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MIDDLE DARRIWILIAN CONODONT ZONES IN THE UPPERMOST SAN JUAN LIMESTONE AND THE LOWER MEMBER OF THE LAS AGUADITAS FORMATION, CENTRAL PRECORDILLERA OF SAN JUAN, ARGENTINA

FELTES, N. [1], ALBANESI, G. L. [1, 2] AND BERGSTRÖM, S. M. [3]

[1] CONICET, Museo de Paleontología, CIGEA FCEFyN, UNC, Av. Vélez Sarsfield 299, Córdoba X5000FCO, Argentina; *nicofeltes@gmail.com; galbanesi@arnet.com.ar*
[2] CICTERRA - CONICET, Córdoba, Argentina.
[3] School of Earth Sciences, Division of Historical Geology, The Ohio State University, 125 South Oval Mall, Columbus, OH 43210, USA; *stig@geology.ohio-state.edu*

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THE geological province of Precordillera is located in western Argentina. It extends 450 km meridionally and 110 km from east to west (Fig. 1) (Furque and Cuerda, 1979). The Lower Paleozoic stratigraphy is characterized by a thick succession of Cambro-Ordovician limestones, which were deposited in platform environments and interdigitate with clastic slope deposits toward the west (Keller *et al.*, 1993; Astini, 1995).

Our study unit is the Las Aguaditas Formation at its type section, which is located on the eastern flank of the Los Blanquitos Range, 15 km to the southwest of Jachal City, in the Central Precordillera of San Juan Province (Keller *et al.*, 1993). This formation consists of marls, limestones, and reef limestones. It is characterized by a yellowish weathering color that makes it easily separable from the underlying San Juan Formation (Baldis *et al.*, 1982), whose upper part consists of nodular limestones. The Las Aguaditas Formation is 285 m thick at our study locality and ranges in age from the middle Darriwilian to the early Sandbian (Keller *et al.*, 1993).

The Las Aguaditas Formation was originally described by Baldis and Blasco (1974). These authors recognized four members (a 54 m thick lower member; an 110 m thick slaty member; a 40 m thick lower member; and an 80 m thick upper member). In the type section, the Las Aguaditas Formation paraconformably overlies the San Juan Formation, with the contact marked by a regional hardground surface (Astini, 1995). Albanesi *et al.* (1998) reviewed the biostratigraphic dating of the top part of the San Juan Formation in the Las Aguaditas creek section, and referred this interval to the middle Darriwilian. The lower member of the Las Aguaditas Formation correlates with the Las Chacritas Formation (Serra *et al.*, 2011), the lower member of the Los Azules Formation (Ortega *et al.*, 2007), and the lower member of the Gualcamayo Formation in the central area of the Precordillera (Albanesi *et al.*, 1998; Astini, 1995), *i.e.* in the outcrops between the San Juan and the Jachal rivers.

In the Las Aguaditas creek section, Albanesi *et al.* (1998a) identified the Lenodus variabilis conodont zone in the upper part of the San Juan Formation. More recently, Serra *et al.* (2011) recognized the index species *Yangtzeplacognathus crassus* in the contact interval between the San Juan Formation and the Las Aguaditas and Las Chacritas formations.

The present contribution presents a high resolution conodont biostratigraphy for the upper parts of the San Juan Formation and the lower member of the Las Aguaditas Formation in order to establish its precise age.

MATERIAL AND METHODS

A collection of 38 samples for conodonts (*ca.* 1.2 kg each) from the top part of the San Juan Formation and the lower member of the Las Aguaditas Formation (Fig. 2) was digested using conventional acid etching techniques, and 2290 identifiable conodont elements were recovered. The conodont collections are stored in the Museo de Paleontología, FCEFyN, UNC, under repository codes CORD-MP.

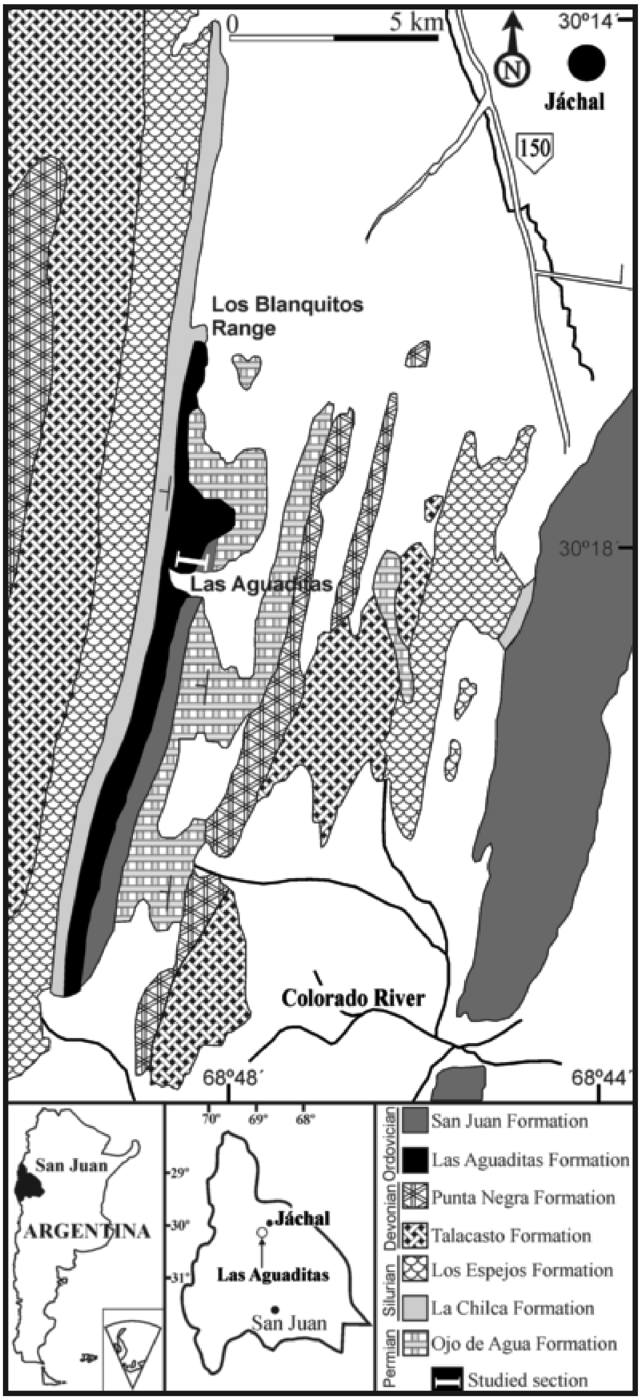

Figure 1. Location map of the Las Aguaditas creek at the Precordillera of San Juan, Argentina.

BIOSTRATIGRAPHY

The first formal conodont biostratigraphic scheme for the middle Darriwilian of the Precordillera included the *Lenodus variabilis* Zone, with the *Periodon gladysae* and Paroistodus horridus subzones, and the *Eoplacognathus suecicus* Zone, with the *Histiodella kristinae* and *Pygodus anitae* subzones (Albanesi *et al.*, 1998). Based on the recovery of key zonal species this original scheme has been gradually revised in successive contributions and the current scheme is shown in Fig. 3. The presence in the Precordillera of important conodont species known also from the Baltic Region, Laurentia and South China now makes it possible to establish accurate long-distance correlations (Fig. 3).

Yangtzeplacognathus crassus Zone

In this study the base of the middle Darriwilian conodont zonation begins with the FAD of *Y. crassus*, which is identified in our stratigraphic lowest sample, which was collected from the upper part of the San Juan Formation, 4.2 m below the contact with the overlying Las Aguaditas Formation. The upper boundary of the the *Y. crassus* Zone is defined by the FAD of *Dzikodus tablepointensis* and *Eoplacognathus pseudoplanus* at 10.1 m and 14.7 m respectively, above the base of the Las Aguaditas Formation. The *Y. crassus* Zone is 14.3 m thick in the studied section.

This *Y. crassus* Zone is characterized by the presence of several species associated with the index species, such as *Ansella jemtlandica, Drepanoistodus basiovalis, D. bellburnensis, Fahraeusodus marathonensis, Histiodella holodentata, Parapaltodus simplicissimus, Paroistodus horridus, Periodon macrodentatus*, and *Protopanderodus gradatus*. Other species, such as *Cornuodus longibasis, Costiconus costatus, Drepanodus arcuatus, D. reclinatus, Drepanoistodus costatus, Erraticodon alternans, Paroistodus originalis, Rossodus barnesi,* and *Semiacontiodus potrerillensis*, are present but are less abundant.

The biostratigraphic chart for the Argentine Precordillera, which was based on conodonts and graptolites and published by Albanesi and Ortega (2002), follows the previously cited succession of zones proposed by Albanesi *et al.* (1998a). Heredia *et al.* (2005; 2011) introduced an alternative scheme based on the identification of the zone index species *Eoplacognathus pseudoplanus* and *Dzikodus tablepointensis* in the top part of the San Juan Formation and the basal part of the overlying Las Chacritas Formation at the La Trampa Range. Serra *et al.* (2011) identified the zone index species *Y. crassus* in the uppermost part of the San Juan Formation in the sections at the Las Aguaditas creek and at the La Trampa Range. The index species *Dzikodus tablepointensis* was identified by us also in the middle part of the lower member of the Las Aguaditas Formation and *E. pseudoplanus* was recorded in younger strata.

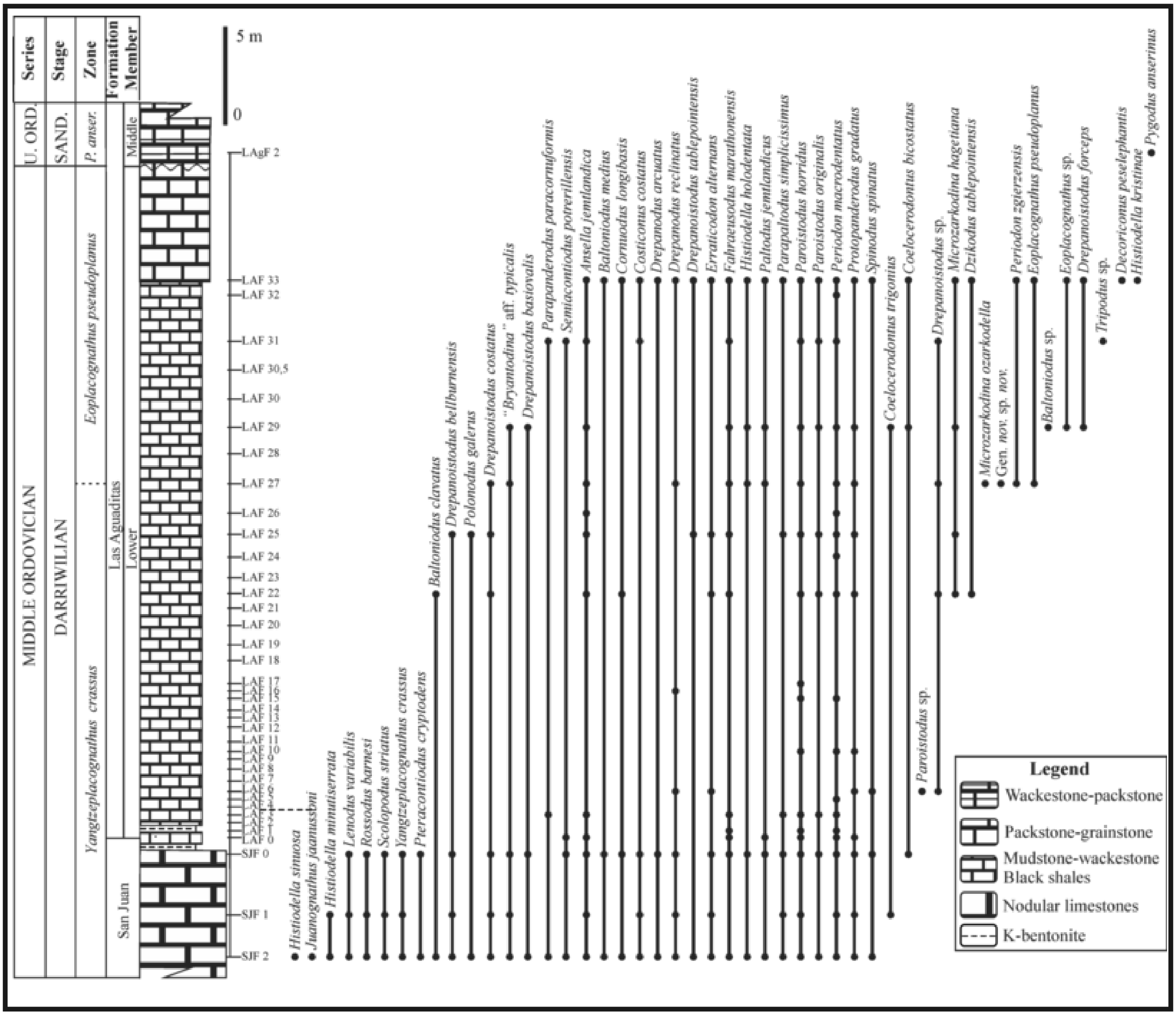

Figure 2. Stratigraphic column of the Las Aguaditas study section and ranges of conodont species.

A K-bentonite bed from the lower part of the Los Azules Formation at Cerro Viejo de Huaco, which was dated at 461 + 7/-10 Ma (Huff *et al.*, 1995), is in the *Yangtzeplacognathus crassus* Zone. This record of the index conodont *Y. crassus* indicates that the contact between the San Juan Formation and the overlying units in the central area of the Precordillera, such as the Las Aguaditas, Las Chacritas, Gualcamayo, and Los Azules formations (Serra *et al.*, 2011) are synchronous.

The presence of the index species *Y. crassus*, along with other similarities in the conodont species successions between the Precordillera and the Baltic region (Mellgren and Eriksson, 2009), form a basis for a precise trans-Atlantic correlation of this zone.

***Eoplacognathus pseudoplanus* Zone**

The platform-bearing index taxa *Eoplacognathus pseudoplanus* and *Dzikodus tablepointensis* were identified in the middle part of the lower member of the Las Aguaditas Formation. Although the elements of these species are not abundant in the study section, they do occur associated at one level (LAF 33), and are useful for global correlation. *D. tablepointensis* first appears in the succession in sample LAF 22, which was collected 10.1 m above the base of the formation, whereas *E. pseudoplanus* makes its entrance in younger strata in sample LAF 27, which was collected 14.7 m above the base of the formation. *Dzikodus* was more common in deeper water environments (Pyle and Barnes, 2002), such as those in south-central China

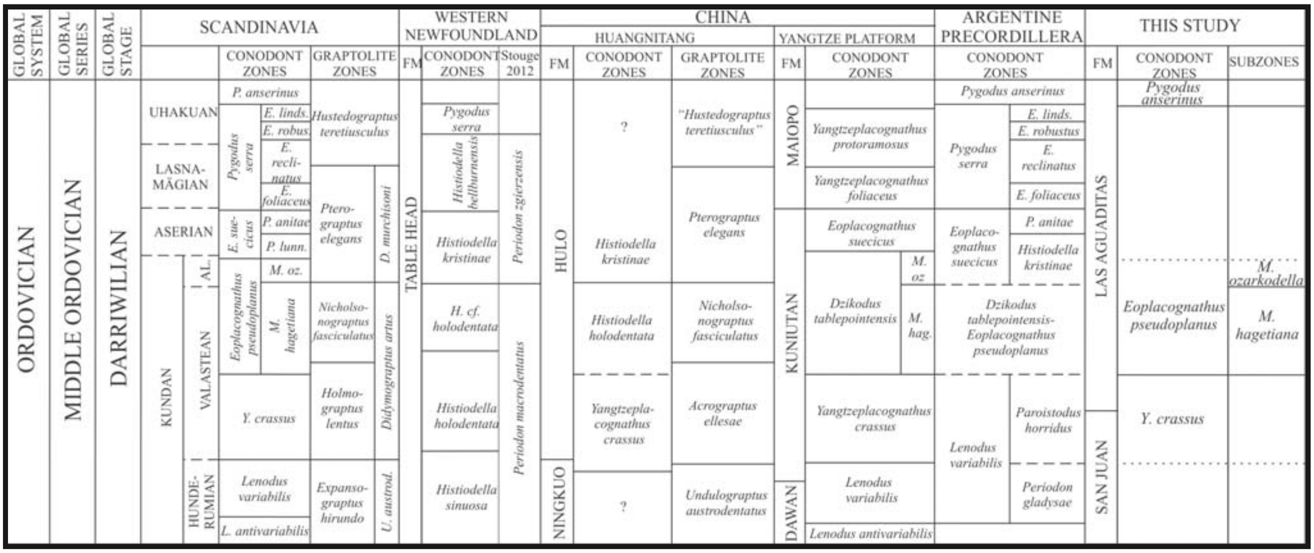

Figure 3. Darriwilian conodont and graptolite zones in Scandinavia, Western Newfoundland, China, and the Precordillera summarized in the biostratigraphic chart proposed in this paper.

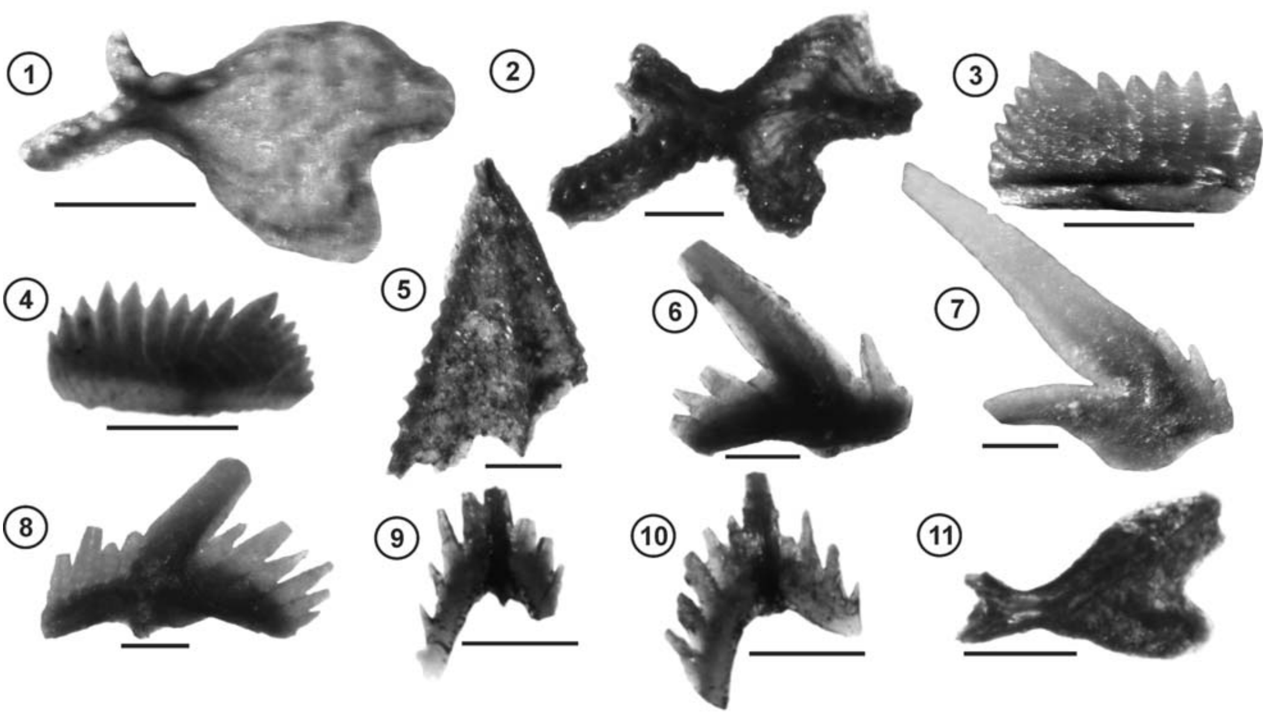

Figure 4. OM photographs (scale 0.2 mm). **1,** ***Yangtzeplacognathus crassus*** (Chen and Zhang, 1993), CORD-MP 20499; Pa element, oral view, sample FmSJ2; **2,** ***Dzikodus tablepointensis*** (Stouge, 1984), CORD-MP 21723; Pb element, oral view, sample LAF33; **3,** ***Histiodella holodentata*** Ethington and Clark, 1981, CORD-MP 20533 Pa element, lateral view; **4,** ***Histiodella kristinae*** Stouge, 1984, CORD-MP 20579; Pa element, lateral view, sample LAF33; **5,** ***Pygodus anserinus*** Lamont and Lindström, 1957, CORD-MP 25001, Pa element, oral view, sample LAgF2.**6-7,** ***Periodon macrodentatus*** (Graves and Ellison, 1941) 20758-20759; **6,** Pa element, lateral view, sample LAF27; **7,** M element, lateral view, sample LAF33; **8,** ***Periodon zgierzensis*** Dzik, 1976, CORD-MP 25003, Pa element, lateral view, sample LAF27; **9,** ***Microzarkodina ozarkodella*** Lindström, 1971, CORD-MP 25001; Sa element, anterior view, LAF27; **10,** ***Microzarkodina hagetiana*** Stouge and Bagnoli, 1990, CORD-MP 21601, Sa element, anterior view, LAF27; **11,** ***Eoplacognathus pseudoplanus*** (Viira, 1974), CORD-MP 20492, Pa element, oral view, sample LAF 27.

(Zhang, 1998) and western Newfoundland (Stouge, 1984). *Eoplacognathus pseudoplanus*, on the contrary, was more common in slightly shallower waters, as in northern Estonia (Viira *et al.*, 2001). Different migration steps of key species may be related to the drowning episode of the carbonate platform that changed the paleoenvironments from the San Juan to the Las Aguaditas formations.

The index species *Microzarkodina hagetiana* and *M. ozarkodella* that define, respectively, the lower and upper subzones of the *E. pseudoplanus* Zone were identified in the lower member of the Las Aguaditas Formation. These Precordilleran subzones are used for precise correlation with the homologous subzones in the Baltoscandic region (Löfgren, 2004; Stouge and Bagnoli (1990). Most of the *E. pseudoplanus* Zone is equivalent to the *D. tablepointensis* Zone in South-Central China (Zhang, 1998). Löfgren (2004) documented a great abundance of *D. tablepointensis* in the upper subzone of the *E. pseudoplanus* Zone in the Jämtland sections in Sweden. In our study section, the FAD of *D. tablepointensis* is slightly lower than that of *E. pseudoplanus*, hence the reverse of that in Sweden. This difference in the appearances of the two species may be due to differences in the environmental conditions of the basin or by sampling failure. Also, the presence of Periodon macrodentatus through our study succession and the occurrence of *P. zgierzensis* in the upper part of the lower member of the Las Aguaditas Formation serve as a basis for correlation with the Table Head succession on Newfoundland (Stouge, 2012). Other common species in this zone are *Ansella jemtlandica*, *Fahraeusodus marathonensis, Drepanoistodus tablepointensis*, *Paroistodus horridus* and *Protopanderodus gradatus*.

In the Precordillera, the *E. pseudoplanus* Zone is also recognized in the upper lower member of the Los Azules Formation (Ortega *et al.*, 2007), in coeval strata of the Sierra de la Invernada Formation (Albanesi *et al.*, 2009; Ortega *et al.*, 2010), and in the upper middle part of the Las Chacritas Formation (Serra *et al.*, this volume; Albanesi and Astini, 2000).

The similar ranges of *E. pseudoplanus* and *D. tablepointensis* may be used for the definition of an association zone for the region. The latter taxon can be employed as an auxiliary zone index species when the eponymous taxon is not recorded; for example, *D. tablepointensis* was recovered from the higher parts of the lower member of the Los Azules Formation whereas *E. pseudoplanus* has still not been found in that particular facies (Ortega *et al.*, 2007).

The index species *Histiodella kristinae* was recorded at 23 m above the base of the Las Aguaditas Formation, a level close to the top of the lower member. Although it is the index species of the lower Subzone of the *Eoplacognathus suecicus* Zone, *H. kristinae* appears earlier in the record, namely inthe upper part of the *E. pseudoplanus* Zone, where *E. suecicus* is not present (Zhang, 1998; Löfgren, 2004). A major stratigraphic gap between the lower and middle members in the Las Aguaditas Formation is shown by the recovery of the zone index species *Pygodus anserinus* at the base of the middle member. The hiatus includes, at least, the upper part of the *E. pseudoplanus* Zone, the *E. suecicus* Zone, and the *Pygodus serra* Zone, as well as probably part of the *P. anserinus* Zone. In western Newfoundland, the *H. kristinae* Zone of Stouge (1984) correlates with the transitional interval between the *E. pseudoplanus* and *E. suecicus* zones in Sweden (Zhang, 1998). In South China, the proposed correlation is with the upper part of the *D. tablepointensis* Zone and the lower part of the *E. suecicus* Zone (Zhang, 1998). The most recent biostratigraphic scheme of the table Head Formation of Newfoundland (Stouge, 2012) shows a *H. kristinae* Subzone of the *Periodon zgierzensis* Zone, which correlates with the upper part of the lower member in our study succession. This interval was recognized also at other localities of the Precordillera, for instance, in the Gualcamayo Formation in the Sierra de Villicum (Sarmiento, 1991), and in the Las Chacritas Formation (Serra *et al.*, this issue).

CONCLUSIONS

The conodont fauna and the index species recorded from the uppermost San Juan Formation, and the lower member and the lower part of the middle member of the Las Aguaditas Formation, make it possible to establish a high resolution biostratigraphic scheme for the Darriwilian Stage in the Precordillera, which is useful for global correlation. The *Yangtzeplacognathus crassus*, *Eoplacognathus pseudoplanus* and *Pygodus anserinus* zones have been identified and we propose herein to introduce the *Y. crassus* Zone to the Central Precordillera biostratigraphic scheme.

In western Newfoundland, our Precordilleran study interval corresponds to the *Histiodella holodentata* and *H. kristinae* zones (Stouge, 1984) or to the *Periodon macrodentatus* and *P. zgierzensis* zones (Stouge, 2012), in Baltoscandia to the *Y. crassus* and *E. pseudoplanus* zones (Zhang, 1998; Löfgren, 2004), and in

China to the *Y. crassus* and *D. tablepointensis* zones (Zhang, 1998).

NOTE ON SYNONYMY LIST

This section includes taxonomic references, stratigraphic, and repository information for taxa with biostratigraphic significance.

Yangtzeplacognathus crassus (Chen and Zhang, 1993)

(Fig. 4, 1).

Eoplacognathus crassus n. sp. Chen and Zhang, 1993, pl.3, fig.1.

Yangtzeplacognathus crassus (Chen and Zhang, 1993); Zhang, 1998, p.96.pl.20, figs.5–8.

Samples. FSJ2, FSJ1, FSJ0.

Material. 17 elements

Repository. CORD-MP 20499-20515

Dzikodus tablepointensis (Stouge, 1984)

(Fig. 4, 2)

Polonodus tablepointensis Stouge, 1984:72, pl.12, fig.13, pl.13, figs.1–5 (cum syn.).

Dzikodus tablepointensis (Stouge).–Zhang, 1998c: 65–69, pl.7, figs.1–12, pl.8, figs 1–6 (cum syn.).

Samples. LAF22, LAF33.

Material. 4 elements

Repository. CORD-MP 19495-19498

Eoplacognathus pseudoplanus (Viira, 1974)

(Fig. 4, 11)

Ambalodus pseudoplanus; Viira, 1972, fig.2; Viira, 1974, p.54, figs.43-46, pl.6, figs.25, 29, 31

Eoplacognathus pseudoplanus (Viira); Dzik, 1976, fig.30 g-n; Löfgren and Zhang, 2003, pp.735-736, figs.7-8, 13.

Samples. LAF27, LAF33.

Material. 2 elements

Repository. CORD-MP 20492-20493

Microzarkodina hagetiana Stouge and Bagnoli, 1990

(Fig. 4, 10)

Prioniodina sp. Lindström, 1974; Viira, fig. 14B.

Microzarkodina hagetiana Stouge and Bagnoli; Löfgren and Tolmacheva (2008), p.36, figs.7 a-f, j-m, 9 a-w

Occurrence. Samples LAF22, LAF25, LAF27, LAF29

Material. 12 elements

Repository. CORD-MP 21589-21600

Microzarkodina ozarkodella Lindström, 1971

(Fig. 4, 9)

Prioniodina n.sp.1; Lindström, 1960, fig.5:1.

Microzarkodina ozarkodella n. sp.; Lindström, 1971, p.59, pl.1–15–17.

Microzarkodina ozarkodella Lindström; Löfgren, 2004, fig.12h–n.

Sample. LAF27

Material. 2 elements

Repository. CORD-MP 21601-21602

Pygodus anserinus Lamont and Lindström, 1957

(Fig. 4, 5)

Pygodus anserinus Lamont and Lindstróm, 1954: 67, pl.5, figs.12-13, fig. las-c (non d).

Pygodus serrus (Hadding). Zhong, 1990: 152, pl. 20, partim only, fig.17.

Pygodus anserinus; Zhen *et al.*, 2009a: 152-157, figs 8N, 9A-I, 10A-L (cum syn.)

Sample. LAgF2

Material. 2 elements

Repository. CORD-MP 25001-25002

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