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Silurian graptolites of Sardinia: assemblages and biostratigraphy

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ABSTRACT - 155 taxa of planktic graptolites are reported from the Silurian pelagic succession of southern Sardinia, and 24 graptolite assemblage biozones are recognized and briefly described. The *Cyrtograptus insectus*, *Monograptus riccartonensis*, *Pristiograptus dubius* and *Cyrtograptus ramosus – Cyrtograptus ellesae* biozones are recorded for the first time in Sardinia; most other biozones are redefined. This is the first compilation on Sardinian graptolites that comprises critically assessed published data combined with new records.

KEY WORDS - Graptolites, Silurian, Sardinia, biostratigraphy, assemblages.

INTRODUCTION AND HISTORICAL OVERVIEW

Offshore, largely anoxic or dysoxic Silurian sedimentary rocks, exposed discontinuously in southern Sardinia, are rich in diverse graptolite associations. Together with Corsica, Sardinia belongs to a collisional chain of Variscan Europe with strong faunal affinities to other parts of northwestern Gondwana. Lower Palaeozoic rocks were affected by Variscan tectonic deformation, metamorphism and magmatic activity. Southwestern Sardinia exhibits Silurian facies suite similar to the Barrandian area of Bohemia (Gnoli et al., 1990); southeastern Sardinia seems to have close affinities to the basinal facies of Thuringia (Helmcke, 1973; Jaeger, 1976; a.o.). This difference justifies separate treatment of the western and eastern parts of southern Sardinia. Fossiliferous localities are concentrated in the Iglesiente and Sulcis regions in the South-West, and in the Gerrei and Sarrabus subregions of the southeastern part of the island (Fig. 1).

Sardinian graptolites have been known since 1838 when General Alberto La Marmora found graptolite-bearing black shales in Goni. Those graptolites were described and figured in a monographic paper by Meneghini (1857). The wide distribution of Silurian graptolitic black shales in the Gerrei, Iglesiente and Fluminese areas was demonstrated by Taricco (1911, 1922) and Novarese & Taricco (1922). Gortani (1923a, b) published a well-illustrated monograph of the then-known Silurian graptolites of Sardinia. Biostratigraphical work based upon bed by bed sampling was carried out by Helmcke (1973) and Helmcke & Koch (1974). Jaeger (1976) correlated the graptolite-bearing Silurian sections of Sardinia with Thuringia and other parts of Variscan Europe.

Jaeger & Barca (1990) summarized graptolite records from southeastern Sardinia and recognized the *Lituigraptus convolutus* Biozone with *Cephalograptus cometa* Subzone, *Spirograptus turriculatus* Biozone with *Rastrites linnaei* Subzone, *Streptograptus crispus-Monoclimacis griestoniensis* Biozone, *Cyrtograptus lundgreni* Biozone with *Testograptus*

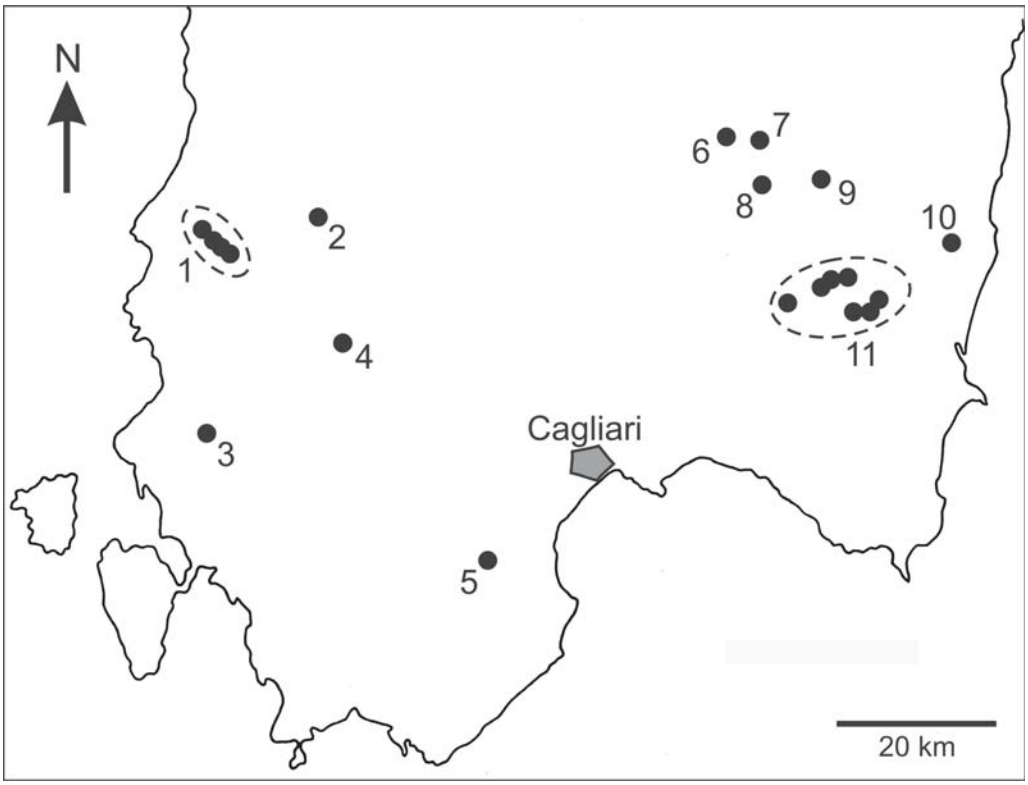


Fig. 1 - Location map of the graptolite-bearing outcrops referred to in the text: 1) Fluminimaggiore area (Cantoniera Flumini, Galemmu, Genna Quadroxius, northern outskirts of the village, Sentiero Flumini, road-cut to Mason Porcus, Terra Murus); 2) Genna Muxerru (GMX A, GMX F, GMX P); 3) Monte Cortoghiana Becciu; 4) Argiola; 5) Punta S'Omu de Is Abis; 6) Sedda de S'Ortu; 7) Goni; 8) Cungiareddu (A and B); 9) Lantini Tunnel (Ballao-Muravera road cutting E of the tunnel); 10) Baccu Scottis, 11) Rio Ollastu Area (Baccu sa Rutta, Baccu Perdaccia, Rio Brabaisu-Rio Ollastu confluence, Rio Minderri, road section above Rio Ollastu, road-cut S of Mt. Bisaccu, Sarcilloni, SE of Punta 324, WSW of Punta 324).

testis Subzone, *Pristiograptus parvus* Biozone, *Pristiograptus dubius – Gothograptus nassa* Biozone, *Colonograptus praedeubeli* Biozone and *Colonograptus deubeli* Biozone. Their lists of graptolites were supplemented by illustrations of selected material.

Gnoli et al. (1990), followed by Storch & Serpagli (1993), paid attention to southwestern Sardinia. The latter authors described 44 lower Silurian graptolite taxa and recognized the *Parakidograptus acuminatus* Biozone, *Cystograptus vesiculosus-Coronograptus cyphus* Biozone, *Demirastrites triangulatus* Biozone, *Lituigraptus convolutus* Biozone, *Spirograptus turriculatus* Biozone, probable *Streptograptus crispus* Biozone, and *Monoclimacis griestoniensis* Biozone from the Fluminimaggiore area, Monte Cortoghiana Becciu near Barbusi, and Genna Muxerru near Gonnosfanadiga. Rickards et al. (1995) reviewed new and earlier finds of largely upper Silurian graptolites. Storch et al. (2002) described the upper Llandovery *Oktavites spiralis* and *Cyrtograptus lapworthi* biozones from a large Variscan olistolith in Sulcis area.

Localities and preservation

Flattened Silurian graptolites are the only macrofossils preserved in the more or less siliceous, organic-rich Lower Graptolitic Shales (Barca & Jaeger, 1990; a.o.) of southeastern Sardinia. The anoxic succession of this, essentially informal lithostratigraphical unit has been subsequently affected by cleavage and/or contact-metamorphosed to various degrees. As a result, graphitic slates, siliceous shales and silicites predominate in the lower Silurian succession of this region. The Pridoli Series and most of the Ludlow are formed of peculiar, deep-water nodular limestones, the so-called Ockerkalk (e.g. Jaeger, 1976). No graptolites were found in the limestone.

Soft clayey graphitic shales and/or slates have been termed alum slates in Sardinia (Jaeger, 1976; Barca & Jaeger, 1990); highly siliceous rocks are known as lydites. Black, bedded siliceous slates are common throughout the Llandovery and Wenlock succession in the southeastern part of the island, while typical massive lydites with conchoidal fractures are confined to the Llandovery. Alum slates are present in the upper Llandovery and Wenlock.

Graptolites are common to abundant in the black shales and silicites of southeastern Sardinia. The best preserved graptolites come predominantly from siliceous shales because larger rhabdosomes and/or rhabdosome fragments are inaccessible in lydites due to the irregular conchoidal splitting which is not bedding parallel. In the alum slates, even though the graptolite rhabdosomes are commonly large and complete, tectonic deformation may prevent or complicate their identification. Thick stipes of robust monograptids without any apparent thecal detail, can be found in many exposures. All dimensions of the graptolite rhabdosome may be considerably enlarged in the alum slates, by comparison with flattened rhabdosome of the same taxon preserved in siliceous rock or limestone. Despite this tendency, fairly well preserved graptolites occur in the alum shales and slates in the Goni, Cungiareddu, Sarcilloni and Sedda de S'Ortu sections.

Silurian rocks with graptolites are widespread also in southwestern Sardinia. The Llandovery is represented by the Genna Muxerru Formation (Gnoli et al., 1990): a rather monotonous succession of black, carbon-rich shales and/or slates affected by cleavage, faulting and small-scale folding. Graptolite rhabdosomes are flattened and usually deformed in the alum slates which are exposed at several places in the vicinity of Fluminimaggiore (Terra Murus, Cantoniera Flumini, Genna Quadroxius). The specimens are silver-coloured on black bedding planes or preserved as shallow imprints infilled by black oxide on glossy grey, sheared bedding planes. At Genna Muxerru hill, near Gonnosfanadiga, the graphitic slates are often so much sheared that graptolites are undeterminable. In the same locality (outcrop GMX A of Storch & Serpagli, 1993) a distinct part of the *Spirograptus turriculatus-Streptograptus crispus* Biozone is developed in the form of black, fine grained greywacke with limonitized graptolite rhabdosomes preserved in partial relief. Little tectonized black shales, with well preserved flattened, almost undeformed graptolites of the *Akidograptus ascensus-Parakidograptus acuminatus* Biozone, are known from Monte Cortoghiana Becciu in the Barbusi – Caput Aquas area (Storch & Serpagli, 1993).

The upper Wenlock through Lower Devonian Fluminimaggiore Formation (Gnoli et al., 1990), recognized in southwestern Sardinia, consists of predominantly black, often lenticular beds of cephalopod limestones intercalated with sheared graphitic slates. Low diversity graptolite assemblages preserved in partial relief are known from the cephalopod-bearing limestones at Sentiero Flumini and Terra Murus in the Fluminimaggiore area (Gnoli & Palmer, 1985), and from Argiola, east of Domusnovas (Rickards et al., 1995).

Loose, displaced boulders of pale-coloured sparitic limestones of early Pridoli age, densely packed with monospecific three-dimensional rhabdosomes of "*Monograptus*" *parultimus* Jaeger, have been found in Fluminimaggiore (e.g. Rickards et al., 1995; see also Ferretti & Serpagli, 1996). Graptolitic limestones crowded with colonograptids and straight saetograptids originate from the same outcrop area. A similar microfacies with *Saetograptus jaegeri* Rickards, Holland & Serpagli, of mid-Ludlow age, is known from Argiola (Ferretti, 1989; Rickards et al., 1995).

In the Sulcis area of southwestern Sardinia (Punta S'Omu de Is Abis locality) a sequence of Telychian (upper Llandovery) siliceous black shales has been preserved in a large olistolith within a Culm-type Sulcis flysch complex of Variscan age (Storch et al., 2002). Shales are not affected by cleavage and yield flattened, badly to moderately well-preserved graptolites assigned to *Oktavites spiralis* and *Cyrtograptus lapworthi* biozones, along with a poor record of the *S. turriculatus* Biozone.

Graptolite assemblages and biostratigraphy

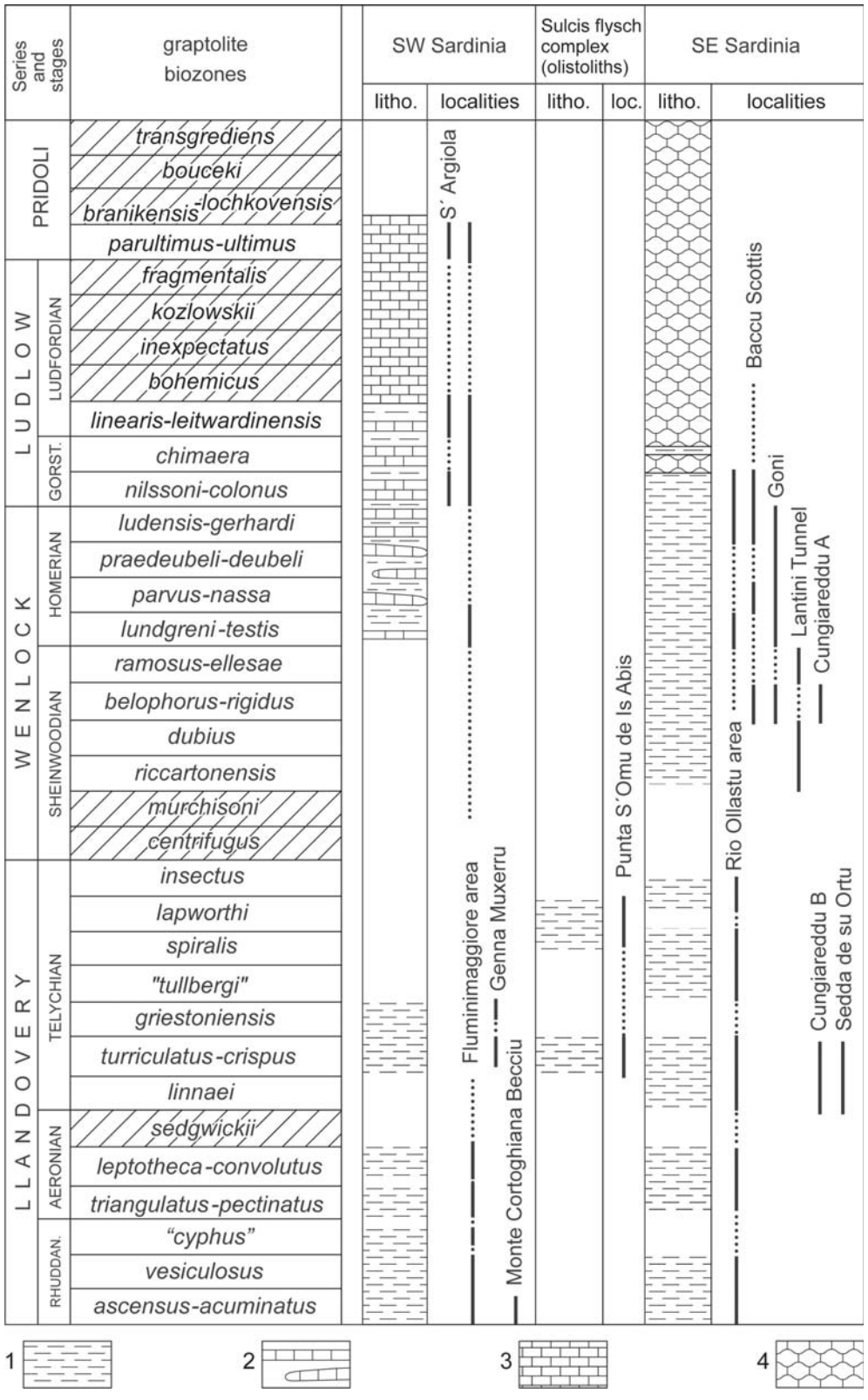
All of the Silurian shaly successions of Sardinia are affected by faulting and are often also complicated by small-scale folding and/or shear-zones. Some graptolite assemblages were found in thin, commonly lenticular bodies of less tectonically affected black shales within intensively sheared successions (e.g. Genna Muxerru GMX P). The upper and lower limits of the biozones cannot be delimited accurately due to strong tectonic deformation. Bed-by-bed sampling is further complicated by the highly variable preservation of graptolites in the alum slates and by the exceptional hardness of the lydites. Only a limited number of relatively complete and thus determinable rhabdosomes was picked up from the less tectonized siliceous shales and the lydites full of well preserved graptolites.

Taxon-range zones, in the sense of International Stratigraphic Guide (Salvador, 1994 ed.), are not applicable in such circumstances, since their recognition requires well exposed, continuous sections with common and well preserved graptolites.

The graptolite biozones described in this and all other papers on the Silurian biostratigraphy of Sardinia (see Jaeger, 1976; Barca & Jaeger, 1990; Storch & Serpagli, 1993; Rickards et al., 1995; Storch et al., 2002) are assemblage zones. Assemblage zones are distinguished by their total graptolite content, with particular importance placed on some characteristic age-diagnostic species. Each zone is named after a zonal-index taxon that is known also from other, well established European graptolite biozonations. Due to limited graptolite material and/or preservation, some classical biozones with similar assemblages had to be combined in a single, composite biozone in Sardinia (e.g. the *Akidograptus ascensus – Parakidograptus acuminatus* Biozone, *Spirograptus turriculatus – Streptograptus crispus* Biozone a.o.). Biozones in quotation marks indicate an insufficient faunal record with tentatively determined or missing zonal-index species.

Some of the 155 graptolite taxa recorded to date are left in open nomenclature; cf. and aff. are used when: 1) these qualifiers were used in the original source of reference or 2) the morphology recorded by the present authors was only comparable with or similar to

Fig. 2 - Graptolite biozonation of the Silurian formations of Sardinia with schematic lithofacies and stratigraphical ranges of the localities. Unrecorded parts of the supposed zonal scheme are hatched. Unconfirmed parts of supposed locality ranges are dotted. 1) black shales and lydites; 2) cephalopod limestone lenses; 3) platy cephalopod limestones; 4) marly nodular limestone (Ockerkalk). So far unknown intervals of the sedimentary succession are blank.


Series and stages
graptolite biozones
SW Sardinia
litho.
localities
Sulcis flysch complex (olistoliths)
litho.
loc.
SE Sardinia
litho.
localities
PRIDOLI
LUDLOW
LUDFORDIAN
GORST.
WENLOCK
HOMERIAN
SHEINWOODIAN
LLANDOVERY
TELYCHIAN
AERONIAN
RHUDDAN.
transgrediens
bouceki
branikensis-lochkovensis
parultimus-ultimus
fragmentalis
kozlowskii
inexpectatus
bohemicus
linearis-leitwardinensis
chimaera
nilssoni-colonus
ludensis-gerhardi
praedeubeli-deubeli
parvus-nassa
lundgreni-testis
ramosus-ellesae
belophorus-rigidus
dubius
riccartonensis
murchisoni
centrifugus
insectus
lapworthi
spiralis
"tullbergi"
griestoniensis
turriculatus-crispus
linnaei
sedgwickii
leptotheca-convolutus
triangulatus-pectinatus
"cyphus"
vesiculosus
ascensus-acuminatus
S´ Argiola
Fluminimaggiore area
Genna Muxerru
Monte Cortoghiana Becciu
Punta S´Omu de Is Abis
Rio Ollastu area
Baccu Scottis
Goni
Lantini Tunnel
Cungiareddu A
Cungiareddu B
Sedda de su Ortu
1
2
3
4

the species concerned. Those taxa whose determinations are based upon poorly preserved material, are suffixed with a question mark.

Graptolite assemblages are mostly composite records from several localities. The primary source of reference has been cited for the respective localities. "Pers. obs." means that the present authors checked the original illustrations and/or specimens. "Unpubl. pers. obs." refers to thus far unpublished data based on material collected by the authors and their fellow workers from the University of Modena and Reggio Emilia and University of Cagliari.

Akidograptus ascensus – Parakidograptus acuminatus Biozone

Well preserved and moderately diverse graptolites of the basal Silurian biozone were found in several isolated exposures and subcrops at Monte Cortoghiana Becciu in southwestern Sardinia (Storch & Serpagli, 1993). Hirnantian strata are missing in the neighborhood and the graptolite assemblage analyzed by Storch (1996) indicates that the lowermost and the uppermost parts of the biozone are probably missing at this site, presumably cut-off by tectonics. The faunal assemblage of the middle part of the biozone, with *Akidograptus ascensus* Davies, *Parakidograptus acuminatus* (Nicholson), and *Neodiplograptus lanceolatus* Storch & Serpagli was reported also by Helmcke & Koch (1974) from southeastern Sardinia (Riu Ollastu area). However, a single specimen of *Cystograptus ancestralis* Storch which they found, was determined as *Cystograptus vesiculosus* (Nicholson) by Jaeger (1976) and Barca & Jaeger (1990), hence the whole assemblage with *A. ascensus* and *P. acuminatus* was assigned by mistake to the *vesiculosus* Biozone. A poor *ascensus-acuminatus* Biozone assemblage is known also from the Fluminimaggiore area (Storch & Serpagli, 1993).

Graptolite fauna: *Normalograptus angustus* (Perner), *Normalograptus ajjeri* (Legrand) (= *N. normalis* of Storch & Serpagli, 1993), *Normalograptus crassus* Storch & Feist (= *N. medius* of Storch & Serpagli, 1993), *Normalograptus trifilis* (Manck), *Normalograptus longifilis* (= *N. trifilis* of Storch & Serpagli, 1993, Pl. 4, fig. 8, text-fig. 7H, I, K), *Neodiplograptus parajanus* (Storch), *Neodiplograptus lanceolatus* (= *Diplograptus modestus* of Helmcke & Koch, 1974; Jaeger, 1976 and Barca & Jaeger, 1990), *Neodiplograptus apographon* Storch, *Cystograptus ancestralis* Storch (= *C. vesiculosus* of Jaeger, 1976 and Barca & Jaeger, 1990), *Sudburiagraptus cortoghianensis* (Storch & Serpagli), *Akidograptus ascensus* and *Parakidograptus acuminatus*.

Localities: Monte Cortoghiana Becciu and Fluminimaggiore area (Terra Murus) (Storch & Serpagli, 1993), Rio Ollastu area (Baccu sa Rutta) (Jaeger, 1976; Barca & Jaeger, 1990).

Cystograptus vesiculosus Biozone

Alum slate exposed along the unpaved road at Terra Murus (southwestern Sardinia) yielded some graptolites of which the zonal index *Cystograptus vesiculosus* (Nicholson) and *Rhaphidograptus toernquisti* (Elles & Wood) are the most prominent forms. Juvenile rhabdosomes of *Cyst. vesiculosus*, typified by its large sicula, were recovered, together with the species listed below, from bedded lydites at Riu Minderri in southeastern Sardinia.

Graptolite fauna: *Normalograptus normalis* (Lapworth)?, *Normalograptus rectangularis* (McCoy), *Cystograptus vesiculosus*, *Neodiplograptus lautus* Storch & Feist?, *Sudburiagraptus cortoghianensis* and *Atavograptus* cf. *gracilis* Hutt.

Localities: Fluminimaggiore area (Terra Murus, road cutting to Mason Porcus) (Storch & Serpagli, 1993), Rio Ollastu area (Rio Minderri) (unpubl. pers. obs., *non* Baccu sa Rutta reported by Barca & Jaeger, 1990).

"Coronograptus cyphus Biozone"

A poorly preserved graptolite fauna assignable, with some reservation, to the upper Rhuddanian *cyphus* Biozone has been reported from both southwestern (Jaeger, 1976; Barca & Jaeger, 1990) and the southeastern (Storch & Serpagli, 1993) part of Sardinia.

Graptolite fauna: *Normalograptus* cf. *normalis* (Lapworth), *Rhaphidograptus toernquisti*, *Atavograptus* sp., *Coronograptus cyphus* (Lapworth)?, *Coronograptus gregarius* (Lapworth)?, *"Monograptus" austerus* Törnquist? and *"Monograptus"* ex gr. *revolutus* Kurck.

Localities: Fluminimaggiore area (Genna Quadroxius) (Storch & Serpagli, 1993), ?Rio Ollastu area (Rio Brabaisu-Rio Ollastu confluence) (Jaeger, 1976; Barca & Jaeger, 1990).

Demirastrites triangulatus – Demirastrites pectinatus Biozone

Poor preservation in the Fluminimaggiore area and modest material from the hard lydites of Riu Ollastu area do not allow further subdivision of the lower Aeronian succession, previously referred to broad *gregarius* Biozone by Jaeger (1976).

Graptolite fauna: *Normalograptus normalis* (Lapworth)?, *Metaclimacograptus hughesi* (Nicholson), *Neodiplograptus thuringiacus* (Kirste)?, *Rhaphidograptus toernquisti*, *Pseudorthograptus* cf. *insectiformis* (Nicholson), *Petalolithus ovatoelongatus* (Kurck)?, *Coronograptus gregarius* (Lapworth), *Demirastrites triangulatus* (Harkness), *Demirastrites pectinatus* (Richter)? and *Rastrites* sp.

Localities: Fluminimaggiore area (Genna Quadroxius) (Storch & Serpagli, 1993), Rio Ollastu area (Rio Brabaisu-Rio Ollastu confluence, road section above Rio Ollastu) (Barca & Jaeger, 1990).

Pribylograptus leptotheca – Lituigraptus convolutus Biozone

Middle and upper Aeronian graptolites are present but poorly preserved in southwestern Sardinia (Storch & Serpagli, 1993). In the siliceous shales and lydites of southeastern Sardinia the specimens are only slightly deformed, but are few and fragmentary. All typical constituents of the *convolutus* Biozone assemblage were recovered by Barca & Jaeger (1990). This original *convolutus* Biozone was subdivided by Storch (1998) into two biozones in Bohemia: 1) The *convolutus* Biozone *s.s.*, characterized by the eponymous species, *Rastrites peregrinus* Barrande and *Cephalograptus cometa* (Geinitz), represents the upper part of the former biozone; and 2) the *leptotheca* Biozone which correlates with its lower part, below the first appearance of *Lituigraptus convolutus* (Hisinger). The *leptotheca* Biozone is distinguished by its index taxon, *Petalolithus praecursor* Boucek & Pribyl, *Campograptus millepeda* (McCoy), *Rastrites approximatus* Perner a.o. Both biozones are present in the Rio Ollastu area but random sampling and specimens coming from float do not allow recognition of original associations. This is why in Sardinia the two biozones are combined in a single *leptotheca – convolutus* Biozone which corresponds to the original *convolutus* Biozone of Barca & Jaeger.

Graptolite fauna: *Normalograptus scalaris* (Hisinger), *Glyptograptus* ex gr. *tamariscus* (Nicholson), *Pseudorthograptus insectiformis* (Nicholson), *Rivagraptus bellulus* (Törnquist), *Petalolithus praecursor*, *Cephalograptus cometa*, *Pseudoretiolites perlatus* (Nicholson), *Coronograptus gregarius* (Lapworth), *Pribylograptus leptotheca* (Lapworth), *Pristiograptus* cf. *regularis* Törnquist, *"Monograptus" limatulus* Törnquist, *Campograptus lobiferus* (McCoy), *Campograptus* cf. *millepeda* (McCoy), *Torquigraptus decipiens* (Törnquist)?, *Torquigraptus magnificus* (Pribyl & Münch), *Rastrites* cf. *approximatus* Perner, *Rastrites peregrinus* and *Lituigraptus convolutus*.

Localities: Fluminimaggiore area (Genna Quadroxius) (Storch & Serpagli, 1993), Rio Ollastu area (Rio Brabaisu-Rio Ollastu confluence, road section above Rio Ollastu, Rio Minderri) (Barca & Jaeger, 1990 and pers. obs.).

Rastrites linnaei Biozone

Rich graptolite faunas of the *Rastrites linnaei* Biozone have been collected from several outcrops in southeastern Sardinia. In all of these sections the eponymous species is associated with *Spirograptus guerichi* Loydell, Storch & Melchin which designates a closely similar stratigraphical interval in British Isles and elsewhere. The easily distinguishable *R. linnaei* is the preferred zonal index taxon in tectonized alum slates of Sardinia where *S. guerichi* is very difficult to distinguish from the morphologically similar *Spirograptus turriculatus* (Barrande), which characterizes the overlying biozone. Several successive assemblages encountered in a large tectonized exposure at Sedda de S'Ortu suggest that most of the biozone is present, including the *Paradiversograptus runcinatus - Monograptus gemmatus* and *Parapetalolithus hispanicus* subzones recognized in Spain (Gutiérrez-Marco & Storch, 1998). Tentative intrazonal correlation is possible also with Wales (Loydell, 1991) and Bohemia (Storch, 1994).

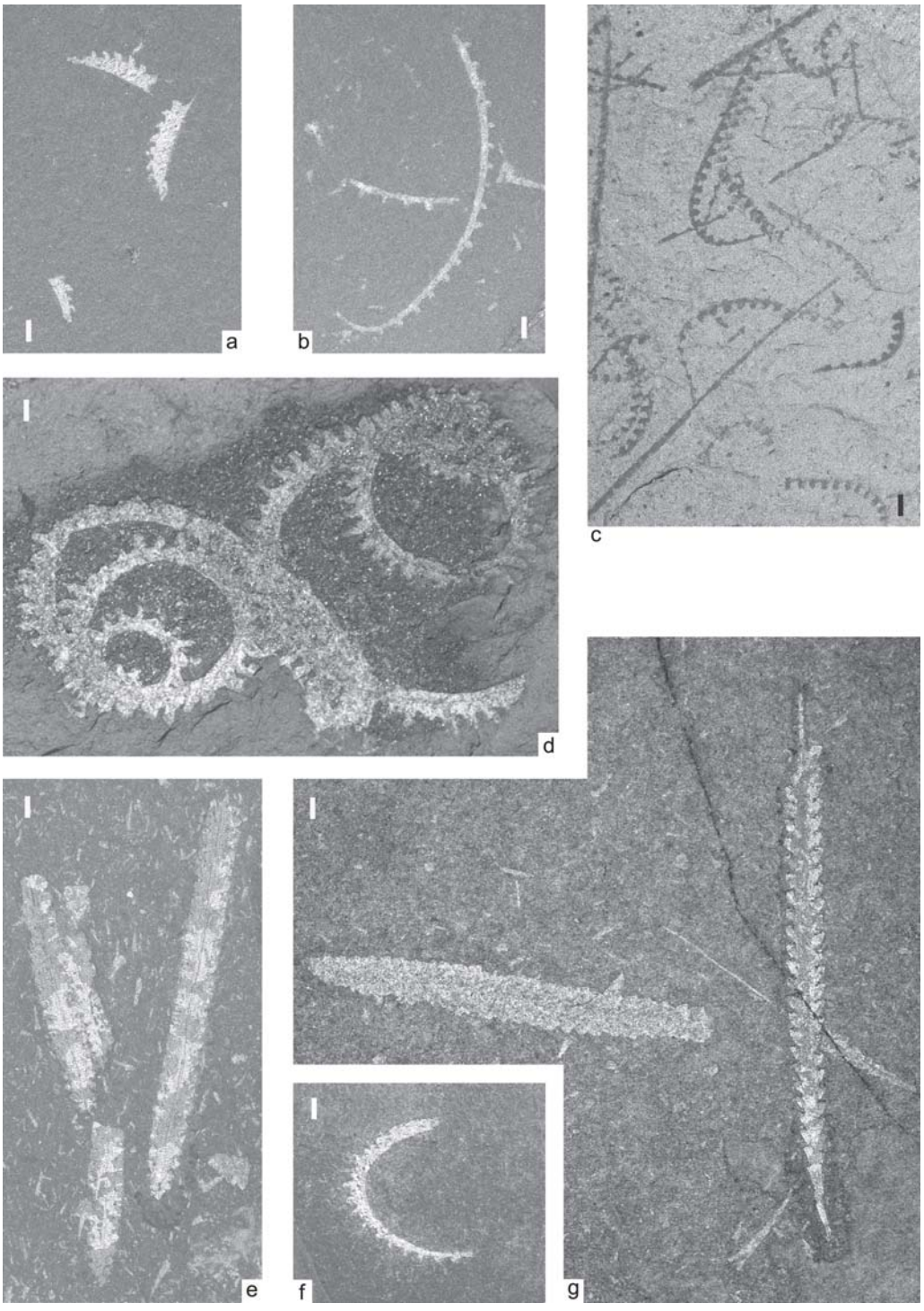
Graptolite fauna: *Glyptograptus* sp. (= *"Orthograptus ultimus" sensu* Manck), *Parapetalolithus ovatus* (Barrande), *Parapetalolithus elongatus* (Boucek & Pribyl), *Parapetalolithus* cf. *hispanicus* (Haberfelner), *Parapetalolithus* sp., *Pristiograptus variabilis* (Perner), *Pristiograptus pristinus* Pribyl, *Pristiograptus* cf. *renaudi* Phillipot, *Stimulograptus becki* (Barrande), *Stimulograptus halli* (Barrande), *Streptograptus* cf. *plumosus* (Baily), *Streptograptus* aff. *storchi* Loydell, *Paradiversograptus runcinatus* (Lapworth)?, *Monograptus gemmatus* (Barrande), *"Monograptus"* cf. *capillaris* (Carruthers), *Rastrites linnaei*, *Rastrites schaueri* Storch & Loydell, *Rastrites abbreviatus* Lapworth, *Rastrites fugax* Barrande, *Torquigraptus planus* (Barrande), *Torquigraptus obtusus* (Schauer), *Torquigraptus contortus* (Perner) and *Spirograptus guerichi*.
Localities: Cungiareddu B and Sedda de S'Ortu (unpubl. pers. obs.), Rio Ollastu area (Rio Brabaisu – Rio Ollastu confluence, Rio Minderri) (Barca & Jaeger, 1990).

Spirograptus turriculatus – Streptograptus crispus Biozone

The lower part of the biozone is marked by a low diversity graptolite assemblage which correlates with the post-extinction fauna of Loydell (1994). Rare *Torquigraptus planus*? and *Pristiograptus* cf. *pristinus* survived from the previous biozone. The appearances of *Monograptus* cf. *galaensis* Lapworth, *Torquigraptus proteus* (Barrande), *Streptograptus* cf. *storchi* Loydell and *Streptograptus exiguus* (Lapworth) characterize the middle part of combined *turriculatus - crispus* Biozone whilst *S. turriculatus* occurs almost throughout. *Cochlograptus veles* (Richter) and *Torquigraptus* cf. *arcuatus* (Boucek)

Fig. 3 - a) *Monograptus pseudocultellus* Boucek, *insectus* Biozone, Sarcilloni; b) *Mediograptus* cf. *vittatus* Storch, *insectus* Biozone, Sarcilloni; c) *Streptograptus loydelli* Storch & Serpagli and *Monoclimacis griestoniensis* (Nicol)?, *griestoniensis* Biozone, Genna Muxerru GMX; d) *Oktavites spiralis* (Geinitz), *spiralis* Biozone, Rio Minderri; e) *Normalograptus crassus* Storch & Feist, *ascensus-acuminatus* Biozone, Monte Cortoghiana Becciu; f) *Cyrtograptus insectus* Boucek, *insectus* Biozone, Sarcilloni; g) *Parakidograptus acuminatus* (Nicholson) and *Neodiplograptus lanceolatus* Storch & Serpagli, *ascensus-acuminatus* Biozone, Monte Cortoghiana Becciu. Scale bars = 1 mm.

appear in the upper part of the biozone, as does *Streptograptus crispus* (Lapworth). The similar ranges of many significant species, incomplete and/or tectonized sections and limited material prevented recognition of two separate biozones in this interval.



Graptolite fauna: *Parapetalolithus tenuis* (Barrande), *Parapetalolithus altissimus* Elles & Wood?, *Pristiograptus* cf. *pristinus*, *Pristiograptus* cf. *bjerringus* Bjerreskov, *Monograptus* ex gr. *priodon* (aff. *marri* Perner), *Monograptus* cf. *galaensis*, *Spirograptus turriculatus*, *Torquigraptus proteus*, *Torquigraptus planus*?, *Torquigraptus* cf. *arcuatus*, *Cochlograptus veles*, *Streptograptus exiguus*, *Streptograptus crispus*, *Streptograptus* cf. *storchi* and *Diversograptus* sp. (extremely slender).

Localities: Sedda de S'Ortu (unpubl. pers. obs.), Genna Muxerru (GMX A and GMX F of Storch & Serpagli, 1993), Punta S'Omu de Is Abis (unpubl. pers. obs.), Rio Ollastu area (Rio Minderri, Baccu sa Rutta) (Barca & Jaeger, 1990 and unpubl. pers. obs.).

Monoclimacis griestoniensis Biozone

Slightly cleaved alum shale, encountered in an otherwise heavily tectonized Llandovery succession at Genna Muxerru, yielded a moderately well preserved fauna, dominated by *Streptograptus loydelli* Storch & Serpagli. Diverse torquigraptids [*Torquigraptus arcuatus* Boucek?, *Torquigraptus australis* Storch and *Torquigraptus pragensis* (Pribyl)] associated with slender *Monoclimacis griestoniensis* (Nicol)? enable correlation with the *griestoniensis* Biozone of Spain (Gutiérrez-Marco & Storch, 1998), Wales (Zalasiewicz, 1994), and Bohemia (Storch, 1994a).

Graptolite fauna: *Retiolites angustidens* Elles & Wood, *Pristiograptus initialis* Kirste, *Torquigraptus arcuatus*?, *Torquigraptus australis*, *Torquigraptus pragensis*, *Monograptus priodon* (Bronn), *"Monograptus"* cf. *speciosus* Tullberg, *Monograptus*? sp. (with flexuous rhabdosome), *Monoclimacis griestoniensis*? and *Streptograptus loydelli*.
Locality: Genna Muxerru (GMX P of Storch & Serpagli, 1993).

"Torquigraptus tullbergi Biozone*"*

Barca & Jaeger (1990) reported *Torquigraptus tullbergi* (Boucek) from the Riu Ollastu area in association with a large form of *Streptograptus exiguus* (Nicholson) (apparently similar to *Streptograptus loydelli*). *T. tullbergi* is a common and prominent associate of the less abundant *Monoclimacis crenulata* Elles & Wood in the Barrandian area of Bohemia and the Central Iberian Zone of Spain (Storch, 1994; Gutiérrez-Marco & Storch, 1998). In both regions the *tullbergi* Biozone has formally replaced the *crenulata* Biozone. The same, easily determinable zonal index can be used for this interval in Sardinia.

Graptolite fauna: *Pseudoplegmatograptus* ex gr. *obesus* (Lapworth), *Monograptus* ex gr. *priodon* (Bronn), *Torquigraptus tullbergi* and *Streptograptus* aff. *loydelli* Storch & Serpagli.

Locality: Rio Ollastu area (float near unpaved road above Rio Ollastu) (Barca & Jaeger, 1990).

Oktavites spiralis Biozone

The lower-middle part of the *spiralis* Biozone with *Oktavites spiralis* (Geinitz), *"Monograptus" flagellaris* Törnquist, *Streptograptus anguinus* (Pribyl), *Streptograptus* cf. *sartorius* Törnquist a.o., was reported by Barca & Jaeger (1990) from the Rio Ollastu area. The middle-upper part of the biozone with the eponym, *Oktavites excentricus* (Bjerreskov), *Streptograptus* aff. *nodifer* (Törnquist), *Monoclimacis geinitzi* (Boucek) and *Diversograptus ramosus* Manck, was found in a large olistolith of lower Silurian black siliceous shales at Punta S`Omu de Is Abis; a similar fauna was recently encountered at Rio Minderri.

Graptolite fauna: *Retiolites geinitzianus* Barrande, *Retiolites angustidens* Elles & Wood?, *Pristiograptus* ex gr. *dubius* (Suess), *Monoclimacis vomerina* (Nicholson)?, *Monoclimacis geinitzi*, *Monoclimacis* cf. *linnarssoni* (Tullberg), *Monograptus priodon*, *"Monograptus" flagellaris*, *Oktavites spiralis*, *Oktavites falx* (Suess), *Oktavites excentricus*, *Streptograptus anguinus*, *Streptograptus* cf. *sartorius* Törnquist, *Streptograptus* aff. *nodifer*, *Lapworthograptus* cf. *grayae* (Lapworth), *Diversograptus pergracilis* (Boucek)? and *Diversograptus ramosus.*

Localities: Rio Ollastu area (road-cut South of Mt. Bisaccu, Rio Minderri) (Barca & Jaeger, 1990 and unpubl. pers. obs.), Punta S'Omu de Is Abis (Storch et al., 2002).

Cyrtograptus lapworthi Biozone

Storch et al. (2002) assigned the uppermost part of the Llandovery succession exposed at Punta S'Omu de Is Abis to the lower half of *Cyrtograptus lapworthi* Biozone. In the uppermost layer, a single, poorly preserved specimen of *Cyrtograptus* (*Cyrtograptus lapworthi* Tullberg?) was found in association with *Streptograptus* aff. *nodifer* and large *Stomatograptus grandis* (Suess). The latter species indicates a level corresponding to the *S. grandis* Subzone of the upper *lapworthi* Biozone in the sense of Storch (2006).

Graptolite fauna: *Retiolites geinitzianus* Barrande, *Stomatograptus grandis*, *Monoclimacis geinitzi*, *Monograptus priodon*, *Oktavites spiralis*, *Streptograptus* aff. *nodifer*, *Diversograptus ramosus* and *Cyrtograptus lapworthi*?.

A graptolite fauna that includes *Monograptus pseudocultellus* Boucek, *Monoclimacis geinitzi*, *Oktavites spiralis*, *Oktavites falx*? and *Cyrtograptus lapworthi*, and corresponds with the upper part of the biozone, has been recorded from the Rio Ollastu area.

Localities: Punta S'Omu de Is Abis (Storch et al., 2002), Sarcilloni in Rio Ollastu area (unpubl. pers. obs.).

Cyrtograptus insectus Biozone

A large and well preserved graptolite fauna referable to the *Cyrtograptus insectus* Biozone was found by one of us (S.P.) at Sarcilloni, in alum slates immediately above the *lapworthi* Biozone. The fossiliferous interval assigned to the *insectus* Biozone (probably just the lower part of the biozone) is about 20 cm thick.

Graptolite fauna: *Retiolites geinitzianus* (Barrande), *Retiolites angustidens* Elles & Wood, *Pristiograptus largus* (Perner), *Mediograptus* cf. *vittatus* Storch, *Mediograptus* ?*morleyae* Loydell & Cave, *Mediograptus* sp., *Monograptus priodon* (Bronn), *Monograptus praecedens* Boucek, *Monograptus pseudocultellus* Boucek, *Monoclimacis geinitzi* (Boucek), *Cyrtograptus insectus* Boucek and *Barrandeograptus pulchellus* (Tullberg).
Locality: Sarcilloni in Rio Ollastu area (unpubl. pers. obs.).

Monograptus riccartonensis Biozone

The zonal index *Monograptus riccartonensis* Lapworth is reported for the first time from Sardinia. Common rhabdosomes, typified by a blunt, slightly dorsally curved proximal end, and associated with robust pristiograptids of the *dubius* Group, have been collected from thin-bedded calcareous black slates in the road-cut Ballao-Muravera, c. 50 m from the eastern mouth of the Lantini Tunnel.

Graptolite fauna: *Pristiograptus dubius* (Suess), *Pristiograptus latus* (Boucek)?, *Monograptus riccartonensis.*

Locality: Lantini Tunnel (unpubl. pers. obs.).

Pristiograptus dubius Biozone

The overlying beds E of the Lantini Tunnel yield abundant but uniform pristiograptid rhabdosomes. *M. riccartonensis* has already vanished in this level and the assemblage equates with that of the *dubius* Interval Biozone described by Boucek (1953) and Storch (1994) in Bohemia.

Graptolite fauna: *Pristiograptus dubius* and *Pristiograptus latus.*

Locality: Lantini Tunnel (unpubl. pers. obs.).

Monograptus belophorus – Cyrtograptus rigidus Biozone

Southeastern Sardinia has been considered a reference area for mid-Wenlock graptolites since the early works by Meneghini (1857) and Gortani (1923a). Several important species were first described from Goni. The section is of particular importance as a type locality of the zonal index *Monograptus belophorus* (Meneghini). Considerable variability in the S-shaped proximal flexure of its rhabdosome, commonly enhanced by tectonic deformation, led Meneghini and Gortani to distinguish several morphospecies within this taxon. Elles (1900) recognized *Monograptus flexilis* - a closely similar species that became a zonal-index of the eponymous biozone in British Isles and elsewhere. Close morphological similarity and the similar/equal stratigraphical range of *M. belophorus* and *M. flexilis* has raised some doubts as to whether the two taxa are closely similar successive members of a single clade, are geographic subspecies, or are morphological variants of the same taxon. All of the Sardinian specimens at our disposal may be well assigned to a single, morphologically variable species – *M. belophorus* (Meneghini, 1857), which is the senior synonym. A combined *belophorus – rigidus* Biozone has been introduced in this paper because of the large overlap in the occurrences of *M. belophorus* and *Cyrtograptus rigidus* Tullberg in the pig-paddock section at Goni (see also Barca & Jaeger, 1990 and Rickards et al., 1995) and in the gorge North of Baccu Scottis. A similar association has been observed at Kosov section in Bohemia (pers. obs.).

Graptolite fauna: *Pristiograptus dubius*, *Pristiograptus meneghinii* (Gortani), *Monograptus flemingii* (Salter), *Monograptus belophorus*, *Monoclimacis flumendosae* (Gortani), *Monoclimacis hemipristis* (Meneghini)?, *"Streptograptus" antennularius* (Meneghini), *Streptograptus retroflexus* (Tullberg) and *Cyrtograptus rigidus*.

Localities: Goni and Baccu Scottis (Barca & Jaeger, 1990 and pers. obs.), Cungiareddu A and Lantini Tunnel (unpubl. pers. obs.).

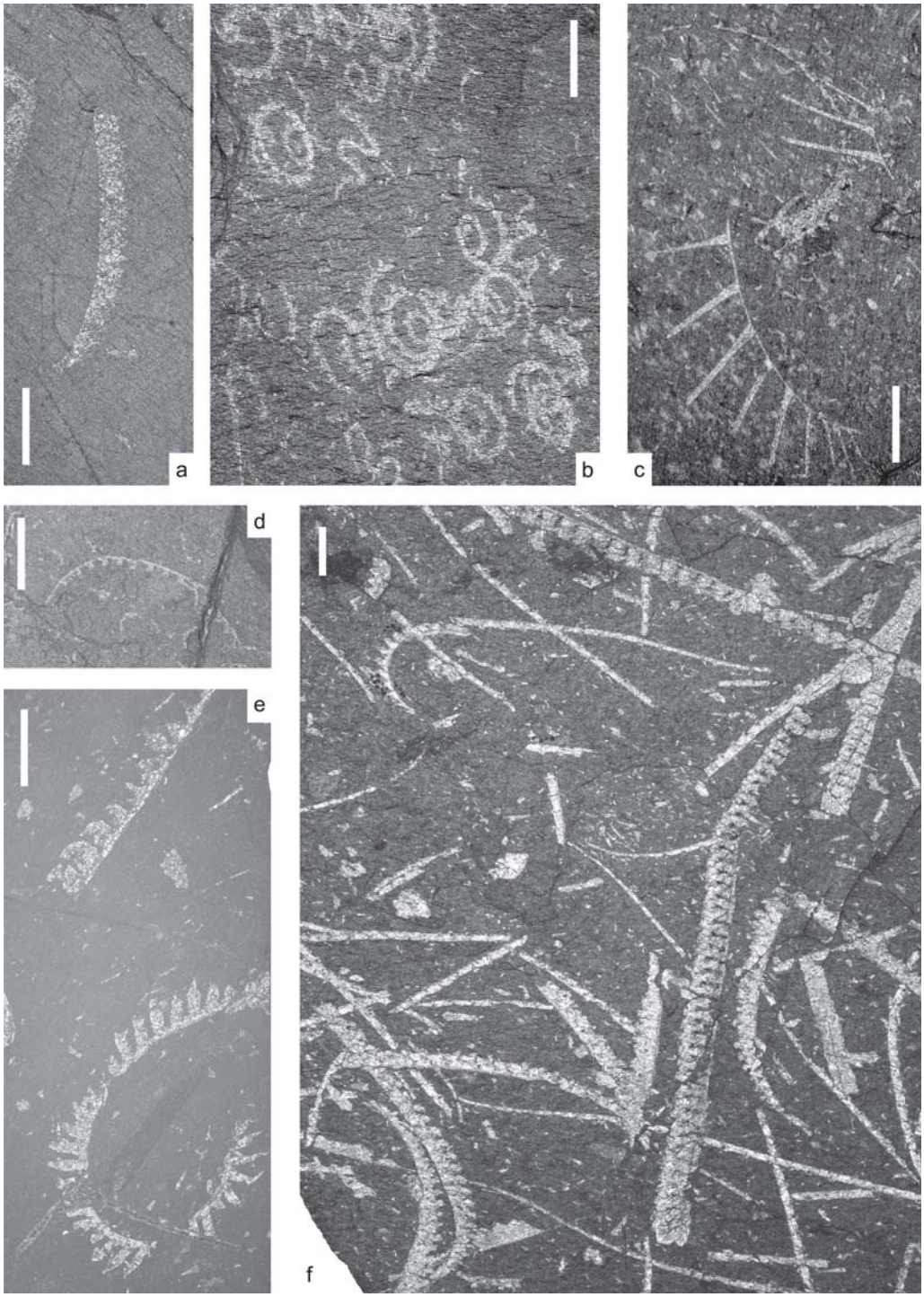
Cyrtograptus ramosus – Cyrtograptus ellesae Biozone

Several graptolite species indicating the stratigraphical interval between the *belophorus* Biozone below and *lundgreni-testis* Biozone above have been recovered from the Ballao-Muravera road-cut East of Lantini Tunnel. The oligospecific assemblage comprises

Fig. 4 - a) *Monograptus riccartonensis* Lapworth, *riccartonensis* Biozone, Lantini Tunnel; b) *Spirograptus guerichi* Loydell, Storch & Melchin, *linnaei* Biozone, Cungiareddu B; c) *Rastrites linnaei* Barrande and *Torquigraptus planus* (Barrande), *linnaei* Biozone, Cungiareddu B; d) *Streptograptus crispus* (Lapworth), *turriculatus-crispus* Biozone, Rio Minderri; e) *Lituigraptus convolutus* (Hisinger) and *Campograptus lobiferus* (McCoy), *leptotheca-convolutus* Biozone, road section above Rio Ollastu; f) *Monograptus belophorus* (Meneghini), *"Streptograptus" antennularius* (Meneghini) and *Cyrtograptus rigidus* Tullberg, *belophorus–rigidus* Biozone, Goni. Scale bars = 5 mm.

pristiograptids, accompanied by slender cyrtograptids, a relatively common diversograptid, rare monoclimacid and flexuous streptograptid.

Graptolite fauna: *Pristiograptus pseudodubius* Boucek, *Pristiograptus dubius*,



Monoclimacis flumendosae?, *Streptograptus* cf. *retroflexus* (Tullberg), *Cyrtograptus ramosus* Boucek or *Cyrtograptus ellesae* Gortani and *Diversograptus gracilis* (Boucek).

Locality: Lantini Tunnel (unpubl. pers. obs.).

Cyrtograptus lundgreni – Testograptus testis Biozone

A typical graptolite assemblage of the lower Homerian *lundgreni* Biozone comes from the pig-paddock section in Goni (Barca & Jaeger, 1990). Barca & Jaeger and the present authors recorded a similar assemblage typified by *Testograptus testis* (Barrande), in the Rio Ollastu area. By comparison with Bohemian sections (Storch, 1994; see also Jaeger, 1991), abundant *T. testis* appears to indicate the upper part of the *lundgreni* Biozone, designated the *testis* Subzone.

Graptolite fauna: *Paraplectograptus eiseli* (Manck), *Gothograptus* aff. *pseudospinosus* (Eisenack), *Pristiograptus dubius*, *Pristiograptus pseudodubius*, *Monograptus flemingii*, *Monoclimacis flumendosae*?, *Monoclimacis hemipristis*?, *Testograptus testis*, *Cyrtograptus lundgreni* Tullberg and *Cyrtograptus* aff. *perneri* Boucek.

Localities: Goni, Rio Ollastu area (Baccu Perdaccia, SE of Punta 324, South of Mt. Bisaccu, Sarcilloni) (Barca & Jaeger, 1990 and unpubl. pers. obs.) and probably Galemmu in the Fluminimaggiore area (Kriz & Serpagli, 1994).

Pristiograptus parvus – Gothograptus nassa Biozone

A uniform graptolite association that survived the severe extinction event at the end of the *lundgreni* Biozone (see e.g. Jaeger, 1993 and Melchin et al., 1998) was identified by Barca & Jaeger (1990) in the pig-paddock section at Goni and in the gorge North of Baccu Scottis. *Pristiograptus parvus* Ulst, that occurs in the lower part of this biozone, is a dwarf form, easily distinguishable from *Pristiograptus pseudodubius*, which is typical of early Homerian strata.

Graptolite fauna: *Gothograptus nassa* (Holm), *Pristiograptus parvus* and *Pristiograptus dubius* (Suess)?.

Localities: Goni and Baccu Scottis (gorge) (Barca & Jaeger, 1990).

Colonograptus praedeubeli – Colonograptus deubeli Biozone

Barca & Jaeger (1990) recorded that the Goni succession continued with an oligospecific assemblage typified by *Gothograptus nassa* and *Colonograptus praedeubeli* (Jaeger) which is replaced by *Colonograptus deubeli* (Jaeger) in the upper part of the interval. The same combined *preadeubeli – deubeli* Biozone was applied by Kozlowska-Dawidziuk et al. (2002) in the Barrandian area of Bohemia.

Graptolite fauna: *Gothograptus nassa*, *Pristiograptus dubius*, *Colonograptus deubeli* and *Colonograptus praedeubeli*.

Locality: Goni (Barca & Jaeger, 1990).

Colonograptus ludensis – Colonograptus gerhardi Biozone

The uppermost Wenlock strata are characterized by a low diversity graptolite assemblage of *Pristiograptus dubius*, *Colonograptus* cf. *ludensis* (Murchison) and *Colonograptus gerhardi* (Kuehne). The latter two species are difficult to distinguish from each other. *C. gerhardi* with its lobate thecal apertures seems to be more common in Sardinia than *C. ludensis* which is marked by simple distal thecal apertures of pristiograptid appearance.

Localities: Rio Ollastu area (SE of Punta 324), Goni and Baccu Scottis (gorge) (Barca & Jaeger, 1990) and probably road-cut 150 m E of Lantini Tunnel (unpubl. pers. obs.)

Neodiversograptus nilssoni – Colonograptus colonus Biozone

A small fauna of the lowermost Ludlow graptolite biozone, including the zonal index *Neodiversograptus nilssoni* (Lapworth), was recovered by Barca & Jaeger (1990) from southeastern Sardinia. In southwestern Sardinia the same interval is marked by abundant colonograptids preserved in graptolitic limestones exposed in the northern vicinity of Fluminimaggiore (Palmer & Gnoli, 1985) in association with cephalopod limestone lenses. Kriz et al. (1993) used the *Colonograptus colonus* Biozone as an equivalent of the *N. nilssoni* Biozone in the limestone dominated sections of the Barrandian area. We combine here the two different, but roughly coeval graptolite assemblages in a single *nilssoni – colonus* Biozone.

Graptolite fauna: *Plectograptus macilentus* (Törnquist), *Spinograptus spinosus* (Wood), *Pristiograptus dubius*, *Colonograptus colonus* (Barrande), *Colonograptus roemeri* (Barrande), *Monograptus uncinatus* Tullberg, *Bohemograptus bohemicus* (Barrande) and *Neodiversograptus nilssoni*.

Localities: Rio Ollastu area (WSW of Punta 324) and Baccu Scottis (gorge) (Barca & Jaeger, 1990), Fluminimaggiore area (Sentiero Flumini) (Palmer & Gnoli, 1985 and pers. obs.).

Saetograptus chimaera Biozone

Kriz and Serpagli (1994) reported the upper Gorstian zonal index species *Saetograptus chimaera* (Barrande) from dark-coloured cephalopod limestones at Galemmu near Fluminimaggiore.

Saetograptus linearis – Saetograptus leintwardinensis Biozone

Early Ludfordian graptolites, herein assigned to the combined *linearis - leintwardinensis* Biozone, originated from scattered loose and displaced blocks of dark-coloured, largely cephalopod limestones of the Fluminimaggiore Formation (Rickards et al., 1995). Some species, such as *Saetograptus linearis* (Boucek), *Saetograptus leintwardinensis* (Hopkinson) and *Saetograptus jaegeri* Rickards, Holland & Serpagli, are abundant. *Bohemograptus tenuis* (Boucek) and *"Monograptus" dalejensis* Boucek? are rare, but all indicate an early Ludfordian age, prior to the *kozlowskii* extinction Event of Urbanek (1993) and Melchin et al. (1998).

Localities: Fluminimaggiore area (Sentiero Flumini) (Palmer & Gnoli, 1985 and pers. obs.), Argiola (Rickards et al., 1995).

Monograptus parultimus – Monograptus ultimus Biozone

Loose slabs and boulders of both dark- and pale-coloured limestones, densely packed with three-dimensional rhabdosomes of *"Monograptus" parultimus* Jaeger?, have been found at the northern periphery of Fluminimaggiore (e.g. Rickards et al., 1995; Ferretti & Serpagli, 1996). Rickards et al. (1995) reported a single specimen, tentatively refered to *M. parultimus*, from Argiola, East of Domusnovas. *"M." parultimus* is the latest Silurian graptolite so far recorded in Sardinia.

State of art and Perspective

The vast majority of the 155 graptolite species recorded from the Silurian succession of southern Sardinia to date, is known also from black shale dominated Silurian formations

in other parts of Variscan, i.e. peri-Gondwanan Europe (i.e. Barrandian area of Bohemia, Thuringia and Saxony, French Montagne Noire, Ossa Morena Zone of Iberian Peninsula). Our knowledge of Sardinian graptolite assemblages has been affected by the poor preservation of graptolites in the heavily sheared sedimentary rocks rather than by true palaeoenvironmental diversity controls.

Despite the tectonic and metamorphic effects, the current graptolite fauna enables detailed correlation with graptolite-based biozonations of Silurian sections in Europe and worldwide.

The proposed biozonal scheme (Fig. 2) consists of 24 graptolite biozones. The standard upper Aeronian *Stimulograptus sedgwickii* Biozone, lower Sheinwoodian *Cyrtograptus centrifugus* and *Cyrt. murchisoni* biozones, middle and upper Ludfordian biozones and all Pridoli biozones except for the *M. praeultimus – M. ultimus* Biozone have not yet been encountered in southern Sardinia. Only the upper Silurian graptolite record may have been limited by environmental factors, suggested by the monospecific taphocoenoses of colonograptid and saetograptid rhabdosomes in nautiloid limestones. No graptolites are known from the Ockerkalk of southeastern Sardinia. It is obvious that further field investigations, new road-cuts, building excavations and other exposures in black shales, may bring to light less heavily sheared blocks that enable more detailed biostratigraphical subdivision than the present scheme or exhibit so far unrecovered parts of the stratigraphical succession.

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