred herein to the Memouniat Formation). The lower and middle parts of the Tanezzuft Formation are



TEXT-FIG. 2. Outcrop area of the Tanezzuft Formation (Llandovery) in the western Murzuq Basin. Location of the composite sections. 3, Wadi Iyadhar section (TR 6); 4, Ghat section (TR 5); 5, Idinene Inaghlashem section (TR 4); 6, Tanesfert section (TR 3); 7, Jabal Tadraq section (TR 2).



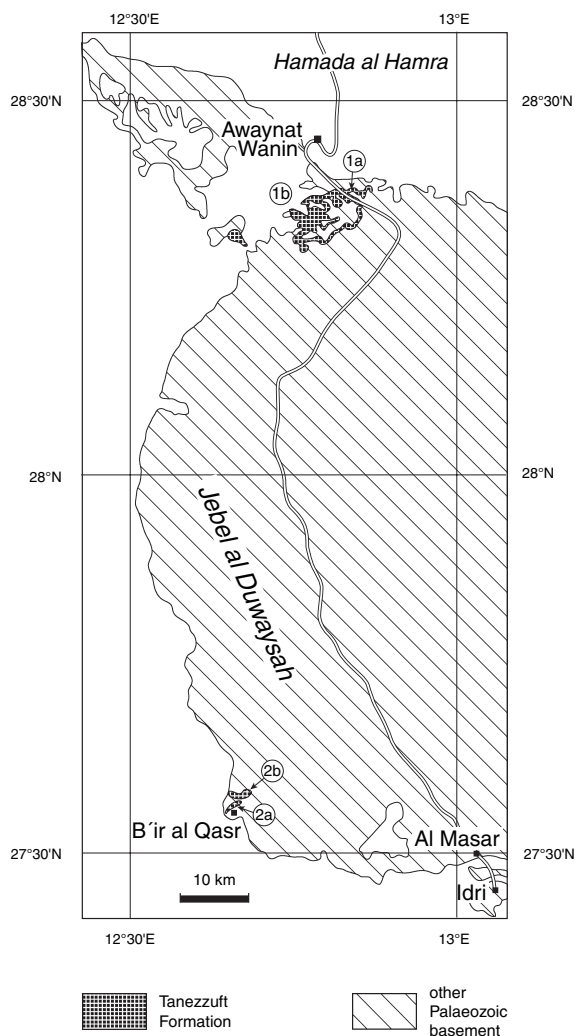
TEXT-FIG. 3. Series of composite sections across the Silurian strata exposed in the western Murzuq Basin: stratigraphy, correlation and graptolite fossil record.

composed of claystones and mudstones (generally shales) with siltstone and fine sandstone intercalations. Rhuddanian graptolites of the *Nd. africanus* – *N. tariti* and *Nd. fezzanensis* biozones have been found in the lowermost 60 m of the Tanezzuft Formation (samples NA 132–232; Štorch and Massa 2003). The base of the Aeronian is taken at the level at which ‘*P.*’ *libycus* makes its first appearance, *c.* 157 m above the base of the Tanezzuft Formation. The same species, occasionally accompanied by *Normalograptus cf. tariti* and other, poorly preserved, normalograptids, continues into the following *c.* 135 m of the section. The upper part of the Tanezzuft Formation can be referred to the upper-middle to upper Aeronian. ‘*P.*’ *libycus* last occurs 292 m above the base of the formation. It is important to note that ‘*P.*’ *libycus* ranges into the *convolutus* Biozone, as shown in the B’ir al Qasr Section. High in the Wadi Iyadhar section (410–420 m above the base), rhabdosomes of *Pristiograptus cf. renaudi* (Philippot) allow a very tentative biostratigraphical assignment (to the *sedgwickii* and/or lower *guerichi* biozones). The upper part of the Tanezzuft Formation is marked by gradual progradation of the deltaic Acacus sandstones. Due to this gradual transition, the position of the base of the Acacus Formation is not yet well established.

Western Al Qarqaf Arch

In the Awaynat Wanin area (Text-fig. 4), a 32-m-thick shaly sequence of the early Silurian (Llandovery) Tane-

zzuft Formation (Text-fig. 5) overlies unconformably the glacially influenced Memouniat Formation (Havlíček and Massa 1973). A sandstone *c.* 0.3 m thick with abundant, poorly preserved normalograptid graptoloids is present at the base of the Silurian sequence and may represent a transgressive deposit of early Llandovery or early mid Llandovery age. Higher in the sequence, a mid Aeronian graptolite fauna was collected by Czechoslovak mapping geologists, still near the base of the shaly succession (Štorch and Massa 2003). This collection includes *Glyptograptus cf. tamariscus* (Nicholson), an extremely slender *Metaclimacograptus?* sp., *Met.?* aff. *hughesi* (Nicholson), *Coronograptus gregarius* (Lapworth), *Neolagarograptus helenae* (Štorch), immature and/or fragmentary rhabdosomes of *Rastrites cf. approximatus* Perner and *Rastrites sp.* (aff. *peregrinus* Barrande). The upper part of the Tanezzuft Formation has a late Aeronian graptolite assemblage composed of *Met. hughesi* (Nicholson) (often having significant genicular hoods), *Pseudoretiolites cf. perlatus* (Nicholson), *Parapetalolithus sp.*, *Pr. regularis* (Törnquist) and *Stimulograptus sedgwickii* (Portlock). This assemblage, both here and elsewhere in Libya, is referred to the *sedgwickii* Biozone. Other late Aeronian graptolites were collected in 2000 by PŠ nearby, at Magbarat Abu al Hayran (28°22'517"N, 012°50'537"E, Text-fig. 5). *Petalolithus clandestinus* Štorch, *Neolagarograptus tenuis* (Portlock) and *Pr. regularis* (Törnquist) indicate the lowermost part of the *sedgwickii* Biozone in the lower part of *c.* 15-m-thick Tanezzuft shales. This assemblage has been identified also in the Ghadames Basin (Štorch and Massa 2003), Bohe-



TEXT-FIG. 4. Silurian outcrops in the western Al Qarqaf Arch. Location of the sections: 1a, Magbarat abu Al Hayran section; 1b, former section in Awaynat Wanin area; 2a, B'ir al Qasr 1 section; 2b, B'ir al Qasr 2 section.

mia and Spain (Štorch 2001). It is assigned to a distinct *tenuis* Subzone herein. Poorly preserved *Glyptograptus* sp. indet. (a long and robust form) and *Pristiograptus* cf. *pristinus* Pribyl were recorded in the upper part of this recently sampled section. The graptoloid rhabdosomes are flattened and often poorly preserved in the heavily weathered, bleached shales. The Tanezzuft shales are overlain unconformably by the sandstones of the Devonian Tadrart Formation in the Awaynat Wanin area.

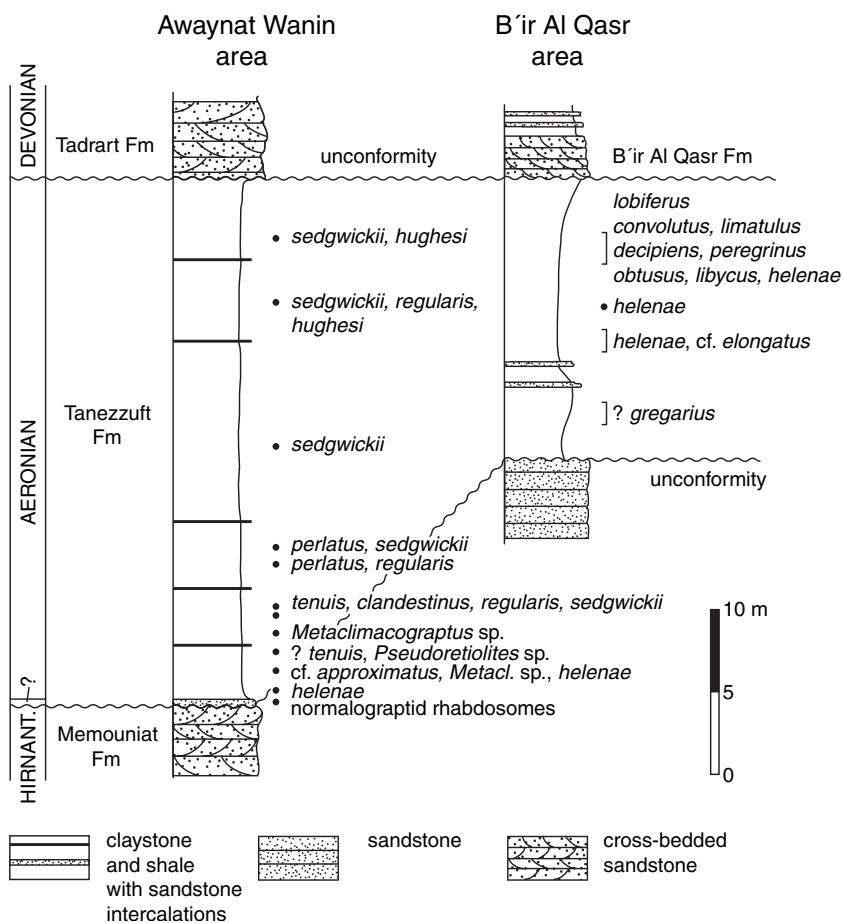
Another two, but incomplete, sections through the Tanezzuft Formation are exposed in the southern part of the Al Qarqaf Arch area (Text-fig. 4) near B'ir al Qasr (Pařízek *et al.* 1984; Sutcliffe *et al.* 2000); for composite section, see Text-figure 5. The exposed Tanezzuft Formation comprises an 18-m-thick succession of clayey shales with rare, thinly bedded, current-laminated (Sutcliffe

et al. 2000), siltstone to fine sandstone intercalations. An unconformity separates the Tanezzuft shales from the underlying sandstones of the latest Ordovician (Ashgill) Memouniat Formation. The shales are overlain, again unconformably, by coarse sandstones of the middle Devonian (Eifelian) B'ir al Qasr Formation. Two successive assemblages of middle Aeronian graptolites were recognized in the B'ir Al Qasr 1 (27°34'466"N, 012°40'257"E) shaly section by Štorch and Massa (2003), based on material collected by DM and listed by the late H. Jaeger (unpublished notes). The lower assemblage is characterized by *C. gregarius* (Lapworth). In the higher one *Neodiplograptus?* sp., *Metaclimacograptus?* sp., *Neolagarograptus helenae* (Štorch), '*Monograptus*' cf. *elongatus* (Törnquist) and *Torquigraptus decipiens* (Törnquist) (single fragment) were recorded by Štorch and Massa (2003). This section and the new exposure at B'ir Al Qasr 2 (27°34'540"N, 012°40'730"E), sampled by PŠ, yielded a rather rich, mid Aeronian graptolite assemblage consisting of *Metaclimacograptus?* aff. *hughesi* (Nicholson), *Clinoclimacograptus* cf. *retroversus* Bulman and Rickards, '*Paraclimacograptus*' *libycus* (Desio), *Glyptograptus tamariscus* (Nicholson), *Neolagarograptus helenae* (Štorch), *Monograptus limatulus* Törnquist, *M. havliceki* Štorch, *Campograptus lobiferus* (M'Coy), *Camp. obtusus* (Rickards), *Lituigraptus convolutus* (Hisinger), *Torquigraptus decipiens* (Törnquist), '*Monograptus*' cf. *elongatus* (Törnquist), *Rastrites peregrinus* Barrande and *R. approximatus* Perner. Neither the base nor the upper boundary of the Tanezzuft shale are exposed in the two sampled sections in the B'ir Al Qasr area.

BIOSTRATIGRAPHY AND CORRELATION

The extensive surface sections of the Tanezzuft shales of the Murzuq Basin, which are up to hundreds of metres thick, have not yet been thoroughly sampled by specialists and their graptolite records are therefore rather incomplete. A few beds contain an abundant but low-diversity assemblage. Many species, in particular those of the Rhuddanian, are not known outside this and adjacent North Saharan basins and thus are of limited value in world-wide biostratigraphical correlation. Recent examination of graptolite collections from Libya and neighbouring sections in south-east Algeria, however, has revealed direct evidence of four graptolite biozones and one subzone within the middle Llandovery portion of the Tanezzuft Formation (Štorch and Massa 2003 and Text-fig. 6 herein). Some of the biozones are directly indicated by their biozonal index taxa. The '*leptothea*' Biozone is tentatively recognized through the occurrence, co-occurrence, appearance and/or disappearance of other age-

TEXT-FIG. 5. Silurian sections of the western Al Qarqaf Arch: stratigraphy, correlation and graptolite fossil record.



diagnostic species even though the index taxon has not been encountered. All the biozones have been treated as assemblage zones in this paper and are distinguished by their total graptolite content, with particular emphasis on zonal index taxa and other characteristic, palaeogeographically widespread and short-ranging, i.e. age-diagnostic, species. Inaccuracies resulting from insufficient density of sampling, low graptolite abundance and/or poor preservation prevent precise definition of the zonal boundaries. At the present state of knowledge, assemblage biozones are the only practical solution in north Saharan basins. They can be easily correlated, although their boundaries cannot be determined with optimal accuracy.

The Rhuddanian graptoloid faunas of the north Saharan basins exhibit such a high degree of endemism that Legrand (1999) defined a local biozonation for south-east Algeria. Some of his biozones may also be applied in Libya. The *Neodiplograptus fezzanensis* Biozone has been identified widely in Libyan and Algerian sections and also occurs in collections from northern Niger that we are studying. The late Rhuddanian age of the strata with common *Nd. fezzanensis*, accompanied by *Glyptograptus* cf. *tamariscus* (Nicholson) and *Normalograptus* cf. *rectangularis* (M'Coy), is indicated by associated monograptoid

dean distal fragments resembling biform monograptids of the *M. vulgaris* group (common element of late Rhuddanian – earliest Aeronian assemblages in Europe). The *fezzanensis* Biozone is correlated with the upper Rhuddanian *cyphus* Biozone of the international biozonal schemes (Massa 1988; Legrand 1999; Lüning *et al.* 1999, 2000; Štorch and Massa 2003) since the biozonal index graptolite has been found together with *Coronograptus cyphus* (Lapworth) and its typical associates in both Bohemia (Štorch 1983, 1994) and Spain (unpublished data). The stratigraphically highest specimens of *Nd. fezzanensis* appear in the lowermost part of the basal Aeronian *triangulatus-pectinatus* Biozone in Bohemia. Rhuddanian faunas have not been identified with certainty in the Al Qarqaf Arch region. Indeterminate biserial (probably normalograptid) rhabdosomes, encountered in the sandstone bed at the base of the Tanezzuft Formation in Awaynat Wanin, may be of either Rhuddanian or Aeronian age. The sandstone bed is overlain by clayey shales containing graptolites of mid Aeronian age.

Aeronian graptolites were found in many sections, although with a remarkably low diversity. The lower part of the Aeronian is presumably represented by the assemblage dominated by either '*P. libycus* (e.g. Wadi Iyadhar

Series	Stage	Generalized graptolite zonation by SSS (Koren' <i>et al.</i> 1996)	Bohemian graptolite zonation (Štorch 1998b, 2001, MS)	Libyan graptolite zonation (this paper)	Ghadamis Basin	Al Qarqaf arch area	W Murzuq Basin	N Al Kufrah Basin
LLANDOVERY	Telychian	<i>insectus-lapworthi</i>	<i>insectus lapworthi</i>	?	?			
		<i>spiralis</i> interval	<i>spiralis</i>					
		<i>crenulata-griestoniensis</i>	<i>tullbergi griestoniensis</i>	<i>flamandi</i>				
		<i>crispus-turriculatus</i>	<i>crispus turriculatus</i>	<i>-meridionalis</i>				
		<i>guerichi</i>	<i>linnaei</i>	' <i>turriculatus-guerichi</i> interval'				
		<i>sedgwickii</i>	<i>sedgwickii tenuis</i>	<i>sedgwickii tenuis</i>				
	Aeronian	<i>convolutus</i>	<i>convolutus</i>	<i>convolutus</i>				
		<i>argenteus</i>	<i>leptotheca simulans</i>	' <i>leptotheca</i>				
		<i>pectinatus-triangularatus</i>	<i>pectinatus-triangularatus</i>	<i>gregarius-libycus</i>		?		
		<i>cyphus</i>	<i>cyphus</i>	<i>fezzanensis tariti-africanus</i>				
	Rhuddan.	<i>vesiculosus</i>	<i>vesiculosus</i>					
		<i>acuminatus</i>	<i>acuminatus-ascensus</i>	?	?		?	

TEXT-FIG. 6. Graptolite biostratigraphy and correlation of the Llandovery strata of Libya. Framed interval and areas are discussed in this paper. Assemblage zones recorded in the respective areas are highlighted in grey.

section, Tanesfert section) or *C. gregarius* (Tanesfert section). The occurrence of the two species on the same bedding plane (F1-66 well in the Ghadames Basin; Štorch and Massa 2003) is exceptional: '*P.* *libycus* and *C. gregarius* were found separately in monospecific or oligospecific (but not together) assemblages in other sections. In Tanesfert, '*P.* *libycus* makes its first appearance a few metres below the first *C. gregarius* and ranges well into the *convolutus* Biozone in the B'ir al Qasr sections. As the precise local ranges of the two species have not been determined due to limited sampling of the sections, a *libycus-gregarius* Assemblage Biozone was introduced by Štorch and Massa (2003). This biozone can be correlated tentatively with the *gregarius* and/or *triangularatus-pectinatus* biozones of the generalized biozonal scheme of Koren' *et al.* (1996); see also zone 19 *sensu* Massa and Jaeger (1971). A *gregarius* Biozone graptolite fauna has also been reported (although not figured) by Mahmoud *et al.* (1992) from the Al Qalibah and Tayma area of central Saudi Arabia. They recorded *Paraclimacograptus* aff. *libycus* associated with *C. gregarius*, *Demirastrites triangularatus*, *Rastrites* sp., *Campograptus communis* (Lapworth) and several other species in the middle part of the Qusayba Member of the Qalibah Formation.

A stratigraphically higher level, corresponding approximately to the middle Aeronian *leptotheca* Assemblage Biozone of Bohemia, is occupied by an assemblage dominated by *Neolagarograptus helenae*, the first rastritids [*Rastrites* sp. (aff. *approximatus*) and '*Monograptus*' sp. (aff. *simulans*)] and *Metaclimacograptus*. Rare, poorly pre-

served rhabdosomes, assigned tentatively to *P. libycus* also occur. This assemblage was encountered in the B'ir al Qasr 1 and Tanesfert sections. *Nl. helenae* has been described, along with the closely related *Neolagarograptus impolitus* Štorch, from the *leptotheca* and *convolutus* biozones of Bohemia (Štorch 1998a). Another, similar species, *Neolagarograptus rickardsi*, has been described from the *convolutus* Biozone of Saudi Arabia (El-Khayal 1987a).

A still higher assemblage, assigned to the *convolutus* Assemblage Biozone, was found in the two B'ir al Qasr sections. The graptolite fauna comprises *Metaclimacograptus*? aff. *hughesi*, *Clinoclimacograptus* cf. *retroversus*, '*P.* *libycus*, *Gl. tamariscus*, *Nl. helenae*, *M. limatulus*, *M. havliceki*, *Camp. lobiferus*, *Camp. obtusus*, *L. convolutus*, *T. decipiens*, '*M.* cf. *elongatus*, *R. peregrinus* and *R. approximatus*?, and includes several important, age-diagnostic species of the *convolutus* Biozone, including the zonal index species. It also attains the maximum diversity among the Rhuddanian and Aeronian graptolite assemblages of the North African basins but is dramatically less diverse than the mid Aeronian faunas of Europe, China, Siberia and Arctic Canada, referred to by Melchin *et al.* (1998). The present assemblage is closely similar to the graptolite association described by El-Khayal (1985, 1987a-c) from the Qusayba Member (Qalibah Formation) of the Al Qasim Province (central Saudi Arabia). The Saudi Arabian fauna comprised 14 graptolite species including *Climacograptus scalaris* (Hisinger) = *Clinoclimacograptus* cf. *retroversus* herein, *Neolagarograptus*

rickardsi (El-Khayal), *L. convolutus*, *T. decipiens* and '*M. elongatus* Törnquist. No detailed information has been provided by El-Khayal as to whether the Qusayba shale graptolites described came from a single bed or several fossiliferous levels within the lowermost 14 m of the graptolitic shale. Some species reported from the Qusayba shale, however, such as *Petalolithus ovatoelongatus* (Kurck) (*Petalolithus clandestinus* herein), *Pristiograptus regularis* and *Glyptograptus incertus* Elles and Wood (?*Metaclimacograptus hughesi* herein) suggest that the boundary beds with the overlying *Stimulograptus sedgwickii* Biozone and its *Neolagarograptus tenuis* Subzone may also be represented in the Saudi Arabian graptolite collections. The *convolutus* Biozone has not been found in the Al Qalibah and Tadla areas, to the south-east of Al Qasim, where the graptolite-bearing sequence is topped by the *gregarius* Biozone (Mahmoud *et al.* 1992).

The upper Aeronian *sedgwickii* Assemblage Biozone is widespread in Libya, being characterized by the occurrence of its zonal-index species: *S. sedgwickii* (Portlock), associated with *Met. hughesi* (Nicholson), *Pr. regularis* (Törnquist), *Pr. cf. renaudi* (Philippot) and rare *Pseudo-retiolites cf. perlatus* (Nicholson). *Glyptograptus* sp. indet. (a long, robust form similar to *G. incertus*) and *Pr. cf. pristinus* Přibyl are also recorded from about this level. This assemblage is known from the Tanesfert, Jabal Tadraq and Wadi Iyadhar sections in the western Murzuq Basin and from the Awaynat Wanin area in the Al Qarqaf Arch. A different assemblage of very limited stratigraphic range has been found at about the base of the *sedgwickii* Biozone at Magbarat Abu al Hayran (Al Qarqaf Arch, Awaynat Wanin area), comprising *Neolagarograptus tenuis* (Portlock), *Pr. regularis* (Törnquist) and *Pet. clandestinus* Štorch. *Pet. clandestinus* has also been found at Tirhemar in the Algerian Eastern Tassili-n. Ajjer (Štorch and Massa 2003). As the corresponding association has been identified in the Ghadames Basin (well F1-66, Štorch and Massa 2003), Bohemia and Spain (Štorch 2001), this level is assigned herein to a distinct *tenuis* Assemblage Subzone of considerable importance for precise international correlation. This *Nl. tenuis*-bearing level was first recognized by Jones and Pugh (1916, p. 346) in mid Wales. Jones and Pugh subdivided their *sedgwickii* Biozone into a *tenuis* Band and a *sedgwickii* Band. The *tenuis* Band was further recognized by Jones (1945). Also, Rickards (1976b, p. 164) wrote that 'it is possible that it [*Nl. tenuis*] is confined to the lower part of the [*sedgwickii*] zone.'

Monospecific associations of fragmented *Pristiograptus* and *Stimulograptus* rhabdosomes are the youngest known graptolites in the Silurian of the Murzuq Basin and Al Qarqaf Arch area. They occur close to the top of the Tanezzuft Formation in the western Murzuq Basin, just below the lowest Acacus sandstones. No Telychian (upper Llandovery) graptolites have been identified in this area.

As there is no apparent gap in sedimentation between the Tanezzuft and Acacus formations, sandstone deposition must have commenced as early as the latest Aeronian or, perhaps, early Telychian. In the Al Qarqaf Arch, shaly sedimentation may have continued during the late Llandovery, but the upper part of the Tanezzuft shales and the sandstones of the Acacus Formation were subsequently eroded. The late Aeronian argillaceous shales here are overlain by early Devonian sandstones of the Tadrart Formation.

ENVIRONMENTAL INTERPRETATION AND PALAEOBIOGEOGRAPHICAL LINKS

During the latest Ashgill and Rhuddanian postglacial transgression, the partly isolated North African shelf basins were inhabited by low-diversity graptolite faunas that exhibited considerable degrees of endemism (Legrand 1999; Lüning *et al.* 2000). North African graptolite assemblages of Rhuddanian age are composed of several normalograptid species (*N. normalis* Group), tolerant generalists that survived the glacial period in various types of environments, and some specific, more-or-less endemic taxa, presumably well adapted to their cold, oxygenated, high-palaeolatitude habitats. Several *Neodiplograptus* (e.g. *Nd. africanus* and *Nd. fezzanensis*) species are particularly common in the North African basins. The latter species extended even into peri-Gondwanan Europe (Štorch 1983), whereas the former closely resembles *Diplograptus* sp. figured by Rickards *et al.* (1996, text-fig. 4e–f) from the lower to middle Llandovery of Argentina. This *Neodiplograptus-Normalograptus* fauna appears in the lowermost parts of the Wadi Iyadhar, Tanesfert and Idinene Inaglashem sections in the western Murzuq Basin. Graptolites occur in monospecific or, exceptionally, oligospecific assemblages in which the rhabdosomes are often aligned on bedding planes. Aligned, fragmented graptolites are present even in rippled silty and sandy beds (Štorch and Massa 2003). Monograptoid rhabdosomes are rarely seen in Rhuddanian samples. In the Hodh area of Mauretania, a moderately diverse normalograptid-dominated fauna of early Rhuddanian age has been found (Underwood *et al.* 1998). A single monograptoid taxon, referred to *Lagarograptus acinaces* (Törnquist), occurs here in the middle–upper Rhuddanian strata along with several *Neodiplograptus* (aff. *Nd. africanus*) common in the North Saharan sections. The biserial graptolite fauna of the Hodh area does not include as many cosmopolitan taxa as indicated by Underwood *et al.* (1998) and needs further systematic examination.

Through the course of the Aeronian, during which sea-level fluctuated, but rose further than in the Rhuddanian (Loydell 1998), former diplograptoid stocks were

replaced in the North Saharan basins by a largely monograptoid immigration from lower latitudes. As a result *Metaclimacograptus*, *Climacograptus*, *Glyptograptus tamariscus*, *Coronograptus gregarius*, *Neolagarograptus*, *Campograptus*, *Torquigraptus*, *Rastrites*, *Lituigraptus* and some other monograptoid taxa appear as far inshore in North Africa as the western Murzuq Basin. By contrast, '*Paraclimacograptus*' *libycus*, a species presumably derived from a local North African *Neodiplograptus* ancestor at the beginning of the Aeronian, is closely related to *P. brasiliensis* (Ruedemann, 1929), which is widespread in South America (Brazil, Argentina). The two species suggest the existence of some faunal stocks that were common to low-latitude faunas over much of northern Gondwana. '*P. libycus*' may be distinguished from *P. brasiliensis* by its robust, more tapering rhabdosome with a rather gracile proximal end. *Climacograptus innotatus jordaniensis* Stein (in Wolfart *et al.* 1968) from southern Jordan is considered to be a probable junior synonym of '*P. libycus*'.

The low diversity of the Aeronian graptolite faunas of the North Saharan basins is even more remarkable when comparison is made with coeval faunas of peri-Gondwanan Europe. More than 100 species have been recorded from the Aeronian black shales of Bohemia for instance (Štorch 1994, 1998a), as opposed to the 22 species so far recorded in Algerian and Libyan sections. The number of species is based on our data and those published by Legend (1995, 1999, 2000) and Štorch and Massa (2003). The apparent low diversity of North African Aeronian graptolite assemblages is not the result of insufficient sampling, as the bedding-plane assemblages include only two or, rarely, three species in the Murzuq Basin and elsewhere in North Africa, while corresponding bedding planes display a dozen species in Bohemia. The differences between coeval assemblages from the North African shelf shales and siltstones and from black shales of the 'European' realm can be explained by different environmental conditions (Štorch 1998b). Shallower water with currents and wave action influenced the sedimentation of the Tanezzuff Formation in the Murzuq Basin, as suggested by cross-bedded and rippled sandy and silty intercalations with aligned graptolite rhabdosomes and scattered shelly fauna (nautiloids, brachiopods, bivalves, trilobites). In the B'ir al Qasr area, for instance, the Tanezzuff shales are laminated, being composed of (1) light coloured, commonly burrowed argillaceous laminae with dispersed, rounded, often coarse, sand grains floating in an argillaceous matrix, and (2) subordinate dark-coloured laminae with common graptolites and an increased content of organic matter. Bivalves and orthoconic nautiloid shells occur in organically lean, burrowed laminae. Unstable conditions, with fluctuating oxygen content on the seabottom and, perhaps, in the water column may have affected graptolite diversity during deposition of the

Aeronian part of the Tanezzuff shales. Similarly unstable conditions, unfavourable to graptolites, may have existed in the Awaynat Wanin area where common trochispiral gastropods, bivalves and orthocone nautiloids appear in oxic laminae. Shelly fossils also occur in the sections exposed along the western limb of the Murzuq Basin. Desio (1940) recorded some bivalves, orthocones, conulariids and also trilobites [*Ampyx balboi* Desio and *Calymene* cf. *blumenbachi* (Brongniart)] associated with '*P. libycus*' between Ghat and Serdeles. El-Chair *et al.* (1985) reported orthocones, hyolithids and cornulitids, and described a trilobite, *Dalmanites?* *fezzanensis*, from the *libycus-gregarius* Biozone of Tahale, 60 km north of Ghat.

Aeronian graptolite assemblages of similar, low diversity, also appear in the North Gondwanan shelf shales in central Saudi Arabia (El-Khayal 1985, 1987a; Mahmoud *et al.* 1992). A still more impoverished graptolite fauna ('*Climacograptus innotatus jordaniensis*', '*Climacograptus scalaris*' and *Demirastrites* ex gr. *triangulatus*) associated with bivalves, conulariids, brachiopods and crinoid columnals, has been recorded from Jordan (Wolfart *et al.* 1968). Very low-diversity graptolite associations are also known from Jujuy Province (Toro 1995) and San Juan Province (Rickards *et al.* 1996), Argentina, and from Estado de Para, Brazil (*P. innotatus brasiliensis* and *C. cf. gregarius*; Jaeger 1976). Correlation with the graptolitic strata of the La Chilca Formation of Talacasto (San Juan Province), tentatively assigned a Rhuddanian age by Cuerda *et al.* (1988), will require further study as Lenz *et al.* (2003) found early Telychian graptolites in the lower part of this unit. Towards the North Gondwanan periphery, beginning with Morocco, a moderately diverse Aeronian graptolite fauna flourished, as shown by Willefert (1963) and Lüning *et al.* (2000). It may be assumed that Moroccan graptolite assemblages of Aeronian age developed under different conditions: open-marine with fully anoxic bottom waters, conditions similar to those widespread in peri-Gondwanan Europe and elsewhere. A direct relationship between high TOC content and graptolite diversity is suggested by the data of Lüning *et al.* (2000). They recorded 4.35 per cent TOC in the Aeronian (upper *convolutus* Biozone) black shales of the Tadla Basin (central Morocco).

The lower Silurian black shales of Peri-Gondwanan Europe were deposited on mid-latitude open shelves influenced by a large upwelling system, as suggested by Wilde *et al.* (1991), Moore *et al.* (1993) and Štorch (1998b). In contrast, the Tanezzuff shales and their equivalents in northern Sahara originated in a complex system of intrashelf basins that were flooded and subsequently merged into a wide shelf sea during the step-wise postglacial transgression (Lüning *et al.* 2000; Ghienne 2003). Factors restricting graptolite diversity in the North African intrashelf basins may have included cold, high-latitude

climatic conditions, shallow water and partial isolation of these basins, episodic changes from oxic to anoxic conditions, and vice versa.

No Telychian graptolites are known from the Murzuq and Al Kufrah basins due to the north-westward progradation of sandy delta deposits (Acacus Formation) into the shallow shelf sea (Massa and Jaeger 1971; Berry and Boucot 1973; Massa 1981). The south-western sections in Algeria (Legrand 1995, 1999), and borehole cores from the Ghadames Basin (Štorch and Massa 2003) and Tripolitania, however, suggest that low to moderate graptolite diversity persisted into the Telychian in the North Saharan basins. Some of the Telychian associations are identical to those of shelf black shales of the Iberian Peninsula and Brittany [*Met. flamandi* (Legrand) associated with *Parapetalolithus meridionalis* (Legrand) and *Torquigraptus australis* Štorch] (Paris *et al.* 1980; Štorch 1998*b, c*). As might be expected, the Ghadames Basin, situated towards the northern shelf margin, yields slightly more diverse faunas with closer links to peri-Gondwanan Europe (Štorch and Massa 2003). The endemism of the North African graptolite faunas disappeared in the course of the Wenlock (Štorch and Massa 2003).

SYSTEMATIC PALAEOLOGY

Of the 22 species identified in our material, and figured in this paper, full descriptions are provided for seven. Short comments are made on other species that are either already well known from classical Aeronian localities of Europe or represented by material too poorly preserved or fragmentary for reliable determination. The short synonymies include the most important and North African–Arabian references and also refer to recent papers with more extensive or full lists of references. Specimens prefixed PŠ are housed at the Czech Geological Survey, Prague; MB.G. denotes the Museum für Naturkunde, Humboldt-Universität, Berlin.

Genus METACLIMACOGRAPTUS Bulman and Rickards, 1968

Metaclimacograptus hughesi (Nicholson, 1869) Text-figure 7N1–O2

- 1869 *Diplograptus Hughesi* Nicholson, p. 235, pl. 11, figs 9–10.
 1870 *Climacograptus Hughesi* Nicholson; Elles and Wood, pp. 208–210, pl. 27, fig. 11a; text-fig. 140.
 1871 *Pseudoclimacograptus undulatus* (Kurck, 1882); Bjerreskov, p. 26, pl. 4, fig. E.
 1872 *Lithuanograptus serus* Paškevičius, p. 147, pl. 1, figs 16–17; pl. 2, figs 21–23.
 1873 *Lithuanograptus serus* Paškevičius, 1976; Paškevičius, p. 114, pl. 2, figs 15–16; pl. 19, figs 9–11.

- ?1987c *Glyptograptus* (*G.*) *incertus* Elles and Wood, 1907; El-Khayal, pl. 1, fig. 3.
 1996 *Metaclimacograptus hughesi* (Nicholson, 1869); Zalasiewicz, p. 2, text-fig. 2A–C.

Neotype. Designated Přibyl (1948). The specimen figured by Elles and Wood, 1906, pl. 27, fig. 11a; from the Skelgill Beds of Ambleside, Lake District, England.

Material. Nearly 50 specimens that are either simply flattened in claystone or preserved as relief moulds in fine sandstone.

Description. The narrow, parallel-sided rhabdosome attains a maximum length of 15 mm. The sicula is 1.3–1.45 mm long, when seen pressed through, but its dimensions and features are more easily observed in very young rhabdosomes composed of just one or two thecal pairs. The sicular aperture is 0.17–0.25 mm wide. The proximal end of the rhabdosome has a blunt, slightly asymmetrical appearance. Th1¹ extends 0.1 mm below the sicular aperture and then turns and extends upwards for 0.7–0.8 mm. The thecae are strongly sigmoidal with parallel and/or slightly inward sloping supragenicular walls and thickened genicula. A narrow apertural incision, usually covered by a prominent roof-like genicular hood, occupies nearly one-third of the rhabdosome width. The aperture is normal to the rhabdosome axis or slightly introverted. The undulating median septum and interthecal septa are difficult to see except in specimens preserved in relief. The robust nema, however, is better seen in flattened specimens and often projects distally for nearly 2 mm. The rhabdosome widens from 0.7–0.9 mm at th1¹–th1² to 0.85–1.1 mm at the third thecal pair. The maximum width of the rhabdosome, 1.0–1.25 mm, is attained at the fourth to ninth thecal pairs. 2TRD is 1.15–1.3 mm at th2¹ and increases distally to 1.3–1.5 mm. The supragenicular walls of distal thecae are 0.5–0.6 mm long.

Remarks. The overall dimensions of the rhabdosome, thecal spacing and well-developed genicular hoods of Libyan specimens match well those of '*Lithuanograptus*' *serus* Paškevičius, 1976 from the *sedgwickii* Biozone of Lithuania. The same broad *Metaclimacograptus* was figured by (Bjerreskov 1975, pl. 4, fig. E) from the lower *convolutus* Biozone of Bornholm and it is also a dominant graptolite taxon in the lower and middle parts of the *sedgwickii* Biozone in Bohemia (*Metaclimacograptus* sp. of Štorch 1994 and '*Pseudoclimacograptus*' *hughesi* of Bouček 1953). All of these forms exhibit a DVW of *c.* 1.2 mm (when in low relief or flattened) and thecal spacing similar to the lectotype of *Met. hughesi* (Nicholson) figured by Zalasiewicz (1996), and differ from the very narrow rhabdosomes referred to *Met. hughesi* by Bulman and Rickards (1968), Hutt (1974), Loydell (1991) and others. It is the greater dorsoventral width, along with the characteristic angular undulation of the median septum, that distinguish *Met. hughesi* (Nicholson) *sensu stricto* from *Met. undulatus* (Kurck) and *Met. slalom* Zalasiewicz, 1996. The last embraces the narrow specimens formerly assigned to

Met. hughesi by Bulman and Rickards (1968) and many others. In the San Juan Province, Argentina, Cuerda *et al.* (1988) recognized the endemic genus *Talacastograptus* in the upper part of La Chilca Formation, which they (probably erroneously, see pp. 31–32) referred to the Rhuddanian. The very robust, *c.* 2-mm-wide rhabdosomes of *Talacastograptus leanzai* Cuerda, Rickards and Cingolani, 1988 have large apertural hoods similar to those in our Libyan specimens of *Met. hughesi*.

Metaclimacograptus? aff. hughesi (Nicholson, 1869)

Text-figure 7L1–L2

Remarks. Several small biserial rhabdosomes of pattern H astogeny, having strongly geniculate, seemingly normalograptid thecae were found in the *leptothea* and *convolutus* biozones of B'ir al Qasr. The proximal end of the *c.* 5-mm-long rhabdosomes is rounded, 0.7 mm wide at the level of the first thecal pair. The DVW increases to 0.95–1.2 mm at the level of the fifth thecal pair and a width of 1.2 mm is attained by the seventh thecal pair. The densely packed thecae possess deeply incised apertures. 2TRD at th2 is 1.25 mm and at th5 is 1.4 mm. The rhabdosome outline, general dimensions and thecal spacing resemble those of *Metaclimacograptus hughesi* but the thecae are of normalograptid appearance and an undulating median septum is difficult to see because of the preservation.

Genus CLINOCLIMACOGRAPTUS Bulman and Rickards, 1968

Clinoclimacograptus cf. retroversus Bulman and Rickards, 1968

Text-figure 7M

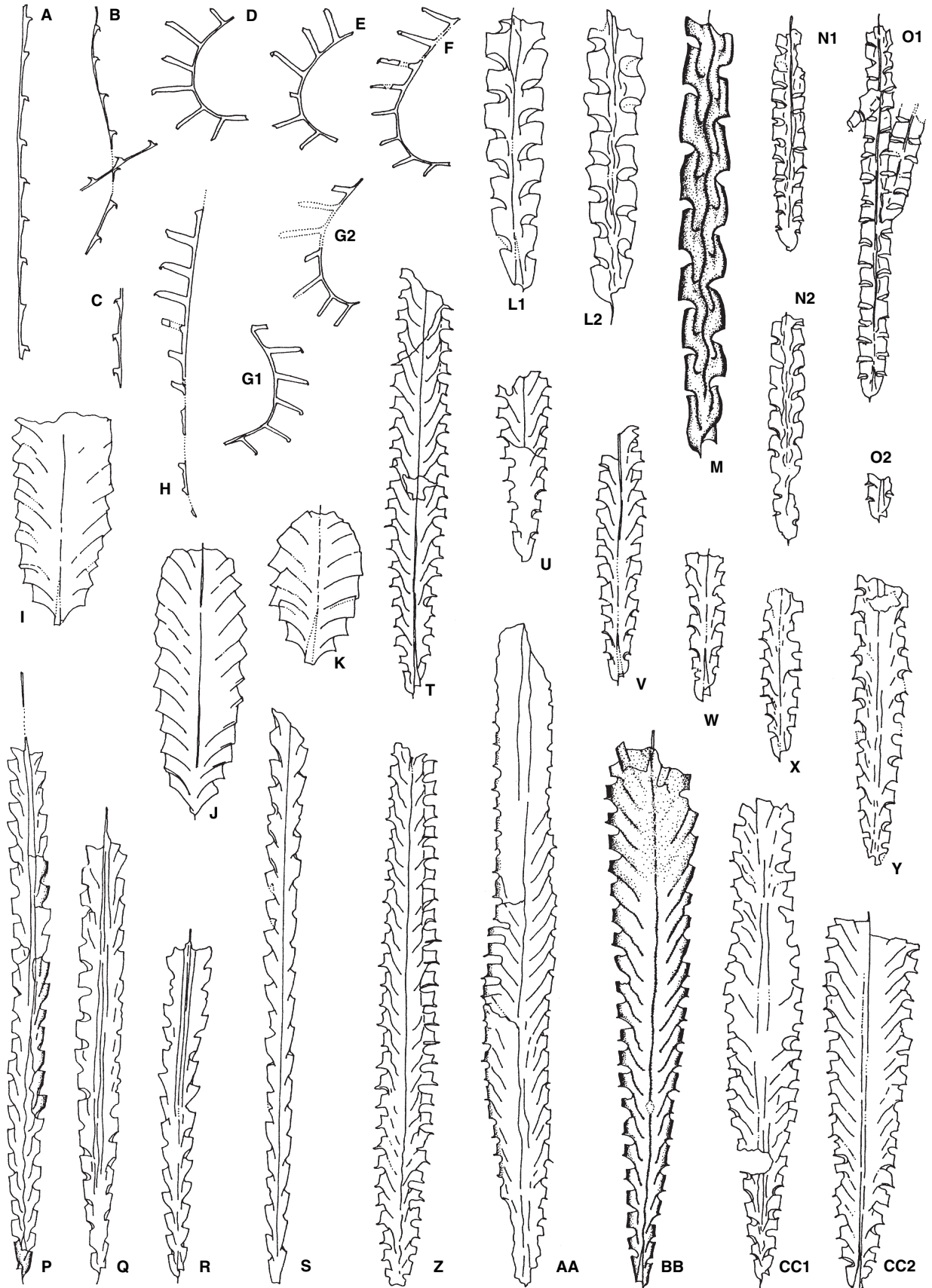
cf. 1968 *Pseudoclimacograptus* (*Clinoclimacograptus*) *retroversus* subgen. et sp. nov. Bulman and Rickards, pp. 8–12, text-figs 3a–c, 4a–c, 5.

Material. Three external moulds of formerly pyritized full relief rhabdosomes and two flattened specimens.

Description. The rhabdosome is 0.6–0.7 mm wide at the level of the first thecal pair, then widens to the maximum of 0.95–1.1 mm (1.3 mm when flattened), attained at the fourth to eighth thecal pair. The longest rhabdosome measures 10.6 mm. The sicula is visible for 0.85 mm in obverse view. The sicular aperture is 0.17 mm wide, furnished with a tiny virgella. The median septum is complete, undulating in the proximal part and straighter distally. Th1¹ grows downwards and then, just below the sicular aperture, turns strongly and grows upwards for 0.75–1.1 mm. The alternating thecae possess strong sigmoidal curvature, sharp genicula and convex, slightly inward sloping supragenicular walls. The apertures, situated in deep excavations, are obscured but appear to exhibit some degree of retroversion. Apertural excavations each comprise one-third to one-quarter of the dorsoventral width. The supragenicular walls are 0.6–0.75 mm long. 2TRD increases from 1.6–1.75 mm at th2¹ to 1.7–2.0 mm distally.

Remarks. The rhabdosomes resemble the pyritized specimens described and figured by Bulman and Rickards (1968) and differ only in having slightly less densely spaced thecae and, probably, less retroverted thecal apertures. The isolated rhabdosomes from Kallholen (Sweden), described by Loydell (1991), however, differ more substantially, having concave supragenicular walls and more densely spaced thecae with 2TRD increasing from 1.2–1.4 mm proximally to 1.45–1.6 mm distally. The Libyan rhabdosomes may also be compared with roughly coeval specimens from the upper part of the *convolutus* Biozone of Bornholm (Bjerreskov 1975), which have an undulating median septum and a larger visible part of the sicula. The steady increase in the dorsoventral width observed in the material from Bornholm, however, has not been observed in our full-relief specimens. The clinoclimacograptids mentioned above probably belong to several different species and the group is in need of revision based upon well-preserved, preferably isolated material.

TEXT-FIG. 7. A–C, '*Monograptus*' *cf. elongatus* Törnquist, 1899. A, PŠ 1108; B, PŠ 1078; C, PŠ 1075; '*leptothea*' – *convolutus* biozones, B'ir al Qasr 1. D–E, *Rastrites approximatus* Perner, 1897. D, PŠ 1110; E, PŠ 1109; '*leptothea*'–*convolutus* biozones, Awaynat Wanin. F–G2, *Rastrites peregrinus* Barrande, 1850. F, PŠ 1087; G1–G2, PŠ 1086; *convolutus* Biozone, B'ir al Qasr 2. H, '*Monograptus*' sp., PŠ 1111b, ?'*leptothea*' Biozone, Awaynat Wanin. I–K, *Petalolithus clandestinus* Štorch, 2001. I, PŠ 1102; J, PŠ 1103; K, PŠ 1105; *tenuis* Subzone, Magbarat Abu al Hayran. L1–L2, *Metaclimacograptus? aff. hughesi* (Nicholson, 1869), PŠ 1082, *convolutus* Biozone, B'ir al Qasr 2. M, *Clinoclimacograptus cf. retroversus* Bulman and Rickards, 1968. PŠ 1095a, *convolutus* Biozone, B'ir Al Qasr 2. N1–N2, O1–O2, *Metaclimacograptus hughesi* (Nicholson, 1869). N1–N2, PŠ 1098; O1–O2, PŠ 1099; *sedgwickii* Biozone, Awaynat Wanin. P–R, *Normalograptus cf. tariti* (Legrand, 1970). P, MB.G 1095 (sample NA 689); Q, MB.G 1104; R, MB.G 1105 (sample NA 690); *libycus-gregarius* Biozone, Wadi Iyadhar. S, *Glyptograptus tamariscus* (Nicholson, 1868), PŠ 1079; *convolutus* Biozone, B'ir Al Qasr 2. T–CC2, '*Paraclimacograptus*' *libycus* (Desio 1940). T, MB.G 1106; U, PŠ 1114; V, PŠ 1064; W, PŠ 1096; X, PŠ 1072; Y, PŠ 1083b; Z, b. 689.1; AA, b. 689.3; BB, PŠ 1094; CC1–CC2, PŠ 1090; T–U, X–Y, *libycus-gregarius* Biozone, Tanesfert (T, sample PC 102; U, X–Y, sample PC 108); V–Y, BB–CC2, *convolutus* Biozone, B'ir al Qasr 2; Z, AA, *libycus-gregarius* Biozone, Wadi Iyadhar (sample NA 482). Specimens figured on L1–L2 and M × 10, other specimens × 5.



Genus *PARACLIMACOGRAPTUS* Přibyl, 1947 (*sensu* Russel
et al. 2000)'*Paraclimacograptus*' *libycus* (Desio, 1940)

Plate 1, figures 1–2, 5–6; Text-figure 7T–CC2

- 1940 *Climacograptus libycus* Desio, pp. 28–30, pl. 1, figs 1–2, ?3, 4–8, 10–14.
- 1941 *Diplograptus modestus* var. *fezzanensis* n.f.; Desio (*partim*), pl. 1, fig. 9.
- ?1968 *Climacograptus innotatus jordaniensis* Stein, in Wolfart *et al.*, pp. 546–548, pl. 50, figs 1–4.
- 1976 *Climacograptus innotatus brasiliensis* Ruedemann; Jaeger, pl. 2, fig. 6; pl. 3, fig. 6.
- 1977 *Climacograptus innotatus brasiliensis* Ruedemann 1947; El Chair *et al.*, pl. 2, figs 1–5.
- 2002 *Normalograptus* (*Paraclimacograptus*?) *libycus* (Desio); Legrand, pp. 219–222, pl. 12, figs 5–6, text-fig. 5l–n.

Lectotype. Designated Legrand (1970). Specimen figured by Desio (1940, pl. 1, fig. 1) from the Tanezzuft Formation (Llandovery) of western Murzuq Basin, km 45 on the Serdeles-Ghat road, south-west Libya. Housed at the Department of Earth Science, University of Milan.

Material. 46 specimens; mostly complete rhabdosomes, preserved in claystone, shale and siltstone; either flattened or preserved in relief.

Diagnosis. Robust, *c.* 3 mm wide distally, 'tapering' septate normalograptid with early astogeny of pattern H. Proximal thecae strongly geniculate, distal thecae of almost glyptograptid type, with long infragenicular portion, overlapping for nearly three-fifths of their length. Supragenicular wall short, nearly parallel-sided. Proximoventrally directed prominent genicular flange on each theca gives the rhabdosome an overall spinose appearance.

Description. The rhabdosome attains a maximum length of more than 30 mm and a maximum width of 2.5–3.0 mm (a width of 3.3 mm being observed in one flattened specimen). Excluding the dorsal apertural processes the rhabdosome widens from 0.75–0.85 mm at the level of $th1^1$ – $th1^2$ (extremes being 0.65 and 0.95 mm, respectively) to 1.0–1.4 mm at the third thecal pair, and 1.9–2.6 mm at the tenth thecal pair. The maximum

width is usually attained at the *c.* seventeenth thecal pair of a mature rhabdosome. Late mature rhabdosomes may taper slightly distally. The sicula is 1.6–1.7 mm long, with a straight aperture, 0.2–0.35 mm wide, possessing a small virgella 0.2–0.3 mm long. The sicular apex reaches a level between the $th2^1$ and $th3^2$ apertures. Early astogeny is of pattern H of Mitchell (1987). $Th1^1$ has a downward-growing portion 0.45 mm long. It turns abruptly 0.25 mm below the sicular aperture and grows upwards for 0.75–0.95 mm. $Th1^2$ originates 0.25–0.3 mm above the sicular aperture and grows upwards for 0.65–0.75 mm. The proximal thecae are strongly geniculate whilst the distal thecae become more glyptograptid in type. The thecal appearance depends upon the mode of preservation. Distal thecae are 1.6–2.0 mm long, overlapping for one-half to three-fifths of their length. The supragenicular thecal walls are short (0.4 mm), parallel-sided or slightly inclined outward (*c.* 5 degrees) to the rhabdosome axis. The broad apertural excavation is furnished with a dorsal, flange-like genicular process projecting ventrally or proximoventrally for 0.2–0.35 mm. The genicular flanges give the thecae a strongly geniculate character (resembling *N. extraordinarius*) and give the rhabdosome an overall spinose appearance. Thecae number 11.5–13 in the proximal 10 mm of the rhabdosome and 11.5–12.5 in 10 mm distally. The 2TRD at $th2$ is 1.45–1.6 mm, 2TRD 5 and 2TRD 10 are 1.55–1.8 mm and 2TRD of the distal thecae is 1.6–1.8 mm (extremes being 1.5 and 1.9 mm).

Remarks. The early astogeny and genicular processes of '*Paraclimacograptus*' *libycus* (Desio, 1940) match well the diagnosis of *Paraclimacograptus* Přibyl as emended by Russel *et al.* (2000) with respect to chemically isolated specimens of *P. innotatus* (Nicholson) and *P. exquisitus* (Rickards). The overall robustness of the rhabdosome, however, and its long, highly overlapping thecae are similar to *Neodiplograptus* (such as *Nd. fezzanensis* and *Nd. africanus*). The genicular processes resemble the strong genicula in *N. extraordinarius*. Herein the species is tentatively assigned to *Paraclimacograptus* until its ancestry is elucidated. Among the early Silurian graptoloids, immature specimens of '*P.*' *libycus* can be easily misidentified as *Paraclimacograptus brasiliensis* (Ruedemann, 1929). *P. brasiliensis* from the type locality at Rio Trombetas (Amazon Basin, Brazil), figured by Jaeger (1976, pl. 3, figs 1–3, 5, 9–10), possesses a narrower (2 mm without apertural processes) and largely parallel-sided rhabdosome. The same form, having a parallel-sided rhabdosome, 2 mm in maximum width, and thecae

EXPLANATION OF PLATE 1

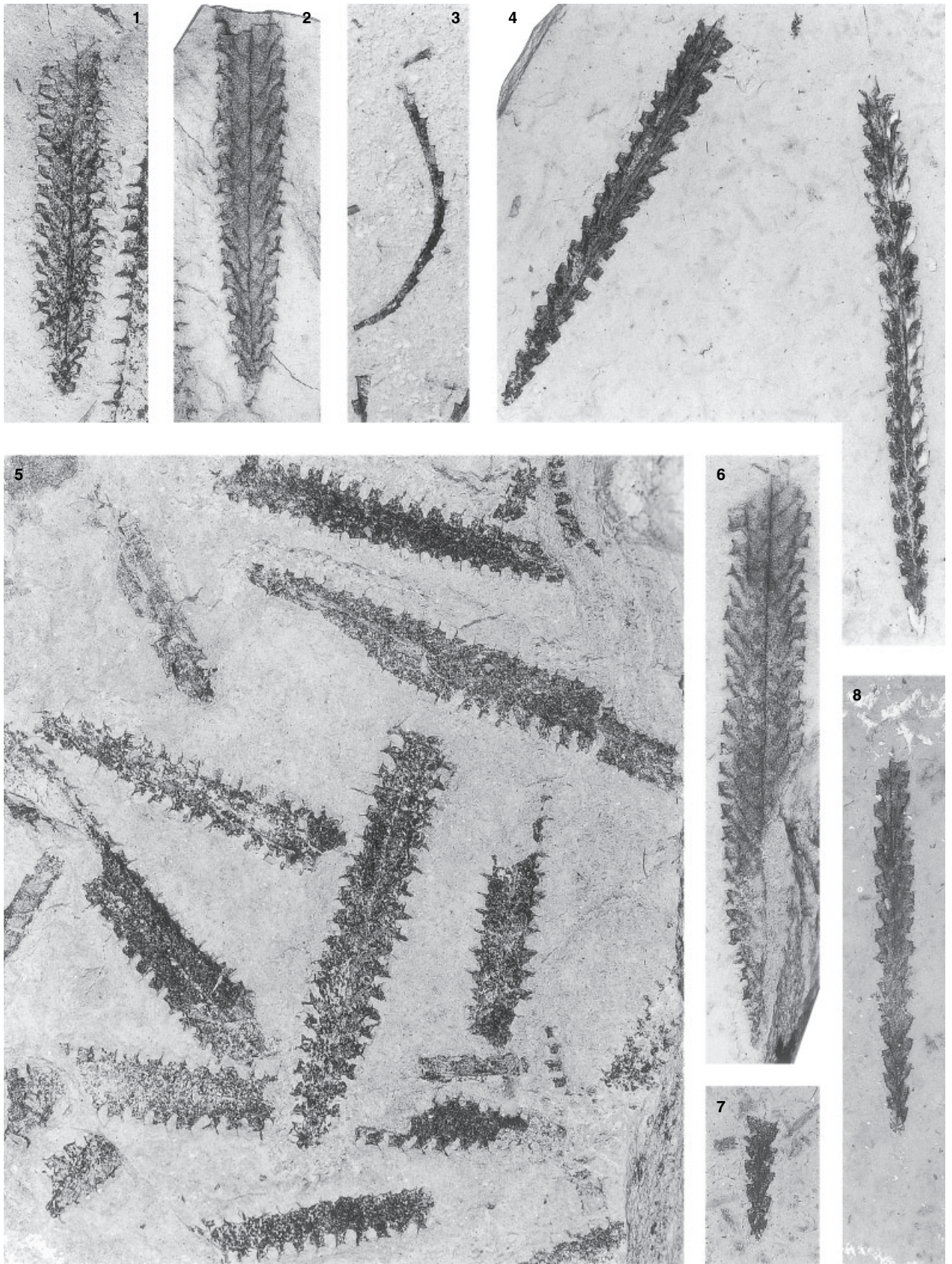
Figs 1–2, 5–6. '*Paraclimacograptus*' *libycus* (Desio, 1940). 1, MB.G 689.2, sample NA 482. 2, 6, MB.G 690, sample PC 102 (same slab). 5, MB.G 689.3, sample NA 482. All *libycus-gregarius* Biozone, 1, 5, Wadi Iyadhar; 2, 6, Tanesfert.

Fig. 3. *Coronograptus gregarius* (Lapworth, 1876). MB.G 1103, sample PC 116, *libycus-gregarius* Biozone, Tanesfert.

Figs 4, 7–8. *Normalograptus* cf. *tariti* (Legrand, 1970). 4, MB.G 1095, sample NA 689. 7, MB.G 1096, sample NA 689. 8, MB.G 1104, sample NA 690. All *libycus-gregarius* Biozone, Wadi Iyadhar.

All $\times 5$.

PLATE 1



ŠTORCH and MASSA, Aeronian graptolites

numbering 12–14 in 10 mm, was described earlier by Ruedemann (in Maury 1929) and Ruedemann (1947). *P. brasiliensis* from San Juan Province, Argentina, described by Rickards *et al.* (1996), also differs from '*P.*' *libycus* in its narrower, rather parallel-sided rhabdosome and thecae which are more densely packed proximally and more widely spaced distally. The type material of '*P.*' *libycus*, described by Desio (1940), the specimens figured by Jaeger (1976, pl. 2, fig. 6; pl. 3, fig. 6), Legrand's (2002) and our specimens from the *gregarius* Biozone of the Murzuq Basin are more robust (c. 3 mm wide without genicular processes) than *P. brasiliensis* and taper markedly proximally, although less than the stratigraphically youngest populations from the *convolutus* Biozone. Both flattened and full-relief rhabdosomes of '*P.*' *libycus* taper proximally in the same manner. '*Climacograptus*' *innotatus jordaniensis* Stein, 1968 described from probable *triangulatus* – *convolutus* biozone strata of southern Jordan matches '*P.*' *libycus* in having a robust and considerably tapering rhabdosome and thecae numbering 12–13 in 10 mm. Generally the Jordanian specimens are narrower, attaining a maximum width of 2.3 mm. All the specimens, however, are preserved in partial or full relief, in sandstone and siltstone (Wolfart *et al.* 1968). The stratigraphical ranges of the two forms also appear to be identical. '*Cl.*' *innotatus jordaniensis* has been accompanied by *Demirastrites* ex gr. *triangulatus* and *Normalograptus* sp. Thus, the species may be a junior synonym of '*P.*' *libycus*. The ultimate assignment of '*Cl.*' *innotatus jordaniensis*, however, requires a more detailed description of topotype material.

Genus NORMALOGRAPTUS Legrand, 1987

Normalograptus cf. *tariti* (Legrand, 1970)
Plate 1, figures 4, 7–8; Text-figure 7P–R

cf. 1970 *Glyptograptus* (*Glyptograptus*) *tariti* Legrand,
pp. 41–46, text-fig. 2–051.

Material. Seven flattened, mostly complete, moderately well-preserved rhabdosomes.

Description. Proximally tapering septate normalograptid rhabdosome with geniculate, glyptograptid thecae. The rhabdosome is up to 20 mm long, widening from 0.6–0.7 mm (at the level of the apertures of the first thecal pair) to 1.2–1.35 mm at the third thecal pair. The maximum width of 1.4–1.75 mm is attained at the eighth–tenth thecal pair. The sicula is c. 1.2 mm long, rarely seen since it is almost fully covered on the reverse side. The apex reaches the level of the th₂² geniculum; the aperture is 0.2 mm wide and possesses a short virgella. Th₁¹ extends 0.25 mm below the sicular aperture before turning strongly upwards. The upward growing portion of th₁¹ measures 0.65–0.8 mm. Th₁²

crosses the sicula, leaving just 0.1 mm of its ventral wall free. The upward growing part of th₁² is 0.55–0.75 mm long. The alternating thecae have prominent genicula; supragenicular walls are inclined at 5–15 degrees to the rhabdosome axis. Thecae overlap for up to one-half their length. Broad apertural excavations occupy one-quarter to almost one-third of the rhabdosome width. The 2TRD at th₂ is 1.6–1.8 mm and at th₅ is 1.75–1.95 mm. Distally the 2TRD attains 1.7–2.05 mm.

Remarks. The geniculate thecae exhibit either a glyptograptid or an almost climacograptid appearance depending upon the orientation and degree of flattening. The overlapping thecae, markedly inclined supragenicular walls, complete median septum and prominent pattern H early astogeny identify the present rhabdosomes as a gracile representative of the *N. ojsuensis*, *N. persculptus*, *N. venustus* Legrand and *Normalograptus tariti* (Legrand) clade. *N. tariti*, which is the most similar, differs in having a more robust rhabdosome (0.85–1.0 mm wide at the level of the first thecal pair, maximum DVW of c. 1.6–1.8 mm attained almost immediately). The thecae of *N. tariti* overlap for half their length, slightly more in general than those of our *N. cf. tariti*.

Genus GLYPTOGRAPTUS Lapworth, 1873 (*sensu* Melchin and Mitchell 1991)

Glyptograptus tamariscus (Nicholson 1868)
Text-figure 7S

Remarks. Two rhabdosomes match well all the parameters of the Bohemian representatives of *G. tamariscus* described by Štorch (1998a) and also match those published by Packham (1962). The sicula is 1.1 mm long and its apex attains approximately the level of th₁² aperture. The rhabdosome widens from 0.6 mm at the first thecal pair to c. 1.2 mm at the tenth thecal pair and then soon attains its maximum width of 1.4 mm. Strongly alternating, glyptograptid thecae number 9.5–10 in 10 mm. 2TRD at both th₂ and th₅ is about 2.0 mm.

Genus PETALOLITHUS Suess, 1851

Petalolithus clandestinus Štorch, 2001
Text-figure 7I–K

Remarks. Small, elongated-ovoid petalolithid rhabdosomes accompany a *Neolagarograptus tenuis* Subzone fauna at Magbarat abu Al Hayran (Awaynat Wanin area). The sicular aperture is rather isolated, slightly protracted beyond the proximal end of the rhabdosome. Proximal thecae are ventrally curved, both proximal and distal

thecal apertures facing ventrally. The mature rhabdosomes attain a maximum width of 3.4–3.8 mm at the level of th6–th8. Mature rhabdosomes recorded in south-east Algeria (Štorch and Massa 2003, text-figs 3, 9–10), and tentatively identified as *Parapetalolithus* cf. *wuxiensis*, are even broader. Thecal length and spacing match well the type rhabdosomes described by Štorch (2001) from the lowermost part of the *sedgwickii* Biozone of Bohemia. However, an ancora, distinguishing the species from *Parapetalolithus wuxiensis* Ye, reported from the *turriculatus* and/or *guerichi* Biozone in China, has not yet been identified in the limited Saharan material.

Genus CORONOGRAPTUS Obut and Sobolevskaya, 1968
(sensu Rickards 1976a)

Coronograptus gregarius (Lapworth, 1876)

Plate 1, figure 3; Plate 3, figures 1–2; Text-figure 8G1–H

- 1876 *Monograptus gregarius* Lapworth, p. 317, pl. 10, fig. 12a–c.
 1940 *Monograptus gregarius* Lapworth; Desio, pp. 31–32, pl. 2, fig. 17 (*non* 16)
 1963 *Monograptus gregarius* Lapworth; Willefert, p. 30, pl. 1, figs 18, ?14 (*non* 9, 17), text-fig. 44a–b.
 1970 *Monograptus gregarius* Lapworth, 1876; Rickards, p. 61, text-figs 14, 35, text-figs 18, 14 (see for further synonymy).
 1988 *Coronograptus gregarius gregarius* (Lapworth, 1876); Štorch, pp. 18–19, pl. 4, figs 1–3; text-fig. 2I–J.

Lectotype. Designated Přibyl (1948). Specimen BU 1435 figured by Lapworth 1876, pl. 10, fig. 12a, and refigured by Elles and Wood 1911, pl. 36, fig. 3a; from the Birkhill Shales at Dob's Linn, Scotland.

Material. Six small, simply flattened rhabdosomes and many fragments.

Diagnosis. See Hutt (1975).

Description. Dorsally curved rhabdosome reaches a maximum length of 15 mm. The sicula is 3.4–4.0 mm long, attaining the level of the aperture of th3 or slightly above. The sicular aperture measures 0.17–0.22 mm in diameter. The first theca originates 1.8–2.4 mm above the sicular aperture and is 1.25–1.5 mm long. The 2TRD at th2 is 1.55–2.35 mm, 2TRD 5 is 1.7–2.1 mm and the distal 2TRD (from th10 onwards) is 1.7–2.3 mm. The thecae are simple tubes with genicula and expanded apertures that occupy about one-half of the rhabdosome width. The dorsoventral width is 0.4–0.45 mm at the level of the first thecal aperture and reaches a maximum of 0.6 mm distally.

Remarks. The Libyan specimens are similar to those described from the English Lake District (Hutt 1975), Born-

holm (Bjerreskov 1975), Siberia (Obut *et al.* 1968) and Bohemia (Štorch 1988). The rather short siculae of the Libyan specimens are 3.4–4.0 mm long and attain a level at or a little above the th3 aperture. These sicular dimensions resemble those of the early forms of *C. gregarius* found in the upper *cyphus* and lower *triangulatus* biozones. Libyan rhabdosomes differ from the majority of European material of *C. gregarius* in being narrower both proximally and in the distal part of the rhabdosome; also the sicular aperture is narrower. *Coronograptus arcuatus* Obut and Sobolevskaya, 1968 has an equally narrow proximal part of the rhabdosome but possesses a longer sicula (up to 6 mm), less overlap to the thecae (one-quarter to one-fifth) and more widely spaced thecae (numbering 5–8 in 10 mm). The sicular apex never attains a level higher than the th3 aperture in *C. arcuatus*. *Coronograptus minusculus* Obut and Sobolevskaya, 1968 differs from the present material in having a shorter sicula (max. 3.0 mm), which attains the level of th2 aperture or slightly above, and in more closely spaced thecae (10–12) in 10 mm. *Coronograptus hipposideros* Toghil, 1968 has much stronger rhabdosome curvature and a shorter sicula (2.5–3.0 mm). Libyan specimens can be most probably referred to the early forms of *C. gregarius*, at least until the time when larger collections allow a more detailed biometric study.

Genus NEOLAGAROGAPTUS Štorch, 1998a

Neolagarograptus helenae Štorch, 1988

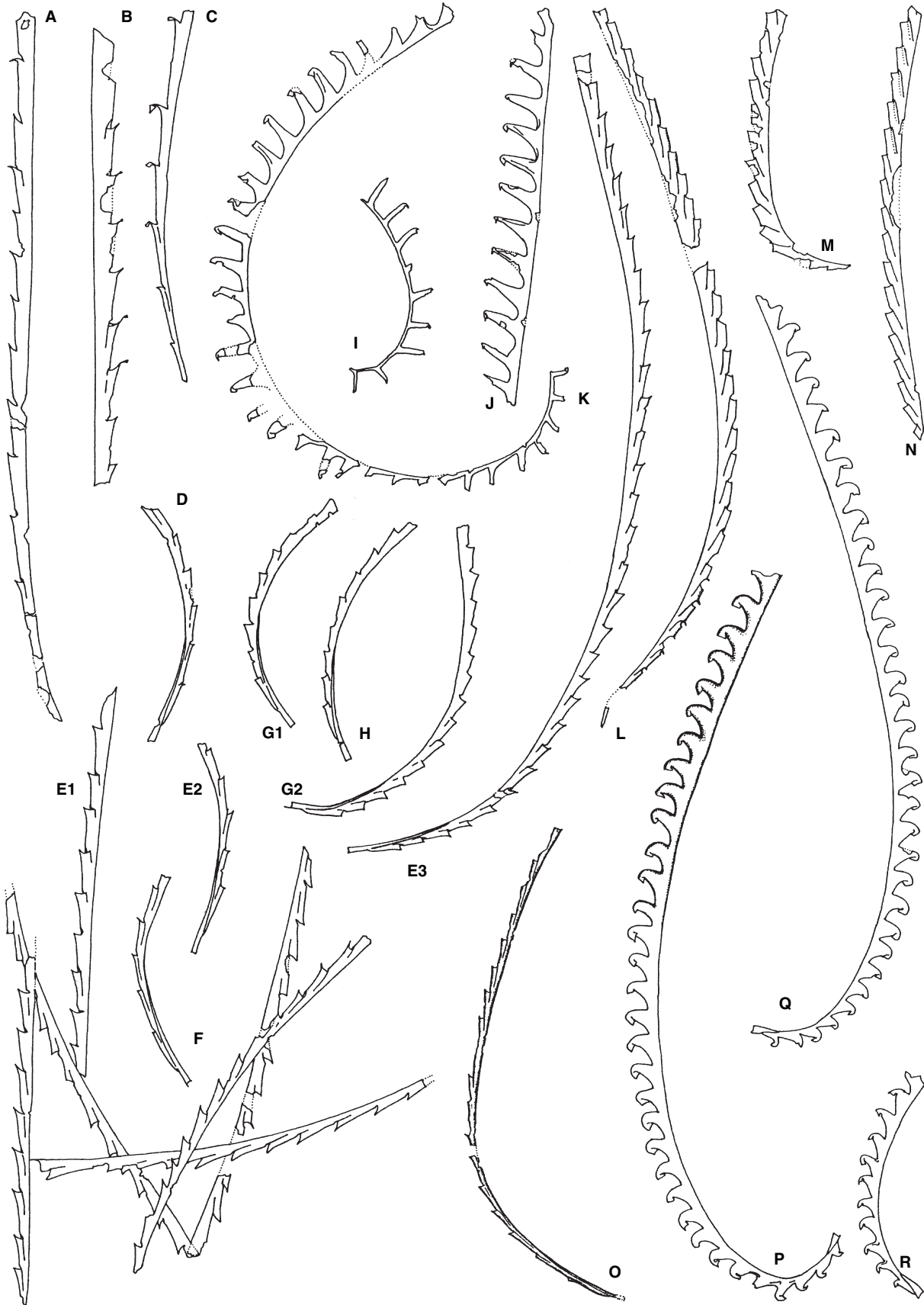
Plate 2, figure 4; Text-figure 8D, E1–E2, ?E3, F, O

- 1988 *Lagarograptus helenae* Štorch, pp. 24, 26, pl. 12, fig. 3; text-fig. 4d.
 1998a *Neolagarograptus helenae* (Štorch, 1988); Štorch, p. 230, pl. 7, figs 3, 8; text-figs 7, 10.

Holotype. By original designation, the specimen figured by Štorch (1988, pl. 12, fig. 3, text-fig. 4d from the middle Llandovery, *leptothea* Biozone), Želkovice Formation, Tmaň-Svatý Jiří, Barrandian area, Bohemia. Housed in the Geological collections of the Czech Geological Survey, Prague.

Material. More than 60 specimens, often complete, mostly flattened but some pyritized or preserved as relief external moulds.

Diagnosis (emended). Rhabdosome widening gradually from 0.25–0.35 mm at the aperture of th1, 0.45–0.65 mm at th10; maximum DVW is 0.7 mm. Arcuate dorsal curvature of the rhabdosome weakly accentuated proximally. Sicula 4–5 mm long; the apex attains a level from th2 aperture to halfway up th3. Thecae slender, tubular, with sharp geniculum and ventrally extended aperture, which is slightly everted in proximal thecae and slightly intro-



verted in distal thecae. Thecae number 9–6·5 in 10 mm both proximally and distally. Neither genicular nor ventral apertural processes developed.

Description. The rhabdosome is more than 50 mm long, arcuate, gradually straightening in the distal part, with thecae on the convex side. The sicula is about 4 mm long (the length varies between 3·7 and 5·0 mm) and its apex reaches to about the aperture of th2 or halfway up th3. The sicular aperture is slightly concave, 0·12–0·18 mm wide, with a short, narrow virgella. Th1 is 1·2–2·1 mm long and originates 0·7–0·85 (max. 1·2) mm above the sicular aperture. The thecae are slender tubes having small, sharp genicula without any genicular process. The concave supragenicular wall is inclined at 10–20 degrees to the rhabdosome axis in the proximal part of the rhabdosome and up to 20–30 degrees distally. Thecal apertures are slightly everted in the most proximal thecae. The distal thecae have straight to slightly concave apertures, which are either introverted or nearly perpendicular to the rhabdosome axis. The aperture occupies almost one-half the rhabdosome width. No apertural process is developed on the dorsally extended thecal apertural margin. Thecae overlap for up to one-half in the distal part of the rhabdosome and number 6·5–9 in 10 mm. Two thecae repeat distance varies considerably. The 2TRD at th2 ranges from 2·3 to 3·0 mm (extremes being 1·9 mm and 3·2 mm, respectively), 2TRD5 is 2·1–3·4 mm, 2TRD10 is 2·0–3·0 mm and distally 2TRD is 2·45–3·4 mm (an extreme being 3·6 mm). The dorsoventral width of the rhabdosome increases gradually from 0·25 to 0·35 mm (maximum 0·4 mm) at the level of th1, 0·35–0·45 mm at th3, 0·4–0·45 mm at th5 and 0·45–0·65 mm at th10. The maximum width recorded in the distal fragments is 0·7 mm, attained at the level of about fifteenth to twentieth theca.

Remarks. The present material has been assigned to *Neolagarograptus helenae* (Štorch, 1988) described from the *leptothea* Biozone of Bohemia. Libyan specimens differ from the Bohemian material only in having more inclined supragenicular walls and a greater maximum width, attained in the distal part of the rhabdosome. Bohemian rhabdosomes, however, never reached the length of the most mature Libyan specimens so that the most distal portions of the rhabdosomes can hardly be compared. *Neolagarograptus impolitus* Štorch, 1998a, recorded from the *leptothea* and *convolutus* biozones of Bohemia, differs from *Nl. helenae* in its shorter sicula (3·5–4·0 mm), the apex of which does not reach the level of the th2 aperture. The thecae of *Nl. impolitus* tend to be more widely spaced

(6·5–8 in 10 mm) and its rhabdosome is more robust proximally (0·4–0·45 mm at th1). *Neolagarograptus rickardsi* (El Khayal, 1987a) described from the *convolutus* Biozone, Tabuk Formation, of Saudi Arabia differs from *Nl. helenae* in having a dorsally curved sicula, the apex of which attains at maximum the th2 aperture, and in attaining a greater maximum rhabdosome width (0·83 mm). The proximal thecae of *Nl. rickardsi* are more geniculate and less densely packed, numbering just 6·5 per 10 mm; their apertures are more everted and situated in more prominent excavations. Thus, the small genicular hoods reported by El-Khayal (1987a) may represent a prolonged dorsal thecal wall rather than the genicular hood of the following theca (see El Khayal, pl. 1, figs 1–2). The most striking difference between the two species, however, is in their thecal apertures. The ventral apertural lips of *Nl. rickardsi* possess prominent triangular flanges resembling those of *Neolagarograptus tenuis* (Portlock, 1843). Neither the Bohemian nor the extensive Libyan material of *Nl. helenae* exhibits any trace of such an apertural structure. *Nl. tenuis*, however, always possesses these lappets. It is obvious that the lack of apertural lappets in *Nl. helenae* is not a preservational feature but reflects the difference in phenotype (?ecophenotype). Cuerdo *et al.* (1988) described *Lagarograptus praeacinaces* from La Chilca Formation of San Juan Province, Argentina, and interpreted their taxon as a sort of intermediate between *Atavograptus atavus* (Jones) and *Lagarograptus acinaces* (Törnquist). '*Lagarograptus? praeacinaces*, however, resembles late Aeronian *Neolagarograptus*. It lacks genicular processes, its 3·5-mm-long sicula resembles that of *Nl. impolitus* (3·5–4·0 mm) or even *Nl. rickardsi* (4·0 mm), its ventrally extended apertures are furnished with prominent triangular lappets and the DVW of the rhabdosome attaining 1·3 mm strongly resemble *Nl. tenuis*. The slender proximal portion of *Lagarograptus? praeacinaces* matches that of *Nl. helenae*, which may also exhibit similarly low thecal spacing. The stratigraphical assignment of the middle and upper parts of La Chilca Formation may need further examination.

One specimen on slab no. PŠ 1075 figured on Plate 2, figure 4 and Text-figure 8E3 ('*leptothea*' Biozone, B'ir al Qasr 2) differs from other specimens on the same slab, as well as from all other available specimens of *Nl. helenae*, in having more densely packed and slightly more inclined

TEXT-FIG. 8. A–C, *Neolagarograptus tenuis* (Portlock, 1843). A, PŠ 1101; B, PŠ 1104; C, PŠ 1100; *tenuis* Subzone, Magbarat Abu al Hayran. D–E2, ?E3, F, O, *Neolagarograptus helenae* Štorch, 1988. D, PŠ 1069; E1–E3, PŠ 1075; F, PŠ 1037a; O, PŠ 1095a; D–F, '*leptothea*' and *convolutus* biozones, B'ir Al Qasr 1; O, *convolutus* Biozone, B'ir al Qasr 2. G–H2, *Coronograptus gregarius* (Lapworth, 1876). G1–G2, MB.G 1101; H, MB.G 1102; *libycus-gregarius* Biozone, Tanesfert (G1–G2, sample PC 116; H, sample PC 114). I–K, *Torquigraptus decipiens* (Törnquist, 1899). I, PŠ 1066; J, PŠ 1071; K, PŠ 1070a; *convolutus* Biozone, B'ir al Qasr 1, 2. L, *Monograptus havliceki* Štorch, 1988, PŠ 1064, *convolutus* Biozone, B'ir al Qasr 2. M, ?N, *Monograptus limatulus* (Törnquist, 1892). M, PŠ 1070b; ?N, PŠ 1074; *convolutus* Biozone, B'ir Al Qasr 2. P–R, *Campograptus obtusus* (Rickards, 1970). P, PŠ 1063; Q, PŠ 1085b; R, PŠ 1081; *convolutus* Biozone, B'ir Al Qasr 2. All $\times 5$.

thecae and a sicula attaining a level well above the th3 aperture. This form suggests that *Neolagaroptus* may well have arisen from the *Coronograptus gregarius* stem by further elongation and geniculation of the thecae, ventral expansion of the thecal aperture and subsequent development of a ventrally projecting apertural lappet. Whilst the sicula of the *C. gregarius* lineage underwent dramatic elongation resulting in the 10–14-mm-long sicula of *C. maxiculus* Štorch (*leptotheca* Biozone of Europe), siculae of *Neolagaroptus* remained 3.5–5.0 mm long until termination of the lineage with *Nl. tenuis* (Portlock).

Neolagaroptus tenuis (Portlock, 1843)

Text-figure 8A–C

Remarks. Fragmentary rhabdosomes collected at Magbarat abu Al Hayran exhibit typical features and parameters of this widespread, age-diagnostic species. Distal fragments are weakly dorsally curved and their maximum width is 0.85 mm, excluding thecal apertural processes. Long tubular thecae are terminated by an acuminate apertural margin that regularly possesses a prominent, ventrally directed or slightly pendent lappet. The 2TRD distally varies between 3.2 mm and 4.1 mm. Proximal fragments are more arcuate; the proximal 2TRD is 4.0–5.1 mm.

Genus PRISTIOGRAPTUS Jaekel, 1889

Pristiograptus regularis (Törnquist, 1899)

Plate 3, figure 5; Text-figure 9H–I

- 1899 *Monograptus regularis* Törnquist, p. 7, pl. 1, figs 9–14.
 1900 *Monograptus gregarius* Lapworth; Desio, pp. 31–32 (*partim*), pl. 2, fig. 16 (*non* 17).
 1940 *Monograptus* cf. *dubius* (Suess); Desio, p. 32, pl. 2, fig. 15.
 1987 *Pristiograptus regularis regularis* (Törnquist, 1899); El-Khayal, pp. 387–391, pl. 1, figs 1–11 (see for further references).

Lectotype. Not yet designated. Törnquist (1899) illustrated specimens from the *Cephalograptus cometa* Zone (Aeronian) of Scania, Sweden.

Material. About 30 fragmentary specimens, including proximal ends, preserved both flattened (in claystones) and in relief (in fine sandstone).

Diagnosis. Rhabdosome straight, apex of c. 0.8-mm-long sicula reaches below the level of the first thecal aperture. Thecae simple slender tubes, inclined at an angle of 20–30 degrees to the rhabdosome axis and overlapping for up to about half their length.

Description. Fragmentary specimens indicate that the complete rhabdosome greatly exceeded 50 mm long. The sicula is straight, 0.8 mm long, having a 0.25-mm-wide aperture. The sicular apex attains a level just below the aperture of th1. The rhabdosome is generally straight. The proximal part widens from 0.4 mm at the level of the first thecal aperture to 0.55 mm at the level of th5. A maximum dorsoventral width of 1.15 mm was recorded in some distal fragments. The simple thecal tubes are inclined at an angle of c. 20 degrees to the axis in the proximal part of the rhabdosome; distal thecae are inclined at 20–30 degrees. Proximal thecae overlap for one-third to one-half their length, the distal thecae one-half to two-thirds their length.

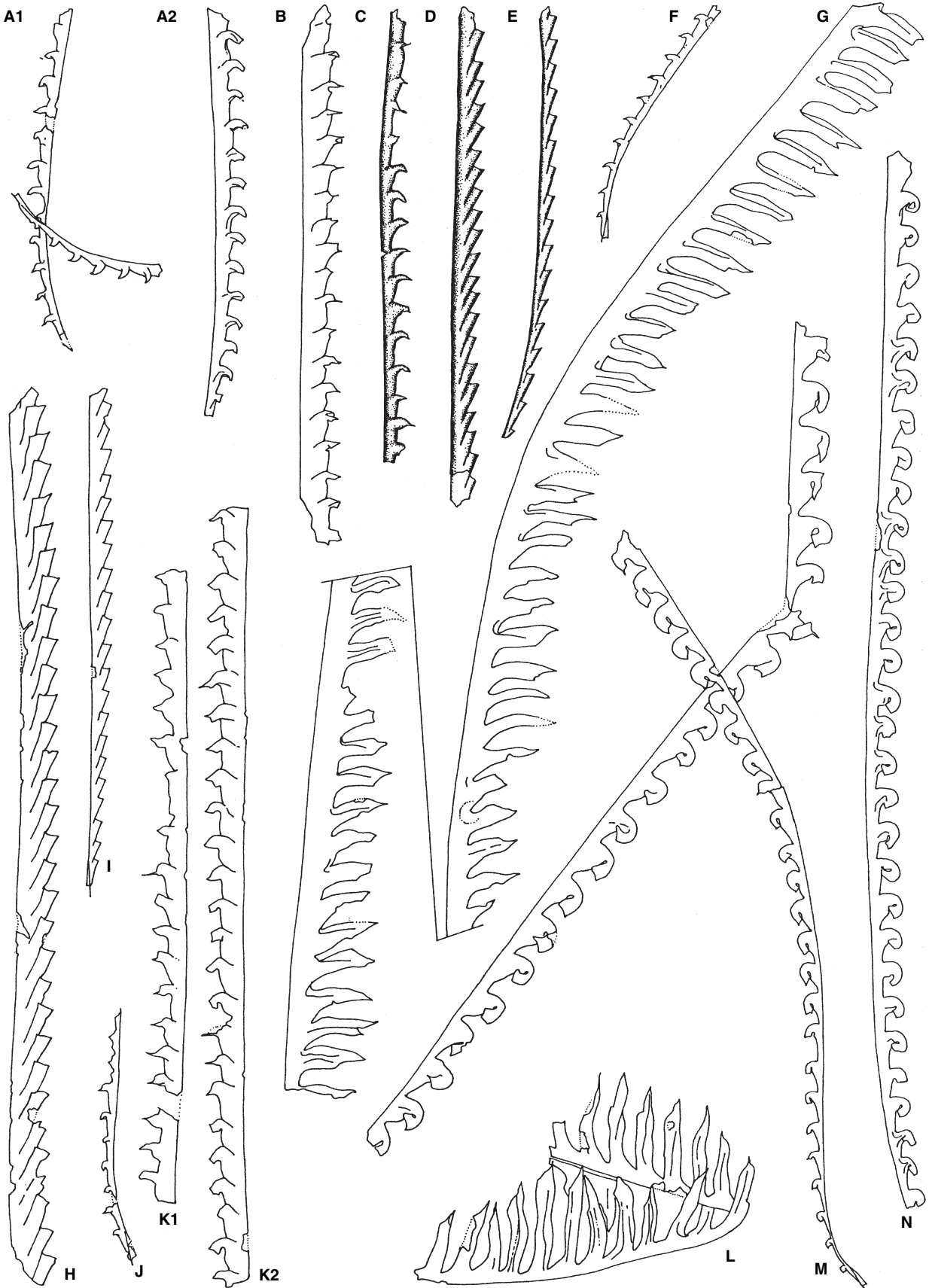
Remarks. Late Aeronian pristiograptids have been regularly misidentified as *Atavograptus atavus* (Jones) in Libyan sections (see Legrand 1999), which resulted in biostratigraphically confusing graptolite associations. *A. atavus* is an index species of the lower part of the mid-Rhuddanian *vesiculosus* Biozone or constitutes its own *atavus* Biozone at about the same level and became extinct in the earliest Aeronian (e.g. Rickards 1976b). *Pristiograptus solidus* Přibyl, 1940 has been distinguished from *Pr. regularis* by its more rapidly tapering proximal part, more inclined and less overlapping thecae and generally more robust rhabdosome. Some features of the present specimens (thecal inclination and overlap) are transient between the two forms and suggest that *Pr. solidus* might be just a junior synonym of *Pr. regularis* although broader population studies are needed.

EXPLANATION OF PLATE 2

- Fig. 1. *Lituigraptus convolutus* (Hisinger, 1837). PŠ 1093, more or less mesial fragment; *convolutus* Biozone, B'ir al Qasr 2.
 Fig. 2. *Campograptus obtusus* (Rickards, 1970). PŠ 1085b, *convolutus* Biozone, B'ir al Qasr 2.
 Fig. 3. *Rastrites peregrinus* Barrande, 1850. PŠ 1087, *convolutus* Biozone, B'ir al Qasr 2.
 Fig. 4. *Neolagaroptus helenae* Štorch, 1988. PŠ 1075, '*leptotheca*' Biozone, B'ir al Qasr 1; ×4. The longest specimen with short sicula and densely spaced thecae, situated on the upper part of the slab, resembles *C. gregarius* phenotype.
 Fig. 5. *Monograptus limatulus* (Törnquist, 1892); PŠ 1070b; *convolutus* Biozone, B'ir al Qasr 2.
 Fig. 6. *Torquigraptus decipiens* (Törnquist, 1899); PŠ 1070a; *convolutus* Biozone, B'ir al Qasr 2.
 All ×5 except when indicated.



ŠTORCH and MASSA, Aeronian graptolites



Pristiograptus cf. renaudi (Philippot, 1950)

Text-figure 9D–E

Remarks. Several specimens from Jebel Tadraq and Wadi Iyadhar differ from *P. regularis* in having dorsally curved proximal part of the rhabdosome. The same taxon was described and figured by Legrand (2002) from Tedjert, south-east Algeria, and assigned to *Pristiograptus renaudi* (Philippot, 1950) a species known from the lower part of the lowermost Telychian *Rastrites linnaei* (and/or *Spirograptus guerichi*) Biozone of Europe (see also Loydell 1993; Gutierrez-Marco and Štorch 1998). Our specimens, however, widen more rapidly than those of *P. renaudi* and their proximal thecae possess a greater overlap. Two thecae repeat distance decreases from 1.9 mm proximally to 1.6–1.8 mm distally. Our specimens are tentatively assigned to *Pr. cf. renaudi* until more extensive collections are available.

Genus MONOGRAPTUS Geinitz, 1852 (*sensu lato*)*Monograptus limatulus* Törnquist, 1892

Plate 2, figure 5; Text-figure 8M, ?N

Remarks. Several flattened, incomplete and/or fragmentary specimens exhibit characteristic features of this age-diagnostic species. The proximal part of the rhabdosome is missing in our material; the mesial part, however, exhibits prominent dorsal curvature and rapid widening within 3–4 slightly geniculate tubular thecae. The thecal apertures of the mesial thecae are straight and slightly everted. The distal portion of the rhabdosome becomes weakly dorsally curved or almost straight. It is 0.75–0.8 mm wide. Distal thecae are slightly geniculate to nearly straight tubes overlapping for half their length and inclined at *c.* 20 degrees to the rhabdosome axis. The straight aperture is perpendicular to the thecal axis. The 2TRD is 1.9–2.0 mm both mesially and distally. Despite its incompleteness, the present material can be identified confidently. *M. limatulus* differs from *M. inopinus* Törnquist, 1899 in its more strongly dorsally curved and rapidly broadening mesial part and straighter distal part of the rhabdosome.

Monograptus havlicei Štorch, 1988

Text-figure 8L

Remarks. A single, 25-mm-long, incomplete rhabdosome from B'ir al Qasr 2, preserved in low relief, matches well the Bohemian specimens of *M. havlicei*. It is broadly dorsally arcuate and straightens distally. The proximal end is missing. The earliest thecae present are 1.15 mm long, overlap for less than half their length and terminate in small dorsal apertural hoods, partly covering the small apertural excavations. The 2TRD is 1.35–1.6 mm. Distally, the rhabdosome widens gradually, and the apertural hoods decrease as does the thecal geniculation. The distal thecae become simple tubes, overlapping for half their length, with straight apertures, resembling those of *M. limatulus*. The distal part of the present rhabdosome is 0.7 mm wide and the thecae number *c.* 10.5 in 10 mm.

'*Monograptus*' cf. *elongatus* Törnquist, 1899

Text-figure 7A–C

Remarks. Many fragments of well-preserved, extremely slender rhabdosomes without any regular curvature, except for two apparently dorsally curved proximal portions, originate from the '*leptotheca*' and *convolutus* biozones of B'ir al Qasr. Our specimens match well the rhabdosome figured by El-Khayal (1985, pl. 1, figs 4–6) as *Monograptus elongatus* Törnquist. The specimens described and figured by Törnquist (1899), however, attain a much greater width, almost 1 mm, and possess thecae that are more triangular and seemingly more densely spaced. Our longest fragment is 11 mm long. The isolated thecae have long, thread-like prothecae which gradually expand into low triangular, robust, hooked metathecae. The ventral wall of the theca is concave, whilst the dorsal wall is normal to the rhabdosome axis. The thecal apertural region is hooked, the hook appearing to be formed by just the dorsal portion of the thecal tube. However, no lateral expansion of the aperture, reported in *M. elongatus* Törnquist, 1899 (Hutt 1975), has been identified. A thecal height of 0.25 mm is maintained throughout the observed specimens except for one rhabdosomal fragment in which the thecal height is 0.35 mm. The apex of a single, poorly preserved sicula does not reach the level of the first thecal aperture. Th2 is *c.* 1.2 mm long; distalwards the 2TRD

TEXT-FIG. 9. A1–C, F, J–K2, *Stimulograptus sedgwickii* (Portlock, 1843). A1–A2, PŠ 1098; B, PŠ 1106; C, PŠ 1115; F, PŠ 1107; J, MG.B 1099; K1–K2, MB.G 1097; *sedgwickii* Biozone; C, Tanesfert (sample UB 201); other specimens, Awaynat Wanin. D–E, *Pristiograptus cf. renaudi* (Philippot, 1950). D, PŠ 1116; E, PŠ 1117; *sedgwickii* Biozone, Jebel Tadraq (sample NB 10). G, L, *Lituigraptus convolutus* (Hisinger (1837)). G, PŠ 1065; L, PŠ 1093; *convolutus* Biozone, B'ir al Qasr 2. H–I, *Pristiograptus regularis* (Törnquist, 1899). H, MB.G 1100; I, MB.G 1098; *sedgwickii* Biozone, Awaynat Wanin. M–N, *Campograptus lobiferus* (M'Coy, 1850). M, PŠ 1067; N, PŠ 1071; '*leptotheca*' – *convolutus* biozones, B'ir al Qasr 1. All × 5.

ranges from 1.7 to 3.0 mm, equivalent to 7–12 thecae in 10 mm. As opposed to *Monograptus capis* Hutt, 1975 the present specimens have smoothly low-triangular thecae without sudden prothecal expansion. The concave ventral thecal walls of the present taxon as well as its dorsal thecal walls perpendicular to the rhabdosome resemble the thecae of '*Monograptus mirus* Perner, 1897. The latter species, however, is distinguished by its loosely enrolled and wider (0.4–0.6 mm) rhabdosome.

'Monograptus' sp.
Text-figure 7H

Remarks. A distal rhabdosome fragment, found with *R. approximatus* at Awaynat Wanin, is characterized by hooked and isolated rastritiform thecae inclined at *c.* 75 degrees to the rhabdosome. The thecae are 1.1 mm high and number 10.5 in 10 mm (2TRD, 2.0–2.1 mm). The apertural hook seems to be formed by the prolonged dorsal side of the thecal tube and is terminated by short lateral lobes. The fragment resembles the material of '*Monograptus simulans* Pedersen described from the Bohemian *leptotheca* Biozone by Štorch (1998a).

Genus STIMULOGRAPTUS Přibyl and Štorch, 1983

Stimulograptus sedgwickii (Portlock, 1843)
Plate 3, figure 3; Text-figure 9A1–C, F, J–K2

Remarks. Libyan specimens differ from those of *Stimulograptus sedgwickii* described by Elles and Wood (1913), Hutt (1975) and Loydell (1993) in having a dorsally curved to arcuate proximal part of the rhabdosome over the first 4–10 thecae. The proximal thecae of the Libyan specimens appear to be less hooked and the apertural spines are rarely seen even on distal thecae. Other parameters match well with *S. sedgwickii*: The sicula is 1.0–1.1 mm long, and its apex reaches to the top or almost to the top of th1. The sicular aperture is 0.25 mm wide. The rhabdosome width increases from 0.45 mm at th1 and 0.45–0.5 mm at th2, to 0.55–0.7 mm at th5, and 0.7 mm at th10, to the maximum of 1.6 mm (without spines) observed in distal fragments.

The rhabdosomes must have been very long, as suggested by the almost negligible increase in the dorsoventral width observed in our material. The 2TRD at th2 is 1.9–1.95 mm and at th5 is 1.9–2.05 mm; distally the 2TRD attains 1.95–2.4 mm.

Genus CAMPOGRAPTUS Obut, 1949 (*sensu* Štorch 1998a)

Campograptus lobiferus (M'Coy, 1850)
Plate 3, figure 4; Text-figure 9M–N

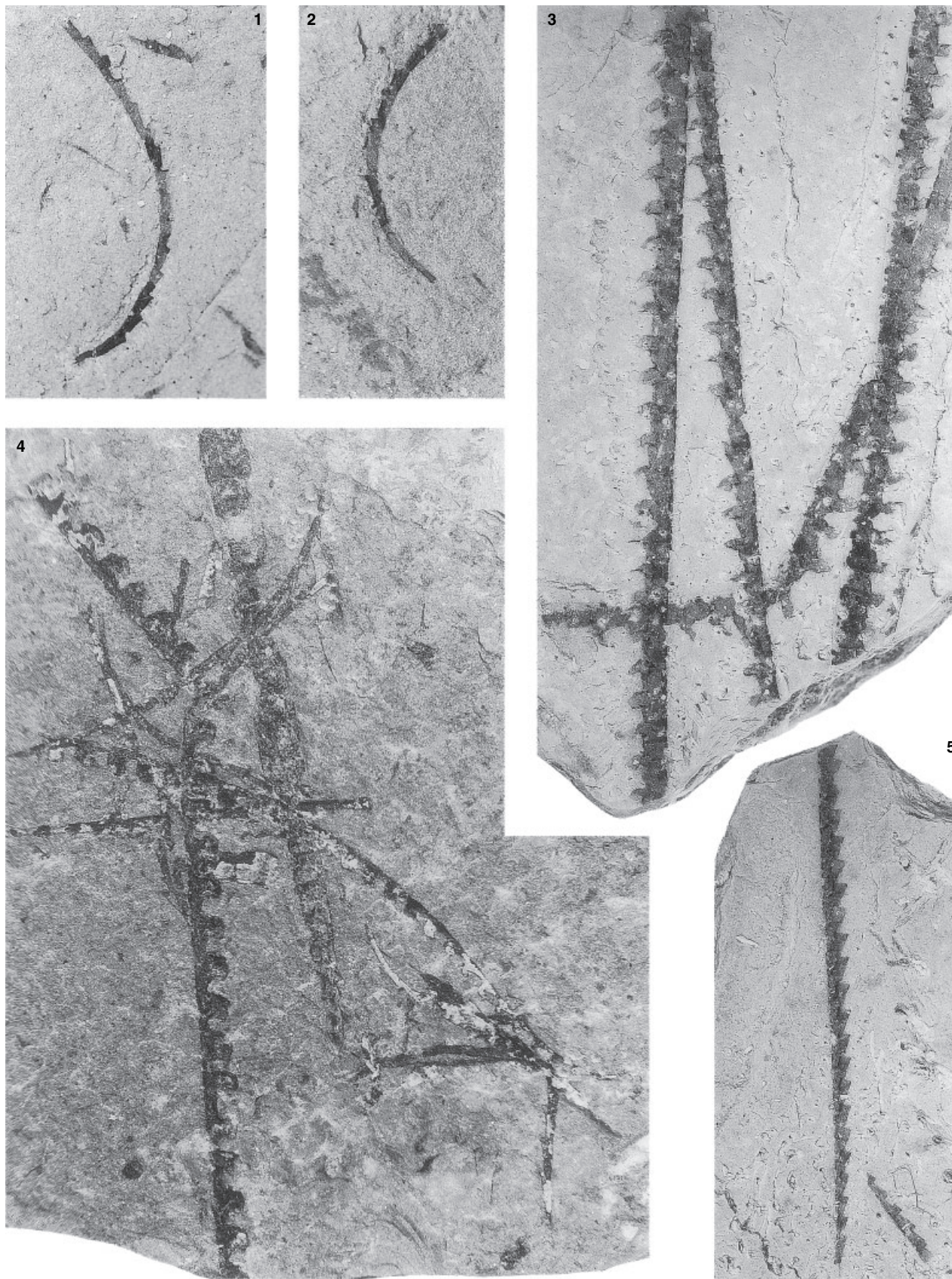
Remarks. Several rhabdosomes found in the *convolutus* Biozone of B'ir al Qasr match *C. lobiferus* well. They are straight distally, but have a gently doubly curved proximal part, and widen slowly from 0.4 mm at th1 to 0.5 mm at th5 and to 0.9 mm at th20. The maximum width is 1.2 mm. The sicula is 0.9 mm long, its apex reaching up to the first thecal aperture. Isolated, triangular thecae are terminated with large, lobate apertural hooks with dorso-proximally facing apertures. The 2TRD at th2 is 1.7 mm and at th5 is 1.85 mm, and distally the 2TRD attains 2.3–2.7 mm (thecae number 7–8.5 in 10 mm). In some distal fragments the thecae exhibit long, recurved apertural lobes, tightly adpressed to the early part of the metatheca and possess dorsally facing apertures. Lateral apertural spines have not been identified in our material. The more recurved distal thecae of one specimen resemble those of the closely related species *Campograptus harpago* Törnquist, 1899 which, according to Chokey-Jones *et al.* (2003), is confined to the upper part of the *convolutus* Biozone of Avalonia and Baltica, but was recorded by Lüning *et al.* (2000) from Morocco. The less recurved thecae of the other rhabdosomes, however, are more similar to those of *Camp. lobiferus*, a widespread species ranging from the *leptotheca* Biozone to the boundary interval of the *convolutus/sedgwickii* biozones.

Campograptus obtusus (Rickards, 1970)
Plate 2, figure 2; Text-figure 8P–R

Remarks. *Campograptus* rhabdosomes with proximally accentuated dorsal curvature and lobate, highly triangular thecae have been found in the B'ir al Qasr 2 sec-

EXPLANATION OF PLATE 3

- Figs 1–2. *Coronograptus gregarius* (Lapworth, 1876). MB.G 1106, sample PC 116, *libycus-gregarius* Biozone, Tanesfert.
Fig. 3. *Stimulograptus sedgwickii* (Portlock, 1843), MB.G 1097, detail of the large slab; *sedgwickii* Biozone, Awaynat Wanin.
Fig. 4. *Campograptus lobiferus* (M'Coy, 1850), PŠ 1067; '*leptotheca*' Biozone, B'ir Al Qasr 1.
Fig. 5. *Pristiograptus regularis* (Törnquist, 1899). MB.G 1098, Sample SM 371, *sedgwickii* Biozone; Awaynat Wanin.
All × 5.



ŠTORCH and MASSA, Aeronian graptolites

tion. The characteristic robust proximal part of the rhabdosome lacking slender, axially elongated proximal-most thecae suggests that our specimens belong in *Camp. obtusus*, the stratigraphically youngest representative of the *Campograptus communis* s.l. lineage. The sicula is 0.8–1.0 mm long, the apex reaching approximately to the dorsal wall of th1. The sicular aperture possesses a gentle dorsal lobe. The thecae are triangular, with broad prothecal bases and hooked, lobate, proximally to dorsoproximally facing apertures. Apertural spines are not observed in our specimens. The rhabdosome widens from 0.5–0.6 mm at th1 to 0.75–0.85 mm at th5 and 0.9–1.05 mm at th10 with a distal maximum of 1.25 mm. The 2TRD increases from 1.6–1.8 mm at th2 to 2–2.2 mm distally. The Libyan rhabdosomes differ from the specimens described from Bohemia (Štorch 1998a) in having a less robust proximalmost part with lesser initial dorsoventral width and greater 2TRD at th2. Their maximum dorsoventral width is similar to that reported by Rickards (1970) in his original description of the species. *Campograptus communis* (Lapworth, 1876) differs from the present material in having a more gracile proximal part with markedly elongated thecae; *Camp. clingani* (Carruthers) has broader prothecae and slender apertural hooks; *Camp. millepeda* (McCoy) has densely packed and higher-triangular thecae.

Genus TORQUIGRAPTUS Loydell, 1993

Torquigraptus decipiens (Törnquist, 1899)

Plate 2, figure 6; Text-figure 8I–K

Remarks. The Libyan specimens match the original description and illustrations of *T. decipiens* (Törnquist, 1899) as well as those published by Sudbury (1958), Rickards (1970), Hutt (1975), Bjerreskov (1975) and Štorch (1998a). The lateral twisting of the thecal apertures refers the species to *Torquigraptus*. The rhabdosome is reported in literature to be coiled into an open spiral from which only a single whorl has been preserved in our material. At least eight proximal thecae are isolated, almost rastritiform, perpendicular or slightly inclined (c. 80 degrees) to the rhabdosome axis. The thread-like prothecae give rise to c. 0.75-mm-high metathecae that terminate in a small hook. The sicula and th1 have not been found. The proximal 2TRD is 1.6–1.95 mm. Towards the distal part of the rhabdosome the metathecae slowly become less isolated and rather high-triangular, inclined at 70 degrees to the rhabdosome axis, again possessing small, laterally twisted apertural hooks. The rhabdosome widens to a maximum of 1.5–1.6 mm and 2TRD increases to 2.1–2.45 mm.

Genus LITUIGRAPTUS Ni, 1978 (*sensu* Štorch 1998a)

Lituigraptus convolutus (Hisinger, 1837)

Plate 2, figure 1; Text-figure 9G, L

Remarks. Several long distal rhabdosomal portions collected at B'ir al Qasr 2 are typical distal portions of *L. convolutus* as known from localities world-wide. Distal portions are up to 80 mm long, straight, or slightly curved, with isolated thecae situated on either the convex or the concave side of the curvature. Distal thecae have broad prothecal bases, the common canal attaining a width of 0.7–1.0 mm. The slightly distally curved, isolated, 0.6–0.75-mm-wide metathecae are inclined at 60–70 degrees to the rhabdosome axis and are separated by interspaces of equal width. The ventrally directed thecal apertures are provided with prominent, high-triangular, horn-like, paired lateral processes. The rhabdosome reaches a maximum width of c. 3.0–3.2 mm including these processes. The thecae number 8–9.5 in 10 mm; the thecal spacing increases distally throughout the rhabdosome. In addition to the present fragmentary specimens a complete, although less well-preserved, spiraliform rhabdosome from the same locality has been examined by one of us (PŠ) at the Petroleum Research Centre, Tripoli.

Genus RASTRITES Barrande, 1850

Rastrites peregrinus Barrande, 1850

Plate 2, figure 3; Text-figure 7F–G2

Remarks. Small, immature rhabdosomes match topotypic Bohemian specimens of *R. peregrinus* in all parameters. The rhabdosome is typically fish-hook shaped with proximally accentuated dorsal curvature. Widely spaced, isolated tubular metathecae are slightly hooked aperturally. Th1 and th2 are directed distally at 50–60 degrees to the prothecal part of the following theca. Th3 is approximately perpendicular and the more distal thecae are pendent, inclined at 100–120 degrees to the rhabdosome axis. Th1 is 0.8 mm long, th2 is 1.1 mm long and th5 is 1.3–1.6 mm long. 2TRD is 1.6–1.9 mm at th2 and 1.9–2.0 mm at th5. At maximum eight thecae are present in our flattened and/or relief specimens from B'ir al Qasr 2.

Rastrites approximatus Perner, 1897

Text-figure 7D–E

Remarks. Several immature rhabdosomes and badly preserved distal fragments with densely packed rastritiform thecae can be assigned to *R. approximatus*. Th1 is 0.8 mm

long, th3 c. 1.3 mm and th5 1.5 mm long. Thecae more distal than th7 (of specimen no. PŠ 1112) are incomplete. The apertures of isolated tubular thecae exhibit proximally curved, roughly triangular, paired lateral processes. The two most proximal thecae are inclined at c. 60 degrees to the rhabdosome axis whereas the succeeding thecae, as opposed to those of *R. peregrinus*, are perpendicular rather than pendent. The 2TRD, of 1.4–1.5 mm, also differs from that of *R. peregrinus*.

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