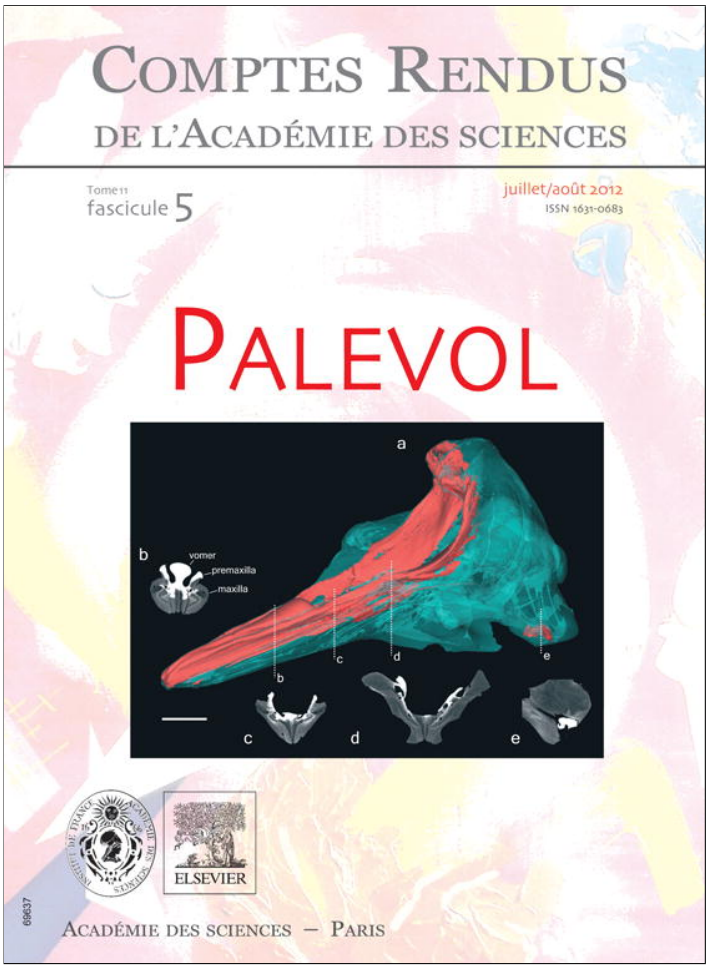

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New insights into the paleobiogeography of the Early Ordovician graptolite fauna of northwestern Argentina

Nouveau regard sur la paléobiogéographie de la faune de graptolites de l'Ordovicien inférieur de l'Argentine nord-occidentale

Bárbara A. Vento[a,*], Blanca A. Toro[a], Jörg Maletz[b]

[a] *Departamento de Paleontología, IANIGLA, CCT-CONICET-Mendoza, Av. Ruíz Leal s/n, Parque General San Martín. c.c. 131, 5500 Mendoza, Argentina*
[b] *Institut für Geologische Wissenschaften, Freie Universität Berlin, Malteser Str. 74-100, Haus B, Raum 322, 12249 Berlin, Germany*

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ABSTRACT

A multivariate analysis was used to determine the faunistic relationships of the northwestern Argentinean graptolite faunas of Floian age to faunas from Baltica, Avalonia, Laurentia and SW China. A statistical analysis at the species level of the five geographic regions for the Lower Floian was performed with the classic Jaccard's index. The resulting affinity dendrogram shows stronger relationships between Early Floian graptolite faunas of northwestern Argentina and those from Baltica, with less obvious similarities to Great Britain (Avalonia) faunas and only weak affinities to North American (Laurentia) and Chinese (SW China) graptolite faunas. The statistical analysis confirms the paleobiogeographic relationships previously observed in other areas of the Cordillera Oriental, and supports the hypothesis that during the Early Ordovician, northwestern Argentina was located at middle to high latitudes, corresponding to the Atlantic Faunal Realm of cold water graptolite biofacies. The studied graptolite material from the Quinilicán and Agua Chica sections is preserved in shales and siltstones interbedded with fine to medium-grained sandstones corresponding to the lower part of the Acoite Formation. The biostratigraphic implications of the associated graptolites are briefly discussed, and *Trichograptus dilaceratus* (Herrmann), *Acrograptus gracilis* (Törnquist), *Expansograptus latus* (T.S. Hall) and *Corymbograptus v-fractus tullbergi* (Monsen) are described from the Argentine Cordillera Oriental for the first time.

Mots clés :
Graptolites
Paléobiogéographie floïenne
Analyse statistique
Argentine nord-occidentale

RÉSUMÉ

Une analyse multivariée a été utilisée pour déterminer les relations faunistiques de faunes de graptolites d'âge Floien d'Argentine nord-occidentale avec des faunes de la Baltique de l'Avalonie, de la Laurentie et du Sud-Ouest de la Chine. Une analyse statistique au niveau de l'espèce de cinq régions du Floïen inférieur a été réalisée grâce à l'indice classique de Jaccard. Le dendogramme d'affinité qui en résulte montre des relations étroites entre les faunes de graptolites du Floien inférieur de l'Argentine nord-occidentale et celles de la Baltique, des similarités moins évidentes avec les faunes de Grande-Bretagne (Avalonie) et seulement de faibles affinités avec les faunes de graptolites d'Amérique du Nord (Laurentie) et de Chine (Sud-Ouest de la Chine). L'analyse statistique confirme les relations

* Corresponding author.
E-mail addresses: bvento@mendoza-conicet.gov.ar (B.A. Vento), btorogr@mendoza-conicet.gov.ar (B.A. Toro), yorge@zedat.fu-berlin.de (J. Maletz).

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paléobiogéographiques précédemment observées dans d'autres régions de la Cordillère Orientale et était l'hypothèse selon laquelle, au cours de l'Ordovicien inférieur, l'Argentine nord-occidentale était située à de moyennes à hautes latitudes correspondant au domaine faunique atlantique à biofaciès de graptolites d'eau froide. Le matériel graptolitique étudié en provenance des coupes de Quinilicán et Aqua Chica a été conservé dans des schistes et siltites avec intercalations de grès à grain fin à moyen, correspondant à la partie inférieure de la Formation Acoite. Les implications biostratigraphiques des graptolites associés sont brièvement discutées et *Trichograptus dilaceratus* (Herrmann), *Acrograptus gracilis* (Törnquist), *Expansograptus latus* (T.S. Hall) et *Corymbograptus v-fractus tullbergi* (Monsen) sont décrites pour la première fois dans la Cordillère Orientale d'Argentine.

1. Introduction

Graptolites are considered an important tool to establish the biostratigraphic framework and regional and worldwide correlations of Lower Paleozoic sedimentary successions of northwestern Argentina. Their faunal affinities also provide valuable information for the understanding of the paleogeographic relationships of the Argentinean Ordovician. During the last decade, most of the efforts have been focused to develop and refine the biostratigraphic framework, as well as to accurately compare and correlate Ordovician biozonation schemes based on various additional fossil groups like trilobites and palynomorphs (Brussa et al., 2008; Rubinstein et al., 2007; Waisfeld et al., 2006). In contrast, paleobiogeographic, phylogenetic and evolutionary aspects of the research of these biostratigraphic relevant taxa remain without a comparable development until now. Even though modern taxonomic revisions frequently apply statistical methodologies to quantify the relevant characters of graptolites, either isolated or preserved in relief, only recently biogeographically important new taxa were recognized and described from the Cordillera Oriental (Toro and Maletz, 2008), and the best preserved material was compared with type material of key species from other regions around the world (Toro and Maletz, 2007; Vento and Toro, 2009).

An exhaustive taxonomic re-evaluation based on the best preserved material of biostratigraphically and paleobiogeographically relevant species from the Lower Ordovician of northwestern Argentina is still lacking. This paper deals with the statistical treatment of the faunal affinities and the biostratigraphic analysis of the graptolite fauna of this region, which enables us to confirm its early Floian age. We also provide systematic descriptions of four paleobiogeographically important taxa, identified for the first time in Argentina.

The described material originates from the Quinilicán and Agua Chica sections, at the northern end of the Aguilar Range, in the Argentine Cordillera Oriental (Jujuy Province) (Fig. 1). This region represents the southern portion of the central Andean Basin, and according to recent studies it evolved as the forebulge depozone of the extended Ordovician foreland basin system in Northwest Argentina. Early Ordovician platform sediments of the Cordillera Oriental are represented by black and grey shales and siltstones interbedded with fine to medium-grained sandstones toward the top of the sequence of the Santa Victoria Group (Upper Cambrian-Middle Ordovician), which include the Santa Rosita and Acoite formations. This succession was deposited on a low gradient ramp, under the influence of a large scale prograding deltaic system from the east and of an active volcanic arc complex to the west (Astini, 2003; Bahlburg and Furlong, 1996).

Numerous sections of an average thickness of approximately 600 m, representing the lower part of the Acoite Formation, are exposed in the northern end of the Aguilar Range (Fig. 1). These are of outstanding interest for research on Early Floian graptolites, because specific investigations of these faunas have not been made there for the past decade, while the taxonomic and biostratigraphic understanding of faunas from this interval has changed considerably, based on new data from Scandinavian successions (Maletz, 2005; Egenhoff and Maletz, 2007; Maletz and Ahlberg, 2011).

The graptolites of the studied area are usually preserved as carbonized films of periderm in grey shales and siltstones in the lower part of the Acoite Formation. They are commonly filled with pyrite in fine to medium-grained sandstones, which appear more frequently intercalated in the upper part of the unit. They may show considerable tectonic deformation and often are encased in a thin layer of chloritic pressure shadow minerals.

The outcome of this work is part of the PhD thesis of one of the authors (B.V.). It is expected that these records, along with other data coming from different areas of northwestern Argentina, will increase the database for the statistical treatment, which allows the quantification of taxonomic and phylogenetic relationships, and the clarification of evolutionary and paleoecological trends of Ordovician graptolites.

2. Regional biostratigraphy

A detailed biostratigraphic analysis exceeds the main scope of this paper, but is under study by Toro and Vento (in press). The new records of key species in the studied area are briefly commented upon and included in Fig. 2, as they allow more accurate identification of the age of the analyzed biostratigraphic interval.

The *Tetragraptus phyllograptoides* Biozone was defined in the Floian stratotype section of Mount Hunneberg, SW Sweden (Maletz et al., 1996) and identifies the base of the Floian at the FAD of *Tetragraptus approximatus* Nicholson and *T. phyllograptoides* Strandmark. The fauna

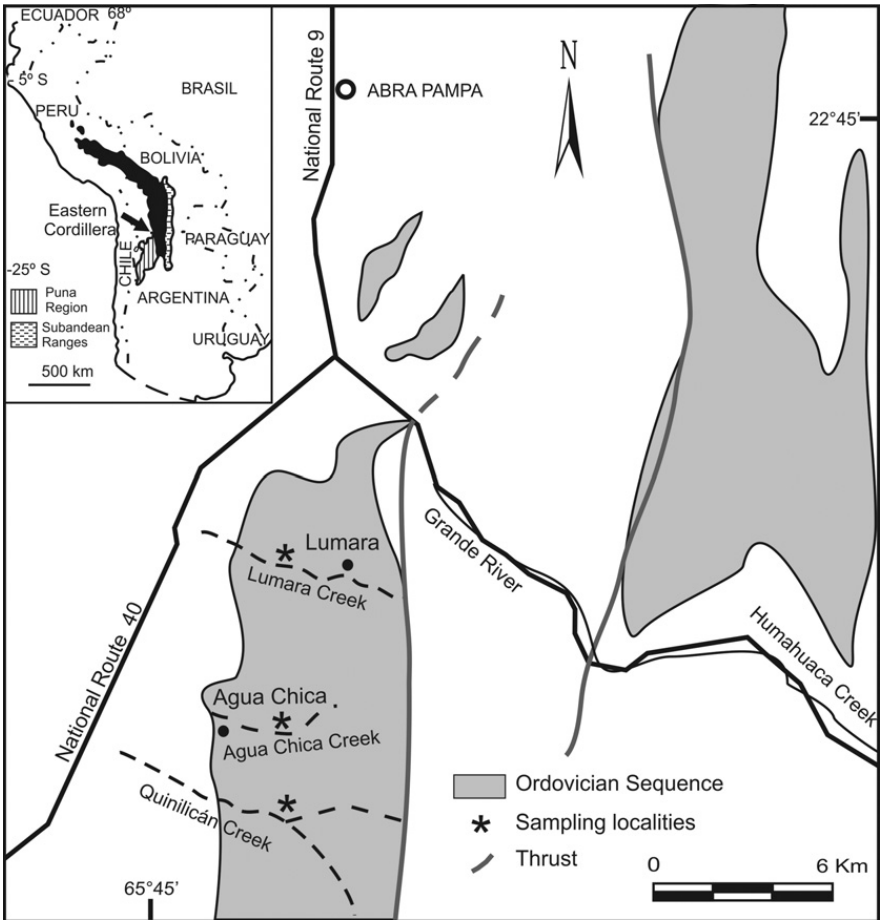

Fig. 1. Location map of the studied area.
Fig. 1. Carte de localisation de la région étudiée.

was recognized for the first time in the Los Colorados area of the Argentinean Cordillera Oriental (Toro, 1994, 1997) and successively identified in other areas of this region, such as the Cajas Range, the Angosto del Moreno, Santa Victoria Range, as well as in equivalent strata in the Cordillera Oriental of Bolivia (Maletz and Egenhoff, 2001; Moya et al., 1998; Ortega et al., 1998).

Previous taxonomic studies carried out on graptolites from the northern border of the Aguilar Range are scarce. Martín et al. (1987) described *T. approximatus* from the basal Floian succession in the Quinilicán and Agua Chica sections, but the *T. phyllograptoides* Biozone was only recently confirmed in the lower levels of the Acoite Formation outcropping in the Quinilicán section (Vento et al., 2010).

In the studied sections the contact with the underlying Santa Rosita Formation is covered by modern alluvium. The fossil bearing levels corresponding to *T. phyllograptoides* Biozone are represented by approximately 145 m of thick gray and green graptolitic shales (Fig. 2). In addition to the index species *T. approximatus*, *Baltograptus geometricus* (Törnquist) and *Cymatograptus* cf. *C. rigoletto* (Maletz, Rushton and Lindholm) are recorded in this interval.

Martín et al. (1987) also mentioned other taxa, such as *Didymograptus deflexus* (Elles and Wood), *D.* aff. *D. v-deflexus* Harris, *D.* aff. *D. v-fractus* (Salter) and *D.* cf. *D. compressus* Harris and Thomas from the Lumará Member of the Sepulturas Formation, which they defined in the Lumará and Mocante sections. Based on the present study and the re-evaluation of the descriptions and illustrations presented by these authors, we suggest that the material identified as *D. deflexus* and *D.* aff. *D. v-deflexus* would better be referred to *Baltograptus vacillans* (Tullberg). *D.* aff. *D. v-fractus* resembles the *B. turgidus* group, while the specimens assigned to *D.* cf. *D. compressus* could belong to *Cymatograptus protobalticus* (Monsen). More recently, Toro (1996) described *B. turgidus* (Lee) and *B. kunmingensis* (Ni) from the upper part of the section exposed at both margins of Lumará creek. These species, which were originally described from the Southwest of China (Mu et al., 1979), were collected from siltstones and interbedded fine sandstones, which the author assigned to the Acoite Formation of Early Arenigian (now Floian) age. Subsequently, Toro and Maletz (2007) reviewed a number of species of the genus *Baltograptus* from northwestern Argentina, assigning an Early to Mid Floian age ("*B.* cf. *B. deflexus*" Biozone) to the levels bearing the *B. turgidus* group species in the Lumará section.

Approximately 145 m above the visible base of the studied section the first appearance of *C. protobalticus* together with *Cymatograptus* cf. *C. balticus* (Tullberg) and *Didymograptus* cf. *D. demissus* Törnquist suggests the presence of a

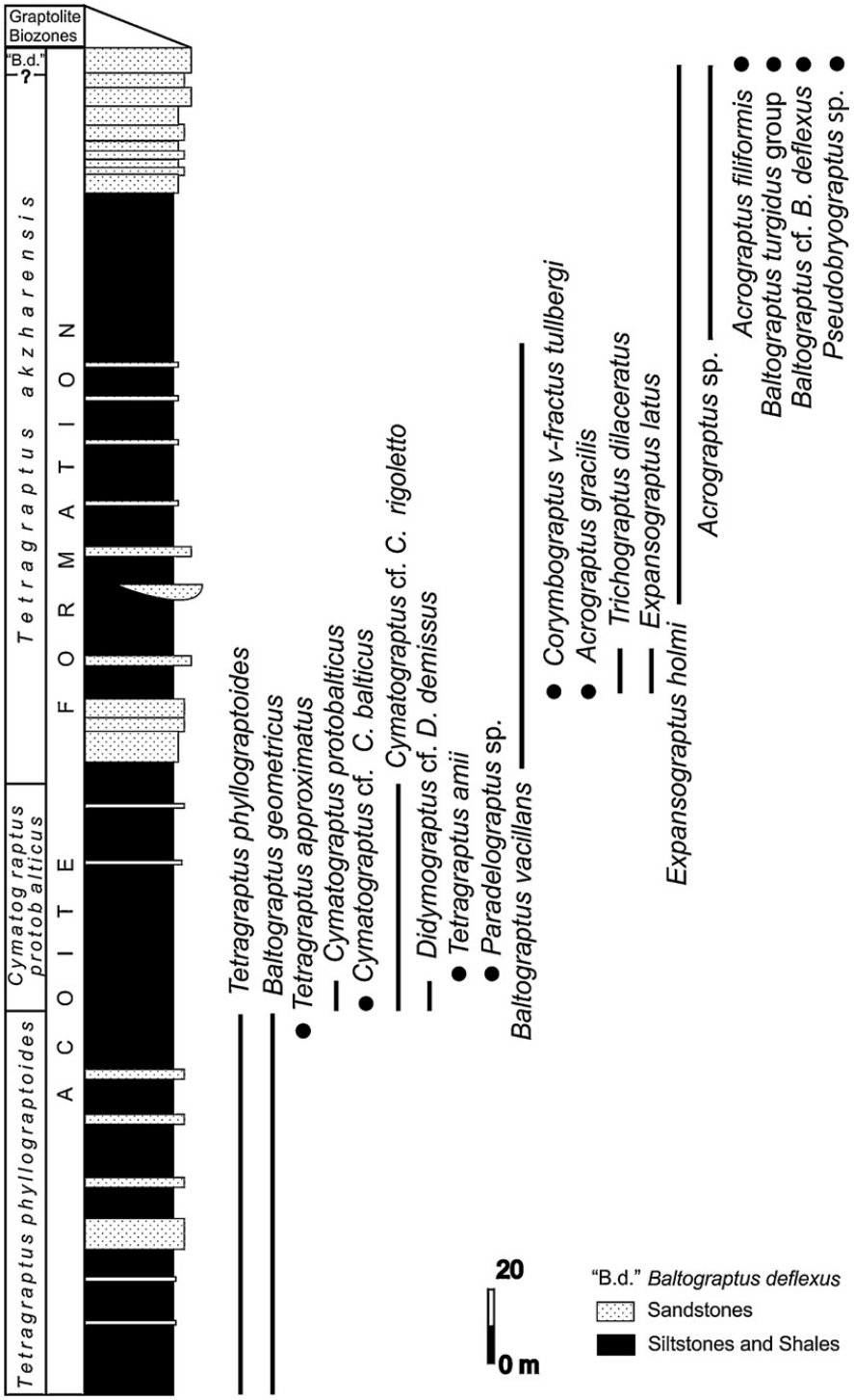

Fig. 2. Combined stratigraphic column of the Quinilicán area.
Fig. 2. Colonne stratigraphique de la région de Quinilicán.

younger biozone, equivalent to the lower part of the *Tetragraptus akzharensis* Biozone (*sensu* Toro, 1997). Although the index species of this biozone is not present in the studied area, other taxa such as *Tetragraptus amii* Elles and Wood and *Paradelograptus* sp. (Erdtmann, Maletz and Gutiérrez Marco), previously recorded from equivalent levels of the western part of the Cordillera Oriental, are also found in the lower part of this interval. *B. vacillans* occurs approximately 90 m above the lower boundary of the *T. akzharensis* Biozone and ranges into the upper portion of this biozone together with *Expansograptus holmi* (Törnquist). Paleobiogeographically important taxa, such as *Trichograptus dilaceratus* (Herrmann), *Acrograptus gracilis* (Törnquist), *Expansograptus latus* (T.S. Hall) and *Corymbograptus v-fractus tullbergi* (Monsen) are recorded in the lower part of this interval, and *Acrograptus* sp. and *A. filiformis* (Tullberg) are present in the upper portion of the succession (Fig. 2).

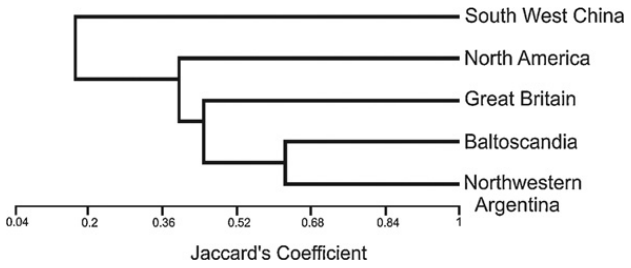

Fig. 3. Cluster analysis showing faunal affinities.
Fig. 3. Analyse de groupes montrant les affinités fauniques.

In the uppermost levels of the Acoite Formation, deflexed didymograptids resembling the *Baltograptus turgidus* group (Lee, 1974), associated with "*B.* cf. *B. deflexus*", suggest the occurrence of the overlaying "*B. deflexus*" Biozone (*sensu* Toro and Maletz, 2007). Nevertheless, a biostratigraphic revision of the "*B. deflexus*" and *D. bifidus* Biozones is still necessary to certify the stratigraphic ranges and faunal affinities of those taxa, and this subject exceeds the objectives of this paper.

The presence of the *T. phyllograptoides* and *T. akzharensis* biozones in the studied area confirms an Early Floian age for the lower levels of the Acoite Formation, and enables the regional correlation of the levels exposed in the Quinilicán and Agua Chica sections with those in which these biozones were previously recognized, such as the Lumará section and Los Colorados and Santa Victoria areas (Toro, 1997; Toro and Maletz, 2007). The intercontinental correlation with the *T. phyllograptoides*, *C. protobalticus* and *B. vacillans* biozones, recently proposed by Maletz and Ahlberg (2011) for Baltoscandia is also possible.

3. Paleoecological and paleobiogeographical analysis

A close paleogeographical relationship of the Argentinean Cordillera Oriental with Baltica was initially postulated by Toro (1993, 1994, 1999) based upon the presence of deflexed didymograptids now generally referred to the genus *Baltograptus*. Other authors pointed out later its affinities with the cold water Atlantic Faunal Realm and especially with the faunas of Baltica (Maletz and Ortega, 1995; Toro and Maletz, 2007). A detailed paleogeographic analysis of the faunas, however, has not been attempted after these revisions. As many new records of important faunal elements of Early Floian graptolites have been made in the northwestern Argentina recently, a cluster analysis was made to support the previously suggested paleogeographic relationships (Fig. 3).

A presence or absence matrix was developed, which includes all Early Floian species previously recognized in the Sierra de Aguilar (Toro, 1996, 1997) and those recently identified from the Quinilicán and Agua Chica sections (Vento and Toro, 2009; Vento et al., 2010). In addition, all confirmed Early Floian graptolite records previously mentioned from the Northwest of Argentina (Toro and Brussa, 2003; Albanesi et al., 2008; Brussa et al., 2008) have been incorporated (presence-absence matrix available upon request to the authors). A comparison was made with those faunal associations recently reviewed from equivalent stratigraphic levels of Baltoscandia (Egenhoff and Maletz, 2007), Great Britain (Zalasiewicz et al., 2009), North America (Jackson and Lenz, 2006; Williams and Stevens, 1988) and Southwest China (Zhang et al., 2007).

The cluster analysis presented in Fig. 3 was carried out using a multivariate state program (MVSP), and the Jaccard's index was used for measuring the biodiversity. The dendrogram shows a Jaccard's index of 0.64 that is coherent to the strong similarities with Baltoscandia, which has most species in common with northwestern Argentina. The presence of *T. dilaceratus*, *A. gracilis*, *E. latus* and *C. v-fractus tullbergi* which are recognized in Argentina for the first time in this paper, reinforce this result. Great Britain is located in an intermediate position in the dendrogram. The Jaccard's index is close to 0.45 and it means less affinity with northwestern Argentina. The Jaccard's index for the North American faunas was 0.39, and it shows less affinity with the northwestern Argentina. Finally, a biodiversity index of 0.15 corresponds to only weak affinities with Southwest China during the Early Floian (*T. approximatus* Zone and lower part of *T. akzharensis* Zone). The statistical analysis confirms the paleobiogeographic relationships previously established in other areas of the Cordillera Oriental, and supports the hypothesis that during the Early Ordovician, Northwestern Argentina as part of the supercontinent Gondwana, was located in middle to high latitudes, corresponding to the Atlantic Faunal Realm of cold water graptolite biofacies (Fig. 4). Similar Floian graptolite faunas

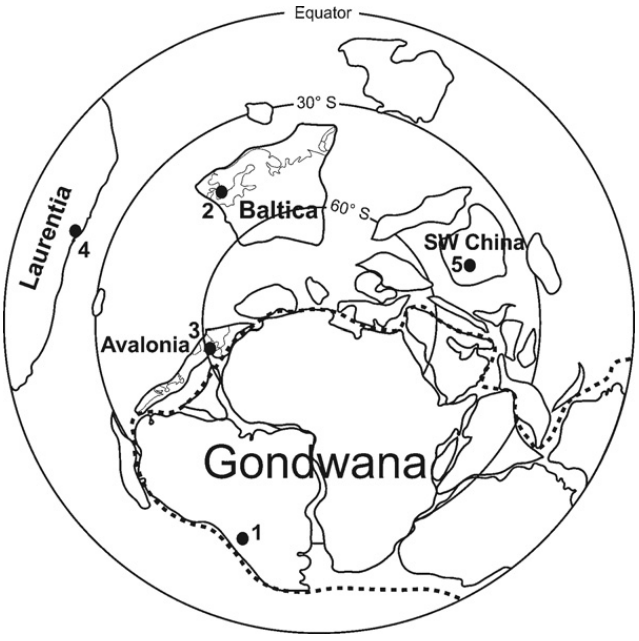

Fig. 4. Paleogeographic reconstruction of the southern hemisphere for the Early Ordovician, based on Cocks and Torsvik (2002) and Egenhoff and Maletz (2007). Labeled regions: 1. Northwestern Argentina. 2. Southern Scandinavia/Baltica. 3. Britain/Avalonia. 4. Western Newfoundland, Laurentia. 5. SW China.
Fig. 4. Reconstitution paléogéographique de l'Hémisphère Sud pour l'Ordovicien inférieur, à partir des données de Cocks et Torsvick (2002) et Egendorf et Maletz (2007). Régions indiquées : 1. Argentine nord-occidentale. 2. Sud Scandinavie/Baltique. 3. Bretagne/Avalonie. 4. Sud Terre-Neuve/Laurentie. 5. Sud-Ouest de la Chine.

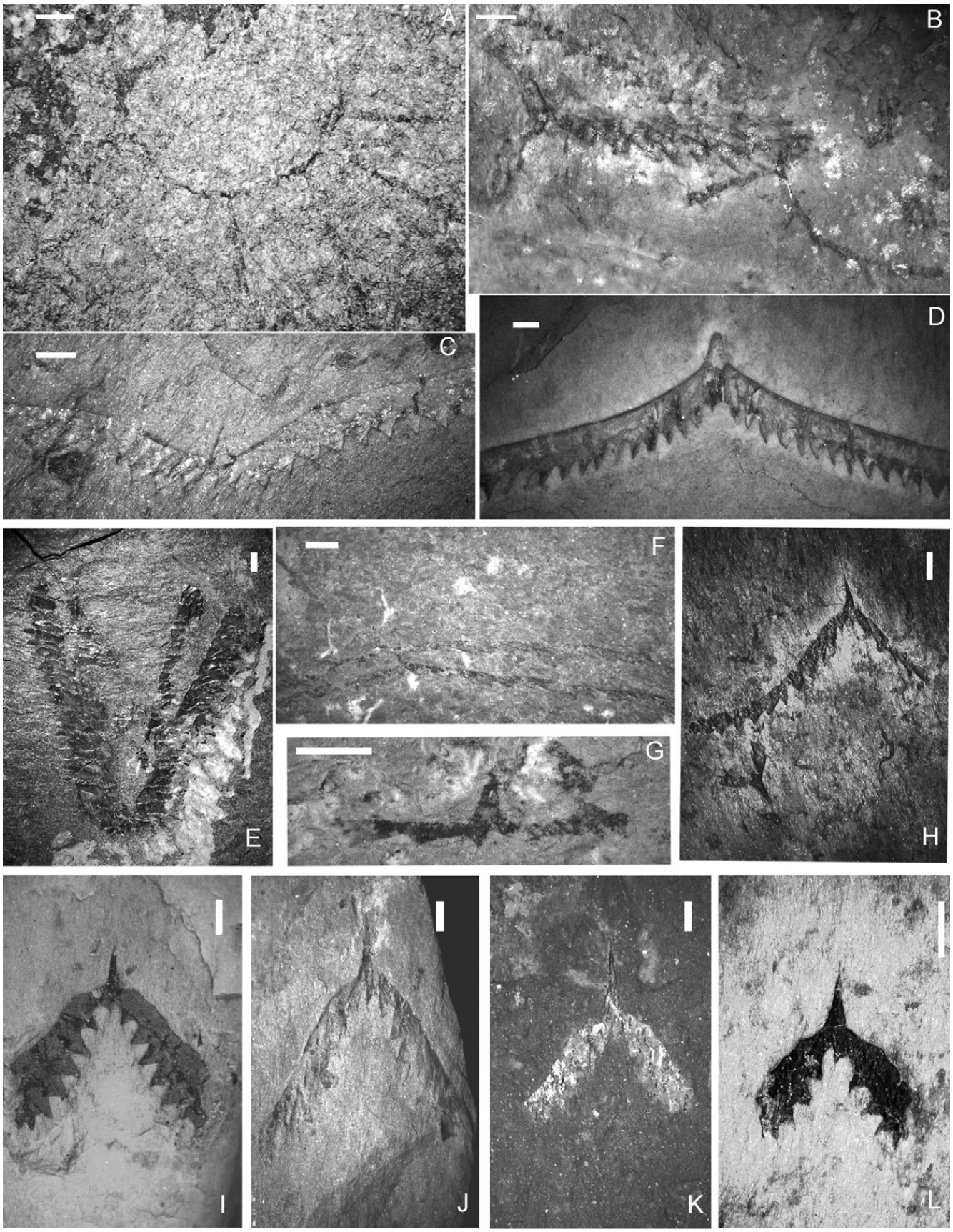

Fig. 5. Argentinean specimens. A-B: *Trichograptus dilaceratus* (Herrmann), *T. akzharensis* Biozone, Agua Chica section. A: IANIGLA-PI 2359 curved first order stipe exhibiting the second order branches. B: IANIGLA-PI 2367 fragmentary rhabdosome showing common flattened preservation of the thecae. C: *Expansograptus latus* (T.S. Hall) IANIGLA-PI 2557 mould filled with sediment, *T. akzharensis* Biozone, Agua Chica section. D: *Cymatograptus protobalticus* (Monsen) CEGH-UNC 13420 proximal part of a mature rhabdosome, *T. akzharensis* Biozone, Agua Chica section. E: *Tetragraptus phyllograptoides* Strandmark

with *Baltograptus* species occur in Southwest China (Mu et al., 1979; Zhang et al., 2007), Avalonia (Zalasiewicz et al., 2009), Baltica (Maletz, 1994; Toro and Maletz, 2007), but not in North America (Williams and Stevens, 1988).

The main result of the paleogeographic analysis is supported by the records of *T. dilaceratus*, *A. gracilis*, *E. latus* and *C. v-fractus tullbergi*, which are reported from Argentina for the first time in this paper. It is important to emphasize that *T. dilaceratus* is restricted to grey and green shales of the lower levels of the Acoite Formation, which according to the sedimentology of this part of the succession indicates the deeper water facies. In addition to the taxa assigned by Cooper et al. (1991) to the deep water biotope, Egenhoff and Maletz (2007) recently identified this species as a deep water pandemic faunal element, which, however, has not been recognized in any Pacific Faunal Realm regions so far. Conversely, the *B. turgidus* group is found in fine to medium-grained sandstones, which commonly appear interbeded to the upper part of the studied sections, corresponding to the shallower water facies. Zhang et al. (2010) recently considered the *B. varicosus* group (allied to *B. turgidus* group in China) as a group of graptolites ecologically related to the shallow water biofacies. The distribution of *T. dilaceratus* and *B. turgidus* group in northwestern Argentina is consistent with previous considerations regarding to the worldwide importance of these taxa as paleoenvironmental indicators.

4. Systematic paleontology

We describe here only four interesting and paleobiogeographically important taxa, which are recognized for the first time from Argentina. They are illustrated in Fig. 5 together with the key species recently recorded in the studied sections. We also include in Fig. 6 well preserved Scandinavian specimens of all considered taxa. The Argentinean material is commonly preserved as flattened remains of carbonized periderm, but a number of rhabdosomes are filled with pyrite or sediments, showing details in partial relief. We follow Maletz (1994) to include *C. v-fractus tullbergi* in the genus *Corymbograptus*, but we prefer to maintain it as suborder and family *inciertae* here as its taxonomical relationships with other pendeograptids remains uncertain. The extensiform species are included in the genus *Expansograptus*, as an upgrade of the subgenus established by Cooper and Fortey (1982). We also used the criteria of these authors for the taxonomic classification of *T. dilaceratus* and *A. gracilis*.

The Argentine collection of studied graptolites is stored as IANIGLA-PI in the Unidad de Paleoinvertebrados of IANIGLA, CCT-CONICET, Mendoza, and CEGH-UNC, CIPAL, Universidad Nacional de Córdoba. Illustrated specimens from Mt. Hunneberg (Sweden) are preserved in the palaeontological collection of the Museum für Naturkunde (Berlin, Germany).

Order GRAPTOLOIDEA Lapworth, 1875 (emend. Fortey and Cooper, 1986)

Incertae sedis

Genus ***Corymbograptus*** Obut and Sobolevskaya, 1964

Type species: *Didymograptus v-fractus* Salter, 1863

Corymbograptus v-fractus tullbergi (Monsen, 1937)

Fig. 5J-K; Fig. 6A.

1937 *Didymograptus v-fractus tullbergi* Monsen, 1937, p. 144–145, Pl. 3, figs. 12, 16, 23; Pl. 9, fig. 3; Pl. 10, figs. 9, 10

1994 *Corymbograptus v-fractus tullbergi* Maletz, p. 35, fig. 4e–g

1996 *Corymbograptus v-fractus tullbergi*; Maletz, figs. 1i, 3e

Material. Two juvenile specimens, one preserved as a flattened film and another filled with pyrite in partial relief. IANIGLA-PI 1838, IANIGLA-PI 2353.

Description. Both available specimens exhibit a conspicuous long and slender sicula with a strong nema. The sicula reaches up to 3.25 mm in length and is 0.5 mm wide at the aperture (Fig. 5J-K). The proximal end shows the characteristic pendent mode of the genus *Corymbograptus*, with stipes diverging at an angle of approximately 85°. The presence of the isograptid crossing canal is vaguely observed in both counterparts of the specimen preserved in partial relief. The stipe width increases from 1.25 mm at level of the aperture of th 1^1 to a maximum of 1.5 mm at th 2^1. Thecal inclination is about 35° proximally, but the distal portions of thecae are suddenly curve, leading to a serrated aspect of the ventral side of the stipes. There are approximately 11 thecae in 10 mm. All the characteristics of this specimen match with *C. v-fractus tullbergi*, largely known from the *B. vacillans* Zone of

IANIGLA-PI 2358 mature flattened rhabdosome, *T. phyllograptoides* Biozone, Quinilicán section. F-G: *Acrograptus gracilis* (Törnquist), *T. akzharensis* Biozone, Agua Chica section. F: IANIGLA-PI 2354, two complete flattened specimens. G: IANIGLA-PI 2368 young specimen. H: *Baltograptus vacillans* (Tullberg) IANIGLA-PI 2357 mature and young specimens, *T. akzharensis* Biozone, Agua Chica section. I: *Baltograptus kunmingensis* (Ni) CEGH-UNC 12426, juvenile rhabdosome filled with pyrite "*B. deflexus*" Biozone, Lumará section. J-K *Corymbograptus v-fractus tullbergi* (Monsen), *T. akzharensis* Biozone, Agua Chica section. J: IANIGLA-PI 1838, juvenile flattened specimen. K: IANIGLA-PI 2353 young specimen filled with pyrite showing the sicula in partial relief. L. *Baltograptus turgidus* (Lee) juvenile rhabdosome preserved in partial relief, CEGH-UNC 12420, "*B. deflexus*" Biozone, Lumará section. Magnification provided by 1 mm long bar in each photo.

Fig. 5. Spécimens argentins. A-B : biozone à *Trichograptus dilaceratus* (Herrmann), *T. Akzharensis* Biozone, coupe d'Aqua Chica : A : IANIGLA-PI 2359, branche courbe de premier ordre montrant des branches de second ordre. B : IANIGLA-PI 2367 ; fragment de rhabdosome montrant la conservation commune aplatie de thèques. C. *Expansograptus latus* (T. Hall), IANIGLA-PI 2557, moule rempli de sédiment, biozone à *T. akzharensis*, coupe d'Aqua Chica. D: *Cymatograptus protobalticus* (Monsen). CEGH-UNC 13420, partie proximale d'un rhabdosome mature, biozone à *T. akzharensis*, coupe de Aqua Chica. E : *Tetragraptus phyllograptoïdes* Strandmark IANIGLA-PI 2358, rhabdosome aplati mature, biozone à *T. phyllograptoïdes*, coupe de Quinilicán. F-G : à *Acrograptus gracilis* (Törnquist) *T. akzharensis* Biozone, coupe d'Aqua Chica. F : IANIGLA-PI 2354, deux spécimens complets aplatis. G : IANIGLA-PI 2368, spécimen jeune. H : *Baltograptus vacillans* (Tullberg), IANIGLA-PI 2357, spécimens jeunes et matures, biozone à *T. akzharensis*, coupe d'Aqua Chica. I : *Baltograptus kunningensis* (Ni), CEGH-UNC 12426, rhabosome juvénile rempli de pyrite, biozone à « *B. deflexus* », coupe de Lumará. J-K : *Corymbograptus v-fractus tullbergi* : (Monsen), biozone à *T. akzharensis*, coupe d'Aqua Chica. J : IANIGLA-PI 1838, spécimen juvénile aplati. K : IANIGLA.PI 2353, spécimen jeune rempli de pyrite montrant la sicula partiellement en relief. L : *Baltograptus turgidus* (Lee), rhabdosome juvénile conservé partiellement en relief, CEGH-UNC 12420, biozone à « *B. deflexus* », coupe de Lumará. Barre d'échelle : 1 mm.

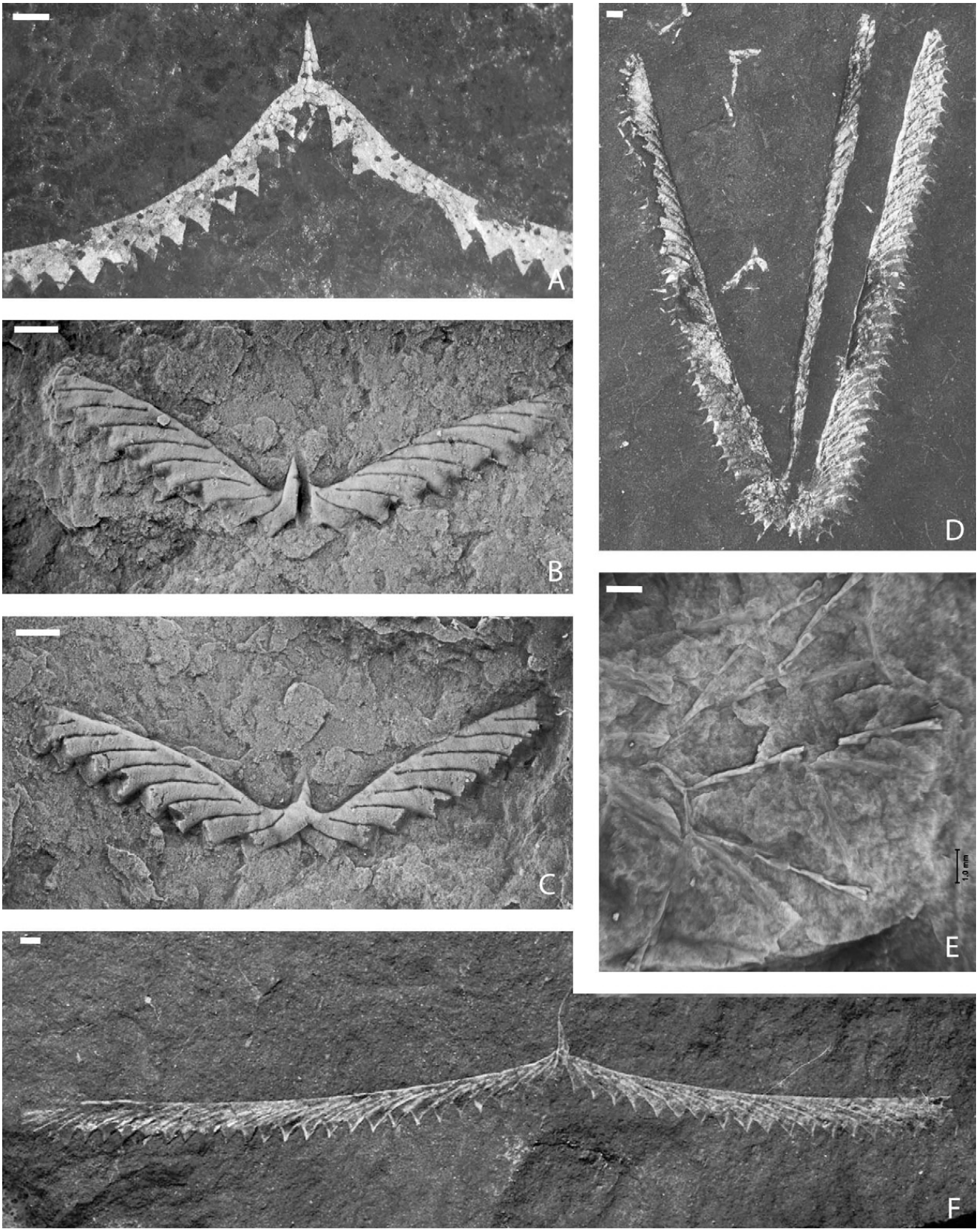

Fig. 6. Scandinavian specimens. A. *Corymbograptus v-fractus tullbergi* (Monsen), Diabasbrottet, 4.2–4.3 m. B, C. *Expansograptus latus* (Hall), latex casts of obverse (B) and reverse (C) views, Diabasbrottet. D. *Tetragraptus phyllograptoides* Strandmark, large specimen, Diabasbrottet. E. *Trichograptus dilaceratus* (Herrmann), Diabasbrottet, latex cast. F. *Cymatograptus protobalticus* (Monsen), Diabasbrottet, 4.1–4.2 m. Magnification provided by 1 mm long bar in each photo.

Fig. 6. Spécimens scandinaves. A : *Corymbograptus v-fractus tullbergi* (Monsen), Diabasbrottet, 4,2–4,3 m. B, C : *Expansograptus latus* (Hall), moulage en latex vu de face (B) et à l'envers (C), Diabasbrottet. D : *Tetragraptus phyllograptoïdes* Strandmark, grand spécimen. E : *Trichograptus dilaceratus* (Herrmann), Diabasbrotteit, moulage en latex. F : *Cymatograptus protobalticus* (Monsen), Diabasbrotteit, 4,1–4,2 m : barre d'échelle : 1 mm.

Baltoscandia (Fig. 6A). The sicular length is noticeable smaller in other possible corymbograptids previously mentioned from northwestern Argentina, like *C. v-fractus* (Loss, 1951; Martín et al., 1987). Nevertheless, the occurrence of *C. v-fractus* in Argentina is still uncertain, and it is under re-evaluation by Vento. *C. v-fractus tullbergi* can be easily distinguished from other deflexed forms with isograptid proximal development, which are common in the upper portion of the studied sections, like *B. turgidus* and *B. kunmingensis* (Fig. 5I, L). The length of the sicula in *B. turgidus* group rarely exceeds 1.7 mm, while in *C. v-fractus tullbergi* the sicula is noticeable longer and slender (Fig. 5J–K).

Occurrence. The subspecie *C. v-fractus tullbergi* is found from northwestern Argentina for the first time in the lower part of the Acoite Formation exposed in the Quinilicán and Agua Chica sections (Jujuy Province) (Fig. 2). It is associated with *B. vacillans*, *E. latus*, *A. gracilis* and *T. dilaceratus* in the Early Floian strata (*T. akzharensis* Biozone). *C. v-fractus tullbergi* is a common taxon in the early Floian strata of Baltoscandia, originally described from the *B. vacillans* Subzone (*C. protobalticus* Zone) of the Oslo Region of Norway (Monsen, 1937) and Mt. Hunneberg, Sweden (Maletz, 1994, 1996). Recently, Maletz and Ahlberg (2011) presented a re-evaluated biostratigraphic scheme for North-West Scania based on the Lerhamn drill core in which *C. v-fractus tullbergi* ranges through the *B. vacillans* and *B.* sp. cf. *B. deflexus* biozones and it is associated with *T. dilaceratus* in levels corresponding to *B.* sp. cf. *B. deflexus* Biozone.

Suborder DIDYMOGRAPTINA Lapworth, 1875

Family DICHOGRAPTIDAE Lapworth, 1873 (emend. Fortey and Cooper, 1986)

Genus ***Expansograptus*** Bouček and Přibyl, 1951

Type species: *Graptolithus extensus* Hall, J. 1858

Expansograptus latus (T.S. Hall, 1907)

Fig. 5C; Fig. 6B-C.

Didymograptus constrictus Törnquist, 1901, p. 17–18, Pl. 2, figs. 13-17

Didymograptus latus T. S. Hall, 1907, p. 141–142, pl. 15, fig. 7

?1937. *Didymograptus validus* Monsen, p. 96–97, Pl. 1, figs. 3, 12, 13, 16

Didymograptus urbanus n. sp. Monsen, 1937, p. 99–100, Pl. 1, figs. 18, 19, 28, Pl. 8, fig. 10

Didymograptus constrictus Monsen, 1937, p. 101–102, Pl. 1, fig. 23, Pl. 7, fig. 2, Pl. 8, fig. 2

Didymograptus constrictus var. *repandus* n. var. Monsen, 1937, p. 102–103, Pl. 1, fig. 20, Pl. 7, fig. 5, Pl. 8, fig. 4

Didymograptus latus latus Hall, T.S., Rickards and Chapman, 1991, p. 78–80, pl. 24a

Expansograptus urbanus Maletz et al., 1996, fig. 13–10.

Material. Two complete rhabdosomes, one of which is filled with sediment showing details in partial relief, and a number of additional poorly preserved specimens. IANIGLA-PI 2351, IANIGLA-PI 2557.

Description. The specimens display similar extensiform rhabdosomes, formed by two robust stipes with the characteristic reflexed attitude in the proximal part, as found in the Australasian material of Hall (1907) and the Norwegian specimens of Monsen (1937) (Fig. 5C). They show a conspicuous 2 mm long sicula with an apertural width of 0.5 mm. The stipe width increases from 1.0–1.1 mm in the proximal part up to 2 mm in the distal portion. The thecal inclination is about 50° and there are 12 thecae in 10 mm. These measurements agree with those of *E. latus latus* (T.S. Hall), as redescribed by Rickards and Chapman (1991). Egenhoff and Maletz (2007) (appendix) synonymized the Scandinavian species *E. urbanus* (Fig. 6B–C) with *E. latus*, but did not illustrate any specimens.

Occurrence. Early Floian strata of the Quinilican and Agua Chica sections (Jujuy Province), Sierra de Aguilar (Fig. 2). It is recorded from northwestern Argentina for the first time together with *B. vacillans*, *C. v-fractus tullbergi*, *A. gracilis* and *T. dilaceratus* in the *T. akzharensis* Biozone. The species was described originall y by Hall (1907) from the Bendigonian of Victoria, Australia and by Monsen (1937) under a variety of names from the *D. validus* and *D. balticus* zones of Galgeberg, in the Oslo Region, Norway. Subsequently, Maletz (1992) assigned the records of *E. latus* from Diabasbrottet (Västergötland, Sweden) and from the Tøyen section (Oslo, Norway) to the *D. holmi* Subzone (*T. approximatus* Zone) of Baltoscandia, while Egenhoff and Maletz (2007) indicated the presence of this species in their *C. protobalticus* to *B. vacillans* biozones.

Family SINOGRAPTIDAE Mu, 1957

Subfamily SIGMAGRAPTINAE Cooper and Fortey, 1982

Genus ***Trichograptus*** Nicholson, 1876

Type species: *Dichograptus fragilis* Nicholson, 1869

Trichograptus dilaceratus (Herrmann, 1885)

Fig. 5A–B; Fig. 6E

Pterograptus (?) *dilaceratus* n. sp. Herrmann, 1885, p. 69, Fig. 7

Trichograptus crinitus Törnquist, 1904, p. 4, Pl. 1, figs. 5–7

Trichograptus dilaceratus Monsen, 1937, p. 200, Pl. 5, figs. 4,13; Pl. 14, figs. 1, 7; Pl. 16, fig. 3

Trichograptus dilaceratus Rushton, 1996, p. 67, figs. 4a–d, 6

Material. Two specimens identified as IANIGLA-PI 2359 and IANIGLA-PI 2367, and a number of fragmentary branches. The material is poorly preserved as flattened films.

Description. Although the rhabdosome is not preserved in relief, the most relevant characteristics that enable to assign it to *T. dilaceratus* are still present. The slender, slightly declined first order stipes is visible, and the curved second order branches are clearly recognizable in the distal part of the colony (Fig. 5A–B). The stipe width, thecal spacing and low inclination of thecae also are comparable with previous descriptions of *T. dilaceratus* (Maletz, 1992; Monsen, 1937; Rushton, 1996), as well as those observed in the Swedish specimen illustrated in Fig. 6E.

Occurrence. *T. dilaceratus* is recorded from the Agua Chica section for the first time, where it occurs in the lower part of the Acoite Formation. It is associated with *C. v-fractus tullbergi*, *A. gracilis* and *E. latus* in the same stratigraphic level at which *B. vacillans* appears. The interval, therefore, can be assigned to the Early Floian,

the upper part of the *T. akzharensis* Biozone (*sensu* Toro, 1997). *T. dilaceratus* was originally described from the Oslo Region of Norway (Herrmann, 1885) and subsequently from the Diabasbrottet and Mossebo sections in Sweden (Törnquist, 1904: as *Trichograptus crinitus*), found in Early Floian levels corresponding to the *B. vacillans* Biozone. It is important to point out that this new record reinforces the paleobiogeographic affinities with Baltoscandia and the cold water Atlantic Faunal Realm. The species was recently considered as a deep-water graptolite (Egenhoff and Maletz, 2007).

Genus ***Acrograptus*** Tzaj, 1969

Type species: *Didymograptus affinis* Nicholson, 1869

Acrograptus gracilis (Törnquist, 1890)

Fig. 5F–G

1890. *Didymograptus gracilis* Törnquist, p. 17, pl. 1, figs. 9–12

1982. *Acrograptus gracilis* Cooper and Fortey, p. 272, figs. 66c–g

1988. *Acrograptus gracilis* Williams and Stevens, p. 88, Text-fig. 79 O.

Material. Two complete pyritized specimens and additional flattened rhabdosomes. IANIGLA-PI 2354, IANIGLA-PI 2368.

Description. Slightly declined rhabdosomes composed of two slender stipes diverging horizontally at different levels from a small sicula, 1.1 mm long and 0.3 mm wide at the aperture. The stipes are very gently declined at the distal portion and slightly increase in width from 0.4 mm at level of the aperture of the first theca to a maximum of 0.5 mm distally. The thecae have a free ventral wall up approximately 1.3 mm and there are 8 thecae in 10 mm. The studied material compares well in all described aspects with the species *A. gracilis*, originally described by Törnquist (1890) from Baltoscandia.

Occurrence. It is associated with *B. vacillans*, *E. latus*, *C. v-fractus tullbergi*, *Acrograptus* and *T. dilaceratus* in the early Floian strata of the Agua Chica section (Jujuy Province), Sierra de Aguilar (Fig. 2). The species is widely distributed in equivalent levels of Baltoscandia (Törnquist, 1890) and Great Britain (Zalasiewicz et al., 2009). It was also registered in the later levels of Spitsbergen (Cooper and Fortey, 1982) and Newfoundland (Williams and Stevens, 1988). Recently, Egenhoff and Maletz (2007) compared this taxon with the forms recorded in the *B. vacillans* Biozone at Diabasbrottet, Sweden, the Global Boundary Stratotype Section and Point of the Floian.

5. Conclusions

The statistical analysis confirms the strongest faunal affinities with graptolite faunas from Baltica and supports the paleobiogeographic hypothesis that northwestern Argentina was located in middle to high latitudes, corresponding to the Atlantic Faunal Realm of cold water graptolite biofacies during the early Floian.

The records of *T. phyllograptoides*, *C. protobalticus*, *B. vacillans*, *A. filiformis* and *E. holmi* enable us to assign the lower part of the Acoite Formation of Northwestern Argentina to the Early Floian (*T. phyllograptoides* and *T. akzharensis* biozones). These biozones suggest a regional correlation with the homonymous biozones previously recognized in different areas of the Central Andean Basin and the intercontinental correlation with the *T. phyllograptoides*, *C. protobalticus* and *B. vacillans* biozones of Baltoscandia.

C. v-fractus tullbergi, *E. latus*, *A. gracilis* and *T. dilaceratus*, described herein from northwestern Argentina for the first time, enhancing the outstanding record of graptolite taxa shared with Baltica.

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