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Darriwilian (Middle Ordovician) graptolite faunas of the Sandia Region, southern Peru

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Ordovician graptolite faunas of Peru are restricted to a short interval in the Middle to basal Upper Ordovician, found in three regions of the country. All Peruvian graptolite faunas are strongly dominated by shallow water elements of the Atlantic Faunal Realm, represented largely by *Didymograptus* s. str. and *Aulograptus*, but a number of faunal elements of the pandemic isograptid biofacies have recently been discovered in the Sandia Region of SE Peru. Peruvian graptolite faunas are reviewed and the new records from the Sandia Region are discussed in detail. The faunas from the Purumpata and Iparo members of the San José Formation range in age approximately from the *Undulograptus austrodentatus* Biozone to the *Holmograptus lentus* Biozone (early to middle Darriwilian). The faunas provide a better understanding of faunal composition and diversity in this region and help to correlate shallow water and deeper water graptolite faunas from this time interval. Biserial graptolites are rare in most samples and usually indeterminable, but a single identifiable specimen of *Undulograptus austrodentatus* was found, indicating a level close to the base of the Darriwilian. A number of specimens of the genera *Isograptus* and *Arienigraptus* from the Sandia Region represent pandemic graptolite faunas of the isograptid biofacies, described for the first time from this region. Copyright © 2009 John Wiley & Sons, Ltd.

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1. INTRODUCTION

Graptolites are the typical fossils found in many Ordovician shale successions all over the world. They provide important biostratigraphic and biogeographic information for the facies interpretation of Palaeozoic marine successions. Unfortunately, graptolites are uncommon in most Ordovician successions in Peru and only a very incomplete record exists. Earliest information was provided by Newton (1901) on Middle to Upper Ordovician graptolites, but was not based on a systematic investigation. A number of expeditions further provided data on the Ordovician graptolite faunas of Peru, namely the Balston-Douglas (in 1929) and Nordenskjöld (in 1904–1905) expeditions (Lapworth, 1917; Bulman, 1931, 1933; Douglas, 1933). These provide important data on the distribution of Ordovician graptolite faunas in northwestern Bolivia and southern Peru. Especially Bulman (1931, 1933) described in some detail the graptolite faunas and erected a number of new species from this material. Nearly all known graptolite faunas originate from the Peruvian part of the Altiplano and Eastern Cordillera (Figure 1). The faunas are from an interval ranging from mid Darriwilian to Katian in age and, thus, represent only a small fraction of the Ordovician time period. Lower Ordovician faunas have been claimed to be present (De La Cruz and Carpio, 1996), but are not documented unequivocally. Subsequently, very few new records of Peruvian graptolite faunas have been made.

The graptolite faunas of South America belong mostly to the Atlantic Faunal Realm as is shown by the occurrence of common pendent didymograptids in the Darriwilian (Maletz and Ortega, 1995; Toro and Brussa, 2003) and numerous Atlantic type Floian to Dapingian species common also in Baltica and Southwest China, including those of the genera *Cymatograptus* and *Baltograptus* (Toro and Brussa, 2003; Toro and Maletz, 2007). Only the Ordovician graptolite faunas of the Argentine Precordillera were interpreted to belong to the Pacific Faunal Realm as defined by Cooper

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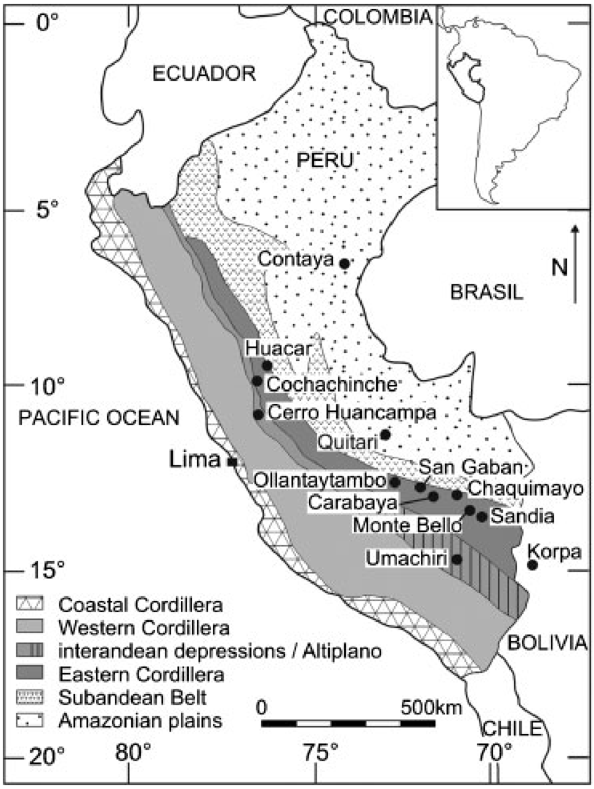

Figure 1. Map of Peru with the localities mentioned in the text.

et al. (1991) and differ considerably in their composition. Faunal differentiation, however, has been done often through the presence of the characteristic and easily identifiable isograptids. The assignment of the graptolite faunas of the Argentine Precordillera to the Pacific Faunal Realm was made based on the common occurrence of these isograptids without taking into consideration most of the other faunal elements.

Fortey (1984) and Fortey and Cocks (1986) first recognized the possibility to use isograptids for palaeogeographic interpretations and described the isograptid biofacies as the pandemic, deep-water graptolite biofacies of the Middle Ordovician, not restricted biogeographically. Recently, isograptids were found to be present in various regions of Gondwanan South America (Bahlburg *et al*., 1990; Maletz and Egenhoff, 2003; Mitchell *et al*., 2008), supporting the notion of their pandemic distribution and questioning their affiliation with the Pacific Faunal Realm graptolite faunas. Isograptids are highly useful for biostratigraphic correlations and have been used frequently for this purpose (e.g. Harris and Thomas, 1938; Cooper, 1973; Cooper and Ni, 1986; Williams and Stevens, 1988; VandenBerg and Cooper, 1992). Their distribution, thus, aids to the biostratigraphic correlation of endemic shallow water faunas of the Atlantic and Pacific Faunal Realms. Finding the pandemic isograptids associated with endemic graptolite faunas of any origin, enhances the possibility of a precise dating and correlation of graptolitic intervals.

2. ORDOVICIAN GRAPTOLITES OF PERU

Ordovician graptolites have been described from a number of localities in three regions of the Altiplano and Eastern Cordillera of central to southeastern Peru (Figure 1). They are represented mainly by faunas including pendent didymograptids of the Atlantic Faunal Realm, indicating a mid to late Darriwilian age, but younger, Sandbian, faunas are also present. The preservation of the graptolites in general is poor, as the material is invariably tectonically distorted and often preserved mainly as pressure shadow minerals with a few flakes of periderm, similar to the material recently described from NW Bolivia (Mitchell *et al*., 2008). As graptolite faunas are rare in Peru, an interpretation of their value for biostratigraphy and biogeography has to take into consideration all available information.

2.1. Contaya Region-East Peru

The northernmost record of Ordovician graptolites in Peru is from the Contaya Region, close to the border to Brazil (Figure 1), included in the Subandean belt by Suárez-Soruco (1992). The Ordovician succession of the region is poorly known and detailed sedimentological investigations do not exist. Suárez-Soruco (1992) referred the Contaya Formation to the Llanvirn, based on the known fossil record of graptolites, brachiopods and trilobites described by Hughes *et al*. (1980). Hermoza *et al.* (2005, Figure 2) provided a synthetic lithostratigraphic succession including the pre-Andean Series for the Cenozoic Huallaga Basin to the west and included all Ordovician rocks of the region as the Contaya Formation. Ordovician rocks of the region are usually strongly tectonized and faunas are not available for dating.

Newell and Tafur (1944) first discussed the Contaya fauna and provided a few illustrations of specimens identified as *Didymograptus murchisoni geminus* (Hisinger), *Didymograptus murchisoni* (Beck)?, *Glossograptus exiguus* Bulman and *Amplexograptus* cf. *A. confertus* Lapworth. Hughes *et al*. (1980) revised the fauna and identified the following species: *Didymograptus murchisoni* (Beck), *Pseudoclimacograptus* sp., *Glyptograptus* sp., *Amplexograptus* aff. *A. confertus* (Lapworth) and *Glossograptus* cf. *G. holmi* Bulman. The material is well preserved and appears not to show profound tectonic distortion (Hughes *et al*., 1980, p. 10). The age of the fauna can be confirmed to be Middle Ordovician, but it is too poor for a more precise attribution as

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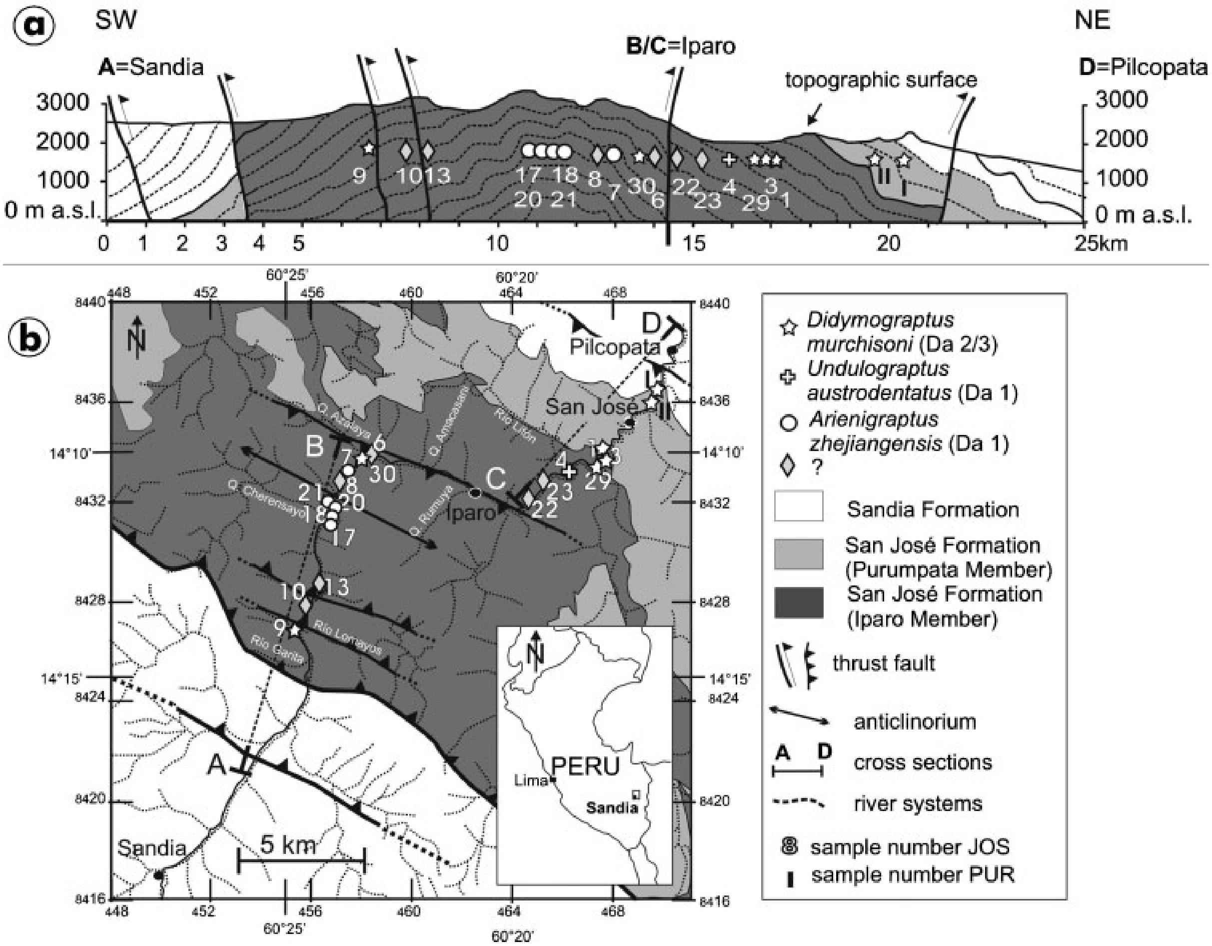

Figure 2. **a**: Profile of the Sandia Region anticline with the interfered folding and the position of the graptolite-bearing samples. **b**: Simplified geological map (after De La Cruz and Carpio, 1996) of the Sandia Region including the sample sites and the position of the profile (**a**).

index species are lacking. However, the presence of pendent didymograptids of the *D. murchisoni* type indicates a mid-Darriwilian age.

2.2. Ambo – Huánuco Region, Central Peru

Early Palaeozoic marine successions in the Ambo – Huánuco Region in the Eastern Cordillera are included in the Contaya and San José formations (Jacay *et al*., 2007). The comparison with the Contaya Formation at Contaya, however, is unclear. Only a few localities from the Ambo – Huánuco Region provided Ordovician graptolites and little is known about the detailed biostratigraphy of most of the described faunas. Steinmann (1929) provided the earliest record of graptolites from Cochachinche, referred to the Llandeilo by Bulman (1931). All faunas indicate a mid to late Darriwilian age. The most precise dating can be attained from the Huácar fauna (see below) as this is the only fauna from which biostratigraphic index species have been recorded.

2.2.1. Huácar

The graptolite fauna from Huácar was collected from a ravine, thus, no information can be given about the lithological succession and the actual faunal associations. Lemon and Cranswick (1956) suggested that the fauna may include several fossiliferous horizons. The authors provide an extensive list of species as well as good illustrations. The fauna has not been re-investigated, but from the illustrations a number of observations can be made: The frequency of pendent didymograptids associated with a few biserial graptolites and glossograptids indicate a mid Darriwilian age. The presence of *Didymograptellus bifidus* (Hall) can be excluded as this species originates from the Upper Floian or Chewtonian and the specimens are certainly misidentified. The specimens identified as *Didymograptus nitidus* (Hall) may belong to the genus *Xiphograptus*. *Isograptus caduceus*? *armatus* Ruedemann clearly is a species of the glossograptid genus *Kalpinograptus*. The genus has been recognized also in the Cordillera Real of Bolivia (Tistl, 1985; Maletz and Egenhoff, 2003). The biserials include a

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few specimens that are almost impossible to identify from the illustrations, but possibly belong to *Archiclimacograptus* and *Normalograptus* or *Hustedograptus*. The most important species for a precise biostratigraphic identification of the fauna is *Nicholsonograptus fasciculatus* (Nicholson). The species cannot be mistaken and is restricted to its own biozone in the lower Darriwilian (Maletz, 1997b). All described and illustrated species can be found in the *Nicholsonograptus fasciculatus* Biozone, thus, a single horizon or a short biostratigraphic interval may expected to be the origin of this fauna.

2.2.2. *Cochachinche*

The locality Cochachinche lies in the Ambo district, between Huánuco and Cerro de Pasco. Steinmann (1929) mentioned the graptolites from this locality, subsequently identified by Ruedemann. Bulman (1931, p. 4, 7) provided a list of the identifications: *Didymograptus serratulus* Hall, *Didymograptus sagitticaulis* Hall, *Climacograptus tubuliferus* Lapworth, *Climacograptus ruedemanni* Steinmann, *Diplograptus* cf. *foliaceous* Murchison, *Glossograptus ciliatus* Emmons, several dendroids. The material is poorly preserved, tectonically distorted and difficult to identify. The lack of pendent didymograptids in the fauna may indicate a latest Darriwilian age, but the fauna could also originate from the Sandbian. However, index species for these intervals are not present in the fauna. The lack of specimens of the genus *Dicellograptus* needs to be noted also, as this genus tends to be frequent in the latest Darriwilian and Sandbian faunas. The presence of dichograptids (*Didymograptus sagitticaulis* Gurley) makes a younger, Katian interval unlikely.

2.2.3. *Cerro Huancampa*

Díaz-Martínez *et al*. (2006) and Chacaltana *et al*. (2006) described the lithostratigraphy and biostratigraphy of the succession at Cerro Huancampa. The strata were included in the San José Formation and compared to the succession of SE Peru. Chacaltana *et al*. (2006) provided detailed biostratigraphic data of an extensive succession showing the presence of *Trichograptus*? sp., *Phyllograptus* sp., *Acrograptus* sp., *Dictyonema* sp., *Didymograptus* cf. *D. murchisoni* (Beck), *Glossograptus holmi* Bulman, *Cryptograptus schaeferi* Lapworth, *Pseudamplexograptus* cf. *confertus* (Lapworth) and *Dicellograptus salopiensis* Elles and Wood. The faunas indicate a mid- to late Darriwilian age, probably an interval from the *Didymograptus murchisoni* to the *Hustedograptus teretiusculus* Biozone, but the graptolites are not illustrated unfortunately. The presence of *Dicellograptus* is especially puzzling as the species is reported from the lowermost graptolitiferous level and is associated with *Didymograptus* cf. *D. murchisoni*. The genus *Dicellograptus* does not appear in earlier Darriwilian strata in other successions (Maletz *et al*., 2007) and a biostratigraphic overlap of pendent didymograptids and *Dicellograptus* is unusual. There is no evidence of Late Ordovician graptolitiferous strata in the region.

2.3. *SE Peru*

Graptolites are known from southeastern Peru since the first discoveries by Newton (1901) at Monte Bello and more importantly through the descriptions by Bulman (1931, 1933). Thus, a number of localities yielding Ordovician graptolites are discussed in the literature. Bulman (1931, pp. 99–100) for the first time described and illustrated the Middle to Upper Ordovician graptolites from this region in some detail, listing graptolites from five collections. Unfortunately, some of the mentioned localities cannot be recognized on available maps. Bulman (1931) also revised the material of Newton (1901) and referred the specimens to the species *Orthograptus* cf. *calcaratus acutus* Lapworth.

The graptolites range in age from Darriwilian to Sandbian. The youngest graptolites include specimens of *Nemagraptus gracilis* (Hall) and *Dicranograptus nicholsoni* Hopkinson, indicative of the *Nemagraptus gracilis* Biozone of the early Sandbian. Laubacher (1974, 1978) mentioned *Nemagraptus gracilis* from the Sandia Region, but did not provide illustrations. Martínez (1998b) quoted the presence of *Nemagraptus* sp., indicating a possible early Sandbian age for the base of the Sandia Formation. The youngest graptolites may be specimens of *Dicranograptus nicholsoni* and *Orthograptus truncatus* cf. *pauperatus* Elles and Wood (distal fragment illustrated only) from the locality Huichiyuni in the Sandia Region (Bulman, 1931).

2.3.1. *Quitari*

Bulman (1933) described the graptolites from Quitari and recognized biostratigraphically useful elements in the fauna. The presence of *Aulograptus climacograptoides* (Bulman) and other pendent didymograptids (*Didymograptus* s. str.) indicate an early to middle Darriwilian age. Younger faunal elements like *Dicellograptus* indicate also the presence of late Darriwilian to possibly Sandbian age strata in the region.

2.3.2. *Chaquimayo*

Bulman (1931) described in detail the graptolite fauna from Chaquimayo, listed first by Lapworth (1917). Brussa *et al*. (2007) recognized the presence of *Nemagraptus gracilis* at Chaquimayo, based on material from the Balston collection originally described by Bulman (1931) as *Trichograptus* (?) *balstoni*. The fauna, thus, proves the presence of a

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stratigraphical succession of mid- to late Darriwilian to Sandbian age in this locality.

2.3.3. Ollantaytambo

Egeler and De Booy (1961) discussed the Palaeozoic succession in the Cordillera Vilcabamba and referred to a few graptolite collections providing an age. The authors took the presence of *Tetragraptus quadribrachiatus* (Hall) and of 'small extensiform didymograptids' as first evidence of the presence of the Arenig (now Floian to early Darriwilian) in Peru, while other faunas from the regions were indicated to belong to the Llanvirn (late Darriwilian). Bahlburg *et al.* (2006, Figure 2) showed the Ollantaytambo Formation as of Tremadocian to early Arenigian age overlain by the Veronica and San José formations. The Ollantaytambo Formation bears no fossils and is dated by the overlying units (Marocco, 1978), from which poor graptolites are known. The fossil list of Egeler and De Booy (1961) is inconclusive, as tetragraptids of the general *Tetragraptus quadribrachiatus* Hall type (see discussion on this species in Williams and Stevens, 1988) and extensiform didymograptids (e.g. *Xiphograptus*) range into the late Darriwilian. Marocco (1978, p. 29) provided revised identifications of the graptolite material from the Veronica and San José formations (identified by I. Strachan, Birmingham). The fauna suggests a Darriwilian age based on the presence of the genera *Glossograptus* and *Cryptograptus* together with biserial graptolites identified as *Glyptograptus* cf. *dentatus* (Brongniart).

2.3.4. Umachiri

Little is known about the fossil record in the Umachiri beds (Flores and Rodriguez, 1999) in the Altiplano of SE Peru, recently discussed by Bahlburg *et al.* (2006). Cerrón and Chacaltana (2002) mentioned *Diplograptus foliaceous* from a locality west of the town of Ayaviri (Departamento de Puno), but did not illustrate the specimens. Bahlburg *et al.* (2006) interpreted the Umachiri beds as an equivalent of the Ollantaytambo Formation of the Eastern Cordillera and inferred a Middle Ordovician age based on the graptolite and trilobite fauna. Without further evidence and documentation of the graptolite fauna the age of this unit remains uncertain, especially as biserial graptolites of the general type of *Diplograptus foliaceus* are long ranging in the Late Ordovician and may easily be misidentified.

3. NEW RECORDS FROM THE SANDIA REGION

Diverse new graptolite collections were made recently (Spiske, 2005; Spiske *et al.*, 2006; Reimann *et al.*, 2006) from a number of localities in the San José Formation of the Sandia Region. The graptolite faunas indicate the presence of a fossiliferous interval spanning at least the early to mid Darriwilian time interval. Graptolites are present in the local Purumpata and Iparo members of the San José Formation (Spiske *et al.*, 2006). A detailed biostratigraphy, however, cannot be established. The faunas from the Iparo Member indicate an early Darriwilian age. The youngest faunal elements can be compared to the *Holmograptus lentus* Biozone, based on the presence of *Holmograptus bovis* Williams and Stevens in association with pendent didymograptids and *Aulograptus climacograptoides* (Bulman). The material from the Purumpata Member is extremely poor and consists of common pendent didymograptids of mid Darriwilian (Abereiddian) age, at least of *Holmograptus lentus* Biozone age or younger, but important index species are not present. The newly discovered graptolite faunas show, among a number of species well known from the Gondwanan part of South America, the first specimens of pseudisograptids recovered outside the Argentine Precordillera.

Laubacher (1974, 1978) previously reported the presence of graptolites in the Eastern Cordillera of the Sandia Region, but the material was not illustrated. De La Cruz and Carpio (1996) discovered and described the majority of graptolite localities in the Sandia Region and their faunas are basically identical to the ones in this investigation. Martínez (1998a) discussed the Ordovician graptolite faunas and provided illustrations of important species. Martínez (1998b) mentioned, but did not illustrate specimens of *Isograptus* and discussed the presence of *Didymograptus v-deflexus* Harris from the San José Formation. Gutiérrez-Marco *et al.* (2006a) referred this form to *Xiphograptus v-deflexus*, which is typical of the uppermost Dapingian to basal Darriwilian. De La Cruz and Carpio (1996) discussed the San José Formation and suggested that it spans an interval from the early Arenig (earliest Floian) to late Llanvirn (late Darriwilian). Gutiérrez-Marco and Villas (2007) reported graptolites including biserial forms, pendent didymograptids and the genus *Aulograptus* from San Gabán, where they occur above a level with palaeogeographically significant brachiopod faunas.

3.1. List of graptolites

3.1.1. Samples JOS 1–30. Iparo Member

The material derives from mostly dark grey to black mudstones of the Iparo Member, within an anticlinorium whose axis lies *ca.* 10 km NE of the village of Sandia (Figure 2).

JOS 1: *Didymograptus murchisoni*, biserial indet
JOS 3: *Didymograptus murchisoni*, *Acrograptus* sp., *Glossograptus* sp., *Cryptograptus schaeferi*

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JOS 4: *Tetragraptus* sp., *Holmograptus bovis*, *Undulograptus austrodentatus*
JOS 6: *Holmograptus bovis*, *Etagraptus harti*, ?*Pseudotrigonograptus ensiformis*, *Acrograptus* sp.
JOS 7: *Aulograptus climacograptoides*, *Tetragraptus* sp., *Laxograptus* sp., ?*Xiphograptus* sp., ?*Arienigraptus* sp.
JOS 8: *Xiphograptus* sp. cf. *X. robustus* (Ekström)
JOS 9: *Didymograptus murchisoni* type, *Aulograptus climacograptoides*, *Glossograptus* sp., biserial indet.
JOS 10: *Glossograptus* sp.
JOS 13: *Holmograptus bovis*, *Xiphograptus* sp.
JOS 17: *Holmograptus bovis*, *Etagraptus harti*, *Glossograptus* sp., *Isograptus* sp., *Arienigraptus* sp.
JOS 18: *Tetragraptus* sp., *Etagraptus harti*, *Acrograptus* sp., *Anomalograptus reliquus* T. S. Clark, *Holmograptus bovis*, *Arienigraptus zhejiangensis* Yu & Fang, *Isograptus* sp.
JOS 20: *Aulograptus climacograptoides*, *Laxograptus* sp., *Holmograptus* sp., *Xiphograptus lofuensis* Lee, *Anomalograptus* sp., ?*Arienigraptus zhejiangensis*
JOS 21: *Arienigraptus zhejiangensis*
JOS 22: *Holmograptus bovis*
JOS 23: *Anomalograptus reliquus*, *Holmograptus* sp., dichograptid stipe fragments
JOS 29: *Cryptograptus schaeferi*
JOS 30: *Didymograptus murchisoni*

3.1.2. Samples PUR 1–2

Purumpata Member. The material come from the NE side of the anticline, at the top of the Purumpata Member, close to the contact with the overlying Sandia Formation. The samples include poorly preserved specimens of *Didymograptus artus* type associated with *Cryptograptus* sp. and *Glossograptus* sp. None of the faunal elements are useful for a precise dating of the samples.

3.1.3. Lithostratigraphy of the Sandia Region

The sedimentary rocks of the Sandia Region can be divided into the San José Formation and the conformably overlying Sandia Formation. A further subdivision of the San José Formation is controversial. While the geological map and description of Urubamba and Calca (Carlotto *et al*., 1996) refers to the original definition of Laubacher (1974, 1978) without subdivisions of the San José Formation, the Sandia and San Ignacio map and description (De La Cruz and Carpio, 1996) uses the term San José Group which is subdivided into the Iparo and Purumpata formations. In our study we refer to the San José Formation, which is subdivided into the lower Iparo and upper Purumpata members. The slight difference in lithology between the subunits only justifies a subdivision into different members, not into different formations.

The overall thickness of the Iparo Member is estimated as 2880 m (De La Cruz and Carpio, 1996) and 2110 m (Martínez 1998a). In the Sandia Region, the rocks are strongly folded and a probable stratigraphic repetition has not been considered by the mentioned authors in their thickness estimates. Thicknesses may consequently be exaggerated, but cannot be tested because only the upper part of the Iparo Member is exposed in the Sandia Region. The Iparo Member consists mostly of dark grey to black mudstones containing the graptolite faunas presented in this contribution (Figure 3). Whereas quartz-sandstone beds

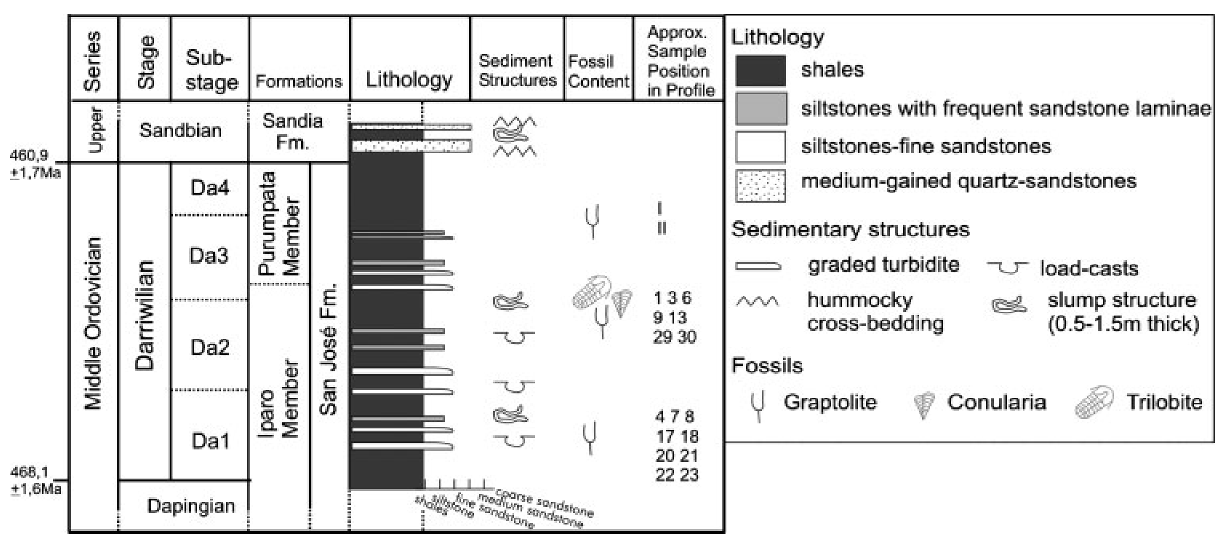

Figure 3. Lithostratigraphy of the Iparo and Purumpata members in the Sandia Region including sedimentary structures and approximate sample position in the profile.

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occur at the base of the Iparo Member in the Calca Region (Carlotto *et al*., 1996), these are not found in the Sandia Region. Fine silt laminations (0.5 cm, rarely 5 cm) or flattened silt lenses occur in the middle and upper part of the Iparo Member (Reimann *et al*., 2006; Spiske *et al*., 2006). Alongside with thin Bouma Tc ripple 'cross-laminations', these can be interpreted as incomplete fine-grained turbidites. Rare slumping-units indicate either an occasionally high sediment input and resulting slope instability, or may have been triggered by earthquakes. Diagenetic pyrite in the form of cubic crystals (max. 1 cm), concretions or pyrite discs is common.

The transition to the Purumpata Member is gradual and marked by a decrease in grain size. The Purumpata Member has an estimated thickness of 1800 m (Martínez 1998a), again this value may be exaggerated. The succession consists of strongly weathered mudstones with a bleached grey colour. Few small silt-lenses occur but the dominant lithology is shale. The Purumpata Member is conformably overlain by the Sandia Formation which consists predominatly of quartz-sandstone beds.

The sedimentary rocks described above are subject to tight folding and lie within an anticlinorium (Figure 2). Within this anticlinorium at least two fold structures of lower order can be recognized. All fold axes are aligned in NW-SE direction. In addition, some fault planes verge towards the NE on the southern flank of the anticlinorium and towards the SE on the northern flank. This fault alignment allows the deeper stratigraphic layers around the nucleus to be exposed. The sedimentary rocks underwent a low-grade metamorphism which together with the folding took place during the Eohercynian tectonic phase (340–330 Ma: Laubacher, 1978; Cobbing, 1985).

3.1.4. Biostratigraphy

One of the major difficulties in unravelling the Ordovician succession in southern Peru is the extreme thickness of most sections, large outcrop areas, but extremely poor fossil record (Gutiérrez-Marco *et al*., 2006a). Therefore, biostratigraphic range charts exist for very few sections, a notable exception being the Cerro Huancampa section described by Chacaltana *et al*. (2006). Gutiérrez-Marco and Villas (2007) provided detailed biostratigraphic data for the Carcel Puncco section *ca.* 20 km NW of the town of San Gabán, based on the presence of conodonts, brachiopods and a few graptolites. The succession probably starts in the Floian. Conodonts from *ca.* 100 m above the local base of the San José Formation indicate the *Oepikodus evae* conodont Zone of late Floian age (Gutiérrez-Marco and Villas, 2007; Gutiérrez-Marco *et al*., 2008). Graptolites from a level *ca.* 30–60 m higher up already include *Aulograptus*, pendent didymograptids of the genus *Didymograptus* s. str. and indeterminable biserials and may be referred to the mid Darriwilian. There is no information on Dapingian to lower Darriwilian faunas available from the section and this interval might be strongly condensed. The base of the San José Formation in the section is not tightly constrained, but might be within the Floian Stage, even though there is no biostratigraphic control based on graptolites faunas for this level (Figure 4).

New graptolite faunas from the Sandia Region (Figures 5 and 6) invariably are of Darriwilian age and no evidence is

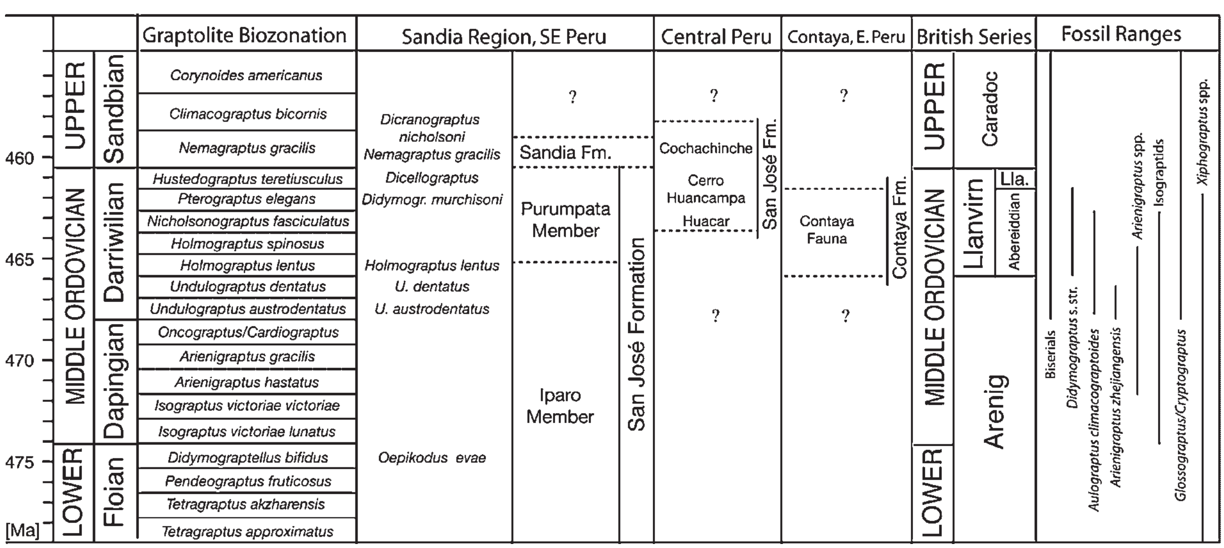

Figure 4. Lithostratigraphy and graptolite biostratigraphy in Peru, showing general ranges of important species and genera on the right. Origin of data is discussed in detail in the text. Column 'British Series' also shows the correlation with the international Lower, Middle and Upper Ordovician Series for easier correlation; Lla. = Llandelian.

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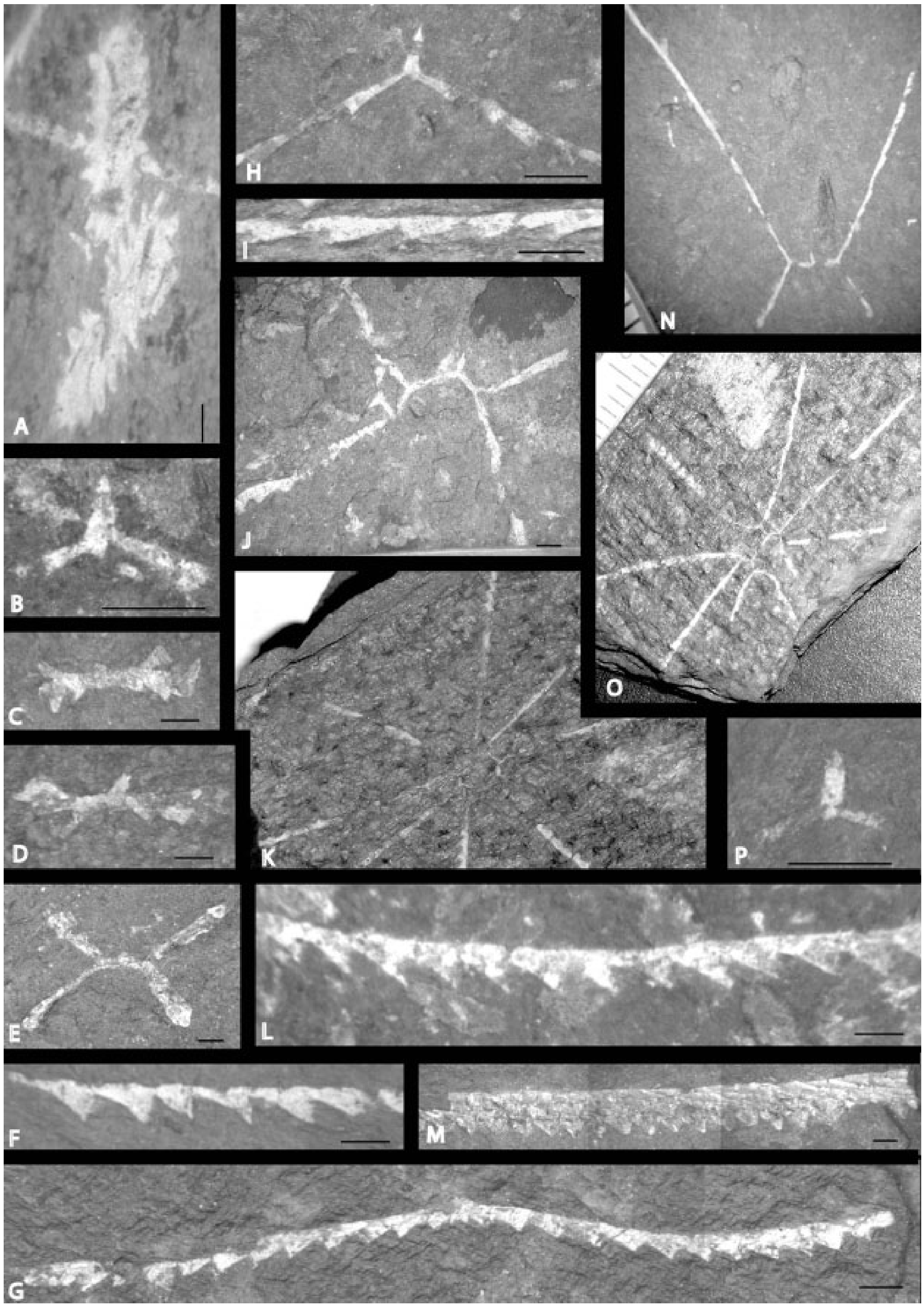

Figure 5. *Pseudotrigonograptus ensiformis* (J. Hall). **A**: JOS 6.2; *Acrograptus* sp. **B**, **F**, **L**: Proximal end and distal stipe fragments, JOS 18.1, JOS 6.3, JOS 18.1; *Tetragraptus* sp. **C**, **D**, **E**: JOS 7.4a, JOS 7.4b, JOS 18.5; *Xiphograptus lofuensis* (Lee), **G**: JOS 20.3; ?*Xiphograptus* sp. **M**: JOS 7.8, stipe fragment; *Holmograptus bovis* Williams and Stevens. **H**, **I**, **P**: JOS 13.1, proximal end of long specimen; JOS 6.2, stipe fragment showing thecal style; JOS 6.5b1, proximal end showing sicula shape; *Etagraptus harti* (Hall). **J**, **N**: JOS 18.7, proximal end; JOS 6.5; *Anomalograptus reliquus* (Clarke). **K**, **O**: JOS 18.2, JOS 18.4. A black bar indicates the distance of 1 mm in each photograph.

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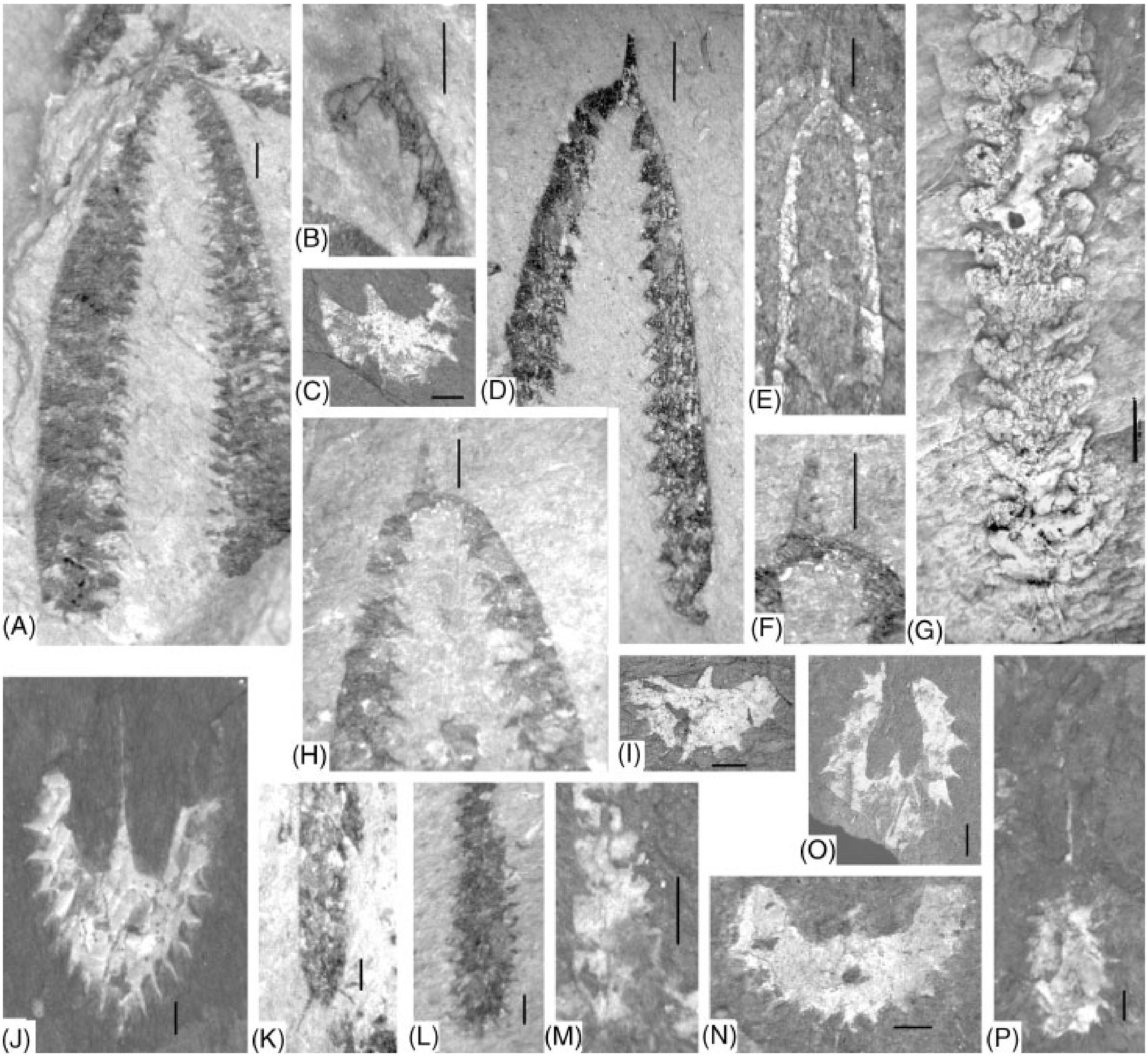

Figure 6. *Didymograptus murchisoni* (Beck) type **A**: PUR 2.4, large specimen with incomplete proximal end; **B**: JOS 3.4, juvenile, possible isograptid type development; **D**: JOS 1.2, slender specimen; **F**, **H**: JOS 3.4b, proximal end in low relief, possibly isograptid type development. *Isograptus* sp. **C**: JOS 17.4; **I**: JOS 18.8. *Aulograptus climacograptoides* (Bulman), **E**: JOS 7.1; *Undulograptus austrodentatus* (Harris and Keble); **G**: JOS 4.2, latex cast of specimen; *Arienigraptus zhejiangensis* Yu and Fang; **J**: JOS 21.1, specimen with distinct horizontal manubrium shoulders; **N**: JOS 21.2; **O**: JOS 18.6; *Cryptograptus schaeferi* (Lapworth); **K**: JOS 3.7; **L**: JOS 29.2; Biserial indet. **M**: JOS 09.1, poor flattened specimen; *Glossograptus* sp. **P**: JOS 10.2, juvenile with long nema. A black bar indicates the distance of 1 mm in each photograph.

present of older graptolite faunas. However, De La Cruz and Carpio (1996) mention the presence of *Tetragraptus approximatus* Nicholson in the Iparo Member, indicating an early Ordovician (basal Floian) age for part of this unit. The illustrated specimen (De La Cruz and Carpio, 1996: pl. 4, Figure 2), however, represents two overlapping distal dichograptid stipes with the thecae running in the same direction. They originate from a place roughly equivalent to the present locality JOS 4 (close to the Azalaya tributary river), from beds clearly younger than Lower Ordovician. The palaeontological data do not provide enough information to establish a biozonation for the San Jose Formation. Thus, local graptolite biohorizons (Figure 4) are recognized by assemblage and boundaries between units are not established.

A number of faunas from the Sandia Region do not bear pendent didymograptids and may be of the earliest Darriwilian age. In these cases, isograptids and pseudisograptids can provide a more precise date. *Arienigraptus zhejiangensis* ranges from the base of the Darriwilian (Mitchell and Maletz, 1995; Maletz, 1997a, 2005) through the *Undulograptus austrodentatus* and the lower part of the *Undulograptus dentatus* biozones. The species is present in a number of specimens showing the subhorizontal manu-

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brium shoulders clearly. Other specimens do not show the manubrium shoulders and may be included in *Arienigraptus angulatus* Mu, Geh and Yin or represent juvenile isograptids. Unfortunately, a differentiation is impossible for some of the strongly tectonized specimens. This material could indicate the *Undulograptus dentatus* Biozone. A single specimen of *Undulograptus austrodentatus* was found in sample JOS 4 (Figure 6G) and supports the identification of the *Undulograptus austrodentatus* Biozone. The presence of a fauna of multiramous to two-stiped dichograptids or sigmagraptines including *Holmograptus bovis*, *Etagraptus harti* and *Anomalograptus reliquus* indicates again an early Darriwilian age, as these faunal elements do not reach the middle to late Darriwilian.

The presence of pendent didymograptids of the *Didymograptus murchisoni* type and *Aulograptus climacograptoides* in the Sandia faunas indicates a mid-Darriwilian age for part of the succession. Pendent didymograptids have fairly long range through most of the Darriwilian. Maletz (1997a) indicated that their first occurrence is correlatable with the base of the *Holmograptus lentus* Biozone. *Aulograptus climacograptoides* originates earlier, probably in the *Undulograptus austrodentatus* Biozone, and ranges to the top of the *Nicholsonograptus fasciculatus* Biozone (Maletz, 1997b). The co-occurrence of pendent didymograptids with *Aulograptus* (JOS 9), thus, indicates the presence of faunas from the *Holmograptus lentus* Biozone and provide an upper limit for the age of the investigated faunas.

Younger faunas have not been found during this investigation and biostratigraphic information (Figure 4) is taken from previously published data, especially from Bulman (1931) and Laubacher (1974, 1978). The presence of Sandbian faunas was verified by the identification of *Nemagraptus gracilis* (Brussa *et al*., 2007) in the Balston collection from Chaquimayo.

4. BIOGEOGRAPHY

Maletz and Ortega (1995) discussed for the first time the biogeographic implications of Ordovician graptolite faunas in South America and showed the pronounced differences between Gondwanan type and Precordilleran type graptolite faunas. The biogeographic faunal differentiation of South America has been discussed more frequently in later years (see Toro and Brussa, 2003 for a review), but an assessment of the poor Peruvian faunas is still lacking. Gutiérrez-Marco *et al*. (2006a) discussed the affinities of benthic faunas of southern Peru, trilobites and brachiopods mainly, and showed relationships to eastern Avalonia and Gondwana, based on shared faunal elements. The authors also referred the planktic graptolite faunas to the Atlantic Faunal Realm.

The graptolite faunas of the Sandia Region typically show the faunal relationships expressed through the presence of common pendent didymograptids of the *Didymograptus murchisoni* type and the genus *Aulograptus*, forms that are restricted to the Atlantic Faunal Realm (Maletz, 1997b). Unfortunately, these forms have a long biostratigraphic range and are not useful for a detailed biostratigraphic analysis. Many other faunal elements are widely distributed and may be helpful in a precise biostratigraphic correlation and understanding of biogeographical relationships.

Faunal elements of more interest are pseudisograptids (*Arienigraptus*), isograptids and *Holmograptus bovis*. The isograptids and pseudisograptids are generally referred to the Pacific Faunal Realm (Cooper *et al*., 1991). Originally, Fortey (1984) and Fortey and Cocks (1986) used the distribution of isograptids in the Middle Ordovician for palaeogeographic interpretations based on their affiliation with deeper water faunas and a more basinal distribution. The authors described the isograptid biofacies to represent the pandemic, cosmopolitan graptolite faunas of the Middle Ordovician and used them to trace continental outlines.

Isograptids have rarely been described from Gondwanan South America, but are common in the Argentine Precordillera. Toro and Brussa (2003) discussed the biogeographic relationship of Argentinian Ordovician successions in which graptolites were found. They quoted the presence of upper Arenigian (upper Dapingian) to lower Darriwilian isograptids in the Argentine Precordillera. The presence of isograptids in various regions of Gondwanan South America (Turner, 1960; Bahlburg *et al*., 1990; Maletz and Egenhoff, 2003; Egenhoff *et al*., 2004; Gutiérrez-Marco *et al*., 2006b; Mitchell *et al*., 2008) supports their identification as pandemic faunal elements and questioning their affiliation with the Pacific Faunal Realm graptolite faunas. Based on the precise biostratigraphy of Middle Ordovician graptolite faunas, in particular on successive ranges of isograptid species (Cooper, 1973; Cooper and Ni, 1986; Williams and Stevens, 1988; Vandenberg and Cooper, 1992), this group of pandemic graptolites can be used easily if associated with endemic faunal elements to date and correlate these. Therefore, the presence of isograptids and pseudisograptids is an important aspect of the faunal association in the Sandia Region.

5. TAXONOMIC NOTES

Notes are given here for important species and illustrated material. Most of the graptolite material is poorly preserved and shows considerable tectonic distortion. Thus, internal

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details and rhabdosome development structures have not been recognized. The graptolites generally consist of fractured periderm (organic material) surrounded by a variable amount of pressure shadow minerals (see Underwood, 1992; Underwood and Bottrell, 1994; Mitchell *et al*., 2008). The material is not well enough preserved for a detailed taxonomic analysis.

5.1. Family Dichograptidae Lapworth 1873

5.1.1. Pseudotrigonograptus ensiformis (Hall, 1865)

The material consists of a few poorly preserved specimens showing the elongated rhabdosome shape of *Pseudotrigonograptus* with the development of possibly four rows of thecae (Figure 5A). Alternatively, the specimens may represent phyllograptids of the genus *Pseudophyllograptus*. They do not show indication of the dorsal virgella of *Phyllograptus* and do not possess a distal nema. *Pseudotrigonograptus ensiformis* first appears in the Lower Dapingian (Lower Castlemainian: Maletz, 2005) and ranges into the Lower Darriwilian (Williams and Stevens, 1988).

5.1.2. Tetragraptus sp.

A few juvenile specimens are here identified as *Tetragraptus* sp. (Figure 5C–E). The material is specifically indeterminable. All specimens show a tetragraptid rhabdosome with short, possibly reclined stipes, reminiscent of *Tetragraptus bigsbyi* (J. Hall) or similar forms, but a specific identification is impossible. *Tetragraptus* specimens occur from the Lower Ordovician (Lower Floian) to the Middle Ordovician (Middle Darriwilian). There are numerous species described, but juveniles are often impossible to identify to the species level.

5.1.3. Didymograptus murchisoni (Beck, 1839)

Pendent didymograptids of the *D. artus* or *D. murchisoni* type are common at a number of levels. Many of the collected specimens show fairly wide stipes (Figure 6A, B, D, F, H) and may be referred to *D. murchisoni*. However, Maletz (1997b) considered the differentiation of *D. murchisoni* and *D. artus* to be difficult, especially in tectonically distorted material. A few specimens may indicate an isograptid type development in low relief (Figure 6F, H). They may belong to *Didymograptus* (*Jenkinsograptus*) *spinulosus*, one of the earliest species of the group (Gutiérrez-Marco, 1986; Fortey and Owens, 1987). The pendent didymograptids of the genus *Didymograptus* s. str. appear at the base of the Abereiddian *Didymograptus artus* Biozone or approximately at the base of the *Holmograptus lentus* Biozone (Fortey *et al*., 1990; Maletz 1997a) and range to the base of the *Hustedograptus teretiusculus* Biozone (Maletz, 1997b). Pendent didymograptids define the base and the top of the Abereiddian Stage of the British Ordovician System (Fortey *et al*., 1990, 1995, 2000) and are typical for this interval anywhere in the Atlantic Faunal Realm (Fortey and Owens, 1987; Maletz, 1994).

5.1.4. Aulograptus climacograptoides (Bulman, 1931)

The specimens (Figure 6E) are easily identified through their slender, pendent form with the conspicuous 'climacograptid-like' thecal apertures. Maletz (1997b) synonymized *Aulograptus cucullus* (Bulman, 1933) with *Aulograptus climacograptoides* (Bulman, 1931) and concluded that the type material of both differs only through the tectonic deformation of the latter. The species has been recognized frequently in Gondwanan South America (Bulman, 1931; Loss, 1953; Gutiérrez-Marco *et al*., 1996; Gutiérrez-Marco and Villas, 2007), but is not present in the Argentine Precordillera. It ranges from the *Undulograptus austrodentatus* Biozone to the top of the *Nicholsonograptus fasciculatus* Biozone (Maletz, 1997b). Rushton (in Cooper *et al*., 2004), however, kept *Aulograptus climacograptoides* and *Aulograptus cucullus* as separate species. While *Aulograptus climacograptoides* is found in the *Isograptus gibberulus* zone of the Skiddaw Slates, *Aulograptus cucullus* is regarded as the index species of the overlying graptolite zone.

5.1.5. Xiphograptus spp.

Specimens of the genus *Xiphograptus* are common Middle Ordovician faunal elements (Williams and Stevens, 1988). The oldest species comes from the *Pendeograptus fruticosus* Biozone of western Newfoundland (Maletz, 1998). A few poorly preserved, relatively wide stipe fragments from the Sandia Region may belong to the mid-Darriwilian species *Xiphograptus robustus* (Figure 5M). The material is complemented with a single proximal end showing the dorsal virgella typical of the genus *Xiphograptus*. Maletz (1997b) described Scandinavian specimens of the species showing the proximal end in full relief. *X. robustus* is widely distributed in the middle Darriwilian, but most specimens are fragmentary and good proximal ends are rare. Older species of *Xiphograptus* are more slender and most specimens are here included with *Xiphograptus lofuensis* (Figure 5G), a horizontal to slightly declined or deflexed form (Lee, 1961; Ni, 1991).

5.2. Family Sigmagraptidae Cooper and Fortey 1982

5.2.1. Acrograptus sp. (Figure 5B, F, L)

A few small specimens and stipe fragments are here referred to *Acrograptus* sp. The proximal ends show a conspicuous asymmetry in origin for the first thecae in contrary to

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specimens of *Holmograptus* sp. (Figure 5P). The specimens are specifically indeterminate. The material assembled here under this name may belong to a number of slender sigmagraptine species, but the material is too poor for a further taxonomic treatment.

5.2.2. *Laxograptus sp. (not illustrated)*

A single slender specimen with a 4 mm long funicle and four distal stipes is present in JOS 20. The preservation is very poor and not even the thecal style can be observed. The genus *Laxograptus* is well known from the Dapingian, lower Middle Ordovician (Cooper and Fortey, 1982), but may range into the Darriwilian.

5.2.3. *Etagraptus harti (Hall, 1914)*

Several specimens (Figure 5J, N) are present in the sample. Little detail on their rhabdosome structure is recognizable. The specimens are referred to *E. harti* due to the slender rhabdosome only. The type material of *E. harti* comes from the Bendigonian of Australia (Hall, 1914) and, thus, is considerably older than the Peruvian material. Alternatively the material may be referred to the genus *Allograptus*.

5.3. *Subfamily Sinograptinae Mu, 1957*

5.3.1. *Holmograptus bovis Williams and Stevens 1988 (Figure 5H, I)*

Williams and Stevens (1988) differentiated this species from the similar, but more complex *Holmograptus lentus* (=*H. callotheca*). The species is widely distributed in the lower Darriwilian *Undulograptus austrodentatus* to *Undulograptus dentatus* biozones (Maletz 1997a). A few slabs are crowded with stipes fragments belonging to this species, otherwise represented by a number of small proximal ends. The species is more slender and delicate than material described from the Quitari Region by Bulman (1933) as *Didymograptus euodus*.

5.3.2. *Anomalograptus reliquus (Clarke, 1924) (Figure 5K, O)*

The genus *Anomalograptus* includes a number of sinograptid species with a multiramous rhabdosome and a variable number of stipes, restricted to the lower Darriwilian. The thecae show comparatively low inclination and overlap and cannot be referred to the much older, Floian to Dapingian, genera *Dichograptus* or *Loganograptus* (Maletz 1997a). Maletz (1997a) illustrated well-preserved specimens from the lower Darriwilian (Da 1–2) of Levis, Quebec. Bulman (1931) described under the names *Dichograptus octobrachiatus* var. and *Loganograptus logani* var. *boliviensis* material, that might be identical to the Peruvian material. Bulman's specimens come from the 'Llanvirn' of Korpa, Bolivia.

5.4. *Family Glossograptidae Lapworth 1873 (emend. Maletz and Mitchell, 1996)*

5.4.1. *Isograptus sp. (Figure 6C, I)*

A few juvenile specimens of possible isograptids are present in the collection. Even though distorted, they show an isograptid symmetry, but there is no evidence of a manubrium structure. Thus, they do not appear to belong to the genus *Arienigraptus*. Very few isograptids are still present in the lower Darriwilian, but it is still impossible to assign the specimens here identified to any of these. Mitchell *et al*. (2008) described a Darriwilian graptolite fauna from NW Bolivia yielding pendent didymograptids associated with *Parisograptus caduceus*. Their fauna is comparable in age to the Peruvian faunas discussed herein. It does not, however, bear any specimens of *Arienigraptus*, but includes a variety of biserial graptolites.

5.4.2. *Glossograptus sp. (Figure 6P)*

Glossograptus specimens are not uncommon in the collections, but mostly poorly preserved and do not show much detail. One juvenile specimen bears a long nema (Figure 6P), easily differentiating it from superficially similar phyllograptids. The genus *Glossograptus* appears at the base of the Darriwilian and ranges into the Upper Ordovician (Sandbian, *Nemagraptus gracilis* Biozone), thus, does not offer any information on the age of the succession.

5.4.3. *Cryptograptus schaeferi (Lapworth, 1873)*

The species is easily recognized by its paired proximal end spines (Figure 5K, L). *Cryptograptus schaeferi* is a common species in many Middle Ordovician successions and has been described from isolated flattened specimens from the Table Head Group of western Newfoundland (Maletz and Mitchell, 1996).

5.4.4. *Arienigraptus zhejiangensis Yu and Fang, 1981*

A number of specimens of *Arienigraptus* are present in the collections. The material is here referred to *Arienigraptus zhejiangensis*, even though it is poorly preserved. Most of the specimens show a distinct horizontal manubrium (Figure 6J, N. O), typical of the species. *Arienigraptus zhejiangensis* is the index species of the lower subzone of the *Undulograptus austrodentatus* Biozone (Mitchell and Maletz, 1995), but ranges into the lower *Undulograptus dentatus* Biozone (Maletz 1997a). The lower Darriwilian includes a number of *Arienigraptus* species (Maletz, 2005) and a differentiation is difficult due to the tectonic

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deformation of the Peruvian material. Thus, there might be more than one species included under this name.

5.5. Order Diplograptacea Lapworth 1873

Biserial graptolites (Figures 5G and Figure 6M) are extremely rare in the collections. The material consists of a few distal rhabdosome fragments showing thecae with a rounded geniculum and a nearly horizontal aperture (Figure 6M). The material could be referred to *Hustedograptus*, *Eoglyptograptus* or *Normalograptus*. Bulman (1931, 1933) described a number of biserial graptolites from SE Peru, associated with pendent didymograptids.

Undulograptus austrodentatus (Harris and Keble, 1932) was found in a single, poorly preserved relief specimen (Figure 6G). The identification is based on the outline of the rhabdosome and its dimensions. Structural details are not available. The proximal end is very symmetrical with nearly horizontal growth of the first thecal pair. The proximal end bears a robust, short virgella and apertural spines on the first thecal pair. The rhabdosome is about 1.8–1.9 m wide and is nearly parallel-sided. The thecal density appears to be affected by tectonic deformation shortening the rhabdosome. *Undulograptus austrodentatus* is the index species of the basal Darriwilian biozone (Mitchell and Maletz, 1995; Mitchell *et al*., 1997) and, therefore, the record is of high importance for dating the succession.

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