

Journal Pre-proof

Ordovician (Floian-lower Darriwilian) conodont biofacies of the San Juan formation in the cerro viejo of huaco, Argentine Precordillera

M.J. Mango, G.L. Albanesi



PII: S0377-8398(19)30078-7

DOI: <https://doi.org/10.1016/j.marmicro.2019.101784>

Reference: MARMIC 101784

To appear in: *Marine Micropaleontology*

Received date: 21 June 2019

Revised date: 3 October 2019

Accepted date: 3 October 2019

Please cite this article as: M.J. Mango and G.L. Albanesi, Ordovician (Floian-lower Darriwilian) conodont biofacies of the San Juan formation in the cerro viejo of huaco, Argentine Precordillera, *Marine Micropaleontology*(2019), <https://doi.org/10.1016/j.marmicro.2019.101784>

This is a PDF file of an article that has undergone enhancements after acceptance, such as the addition of a cover page and metadata, and formatting for readability, but it is not yet the definitive version of record. This version will undergo additional copyediting, typesetting and review before it is published in its final form, but we are providing this version to give early visibility of the article. Please note that, during the production process, errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

© 2019 Published by Elsevier.

Ordovician (Floian-lower Darriwilian) conodont biofacies of the San Juan Formation in the
Cerro Viejo of Huaco, Argentine Precordillera

Mango, M.J.¹, Albanesi, G.L.¹

¹ CICTERRA (CONICET-UNC), CIGEA, Facultad de Ciencias Exactas, Físicas y Naturales, Universidad Nacional de Córdoba, Av. Vélez Sarsfield 1699, X5016GCA, Córdoba, Argentina.

matiasjmango@gmail.com; guillermo.albanesi@unc.edu.ar

ABSTRACT

The conodont biofacies from the San Juan Formation at the Cerro Viejo of Huaco, Central Precordillera of Argentina, are analyzed for the identification of faunal dynamics and sea-level changes. The *Prioniodus elegans* and *Oepikodus evae* zones, Floian in age (Lower Ordovician), are identified in the lower San Juan Formation at the inner part of the Huaco anticline. In the western flank of the anticline the succession of the carbonate stratigraphic unit extends from the Floian/Dapingian boundary (Lower-Middle Ordovician) up to the lower Darriwilian (Middle Ordovician) *Lenodus variabilis* Zone. For the interpretation of conodont biofacies through the Los Gatos Creek section, 5,044 conodonts from rock samples of the Floian to the lower Darriwilian are studied. Conodont abundance and generic diversity graphs, and cluster analysis, reveal the following biofacies. The *Juanognathus-Bergstroemognathus*, *Protopanderodus-Reutterodus-Drepanodus*,

Protopanderodus-Oepikodus, *Juanognathus-Semiacontiodus* and *Rossodus-Periodon-Protopanderodus* biofacies are determined, which indicate various deposits stacking from inner to middle and outer carbonate ramp environments of the San Juan Formation. The associated analysis of biofacies and lithology allow for the recognition of two transgressive events in the San Juan Formation at the Los Gatos creek section, which could be related to transgressive systems tracts (TST) that occurred during the Lower and Middle Ordovician. The recovered conodonts have a CAI that varies from 2 to 2.5, indicating a burial paleotemperature between 60 and 155°C. Furthermore, the variation of CAI in conodonts of the same sample, the presence of conodonts with corroded surface lamella, recrystallization and crystal overgrowths, and the presence of stylolites in limestone beds of the San Juan Formation indicate the circulation of hydrothermal fluids.

Keywords: cluster analysis, conodont biofacies, sea-level changes, San Juan Formation, Ordovician, Precordillera.

1. Introduction

Following Ludvigsen et al. (1986), a biofacies refers to an association of fossil taxa that are recorded together in a rock and whose presence has paleoenvironmental connotation. Because the composition of a biocenosis is indirectly related to the water depth, a relationship between the species communities and the water depth can be stable only if the environmental conditions recorded in previous temporal stages are maintained.

A lithofacies drift would produce changes in biofacies and fossil abundance even if the deposition is continuous, *i.e.* without depositional hiatus and without changes in sedimentation rate. These changes in abundance are the result of changes in lithofacies and some ecological gradient (community structure), and they do not require any special explanation in terms of disturbance of the faunal environment or ecological replacements (Rollins et al., 1979; Brett et al., 2007).

Regarding conodont ecology, several models were proposed to explain their distribution during the Ordovician; for instance, Seddon and Sweet (1971) proposes that the conodonts would have been pelagic organisms, with separate species groupings in strata of the marine water column. This model successfully explains the distribution of cosmopolitan and other widely distributed species. The model proposed by Barnes and Fåhraeus (1975) suggests that most of the Ordovician conodonts would have a nectobenthic life habit, and only genera with multielemental apparatus that consist of coniform morphotypes represent pelagic forms. This model emphasizes the lateral segregation of conodonts, taking into account controlling factors such as temperature, salinity, circulation, energy and substrate as the major for their spatial distribution. Zhen and Percival (2003) propose an alternative model, which combines the two referred models.

According to the model proposed by Seddon and Sweet (1971), the conodont records could be used to establish sea-level curves. This methodology is based on the following principles: 1) the same community maintains a preference for an environment and depth, 2) changes in sea-level result in rapid vertical and lateral communities replacement, 3) during periods of relatively stable sea-level, communities are maintained with stable development (Zhang and Barnes, 2002).

The study area is located to the west of the Huaco town, in the San Juan Province, involving the limestones of the San Juan Formation that conform the Huaco anticline, with a highest peak named to as Cerro Viejo of Huaco (Figs. 1 and 2) of the Central Precordillera or oriental tectofacies (sensu Astini, 1992). The limestones of the San Juan Formation conforms the Huaco anticline, which is the object of investigation in the Los Gatos creek (Fig. 3) located on the western flank of Cerro Viejo of Huaco, 2.5 to 3 km south of La Ciénaga; this creek is a tributary channel of the Zanja Honda ravine, with drainage to the Huaco River. At this creek, the San Juan Formation is well exposed and allows for detailed stratigraphic studies and rock sampling for conodonts.

The conodonts from the San Juan Formation exposed in the Cerro Viejo of Huaco are known after the biostratigraphic studies by Ortega (1987), Hünicken and Ortega (1987), Ottone et al. (1999), Ortega et al. (2007), Mestre et al. (2013), and Mango and Albanesi (2018). The detailed conodont biostratigraphy of the San Juan Formation, including the conodont biofacies analysis for this unit, motivated this work after a reference biostratigraphic scheme for the Precordillera published recently (Albanesi and Ortega, 2016).

Insert Fig. 1

2. Geological setting

The Precordillera is located in the central-western sector of the Argentina territory, between 28° 30' and 33° S and 68° 15' and 69° 45' W. This geological province is

subdivided into three morphostructural units on the basis of their stratigraphic and structural characteristics. These units are known as Oriental (Ortiz and Zambrano, 1981), Central (Baldis and Chebli, 1969) and Occidental Precordillera (Baldis et al., 1982).

The Central Precordillera is composed mainly of carbonate platform deposits (Cerro Totorá, La Laja, Zonda, La Flecha, La Silla, San Juan and Las Chacritas formations) extending for about 2,500 meters in thickness, in an apparently continuous cycle (Baldis and Bordonaro, 1982, 1984, 1985). The carbonate sedimentation occurred under warm to temperate environmental conditions, beginning in the Cambrian and continuing up to the Darriwilian. During the middle-late Darriwilian there were few areas with carbonate sedimentation, such as those represented by the Las Aguaditas Formation (Baldis et al., 1982), interpreted as a carbonate slope (Cabaleri, 1989; Keller et al., 1993; Astini, 1995), cropping out in the Sierra de Los Blanquitos, southwest of the Jáchal town.

Insert Fig. 2

The carbonate sequence of the San Juan Formation (Keller et al., 1994), over 330 meters thick, is made up by skeletal micritic limestones deposited from later Tremadocian on a ramp topography (Cañas, 1995, 1999). This limestone succession begins with a transgressive sequence, at whose base develops a reef horizon that consists of calcimicrobials and sponges (Cañas and Carrera, 2003).

Subsequently, sediments accumulate as high sea-level deposits (mostly bioturbated skeleton wackestones) in a framework of environmental stability, which allows the development of rich subtidal communities dominated by suspension-feeding organisms (Cech and Carrera, 2002).

A second reef horizon formed by microbialites, receptaculitids (*Calathium*) and mainly by stromatoporoids (*Zondarella*) develops near the base of the Middle Ordovician.

During the Darriwilian, the carbonate production is suffocated as a consequence of a relative increase in sea-level that led to the drowning of the platform below the photic zone. This event culminates the carbonate cycle and the subsequent deposition of transitional calcareous-shale facies towards predominantly pelitic sequences (Baldis and Beresi, 1981; Baldis et al., 1984, 1989) known as Gualcamayo and Los Azules formations in diverse localities of the Precordillera. This change represents the passage to more restricted environmental conditions in terms of water circulation and oxygenation, affecting the normal development of the biota, with the consequent replacement of biofacies (Benedetto et al., 1995; Sánchez et al., 1996).

Several authors recognize an open, abundant and diverse marine fauna for the San Juan Formation (Serpagli, 1974; Beresi, 1986; Sarmiento, 1987; Herrera and Benedetto, 1991; Beresi and Rigby, 1993; Vaccari, 1994; Lehnert, 1995; Carrera, 1997; Albanesi, 1998), which contains diverse communities of sponges, brachiopods, bryozoans, trilobites, gastropods, nautiloids, conodonts and ostracods, among others.

Insert Fig. 3

3. Materials and methods

For the processing and search of conodonts of the San Juan Formation, Cerro Viejo of Huaco, 50 micropaleontological limestone samples were taken with a variable weight between 2 and 4 kg from the levels of interest for this work.

The laboratory work involved the processing of the rocks for the recovery of the microfossils, following the method of Stone (1987) (acetic acid or formic acid, concentrated at 10%). For each processed sample, an insoluble material with a variable weight between 20 g and 300 g was recovered, depending on the composition of the limestone, allowing through the picking method of all insoluble material, the recovery of 5,044 conodonts and other associated microfossils (see Appendix, Tables A.1-A.5).

The recovered conodonts were taxonomically determined and later illustrated by conventional optical microphotography, allowing to recognize the biozones of the lower San Juan Formation and make an adjustment of its upper succession.

For the biofacies analysis, the taxonomically identified specimens were counted and a database of absolute abundance of fossils per taxon, per sample, was made. In order to carry out the different analyses, the conodonts were identified at a specific level.

From this database, the total abundance (total conodont elements per sample) and generic diversity graphs (amount of genera per sample) were made using Microsoft Excel. Together, the data were treated using the average linkage method (UPGMA) and similarity was quantified using the Morisita index (Morisita, 1959) because it is particularly insensitive to sample size (Hammer and Harper, 2006). This last procedure was carried out at a specific level to recognize possible variations in biofacies linked to multi-species

genera. Multivariate analysis is carried out using the PAST program (Hammer et al., 2001; Hammer and Harper, 2006). The fossils are housed at the Museo de Paleontología, Universidad Nacional de Córdoba under the repository code CORD-MP.

4. Conodont biostratigraphy

This work will follow the biostratigraphic scheme of conodonts proposed by Albanesi et al. (1998) with successive updatings, including the last one by Albanesi and Ortega (2016).

Mango and Albanesi (2018) studied the conodont biostratigraphy of the middle-upper San Juan Formation in the study section, recorded the *Oepikodus evae*, *Oepikodus intermedius*, *Baltoniodus triangularis-Tripodus laevis* and *Lenodus variabilis* zones (samples LG 0 to LG 42). In this publication, the conodont biostratigraphy of the lower San Juan Formation is analyzed (samples LG -20 to LG 0), completing the biostratigraphic succession.

4.1. *Prioniodus elegans* Zone

The index fossil *Prioniodus elegans* Pander is found from the oldest sample (LG -18) to the sample LG -12.4 (Fig. 4) without being associated with *Oepikodus evae* (Lindström). In this way, the *Prioniodus elegans* Zone is recognized from the profile baseline (sample LG -20) to the sample LG -12, where the *Oepikodus evae* lowest record occurs. The appearance of *Oepikodus communis* (Ethington and Clark) from the sample LG-20 would make it possible to recognize that this section corresponds to the upper subzone or *Prioniodus elegans-Oepikodus communis* Subzone.

In this interval, the species diversity and the abundance increases towards its top, including frequent *Bergstroemognathus extensus* Serpagli, *Drepanodus arcuatus* Pander, *Protopanderodus leonardii* Serpagli, *P. rectus* (Lindström), *P. gradatus* Serpagli, *P. elongatus* Serpagli, *Reutterodus andinus* Serpagli and *Tropodus sweeti* (Serpagli).

4.2. *Oepikodus evae* Zone

This conodont zone is recognized from the sample LG -12 to the sample LG 6.8 by the occurrence of *Oepikodus evae* (Fig. 4) ending in the sample LG 7.3, where *Oepikodus intermedius* (Serpagli) is recorded. During this interval *Juanognathus variabilis* Serpagli and *Scolopodus oldstockensis* Stouge are recognized, so according to the reference scheme they would correspond to the upper subzone or *Oepikodus evae*-*Scolopodus oldstockensis* Subzone, but the lower subzone was not detected, so the assignment of this interval to a subzone will be revised.

At these levels the first occurrences of *Juanognathus variabilis*, *Paroistodus* cf. *P. proteus*, *Periodon flabellum* (Lindström), *Oistodus striolatus* Serpagli, *Semiacontiodus potrerillensis* Albanesi, *Ansella jemtlandica* (Löfgren), *Paltodus? jemtlandicus* Löfgren, *Oepikodus intermedius* and *Pteracontiodus cryptodens* (Mound) are recorded together with the youngest records of *Tropodus comptus* (Branson and Mehl) and *Oepikodus communis*. In addition, the only records of *Erraticodon patu* Cooper, *Oepikodus evae*, *Oistodus multicorrugatus* Harris and *Cooperignathus aranda* (Cooper) are found.

At the Cerro Viejo of Huaco, the division of the *Oepikodus evae* Zone according to its original definition is not applicable due to the distribution of the species record. At the Portezuelo Yanso section, *Scolopodus oldstockensis* firstly occurs in a middle level of the

Oepikodus evae Zone (Albanesi et al., 1998); instead, at the Cerro Viejo of Huaco section, *Oepikodus intermedius* presents its first occurrence towards the middle *Oepikodus evae* Zone, while *S. oldstockensis* meets its first appearance in older strata at the base of the mentioned zone. The absence of *S. oldstockensis* at the Portezuelo Yanso section could be related to a facies control or a bias in the laboratory procedure.

Insert Fig. 4

5. Biofacies

The biofacial determination is accomplished at a generic level according to Ludvigsen et al. (1986) and Patskowsky (1995) who consider that the identification of genera, instead of species, provides more reliable results. Since it represents a longer time interval, it allows the identification of a taxonomic environmental association more clearly. On the other hand, it allows for considering the specimens that can only be determined at a generic level due to deficient preservation.

The analysis of the abundance and generic diversity of conodonts (Figs. 5 and 6) reveal four pulses of abundance and high diversity alternated with three pulses of low abundance and diversity, which were observed in samples of coarser granulometry particularly.

Insert Fig. 5

Insert Fig. 6

From the cluster analysis (Fig. 7) five biofacies are recognized, *Juanognathus-Bergstroemognathus*, *Protopanderodus-Reutterodus-Drepanodus*, *Protopanderodus-Oepikodus*, *Juanognathus-Semiacontiodus* and *Rossodus-Periodon-Protopanderodus*.

5.1. *Juanognathus-Bergstroemognathus* biofacies

The genus *Protopanderodus* is represented by four species with abundant elements on this biofacies, whereas *Juanognathus* has three species and *Bergstroemognathus* has one species, the latter two being more significant for the definition of the biofacies. This is found in two intervals, a lower interval is at the base of the stratigraphic column comprising from the sample LG -20 to the sample LG -17 (Fig. 8), where part of the *Prioniodus elegans* Zone is recognized. The record of *Fahraeusodus adentatus* (Mc Tavish) is restricted to this interval. In addition, the first record of several species is verified, which may be due to the arbitrary bias represented at a level does not represent the beginning of the stratigraphic sequence. The specimens abundance is variable (37-122 conodont elements) (Fig. 5) and the generic diversity is moderate (11-12 genera) (Fig. 6). *Juanognathus variabilis* is the species with the highest number of elements followed by *Bergstroemognathus extensus*, being the nominal genera for the biofacies.

Insert Fig. 7

An upper interval is verified between the samples LG -12 and LG 8, which corresponds to the *Oepikodus evae* Zone and lower *Oepikodus intermedius* Zone. At this interval, the first record of *Scolopodus oldstockensis*, *Erraticodon patu*, *Oepikodus intermedius*, *Periodon flabellum*, *Paltodus* n. sp. A, *Paroistodus* cf. *P. proteus*, *Tropodus australis* (Serpagli), *Oistodus striolatus*, *Paltodus? jemtlandicus*, *Semiacontiodus potrerillensis*,

Ansella jemtlandica, *Pteracontiodus cryptodens*, *Prioniodus adami* Stouge and Bagnoli, and *Stolodus stola* (Lindström) is verified. It has the latest records of *Paroistodus proteus* (Lindström), *Oepikodus communis*, *Bergstroemognathus extensus*, *Tropodus sweeti*, *Prioniodus elegans*, *Acodus deltatus* (Lindström), *Colaptoconus quadraplicatus* (Branson and Mehl), *Tropodus comptus*, *Lundodus gladius* (Lindström) and *Periodon selenopsis* (Serpagli). In addition, this interval presents the only records of *Oepikodus evae* and *Cooperignathus aranda*. The abundance is variable (0-687 conodont elements) as well as the generic diversity (0-22 genera), and the species with the highest number of elements per sample are *Juanognathus variabilis* and *Bergstroemognathus extensus*, followed by *Oepikodus evae*, *Scolopodus krummi* (Lehnert), and *Tropodus sweeti*.

From the study section in western Newfoundland, Pohler (1994) describes the presence of *Juanognathus*, *Tropodus* and *Bergstroemognathus* from inner to outer platform facies, and the record of *Oepikodus* in facies of different depth, with a high frequency of appearance in the platform, while *Scolopodus* is found in facies from inner to outer platform. Stouge (1984) interprets that *Scolopodus* would have inhabited nearby carbonate shoals in western Newfoundland. The genera *Juanognathus*, *Reutterodus*, *Bergstroemognathus*, and *Diaphorodus* would be typical of temperate waters (Albanesi and Bergström, 2004; Bagnoli and Stouge, 1991). Wu et al. (2014) report *Tropodus* as more abundant in shallow facies and warmer environments in the southern China platform. In turn, the lithology of correlative levels from the study section is very variable, from mudstones-wackestones, wackestones-packstones, to packstones and grainstones. The comparison of biofacies and lithology of these strata corresponds to middle to outer ramp deposits.

5.2. *Protopanderodus-Reutterodus-Drepanodus* biofacies

This biofacies extends from the sample LG -17 to the LG -12 and corresponds to part of the *Prioniodus elegans* Zone (Fig. 8). It presents the first record of *Acodus deltatus*, *Paroistodus parallelus* (Pander), *Drepanoistodus forceps* (Lindström), *Protoprioniodus simplicissimus* McTavish, *P. cowheadensis* Stouge and Bagnoli, *Diaphorodus russoi* (Serpagli), *Oelandodus elongatus* (Lindström), *Anodontus longus* Stouge and Bagnoli, *Protopanderodus rectus*, *Colaptoconus quadraplicatus*, *Tropodus comptus*, *Scolopodus krummi*, *Juanognathus* n. sp. A, *Paltodus perrii* Stouge and Bagnoli, *Oistodus lanceolatus* Pander, *O. multicorrugatus*, *Lundodus gladius*, *Periodon primus* Stouge and Bagnoli, and *P. selenopsis*. The records of *Drepanoistodus lucidus* Stouge and Bagnoli, *Paracordylodus gracilis* Lindström, *Paltodus* sp., *Parapanderodus striatus* (Graves and Ellison), *Histiodela donnae* Repetski, *Kallidontus princeps* Pyle and Barnes, *Parapaltodus flexuosus* (Barnes and Poplawski), *Diaphorodus tovei* Stouge and Bagnoli, and *Scandodus furnishi* Lindström, are restricted to this biofacies.

The abundance varies between 25 and 375 conodont elements (Fig. 5) and the generic diversity is moderate to high (9-23 genera) (Fig. 6), while the species with more elements per sample are *Protopanderodus leonardii*, *Reutterodus andinus*, and *Drepanodus arcuatus*, whose genera are adopted to name the biofacies. These taxa are followed by *Prioniodus elegans*, *Tropodus comptus*, *Paroistodus proteus*, *Diaphorodus russoi*, *Protopanderodus rectus* and *Oepikodus communis*, the latter being the most abundant in the sample LG-14.

The pelagic genus *Drepanodus* is found in deposits of variable depth, and *Tropodus* is found in deposits of inner to outer platform in Newfoundland (Pohler, 1994); a similar

distribution is interpreted in this contribution for *Reutterodus*. At the same time, *Protopanderodus* is recovered from outer platform and slope facies in western Newfoundland (Pohler, 1994). Rasmussen and Stouge (2018) argue that it would be typical from distal platform facies of cold-waters in the Balto-Scandinavian Region. The genus *Prioniodus* is found in deposits of variable depth in Newfoundland, but is more abundant in outer platform facies (Pohler, 1994), whereas *Paroistodus* is found in inner platform, outer platform and slope deposits, although Stouge (1984) indicates that the latter is typical of cold or deep waters, being found in deposits of outer platform. Wu et al. (2014) record an association of the genera *Oepikodus*, *Paroistodus*, *Drepanoistodus*, *Protopanderodus*, *Juanognathus*, *Bergstroemognathus* and *Diaphorodus* in facies that represent a transgressive event in China. The strata representing this biofacies consist of wackestones and are interpreted as middle ramp deposits through the comparison between the biofacies and the lithology.

Insert Fig. 8

5.3. *Protopanderodus*-*Oepikodus* biofacies

This biofacies comprises the samples LG 8 to the LG 12 (Fig. 8), which correspond to the *Oepikodus intermedius* Zone. The referred interval presents the lowest record of *Parapanderodus paracornuformis* (Ethington and Clark), and the last occurrences of *Oelandodus costatus* van Wamel, *Texania heligma* Pohler, *Oepikodus intermedius*, *Tropodus australis*, and *Prioniodus adami*.

The abundance is moderate to high (67-279 conodont elements) (Fig. 5) and the generic diversity is on an average (13-17 genera) (Fig. 6); while the species with higher conodont

elements per sample are *Oepikodus intermedius*, *Protopanderodus gradatus* and *P. rectus*, whose genera give name to the biofacies.

According to Pohler (1994), *Protopanderodus* occurs in outer platform and slope facies, whereas for Rasmussen and Stouge (2018) regard it typically dwells in cold-waters of distal platform facies. While *Oepikodus* is found in all mentioned facies from western Newfoundland, being more abundant in the platform (Pohler, 1994), this particular difference is also reported when comparing the Balto-Scandinavian Region biofacies with the one found in shallower-water facies of the Precordillera (Albanesi and Bergström, 2004). Stouge and Bagnoli (1990) consider that in correlative lithological succession of Sweden a high abundance *Oepikodus* and *Protopanderodus* would be typical of deep-waters corresponding to slope deposits of paleocontinental margins. In the study area, the strata with this biofacies consist of mudstones-wackestones and brecciated grainstones interpreted as tempestites, whose comparison with the biofacies allows them to be interpreted as middle to outer ramp deposits.

5.4. *Juanognathus-Semiacontiodus* biofacies

This biofacies extends between the samples LG 14.7 and LG 34.1 (Fig. 8), where the genera *Juanognathus* and *Semiacontiodus* are the most abundant. This interval corresponds to the *Baltoniodus triangularis-Tripodus laevis* Zone.

The first records of *Drepanoistodus basiovalis* (Sergeeva), *Fahraeusodus jachalensis* Feltes and Albanesi, *Drepanodus reclinatus* (Lindström), and *Costiconus costatus* (Dzik) are recorded in this interval. The species *Colaptoconus* cf. *C. quadraplicatus*, *Coelocerodontus bicostatus* van Wamel, *Juanognathus serratus* (Xiang and Zhang),

Tripodus laevis Bradshaw and *Scalpellodus gracilis* (Sergeeva) are just present in this interval. It shall be noted that in this interval a number of species have their last occurrences, such as *Protopanderodus leonardii*, *P. elongatus*, *Reutterodus andinus*, *Periodon primus*, *Drepanoistodus forceps*, *Protoprioniodus simplicissimus*, *P. cowheadensis*, *Diaphorodus russoi*, *Oelandodus elongatus*, *Anodontus longus*, *Scolopodus krummi*, *Juanognathus jaanussoni* Serpagli, *Juanognathus* n. sp. A, *Paltodus? jemtlandicus*, *Paltodus subaequalis* Pander, *P. perrii*, *Paltodus* n. sp. A, *Oistodus multicorrugatus*, *Kallidontus corbatoi* (Serpagli), *Erraticodon patu*, *Paroistodus* cf. *P. proteus*, *Semiacontiodus potrerillensis*, *Ansella jemtlandica*, *Stolodus stola*, *Parapanderodus paracornuformis*, and *Triangulodus brevibasis* (Sergeeva).

The abundance is variable (0-254 conodont elements) (Fig. 5) as well as the generic diversity (0-21 genera) (Fig. 6); meanwhile, the species with the higher number of elements per sample are *Juanognathus jaanussoni* and *Semiacontiodus potrerillensis*, followed by *Tripodus laevis*, *Paroistodus originalis* (Sergeeva), and *Drepanoistodus basiovalis*.

Semiacontiodus is typical of shallow to moderate depth environments in various parts of the world (Pohler, 1994; Löfgren, 1999; Carlorosi et al., 2019), whereas *Juanognathus* is found in inner and outer platform facies (Pohler, 1994). Zeballo and Albanesi (2013) interpret *Semiacontiodus* as a pelagic genus with tolerance and/or preference for low oxygenation conditions. At the same time, *Drepanoistodus* is found in inner platform to slope facies, with a more frequent record on the platform (Pohler, 1994), and it may be a pelagic habit genus (Zeballo and Albanesi, 2013; Serra et al., 2017), while *Tripodus laevis* is typical of shallow facies at moderate depths in Newfoundland (Pohler, 1994). In the study area, these strata are made up of wackestones-packstones and grainstones, whose

relation with the biofacies allows these levels to be interpreted as inner to middle ramp deposits.

5.5. *Rossodus-Periodon-Protopanderodus* biofacies

Between the samples LG 35.9 and LG 40.1 the conodont records are scarce (Fig. 4) with low abundance (0-1 conodont element) (Fig. 5), as well as the generic diversity (0-1 genus) (Fig. 6). From the sample LG 41 it presents some conodonts (18 elements, 8 genera), although they are not sufficient to determine a biofacies.

The top stratum of the San Juan Formation (sample LG 42, *Lenodus variabilis* Zone) (Fig. 8) presents a more diverse record, with abundant conodont elements of *Periodon macrodentatus* (Graves and Ellison), *Protopanderodus gradatus*, *P. robustus* (Hadding), *Drepanodus reclinatus*, *Paroistodus horridus primus* Albanesi, *Rossodus barnesi* Albanesi, and *Parapaltodus simplicissimus* Stouge. Herein, the first records of *Histiodela sinuosa* Graves and Ellison, *H. serrata* Harris, *Erraticodon alternans* (Hadding), *Spinodus spinatus* (Hadding), *Protopanderodus robustus*, *Lenodus variabilis* (Sergeeva), *Periodon macrodentatus*, and *Paroistodus horridus primus* are recorded. The abundance is high (664 conodont elements) and the generic diversity is moderate (16 genera).

Regarding the environmental preference of the genera recorded, *Periodon* is found in slope and outer platform deposits. Although this genus is more frequent in the latter environments (Pohler, 1994; Albanesi, 1998; Serra et al., 2017), it presents isolated occurrences in shallower environments (Stouge, 1984). *Protopanderodus* is typical of outer platform to slope facies and *Paroistodus* is found in deposits of the inner platform, outer platform and slope (Pohler, 1994). Regarding *Paroistodus*, Stouge (1984) considers it as

typical of cold or deep waters, since it is found in outer platform facies. According to Rasmussen and Stouge (2018), in the Balto-Scandinavian Region the *Protopanderodus* biofacies dominated the open platform areas or cold waters, while the *Periodon* biofacies characterized the platform margin or relatively warmer waters. *Parapaltodus* is considered by Stouge (1984) with a necto-benthic habit in open platform environments, while *Histiodelia* is frequent in deep subtidal environments of North America (Ethington and Repetski, 1984). Albanesi and Bergström (2004) indicate that *Rossodus* would have preferred relatively deeper waters. In the study section, the sample LG 42 is composed of grainstone, whose relation with the biofacies allows this level to be interpreted as a middle ramp deposit.

6. Sea-level changes

The conodont biofacies recorded in this study have similar characteristics to those found in successions of the same age in different parts of the world (Ethington and Repetski, 1984; Stouge, 1984; Stouge and Bagnoli, 1990; Bagnoli and Stouge, 1991; Pohler, 1994; Löfgren, 1999; Albanesi and Bergström, 2004; Zeballo and Albanesi, 2013; Wu et al., 2014; Serra et al., 2017; Rasmussen and Stouge, 2018; Carlorosi et al., 2019), allowing their comparison and analysis to recognize sea-level changes that occurred during the Lower and Middle Ordovician.

With the passage from the *Juanognathus-Bergstroemognathus* (samples LG 20 to the LG -17) to the *Protopanderodus-Reutterodus-Drepanodus* biofacies (samples LG -17 to the LG -12) an increase in abundance and generic diversity is recorded. *Protopanderodus*,

Reutterodus and *Drepanodus* become more abundant upwards (Fig. 9), which produces the respective biofacies variation, accompanied by the transition from packstones to wackestones, what is interpreted as an increase in depth within a middle ramp configuration. Towards the sample LG -12 there appears a recurrent change of biofacies deriving to wackestones-packstones and grainstones, which modify the abundance of the dominant genera. *Juanognathus* and *Bergstroemognathus* become abundant again (Fig. 9); consequently, this event is interpreted as a decrease in depth within the middle ramp.

The *Juanognathus-Bergstroemognathus* biofacies show a decrease in specimens abundance and generic diversity in the sample LG -4, increasing from the sample LG 1 where the lithology turn to mudstones-wackestones, then reaching its maximum peak in the sample LG 6. With the lithological modification, the composition of the biofacies shows genera typical of deep-water, such as *Oepikodus* and *Protopanderodus* (Fig. 9). For this interval, a transitional environment from middle ramp to outer ramp is interpreted.

From the sample LG 8, the genus *Bergstroemognathus* has no records and *Juanognathus* continues its presence but in less abundance, while *Oepikodus* and *Protopanderodus* becoming the most abundant forms until the sample LG 12 (Fig. 9). It represents the *Oepikodus-Protopanderodus* biofacies, with isolated levels of brecciated grainstones interpreted as tempestites. From the sample LG 8 to the LG 12, a transitional environment from outer ramp to middle ramp is interpreted.

Abundance and diversity decrease towards the sample LG 14 where a lithological change turns to grainstones and the succeeding wackestones-packstones. From the level LG 14.7, an increase in generic diversity is reported for the *Juanognathus-Semiacontiodus* biofacies,

mainly due to the abundance of the species *Juanognathus jaanussoni*, which is appreciated up to the sample LG 34.1. In this interval, the abundance is usually low and the generic diversity moderate to high. The genera *Periodon* and *Protopanderodus*, which are usually associated with deep-waters, have a few records, while the genera related to shallow waters such as *Semiacontiodus* are abundant (Fig. 9), although a decrease of their abundance occurs towards the top, which suggest a preference for inner to middle ramp environments. The beginning of these levels correlate with the second reef level of the San Juan Formation exposed in the Niquivil and Cerro La Silla sections, Central Precordillera of San Juan (Mango and Albanesi, in press).

From the sample LG 35.9 to the top stratum of the San Juan Formation the samples were almost barren, so the abundance and generic diversity is very low, not favourable for biofacial determination. However, the sample LG 42 shows an increase in abundance and generic diversity, since there are several genera that are abundant; among them, *Rossodus*, *Periodon*, *Protopanderodus*, *Drepanodus*, *Parapaltodus*, and *Paroistodus*, that can be assigned to a middle-ramp deposit. Overlying this stratigraphic sequence, the transitional facies to the shales of the Los Azules Formation reveal the consequent drowning of the carbonate ramp.

In this way, two transgressive events are recognized in the limestone succession of the San Juan Formation at the Los Gatos creek section, the first one from the sample LG -20 to the LG 6, where there is a well-differentiated peak of abundance, and the second one from the sample LG 14 to the top stratum of the San Juan Formation, which could be related to a transgressive systems tract (TST) as recognized by Cañas (1999) for other sections of the Central Precordillera of San Juan.

Insert Fig. 9

7. Preservation of conodont elements

In the present study, the conodonts recovered from the San Juan Formation present a color alteration index (CAI) varying from 2 to 2.5, which refers to burial paleotemperatures of 60-155°C (Epstein et al., 1977). These values correspond to the Niquivil tectonic thrust, which is the easternmost one of the Central Precordillera (Voldman et al., 2010), as part of an orogenic belt that continues in the Cerro Potrerillo exposure (Albanesi et al., 1998), the Cerro Viejo of Huaco (Ottone et al., 1999; Ortega et al., 2007; Mango and Albanesi, 2018), the Las Chacritas (Serra et al., 2015), and the Cerro La Chilca sections (Serra et al., in press).

According to Rejebian et al. (1987), who analyzed the conodont color and textural alterations through experimental and field data, the variation of the conodont CAI (2 to 2.5) among specimens from the same sample, the presence of conodonts with corroded surface lamella, recrystallization and crystal overgrowths, and the presence of stylolites in the bearer rocks, indicate the circulation of hydrothermal fluids within the overburdened strata (Fig. 10). This interpretation is supported according to the referred features as well as the low CAI values recorded in the conodonts of the studied collection.

The conodont elements determined in this study present isolated anhedral to subhedral quartz crystals on the surfaces, such as those ones described by Nöth (1998). The latter author indicates that rosettes of anhedral to subhedral microgranule crystallites occur on the

surfaces of conodonts with low CAI values (<3.5), whereas euhedral apatite crystals are clearly dominant at higher CAI values.

More recently, Blanco-Ferrera et al. (2010) consider that the textures of conodont elements under low CAI values show great variety and are mainly originated by diagenetic processes of apatite dissolution and precipitation, remarking that a clear relation between texture or microtexture types and CAI values of the conodonts is not recognized.

In our study, two microtexture types are recognized; large columnar and blocky crystal microtextures, as described by Ferretti et al. (2017) for conodonts from the Ordovician of Normandy, Northern France. Large columnar microtexture is formed of long prismatic sub-isometric crystals that are approximately aligned with the main axis of the conodont element. Blocky crystal microtexture is formed of isometric crystals developed along the margins or costae. Both microtextures can be found in the same conodont. According to Medici et al. (in press), primary bioapatite appears to imprint a key signature on fossil crystal-chemistry (crystal structure and major chemical element contents), while the contribution of fossilization and diagenetic processes seems less relevant.

Insert Fig. 10

8. Conclusions

At the Los Gatos creek section in the Cerro Viejo of Huaco, the *Prioniodus elegans* and *Oepikodus evae* zones are recorded for the lower San Juan Formation. This completes the biostratigraphic succession, following previous studies that comprise from

the *Prioniodus elegans* Zone to the *Lenodus variabilis* Zone (*Paroistodus horridus* Subzone) of the Ordovician (Floian-lower Darriwilian) for the San Juan Formation, Precordillera. The *Prioniodus elegans* Zone (lower Floian) is documented in the anticline core of Huaco, at the Los Gatos creek.

The subdivision of the *Oepikodus evae* Zone into the *O. evae-Juanognathus variabilis* and *O. evae-Scolopodus oldstockensis* subzones, as originally defined, does not apply to the study section, where the record of *Scolopodus oldstockensis* is lower than that recorded in the section where the subzones were originally defined, since the species is recorded from the base of the *Oepikodus evae* Zone.

At the Los Gatos creek in the Cerro Viejo of Huaco, the conodont biofacies of *Juanognathus-Bergstroemognathus*, *Protopanderodus-Reutterodus-Drepanodus*, *Protopanderodus-Oepikodus*, *Juanognathus-Semiacontiodus* and *Rossodus-Periodon-Protopanderodus* biofacies are recorded for the San Juan Formation, representing inner, middle and outer ramp environments.

The analysis of biofacial and lithological relationships allow us to recognize two transgressive events through the San Juan Formation at the study succession, which could be related to transgressive systems tracts (TST) that occurred during the Lower and Middle Ordovician as documented by Cañas (1999) for other sections of the Central Precordillera of San Juan.

The conodont elements recovered from the San Juan Formation show a CAI from 2 to 2.5, indicating overburden paleotemperature between 60 and 155 °C in the easternmost tectonic belt of the Central Precordillera. Furthermore, the CAI variation in elements of the

same sample and the presence of conodonts with altered surface lamella indicate the circulation of hydrothermal fluids.

Acknowledgments

The authors specially thank the CICTERRA (CONICET-UNC) and the CIGEA (FCEFYN, UNC) for the infrastructure and equipment support. We are grateful to the CONICET and the Universidad Nacional de Córdoba for the continuous funding to conodont studies. Comments and corrections by an anonymous reviewer and Annalisa Ferretti significantly improved our manuscript and are greatly appreciated. This contribution corresponds to part of the Doctoral Thesis in Geological Sciences of the first author.

References

- Albanesi, G.L., 1998. Taxonomía de conodontes de las secuencias ordovícicas del cerro Potrerillo, Precordillera Central de San Juan, R. Argentina. *Actas de la Academia Nacional de Ciencias, Córdoba*, Tomo XII, 102-253.
- Albanesi, G.L., Bergström, S.M., 2004. Conodonts: Lower to Middle Ordovician record. In: Webby, B.D., Paris, F., Droser, M.L., Percival, L.G. (Eds.), *The Great Ordovician Biodiversification Event*. Columbia University Press, New York, 312-336.
- Albanesi, G.L., Ortega, G., 2016. Conodont and graptolite biostratigraphy of the Ordovician System of Argentina. In: Montenari, M. (Ed.), *Stratigraphy and timescales*, 61-121.

- Albanesi, G.L., Hünicken, M.A., Barnes, C.R., 1998. Bioestratigrafía de conodontes de las secuencias ordovícicas del cerro Potrerillo, Precordillera Central de San Juan, R. Argentina. *Actas de la Academia Nacional de Ciencias, Córdoba, Tomo XII*, 7–72.
- Astini, R.A., 1992. Tectofacies ordovícicas y evolución de la Cuenca eopaleozoica de la Precordillera Argentina. *Estudios Geológicos*, 48, 315-327.
- Astini, R.A., 1995. Sedimentología de la Formación Las Aguaditas (talud carbonático) y evolución de la cuenca precordillerana durante el Ordovícico. *Revista de la Asociación Geológica Argentina*, 50 (1-4), 143-164.
- Bagnoli, G., Stouge, S., 1991. Palaeogeographic Distribution of Arenigian (Lower Ordovician) Conodonts. *Anais da Academia Brasileira de Ciencias*, 63 (2), 171-183.
- Baldis, B.A.J., Beresi, M., 1981. Biofacies de culminación del ciclo deposicional calcáreo del Arenigiano de oeste de Argentina. *Anais II Congreso Latinoamericano de Paleontología, Porto Alegre*, 1, 11-19.
- Baldis, B.A.J., Bordonaro, O.L., 1982. Comparación entre el Cámbrico de la "Great Basin" norteamericana y la Precordillera de San Juan, Argentina, su implicancia intercontinental. *V Congreso Latinoamericano de Geología, Buenos Aires, Actas, I*, 97-108.
- Baldis, B.A.J., Bordonaro, O.L., 1984. Cámbrico y Ordovícico en la Sierra Chica de Zonda y cerro Pedernal, provincia de San Juan. Génesis del margen continental en la Precordillera. *IX Congreso Geológico Argentino, San Carlos de Bariloche, Actas*, 4, 190-207.

- Baldis, B.A.J., Bordonaro, O.L., 1985. Variaciones de facies en la cuenca cámbrica de la Precordillera Argentina y su relación con la génesis del borde continental. VI Congreso Latinoamericano de Geología, Colombia, Actas, I, 149-161.
- Baldis, B.A.J., Chebli, G., 1969. Estructura profunda del área central de la Precordillera sanjuanina. Cuartas Jornadas Geológicas Argentinas, 47-66.
- Baldis, B.A.J., Beresi, M., Bordonaro, O., Vaca, A., 1982. Síntesis evolutiva de la Precordillera Argentina. V Congreso Latinoamericano de Geología, Buenos Aires, IV, 399-445.
- Baldis, B.A.J., Beresi, M., Bordonaro, O., Vaca, A., 1984. The Argentine Precordillera as a key to Andean structure. *Episodes*, 7 (3), 14-19.
- Baldis, B.A.J., Bordonaro, O., Armella, C., Beresi, M., Cabaleri, N., Peralta, S., Bastías, H., 1989. La cuenca paleozoica inferior de la Precordillera Argentina. In: Chebli, G.A., Spalletti, L.A. (Eds.), *Cuencas sedimentarias argentinas. Serie Correlación Geológica*, 6, 101-121.
- Barnes, C.R., Fåhraeus, L.E., 1975. Provinces, communities, and the proposed nekto-benthic habit of Ordovician conodontophorids. *Lethaia*, 8, 133-150.
- Benedetto, J.L., Vaccari, N.E., Carrera, M., Sánchez, T.M., 1995. The evolution of faunal provincialism in the Argentine Precordillera during the Ordovician: new evidence and paleogeographic implications. In: Cooper, J.D., Droser, M.L., Finney, S.C. (Eds.), *Ordovician Odyssey: Short Papers for the Seventh International Symposium on the Ordovician System*, Las Vegas, SEPM, Fullerton, 181-184.

- Beresi, M.S., 1986. Paleocología y biofacies de la Formación San Juan al sur del paralelo de 30° sur, Precordillera de San Juan. Tesis Doctoral en Ciencias Geológicas, Universidad Nacional de San Juan, 1-400 (unpublished).
- Beresi, M.S., Rigby, J.K., 1993. The Lower Ordovician sponges of San Juan, Argentina. Brigham Young University Geology Studies, 39 (1), 1-63.
- Blanco-Ferrera, S., Sanz-Lopez, J., Garcia-Lopez, S., Bastida, F., Valín, M.L., 2011. Conodont alteration and tectonothermal evolution of a diagenetic unit in the Iberian Variscan belt (Ponga-Cuera unit, NW Spain). Geological Magazine, 148 (1), 35-49.
- Brett, C.E., Hendy, A.J., Bartholomew, A.J., Bonelli, J.R., McLaughlin, P.I., 2007. Response of shallow marine biotas to sea-level fluctuations: A review of faunal replacement and the process of habitat tracking. Palaios, 22, 228-244.
- Cabaleri, N.G., 1989. Facies de transición en el Ordovícico de la Precordillera sanjuanina. Tesis Doctoral en Ciencias Geológicas, Universidad de Buenos Aires. Vol. 1-2 (unpublished).
- Cañas, F.L., 1995. Estratigrafía y evolución paleoambiental de las sucesiones carbonáticas del Cámbrico tardío y Ordovícico temprano de la Precordillera Septentrional, República Argentina. Tesis Doctoral en Ciencias Geológicas, Facultad de Ciencias Exactas, Físicas y Naturales, Universidad Nacional de Córdoba, 1-216 (unpublished).
- Cañas, F.L., 1999. Facies and sequences of the Late Cambrian-Early Ordovician carbonates of the Argentine Precordillera: A stratigraphic comparison with Laurentian

- platforms. In: Ramos, V.A., Keppie, J.D. (Eds.), *Laurentia-Gowana Connections before Pangea*: Boulder, Colorado, Geological Society of America Special Paper, 336, 43-62.
- Cañas, F.L., Carrera, M.G., 2003. Precordilleran reefs. In: Benedetto, J.L. (Ed.), *Ordovician fossils of Argentina*. Secretaría de Ciencia y Tecnología, Universidad Nacional de Córdoba, 131-153.
- Carlorosi, J. M., Esteban, S. B., Tortello, M. F., 2019. Early Ordovician conodonts from the Santa Rosita Formation at Pantipampa, Iruya area, northwestern Argentina. *Andean Geology*, 46 (1), 168-182.
- Carrera, M.G., 1997. Significado paleoambiental de los poríferos y briozoos de la Formación San Juan (Ordovícico), Precordillera Argentina. *Ameghiniana* 34 (2), 179-199.
- Cech, N., Carrera, M.G., 2002. Dinámica de las comunidades arenigianas de la Formación San Juan (Ordovícico), Precordillera Argentina. *Ameghiniana*, 39, 21-40.
- Epstein, A.G., Epstein, J.B., Harris, L.D., 1977. Conodont color alteration-an index to organic metamorphism. United States Geological Survey Professional Paper, 995, 1-27.
- Ethington, R.L., Repetski, J.E., 1984. Paleobiogeographic distribution of Early Ordovician conodonts in central and western United States. In: Clark, D.L. (Ed.), *Conodont Biofacies and Provincialism*. Geological Society of America. Special Paper, 196, 89-101.

- Ferretti, A., Malferrari, D., Medici, L., Savioli, M., 2017. Diagenesis does not invent anything new: Precise replication of conodont structures by secondary apatite. *Scientific reports*, 7 (1), 1624-1632.
- Hammer, Ø., Harper, D.A.T., 2006. *Paleontological data analysis*. Blackwell Publishing, Oxford, 1-351.
- Hammer, Ø., Harper, D.A.T., Ryan, P.D., 2001. PAST: Paleontological statistics software package for education and data analysis. *Palaeontologia Electronica*, 4 (1), 9.
- Herrera, Z.A., Benedetto, J.L., 1991. Early Ordovician brachiopod faunas from the Precordillera Basin western Argentina: biostratigraphy and paleobiogeography affinities. In: Mackinnon, D.I., Lee, D.E., Campbell, J.D. (Eds), *Brachiopods through Time. 2nd International Brachiopod Congress Proceedings University of Otago, Dunedin, Balkema Ed., Rotterdam*, 283-301.
- Hünicken, M.A., Ortega, G., 1987. Lower Llanvirn-Lower Caradoc (Ordovician) conodonts and graptolites from the Argentine Central Precordillera. In: Austin, R.L. (Ed.), *Conodonts: Investigative Techniques and Applications*. Ellis Horwood Limited, Chichester, 7, 136-145.
- Keller, M., Bordonaro, O., Beresi, M., 1993. The Cambrian of San Isidro, Mendoza, Argentina: Facies and sedimentology at the platform slope transition. *Neues Jahrbuch für Geologie und Paläontologie, Mh., H.*, 6, 373-383.

- Keller, M., Cañas, F., Lehnert, O., Vaccari, N.E., 1994. The Upper Cambrian and Lower Ordovician of the Precordillera (Western Argentina): Some stratigraphic reconsiderations. *Newsletter Stratigr.*, 31 (2), 115-132.
- Lehnert, O., 1995. Ordovizische conodonten aus der Präkordillere westargentinien: Ihre bedeutung für Stratigraphie und Paläogeographie. *Erlanger Geologische Abhandlungen*, 125, 1-193.
- Löfgren, A., 1999. The Ordovician conodont *Semiacontiodus cornuformis* (Sergeeva, 1963) and related species. *Geologica et Palaeontologica*, 33, 71-91.
- Ludvigsen, R., Westrop, S.R., Pratt, B.R., Tuttnell, P.A., Young, G.A., 1986. Dual biostratigraphy: zones and biofacies. *Geosci. Can.*, 13 (3), 139-154.
- Mango, M.J., Albanesi, G.L., 2018. Bioestratigrafía y provincialismo de conodontes del tramo medio-superior de la Formación San Juan en el cerro Viejo de Huaco, Precordillera, Argentina. *Andean Geology*, 45 (2), 274-299.
- Mango, M.J., Albanesi, G.L., in press. Conodont biostratigraphy and correlation of the San Juan Formation at the Cerro La Silla section, middle Tremadocian-lower Dapingian, Central Precordillera, Argentina. *Andean Geology*.
- Medici, L., Malferrari, D., Savioli, M., Ferretti, A., in press. Mineralogy and crystallization patterns in conodont bioapatite from first occurrence (Cambrian) to extinction (end-Triassic). *Palaeogeography, Palaeoclimatology, Palaeoecology*, doi: 10.1016/j.palaeo.2019.02.024.

- Mestre, A., Beresi, M., Heredia, S., Nestell, G., 2013. Microfossils of the *Yangtzeplacognathus crassus* Zone in the middle Darriwilian of the Argentine Precordillera. In: Albanesi, G.L., Ortega, G. (Eds.), Conodonts from the Andes, 3rd International Conodont Symposium. Asociación Paleontológica Argentina. Publicación especial, 13, 79-83.
- Morisita, M., 1959. Measuring of the dispersion and analysis of distribution patterns. Memoires of the Faculty of Science, Kyushu University, Series E. Biology, 2, 215-235.
- Nöth, S., 1998. Conodont color (CAI) versus microcrystalline and textural changes in Upper Triassic conodonts from Northwest Germany. *Facies*, 38 (1), 165-173.
- Ortega, G., Albanesi, G. L., Frigerio, S. E., 2007. Graptolite-conodont biostratigraphy and biofacies of the Middle Ordovician cerro Viejo succession, San Juan Precordillera Argentina. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 245, 245-263.
- Ortiz, A., Zambrano, J., 1981. La Provincia geológica Precordillera Oriental. VIII Congreso Geológico Argentino, San Luis, 3, 59-74.
- Ottone, E.G., Albanesi, G., Ortega, G., Holfeltz, G., 1999. Palynomorphs, conodonts and associated graptolites from the Ordovician Los Azules Formation, Central Precordillera, Argentina. *Micropaleontology*, 45 (3), 225-250.
- Patzkowsky, M.E., 1995. Gradient analysis of Middle Ordovician brachiopod biofacies: Biostratigraphic, biogeographic and macroevolutionary implications. *Palaios*, 10, 154-179.

- Pohler, S.M.L., 1994. Conodont biofacies of Lower to lower Middle Ordovician Megaconglomerates, Cow Head Group, Western Newfoundland. Geological Survey of Canada Bulletin, 459, 1-71.
- Rasmussen, J.A., Stouge, S., 2018. Baltoscandian conodont biofacies fluctuations and their link to Middle Ordovician (Darriwilian) global cooling. *Palaeontology*, 61 (3), 391-416.
- Rejebian, V.A., Harris, A.G., Huebner, J.S., 1987. Conodont color and textural alteration: An index to regional metamorphism, contact metamorphism, and hydrothermal alteration. *Geological Society of America Bulletin*, 99 (4), 471-479.
- Rollins, H.B., Carothers, M., Donahue, J., 1979. Transgression, regression and fossil community succession. *Lethaia*, 12, 89-104.
- Sánchez, T.M., Carrera, M.G., Benedetto, J.L., 1996. Variaciones faunísticas en el techo de la Formación San Juan (Ordovícico temprano, Precordillera Argentina): significado paleoambiental. *Ameghiniana*, 33 (2), 185-200.
- Sarmiento, G.N., 1987. Bioestratigrafía y conodontes de la Formación San Juan (Ordovícico) aflorante en el flanco oriental de la sierra de Villicum, Provincia de San Juan, Argentina. Tesis Doctoral en Ciencias Geológicas, Facultad de Ciencias Exactas, Físicas y Naturales, Universidad Nacional de Córdoba, 1-336 (unpublished).
- Seddon, G., Sweet, W.C., 1971. An ecologic model for conodonts. *Journal of Paleontology*, 45, 869-880.

- Serpagli, E., 1974. Lower Ordovician conodont from Precordilleran Argentina (Province of San Juan). *Bolletino della Societa Paleontologica Italiana*, 13 (1-2), 17-98.
- Serra, F., Albanesi, G.L., Ortega, G., Bergström, S.M., 2015. Biostratigraphy and palaeoecology of Middle–Late Ordovician conodont and graptolite faunas of the Las Chacritas River section, Precordillera of San Juan, Argentina. *Geological Magazine*, 152 (5), 813-829.
- Serra, F., Feltes, N.A., Henderson, M.A., Albanesi, G.L., 2017. Darriwilian (Middle Ordovician) conodont biofacies from the Central Precordillera of Argentina. *Marine Micropaleontology*, 130, 15-28.
- Serra, F., Feltes, N.A., Mango, M.J., Henderson, M.A., Albanesi, G.L., Ortega, G., (in press). Darriwilian (Middle Ordovician) conodonts and graptolites from the Cerro La Chilca section, Central Precordillera, Argentina. *Andean Geology*.
- Stouge, S., 1984. Conodonts of the Middle Ordovician Table Head Formation, western Newfoundland. *Fossils and Strata*, 16, 1-145.
- Stouge, S., Bagnoli, G., 1990. Lower Ordovician (Volkhovian-Kundan) conodonts from Hägudden. northern Öland, Sweden. *Palaeontographia Italica*, 11, 1-54.
- Stone, J., 1987. Review of investigative techniques used in the study of conodontes. *In* Conodonts: Investigative Techniques and Applications (Austin, R. L.; editor). Ellis Horwood Limited, 17-34.
- Vaccari, N.E., 1994. Las faunas de trilobites de las sucesiones carbonáticas del Cámbrico y Ordovícico temprano de la Precordillera Septentrional, República Argentina. Tesis

- Doctoral en Ciencias Geológicas, Facultad de Ciencias Exactas, Físicas y Naturales, Universidad Nacional de Córdoba, 1-271 (unpublished).
- Voldman, G. G., Albanesi, G. L., Ramos, V. A., 2010. Conodont geothermometry of the lower Paleozoic from the Precordillera (Cuyania terrane), northwestern Argentina. *Journal of South American Earth Sciences*, 29 (2), 278-288.
- Wu, R., Stouge, S., Percival, I. G., Zhan, R., 2014. Early–Middle Ordovician conodont biofacies on the Yangtze Platform margin, South China: Applications to palaeoenvironment and sea-level changes. *Journal of Asian Earth Sciences*, 96, 194-204.
- Zeballo, F. J., Albanesi, G. L., 2013. Biofacies and palaeoenvironments of conodonts in Cambro-Ordovician sequences of the Quebrada de Humahuaca, Cordillera Oriental of Jujuy, Argentina. *Geological Journal*, 48 (2-3), 194-211.
- Zhang, S., Barnes, C.R., 2002. Late Ordovician-Early Silurian (Ashgillian-Llandovery) sea level curve derived from conodont community analysis, Anticosti Island, Québec. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 180, 5-32.
- Zhen, Y.Y., Percival, I.G., 2003. Ordovician conodont biogeography-reconsidered. *Lethaia*, 36, 357-370.

Appendix

Insert Table A.1

Insert Table A.2

Insert Table A.3

Insert Table A.4

Insert Table A.5

Fig. 1. A. Satellite image with the geographical location of the study area. **B.** Location of the Los Gatos creek, Cerro Viejo of Huaco. The asterisk indicates the top stratum of the San Juan Formation.

Fig. 2. Geological map of the study area and location of the stratigraphic section. *A: Los Gatos creek (modified from Ortega et al., 2007).

Fig. 3. Photographs of the Los Gatos creek, Cerro Viejo of Huaco. **A.** Profile at the lower San Juan Formation (view to the N). **B, C.** Tectonic folds in the lower San Juan Formation (between the levels LG -18 and LG -17, and between the levels LG 26 y LG 28, respectively) (views to the NE). **D.** Wackestones-packstones of the level LG 36 (graphic scale: 20 cm) (view to the S). **E.** Nodular stratification of the level LG 39.9 (view to the S). **F.** Upper San Juan Formation, the light blue line indicates the contact with the overlying Los Azules Formation (view to the NW). **G.** Ferruginous hardground from the top stratum of the San Juan Formation (view to the NE). **H.** Detail of the Los Gatos creek, view to the S.

Fig. 4. Stratigraphic column of the San Juan Formation at the Los Gatos creek, and the conodont species ranges. (D.: Darriwilian; *O.i.*: *Oepikodus intermedius*; *B. t.*- *T. l.*: *Baltoniodus triangularis*-*Tripodus laevis*; *L. v.*: *Lenodus variabilis*).

Fig. 5. Total abundance of conodonts per sample from the San Juan Formation, Los Gatos creek, Cerro Viejo of Huaco.

Fig. 6. Generic diversity of conodonts per sample from the San Juan Formation, Los Gatos creek, Cerro Viejo of Huaco.

Fig. 7. Results of Q- and R-mode cluster analysis of 51 conodont-bearing samples of the San Juan Formation, Los Gatos creek, Cerro Viejo of Huaco. Limestone samples are in Q-mode clustering order and conodont species are in R-mode clustering order. Species abundance is expressed as a graded series of dots. Green: *Juanognathus*-*Bergstroemognathus* biofacies; orange: *Protopanderodus*-*Reutterodus*-*Drepanodus* biofacies, light blue: *Protopanderodus*-*Oepikodus* biofacies; yellow: *Juanognathus*-*Semiacontiodus* biofacies; red: *Rossodus*-*Periodon*-*Protopanderodus* biofacies.

Fig. 8. Stratigraphic column of the San Juan Formation at the Los Gatos creek, with the conodont biofacies ranges and the paleoenvironment (D.: Darriwilian; *O.i.*: *Oepikodus*

intermedius; *B. t.*-*T. l.*: *Baltoniodus triangularis*-*Tripodus laevis*; *L. v.*: *Lenodus variabilis*).

Fig. 9. Total abundance of the most significant genera between the samples LG -20 and LG 34.1. *J.-B.*: *Juanognathus*-*Bergstroemognathus* biofacies; *P.-R.-D.*: *Protopanderodus*-*Reutterodus*-*Drepanodus* biofacies; *P.-O.*: *Protopanderodus*-*Oepikodus* biofacies; *J.-S.*: *Juanognathus*-*Semiacontiodus* biofacies.

Fig. 10. Conodonts from the San Juan Formation: **1-4.** *Triangulodus brevibasis* (*Sergeeva*); **1.** Sa element, CORD-MP 56611, LG 28, graphic scale: 100 μm ; **2-3.** Details of the cusp showing striae, graphic scales: 10 μm (**2**) and 5 μm (**3**); **4.** Sb element, CORD-MP 56612, LG 28, graphic scale: 50 μm . **5-6.** *Oepikodus intermedius* (*Serpagli*); **5.** Pa element, CORD-MP 56613, LG 4, graphic scale: 50 μm ; **6.** Detail of the cusp showing striae, graphic scale: 10 μm .

Table A.1. Absolute frequency of conodont species from the San Juan Formation (samples LG -20 to LG -8), Los Gatos creek section, Cerro Viejo of Huaco.

Table A.2. Absolute frequency of conodont species from the San Juan Formation (samples LG -6 to LG 7.3), Los Gatos creek section, Cerro Viejo of Huaco.

Table A.3. Absolute frequency of conodont species from the San Juan Formation (samples LG 8 to LG 20), Los Gatos creek section, Cerro Viejo of Huaco.

Table A.4. Absolute frequency of conodont species from the San Juan Formation (samples LG 22 to LG 34.1), Los Gatos creek section, Cerro Viejo of Huaco.

Table A.5. Absolute frequency of conodont species from the San Juan Formation (samples LG 36 to LG 42), Los Gatos creek section, Cerro Viejo of Huaco.

Journal Pre-proof

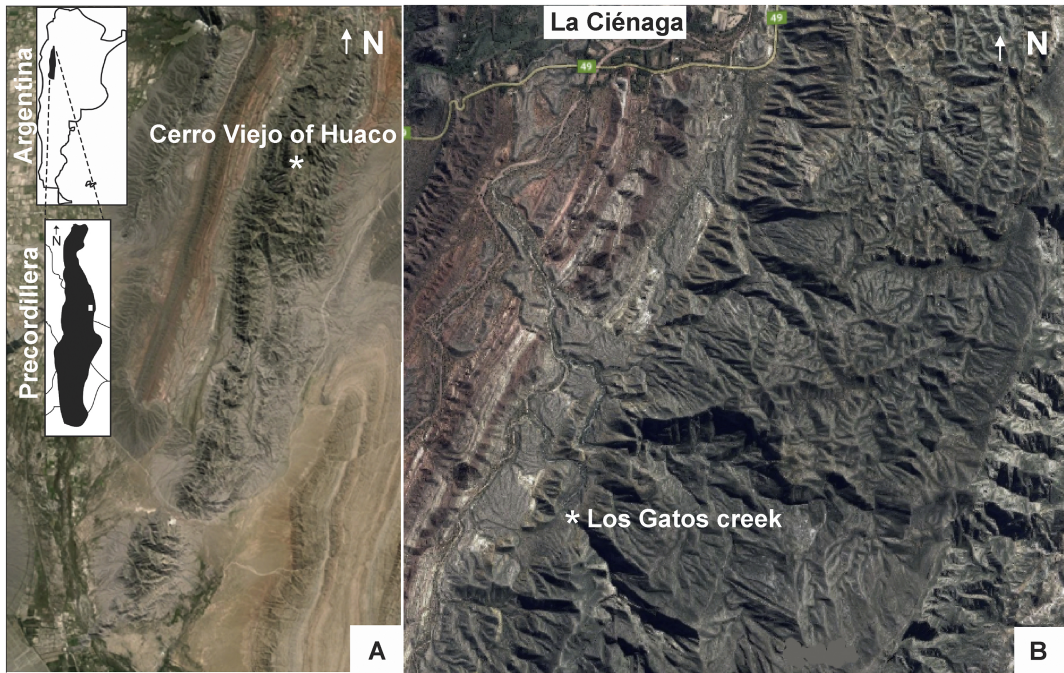


Figure 1

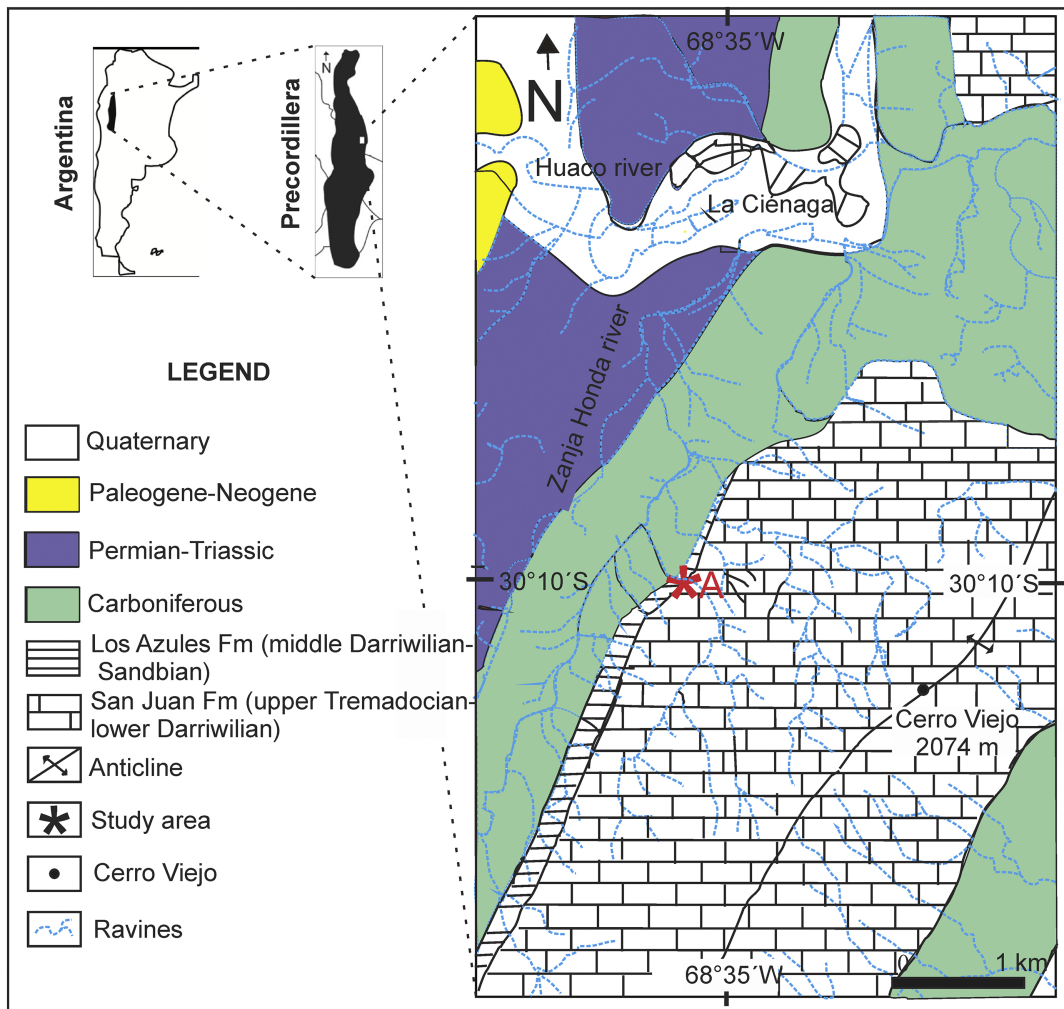


Figure 2

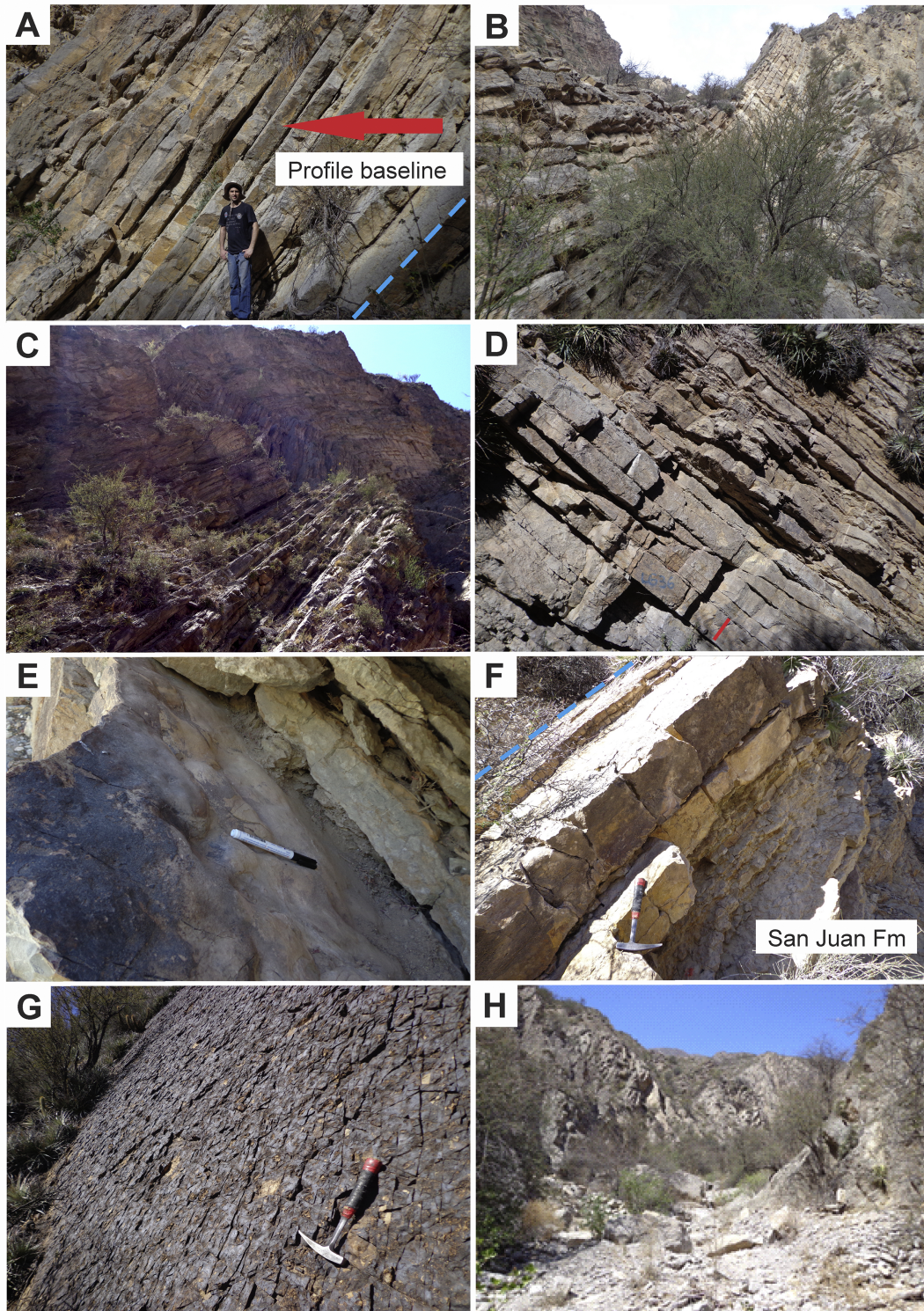


Figure 3

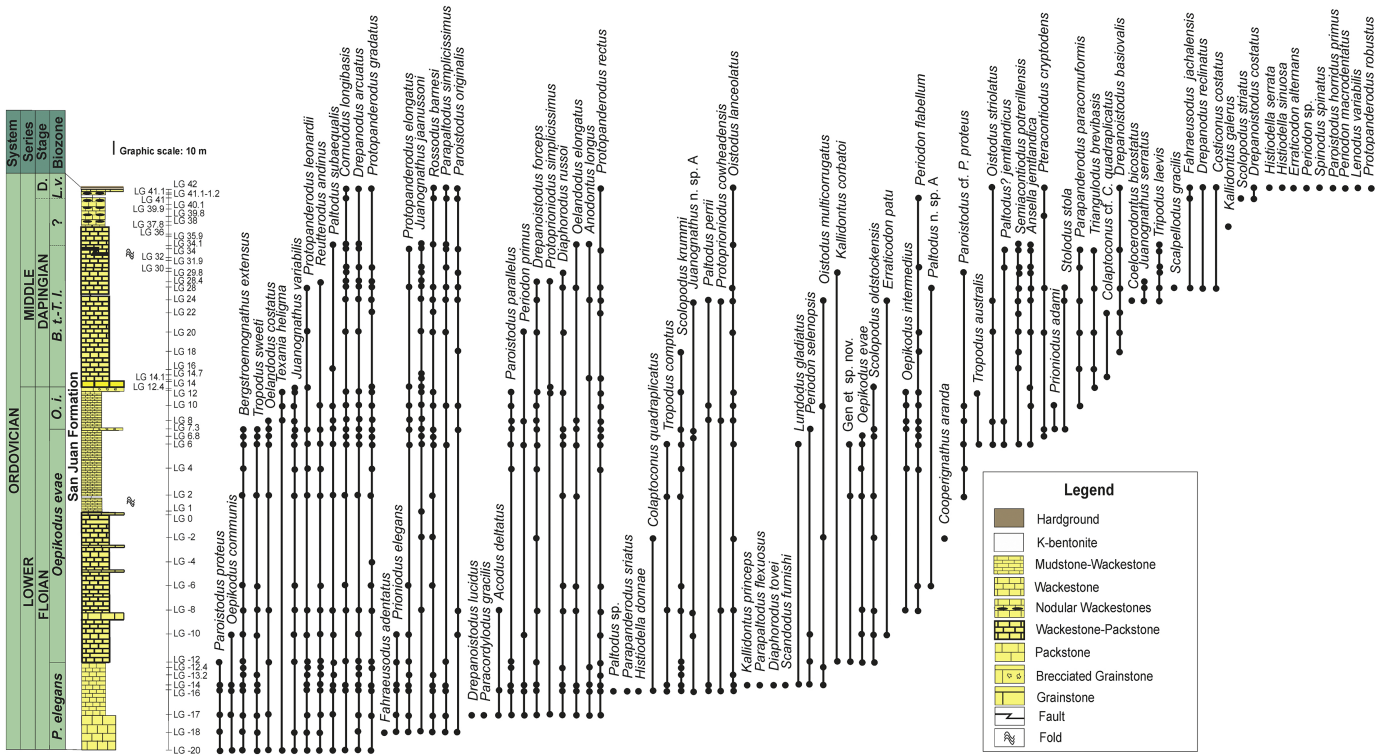


Figure 4

Amount
of conodont
elements

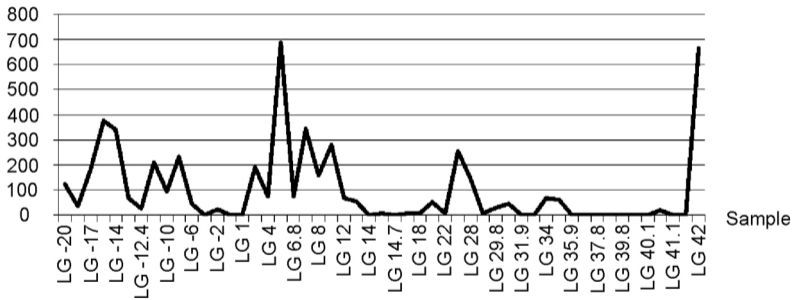


Figure 5

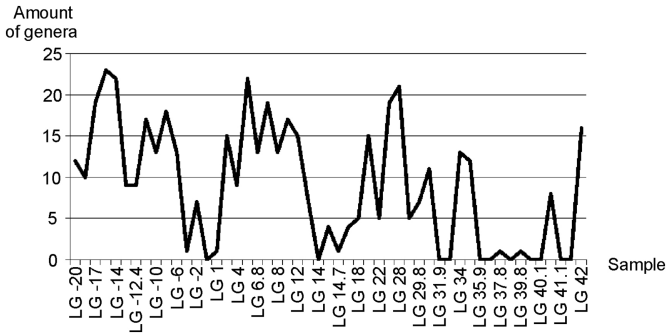


Figure 6

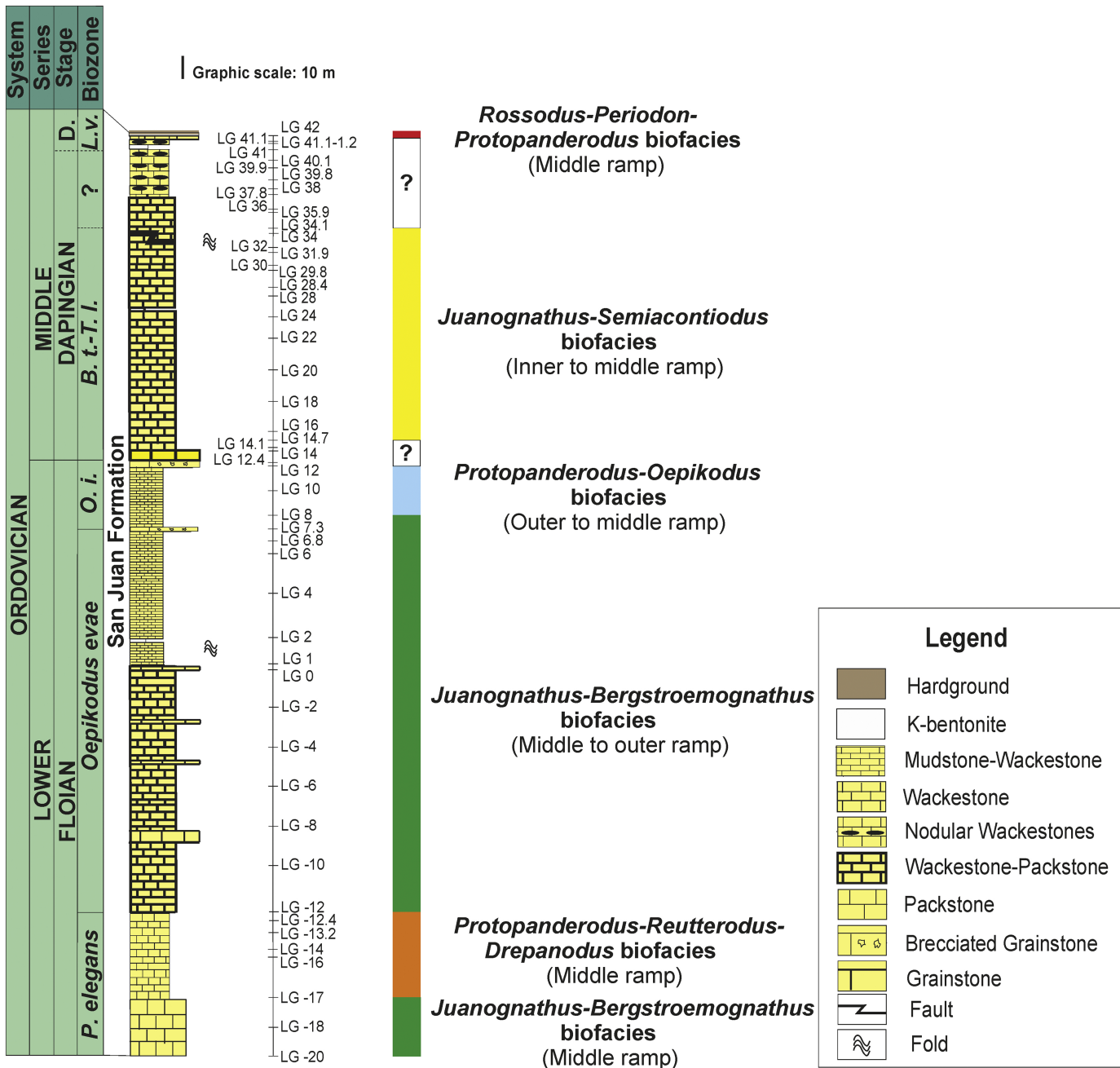


Figure 8

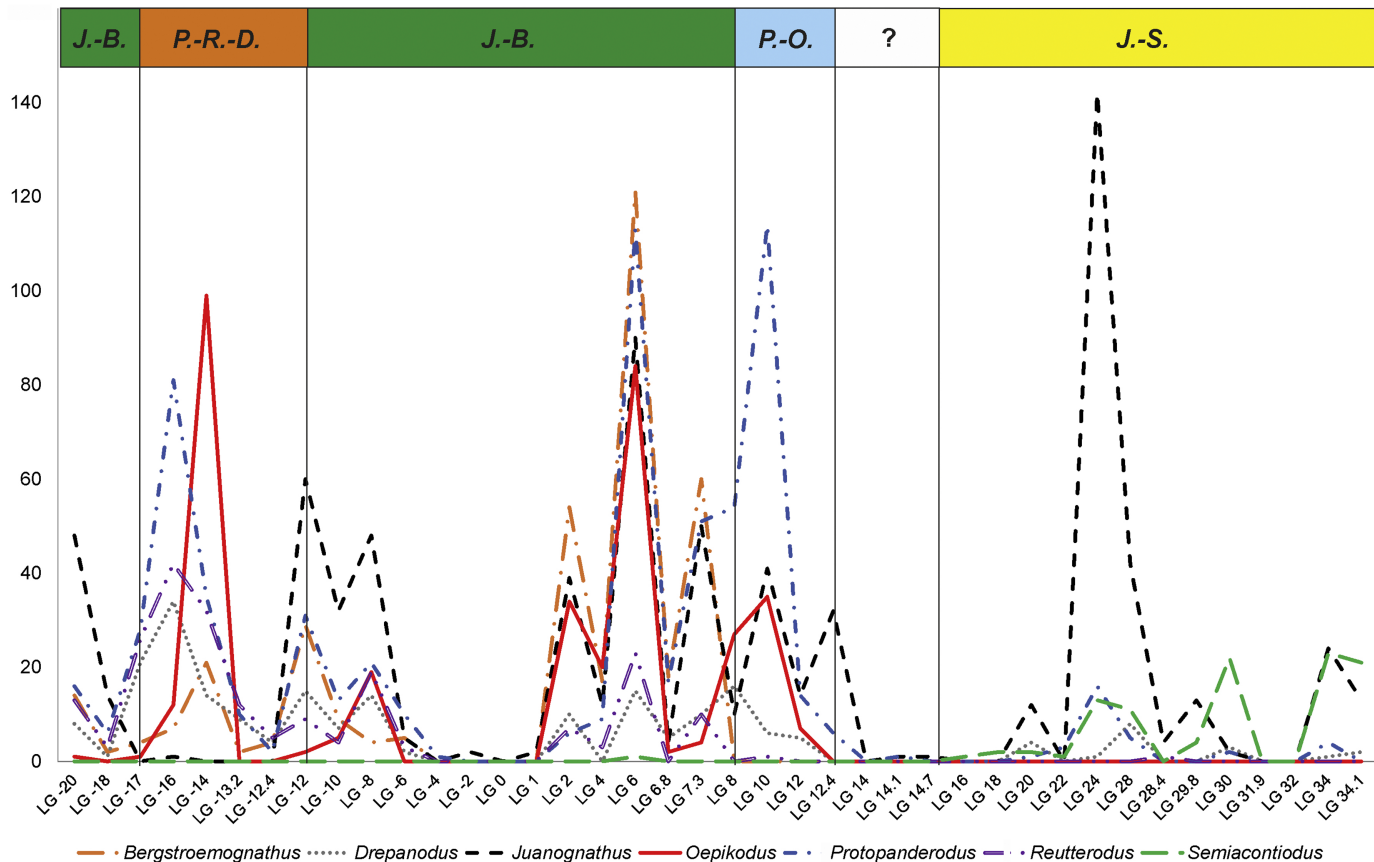
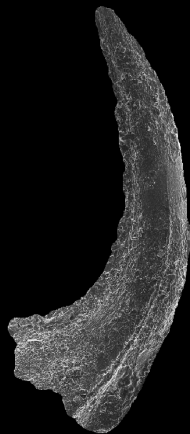
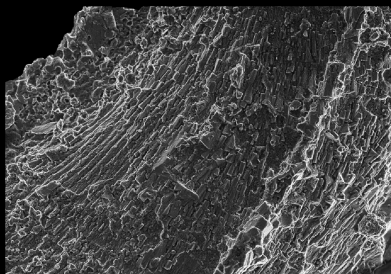


Figure 9

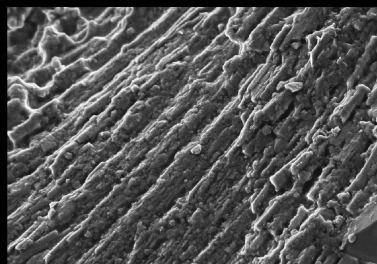
1



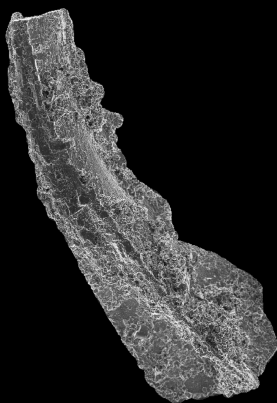
2



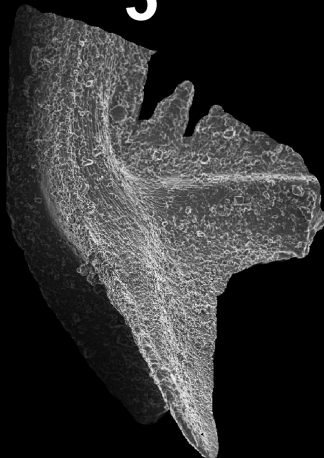
3



4



5



6

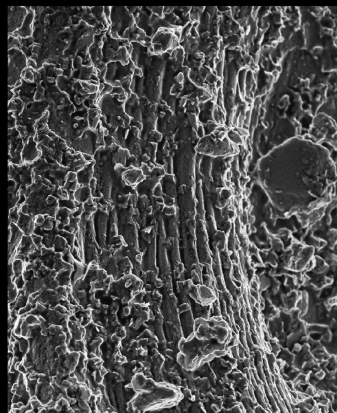


Figure 10