

Ordovician conodont biofacies of the upper La Silla and San Juan formations (middle Tremadocian-lower Dapingian) at Cerro La Silla, Argentine Precordillera

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ABSTRACT

Conodonts from the upper La Silla (9.6 m thick) and San Juan formations (264.7 m thick) at the Cerro La Silla section are analyzed for the identification of faunal dynamics, biofacies and sea-level changes. The conodont collection of 11 388 specimens was recovered after digestion of 41 samples of carbonate rocks, totalizing 88.155 kg. Conodont total abundance and generic diversity graphs, as well as cluster analysis, reveal seven biofacies. The *Colaptoconus*, *Tropodus-Reutterodus*, *Oepikodus-Prioniodus*, *Juanognathus-Bergstroemognathus*, *Juanognathus-Oepikodus-Protopanderodus*, *Juanognathus-Semiacontiodus* biofacies are determined. These biofacies represent middle to outer carbonate ramp environments for 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 Cerro La Silla section, which could be related to transgressive systems tracts (TST) that occurred during the Early and Middle Ordovician (middle Tremadocian-early Dapingian).

RÉSUMÉ

Biofaciès à conodontes ordoviciens de la partie supérieure de la formation La Silla et de la formation San Juan (Tremadocien moyen-Dapingien inférieur) du Cerro la Silla, précordillère argentine.

Les conodontes de la section du Cerro La Silla provenant de la partie supérieure de la formation La Silla (9,6 m de puissance) et de la formation San Juan (264,7 m de puissance) sont analysés afin d'identifier la dynamique faunistique, les biofaciès, ainsi que les changements de niveau marin. La collection de 11 388 spécimens a été récoltée après la dissolution de 41 échantillons de roches carbonatées, totalisant 88,155 kg. Les courbes d'abondance totale et de diversité générique des conodontes, associées à une analyse de groupes, révèlent sept biofaciès. Les biofaciès à *Colaptoconus*, *Tropodus-Reutterodus*, *Oepikodus-Prioniodus*, *Juanognathus-Bergstroemognathus*, *Juanognathus-Oepikodus-Protopanderodus*, *Juanognathus-Semiacontiodus*, indiquent des environnements de rampe carbonatée médians à externes pour la formation San Juan. L'analyse conjointe des biofaciès et de la lithologie permet l'identification, au sein de la formation de San Juan, de deux événements transgressifs qui peuvent être reliés aux cortèges des systèmes transgressifs (TST) qui se sont déroulés au cours de l'Ordovicien précoce et moyen (Tremadocien moyen-Dapingien précoce).

KEY WORDS

Conodont biofacies,
sea-level changes,
La Silla Formation,
San Juan Formation,
Ordovician,
Argentine Precordillera.

MOTS CLÉS

Biofaciès à conodontes,
changements
du niveau marin,
formation La Silla,
formation San Juan,
Ordovicien,
précordillère argentine.

INTRODUCTION

The La Silla and San Juan formations consist of carbonate rocks ranging from the upper Cambrian to the Middle Ordovician in the Central Precordillera of San Juan Province. The lithostratigraphy of these units was studied by various authors (e.g. Keller *et al.* 1994; Cañas 1995a, 1999; Sorrentino *et al.* 2009; Pratt *et al.* 2012).

Previous studies on conodont biofacies of the San Juan Formation were carried out by Albanesi (1998), Feltes *et al.* (2013), Serra *et al.* (2017), and Mango & Albanesi (2019) in various sections of the Central Precordillera, who recognized significant variations in the composition of the faunas. Considering the main changes of conodont associations through time, Albanesi & Bergström (2004, 2010) indicated that sea-level oscillations during the Lower-Middle Ordovician were the main cause of conodont diversity variation in the Argentine Precordillera.

Following Ludvigsen *et al.* (1986), a biofacies refers to an association of taxa recorded in a rock body, whose presence has paleoenvironmental significance. Changes in sedimentation rate can modify the rate of species abundance changes through a stratigraphic section and the rate of biofacies replacement. Accordingly, a decrease in sedimentation rate shall enhance the rate at which the fossil abundance and biofacies change (Patzkowsky & Holland 2012).

When the rate of lithofacies change is high (e.g. across a floodplain with abrupt facies drift towards the depocenter), the faunal change should be abrupt, in direct proportion to the degree of facies change observed (Patzkowsky & Holland 2012).

In order to apply these concepts, it is necessary to know the conodont life habit. Several models were proposed to explain the conodont distribution during the Ordovician; for instance, Seddon & Sweet (1971) proposed that conodonts were pelagic organisms, with separate species groupings in different strata of the marine water column. This model successfully explains the distribution of cosmopolitan and other widely distributed species. The model proposed by Barnes & Fähræus (1975) suggested that most Ordovician conodonts had a nektonic life habit, although genera with coniform multi-element apparatuses represented pelagic forms. According to the model proposed by Seddon & Sweet (1971), the conodont records could be used to depict sea-level curves.

At Cerro La Silla section (Figs 1; 2), the conodont fauna can be analyzed across the contact between the La Silla Formation and the overlying San Juan Formation. In addition, it is possible to study the conodont diversity from the lower-middle San Juan Formation and through the two reef levels that characterize the San Juan Formation. Studies on conodont biostratigraphy of the upper La Silla and San Juan formations exposed at Cerro La Silla were carried out by Lehnert (1995), Thalmeier (2014), and Mango & Albanesi (2020).

A detailed biofacies analysis comprising the upper La Silla and San Juan formations at Cerro La Silla section and a comparison with the Los Gatos Creek section at Cerro Viejo de Huaco are carried out herein. The objective of this study is to record possible modifications in the composition of the

conodont fauna across the basin; subsequently, by means of biofacial composition changes, we advance in the identification of sea-level variations that occurred in the Ordovician.

GEOLOGICAL SETTING

The San Juan Formation is a carbonate succession, over 330 m thick (Kobayashi 1937; emend Keller *et al.* 1994), made up of middle Tremadocian to Darriwilian skeletal micritic limestones deposited in a carbonate ramp environment (Cañas 1995b; Mango & Albanesi 2020). The formation has two reef levels; the lower one consists of calcimicrobials and sponges (Cañas & Carrera 2003), middle Tremadocian in age (Mango & Albanesi 2020), whereas the upper one integrates mainly stromatoporoids (*Zondarella*), microbialites, and receptaculitids (*Calathium*) (Cañas & Carrera 2003) of early Dapingian age (Mango & Albanesi 2020).

Cañas (1995b, 1999) recognized a transgressive-regressive-transgressive sequence representing two transgressive-regressive cycles for the San Juan Formation. At Cerro La Silla, Bugisch *et al.* (2003) indicated the sequence boundaries of two transgressive-regressive cycles, which are located at the base of the San Juan Formation (type 2 sequence boundary) and at the base of the second reef level (type 2 sequence boundary), respectively.

MATERIAL AND METHODS

The study section is located at Cerro La Silla, in the eastern belt of the Central Precordillera of San Juan. Throughout the studied section 41 samples (about 2 kg each) were collected. Two samples were taken from the uppermost 9.6 m of the La Silla Formation and 39 samples from the overlying San Juan Formation, 264.7 m in thickness.

The carbonate samples were processed using the laboratory techniques of Stone (1987) (digestion in 10% acetic acid solution). For each processed sample, an insoluble residue was recovered weighting between 10 and 150 g, according to the limestone composition. Afterward, the picking method was carried out on the entire residue, recovering all conodont elements. The study collection consists of 11 388 conodont elements that were thoroughly identified and mounted on slides. Selected conodonts representing key species were illustrated by conventional optical photomicrography. The microfossil collection is housed at the Museo de Paleontología, Universidad Nacional de Córdoba, under repository code CORD-MP.

For the biofacies analysis, identified specimens were counted and a database of total abundance of conodont elements per genus, per sample, was performed (Tables 1; 2).

The total abundance (total conodont elements per sample) and the generic diversity graphs (number of genera per sample) of this database were prepared with Microsoft Excel. The data were analyzed using the average linkage method (UPGMA) and the similarity was quantified using the Morisita index (Morisita 1959) because of the particular insensitive response

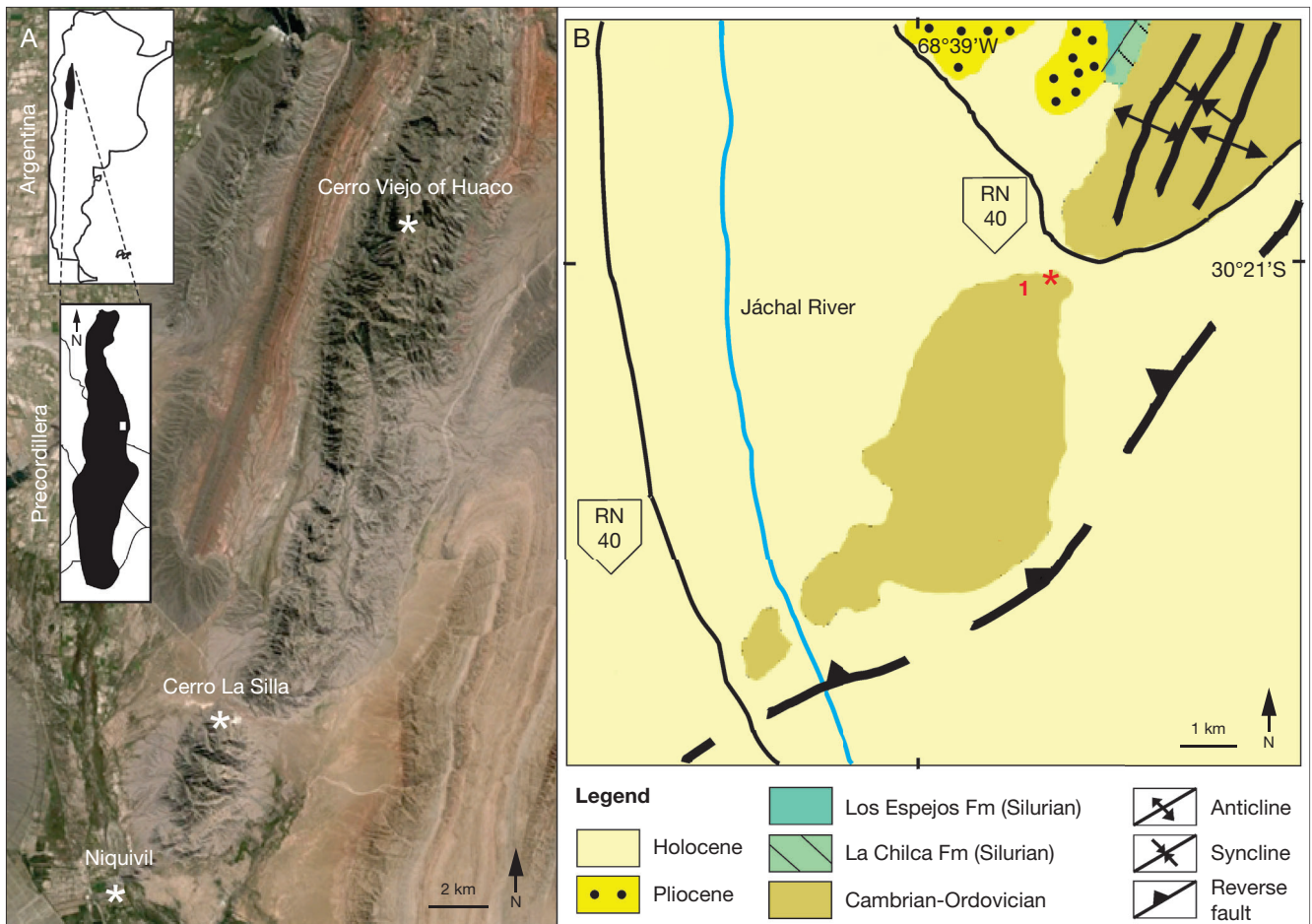


FIG. 1. — **A**, Satellite image with geographical location of the Cerro Viejo of Huaco, Cerro La Silla and Niquivil sections; **B**, geological map of the study area and location of the stratigraphic section. 1*, Cerro La Silla section.

to sample size (Hammer & Harper 2006). The latter procedure was carried out at generic level. Multivariate analysis was carried out using the PAST program (Hammer *et al.* 2001; Hammer & Harper 2006).

The cluster analyses were divided into two parts related to stratigraphy, which were separated by the *Prioniodus elegans* to *Oepikodus evae* zonal boundary. In order to obtain more reliable results, these studies were conducted using samples containing more than 30 conodont elements. Each cluster analysis was performed with genera containing more than 5 conodont elements in at least one sample.

Total abundance is divided into low (0–50 specimens per sample), medium (51–100 specimens per sample), and high (>100 specimens per sample). Generic diversity is divided into low (1–10 genera per sample), medium (11–20 genera per sample), and high (>20 genera per sample).

LITHOLOGY

In order to obtain robust paleoenvironmental interpretations, the sedimentological characteristics related to each biofacies are analyzed as complement support. For this purpose, the lithology of the San Juan Formation in the study section is briefly described.

The San Juan Formation is 264.7 m thick at Cerro La Silla (Mango & Albanesi 2020) (Fig. 3). As mentioned in the geological setting, the earliest reef level (LSSJ 2 and LSSJ 3) is situated in its lowermost part (middle Tremadocian in age), which is composed mostly by boundstones (Fig. 2C, D). On the reef top, a thinning-upward succession (samples LSSJ 3 to LSSJ M) (*Macerodus diana* to upper *Prioniodus elegans* zones) is composed of packstones and brecciated grainstones in its lowermost part, while it consists of wackestones and isolated levels of packstones and brecciated grainstones towards its uppermost part.

The interval between samples LSSJ L3 and LSSJ H (upper *Prioniodus elegans* to *Oepikodus intermedius* zones) (Mango & Albanesi 2020) is composed of alternating wackestones and packstones with isolated levels of grainstones and brecciated grainstones (Fig. 2E).

The second reef level consists of boundstones (early Dapingian in age) (Mango & Albanesi 2020) (Fig. 2E, F). It is followed by another thinning-upward succession (samples LSSJ G to LSSJ tope+) (*Baltoniodus triangularis*–*Tripodus laevis* Zone). It is dominated by packstones and brecciated grainstones in its lower part, whereas the upper part is made up of wackestones and isolated levels of packstones. In addition, a K-bentonite bed is recorded in its upper part (Fig. 2H).

TABLE 1. — Total abundance of conodont genera from the upper La Silla Formation and San Juan Formation (samples LSLS 0 to LSSJ L1), Cerro La Silla section.

CONODONTS/ SAMPLE	LSLS -1	LSLS 0	LSSJ 0	LSSJ 1	LSSJ 2	LSSJ 3	LSSJ 4	LSSJ P2	LSSJ P1	LSSJ P	LSSJ O6	LSSJ O5	LSSJ O4	LSSJ O3	LSSJ O2	LSSJ O1	LSSJ O	LSSJ N	LSSJ M	LSSJ L3	LSSJ L2
<i>Acodus</i>	—	—	—	—	—	—	—	—	—	—	—	1	2	—	1	—	2	2	—	—	—
<i>Anodontus</i>	1	—	—	—	—	—	—	—	—	—	2	—	1	2	—	—	—	—	—	—	—
<i>Ansella</i>	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—
<i>Bergstroemognathus</i>	—	—	—	—	—	—	—	—	—	—	—	—	27	—	—	—	18	9	—	11	12
<i>Colaptoconus</i>	2	32	15	9	1	1	5	3	5	4	22	—	—	—	—	—	—	2	—	—	—
<i>Cornuodus</i>	—	—	—	—	—	—	—	—	—	2	—	—	1	1	—	2	5	18	4	—	—
<i>Diaphorodus</i>	—	—	—	—	—	—	—	—	—	3	—	—	9	8	3	1	106	42	4	—	—
<i>Drepanodus</i>	—	—	—	—	—	1	2	—	—	—	4	1	17	16	14	6	134	180	8	—	7
<i>Drepanoistodus</i>	—	—	—	—	1	—	—	—	—	5	2	2	4	—	2	—	49	14	1	2	2
<i>Juanognathus</i>	—	—	—	—	—	—	—	—	—	—	—	3	—	—	—	—	—	3	2	16	97
<i>Jumudontus</i>	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	5	4	—	—	—
<i>Kallidontus</i>	—	—	—	—	—	—	—	—	3	—	—	—	—	—	1	—	2	1	2	—	—
<i>Lundodus</i>	—	—	—	—	—	—	—	—	—	1	—	4	—	—	—	—	—	4	—	—	—
New, undescribed taxon	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	2	—	—
<i>Oelandodus</i>	—	—	—	—	—	—	—	—	—	—	—	4	9	7	13	1	163	254	7	4	—
<i>Oepikodus</i>	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	7	3,444	5	—	4
<i>Oistodus</i>	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	13	—	—
<i>Paltodus</i>	—	2	2	—	1	3	1	—	1	5	4	1	11	14	2	—	43	59	6	—	1
<i>Paracordylodus</i>	—	—	—	—	—	—	—	—	—	—	—	—	4	1	—	1	70	1	—	—	—
<i>Parapaltodus</i>	—	—	—	—	—	—	—	—	—	—	—	1	—	1	4	—	—	—	2	—	3
<i>Parapanderodus</i>	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	3
<i>Paroistodus</i>	—	—	—	—	—	—	—	—	1	4	14	2	14	9	8	—	179	415	7	1	1
<i>Periodon</i>	—	—	—	—	—	—	—	—	—	—	—	2	1	—	—	—	4	12	—	—	4
<i>Prioniodus</i>	—	—	—	—	—	—	—	—	—	—	—	1	15	—	6	4	84	637	—	—	17
<i>Protopanderodus</i>	—	—	—	—	—	—	—	—	—	3	1	21	9	16	4	115	133	20	12	43	—
<i>Protoprioniodus</i>	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	8	2	5	—	—
<i>Reutterodus</i>	—	—	—	—	—	—	—	—	—	—	—	1	28	18	23	8	287	296	17	2	20
<i>Rossodus</i>	—	—	—	—	—	—	—	—	—	—	—	1	—	4	8	—	28	49	1	—	2
<i>Scandodus</i>	—	—	—	—	—	—	—	—	—	1	—	—	1	1	1	—	5	3	—	—	—
<i>Scolopodus</i>	—	—	—	—	—	—	—	—	—	—	8	1	13	11	4	—	11	57	—	3	1
<i>Semiacontiodus</i>	—	—	—	—	—	—	—	—	—	—	—	2	—	—	—	—	—	—	—	—	—
<i>Tripodus</i>	—	—	—	—	—	—	—	—	—	—	—	—	—	—	4	—	—	5	—	—	—
<i>Tropodus</i>	—	—	—	—	—	—	—	—	—	5	4	13	11	27	53	21	227	68	21	—	27
<i>Variabiloconus</i>	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Total conodont elements per sample	3	36	0	9	3	5	8	3	10	28	66	41	189	131	165	48	1,553	5,720	127	51	244
Amount of processed material (g)	2,865	3,740	2,960	2,405	2,150	2,035	2,230	2,005	2,495	2,075	2,025	2,090	2,005	2,100	2,225	2,090	2,375	2,005	2,105	2,520	1,975
Insoluble material (g)	0	0	0	0	0	0	140	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Soluble material (g)	2,865	3,740	2,960	2,405	2,150	2,035	2,090	2,005	2,495	2,075	2,025	2,090	2,005	2,100	2,225	2,090	2,375	2,005	2,105	2,520	1,975

BIOFACIES

The biofacies determination is accomplished at the generic level following Ludvigsen *et al.* (1986) and Patzkowsky (1995), who considered that the identification of genera, instead of species, provides more reliable results. Paleoenvironmental interpretations based on multivariate analyses of conodont genera have earlier proven efficient (e.g. Driese *et al.* 1984, Rasmussen & Stouge 1995, 2018; Wu *et al.* 2014; Feltes *et al.* 2016). A further advantage with this method is that it allows inclusion of specimens that can only be determined at the generic level due to deficient preservation.

When analyzing the total abundance (Fig. 4A), a peak is mainly observed at sample LSSJ N. However, when the most productive samples (LSSJ O and LSSJ N) (Fig. 4B) are removed from the analysis, smaller peaks are detected. After this examination, two smaller total abundance intervals can be observed between samples LSSJ L3 and LSSJ J1, and between LSSJ I2 and LSSJ H2.

The generic diversity (Fig. 5) is low from the upper La Silla Formation (sample LSLS -1) to sample LSSJ P2 of San Juan Formation. Then it increases up to its maximum in sample LSSJ N, which coincides with the maximum peak of total

abundance (Fig. 4A); thereafter, the generic diversity (Fig. 5) decreases and oscillates between 5 and 20 genera per sample.

The cluster analyses (Figs 6; 7) reveal the biofacies of *Colaptoconus*, *Tropodus-Reutterodus*, *Oepikodus-Prioniodus*, *Juanognathus-Bergstroemognathus*, *Juanognathus-Oepikodus-Protopanderodus*, *Juanognathus-Protopanderodus* and *Juanognathus-Semiacontiodus* (Fig. 8), which share similarities with the conodont biofacies established by Mango & Albanesi (2019) from Cerro Viejo of Huaco.

COLAPTOCONUS BIOFACIES

Definition

The most abundant genus in the samples is *Colaptoconus* (Fig. 9D-J), being selected for the biofacies name and definition. The other genera have less than 14 conodont elements per sample and are not present in all of them.

Characteristics

This biofacies (Figs 6; 8) is recorded in the upper La Silla Formation (sample LSLS 0) and the lower San Juan Formation (sample LSSJ O6), in strata corresponding to the *Macerodus diana* Zone and the *Prioniodus elegans* Zone.

TABLE 2. — Total abundance of conodont genera from the upper La Silla Formation and San Juan Formation (samples LSSJ K2 to LSSJ tope+), Cerro La Silla section.

CONODONTS/ SAMPLE	LSSJ L1	LSSJ K2	LSSJ K1	LSSJ K	LSSJ J1	LSSJ J	LSSJ I2	LSSJ I1	LSSJ I	LSSJ H4	LSSJ H3	LSSJ H2	LSSJ H1	LSSJ H	LSSJ G	LSSJ F	LSSJ D	LSSJ B	LSSJ A+7	LSSJ tope+
<i>Anodontus</i>	—	—	—	—	—	—	—	—	1	—	—	—	—	1	1	—	1	1	—	1
<i>Ansella</i>	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	2	—	2	—
<i>Bergstroemognathus</i>	3	10	28	11	40	10	—	—	—	1	6	—	—	—	—	—	—	—	—	—
<i>Colaptoconus</i>	—	—	—	—	—	—	—	—	6	—	—	—	—	—	—	—	—	—	—	—
<i>Cooperignathus</i>	—	—	—	—	—	—	1	—	2	—	—	—	—	—	—	—	—	—	—	—
<i>Cornuodus</i>	—	—	—	4	1	—	1	1	7	1	4	—	1	—	—	2	2	—	2	—
<i>Diaphorodus</i>	—	2	—	3	—	1	—	—	—	—	1	—	—	—	—	—	1	—	—	—
<i>Drepanodus</i>	1	21	7	29	4	3	9	26	18	6	16	—	7	—	—	—	1	—	—	1
<i>Drepanoistodus</i>	—	8	1	4	—	1	2	15	24	—	1	1	2	—	—	2	2	1	2	2
<i>Erraticodon</i>	—	—	—	—	—	—	—	—	2	—	—	—	—	—	—	—	—	—	—	—
<i>Fahraeusodus</i>	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
<i>Juanognathus</i>	17	67	79	157	15	41	12	68	103	—	19	1	1	—	1	2	8	14	21	20
<i>Jumudontus</i>	—	—	—	—	1	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—
<i>Kallidontus</i>	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
<i>Lundodus</i>	—	—	1	6	1	—	1	—	1	—	—	—	—	1	—	1	—	—	—	—
New, undescribed taxon	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—
<i>Oelandodus</i>	2	1	—	3	—	—	—	—	1	2	—	—	—	—	1	—	—	1	—	—
<i>Oepikodus</i>	—	66	11	179	3	1	6	196	80	6	7	—	1	—	—	—	2	—	—	—
<i>Oistodus</i>	—	—	—	—	—	2	—	8	39	6	6	—	4	—	—	—	13	—	1	3
<i>Paltodus</i>	1	2	3	19	4	—	1	4	4	3	4	—	2	—	—	—	—	—	1	—
<i>Paracordylodus</i>	—	—	—	1	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—
<i>Parapaltodus</i>	1	—	1	—	—	—	—	—	—	4	—	—	—	—	—	—	1	—	—	2
<i>Parapanderodus</i>	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	8
<i>Paroistodus</i>	—	2	8	31	3	—	6	20	8	9	7	—	10	—	—	—	—	—	—	—
<i>Periodon</i>	—	5	—	60	2	2	5	3	72	2	13	—	2	—	—	1	2	1	1	—
<i>Prioniodus</i>	—	2	—	—	—	—	—	4	—	—	—	—	—	—	—	—	—	—	—	—
<i>Protopanderodus</i>	3	34	34	87	23	12	34	81	148	24	27	2	7	—	—	4	8	3	—	—
<i>Pteracontiodus</i>	—	—	—	8	—	—	—	1	—	—	—	—	—	—	—	—	—	2	—	—
<i>Reutterodus</i>	1	18	11	39	5	12	—	—	—	—	—	—	—	—	—	—	—	—	—	—
<i>Rossodus</i>	—	8	—	1	—	—	—	7	16	—	—	1	—	—	—	9	1	4	—	—
<i>Scalpellodus</i>	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—
<i>Scolopodus</i>	—	32	5	7	19	2	—	—	2	—	—	—	—	—	—	—	3	—	—	—
<i>Semiacontiodus</i>	—	—	—	—	—	—	—	—	—	—	—	—	—	1	1	1	2	16	6	4
<i>Stolodus</i>	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2
<i>Texania</i>	—	1	—	—	—	—	—	—	2	—	—	—	—	—	—	—	—	—	—	—
<i>Trapezognathus</i>	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—
<i>Triangulodus</i>	—	—	—	—	—	—	—	—	3	—	—	1	—	—	—	—	6	—	4	—
<i>Tripodus</i>	—	—	—	—	—	—	—	—	—	—	—	—	—	1	1	5	2	2	3	2
<i>Tropodus</i>	5	6	37	10	—	5	—	—	1	3	4	—	—	—	—	1	—	—	—	—
Total conodont elements per sample	35	285	227	659	121	92	80	435	542	63	120	6	37	5	29	29	57	45	43	45
Amount of processed material (g)	2,075	2,140	2,155	2,080	2,120	2,055	2,010	2,105	2,175	2,005	2,400	2,105	2,005	2,255	2,535	2,310	2,355	2,295	2,315	2,770
Insoluble material (g)	0	0	0	0	0	0	0	0	0	0	20	0	0	0	10	0	50	0	0	0
Soluble material (g)	2,075	2,140	2,155	2,080	2,120	2,055	2,010	2,105	2,175	2,005	2,380	2,105	2,005	2,255	2,525	2,310	2,305	2,295	2,315	2,770

In sample LSL 0, a solitary record of the genus *Variabiloconus* is found, and the genus *Paltodus* appears. These first records may be artifacts, since underlying strata are not analyzed in the present study. *Scolopodus*, *Diaphorodus* and *Protopanderodus* make their first appearance in sample LSSJ O6.

The total abundance is low to medium (36–66 specimens per sample) and the generic diversity is low (3–10 genera per sample), increasing in sample LSSJ O6 (Figs 4; 5).

Sample LSL 0 bears almost exclusively *Colaptoconus* elements, while in sample LSSJ O6 its proportion decreases and the proportion of *Paroistodus* elements increases.

Remarks

Species of the genus *Colaptoconus* were recorded in inner to outer platform facies (Pohler 1994), as well as *Cornuodus*, *Scandodus*, *Scolopodus*, and *Lundodus*. In particular, Ji & Barnes (1994) recorded the *Glyptoconus* (synonym of *Colaptoconus*)-*Stultodontus* community, which is restricted to a constrained lithofacies, from peritidal to shallow subtidal environments

in Newfoundland. Similarly, other authors recorded communities where the elements of the genus *Colaptoconus* were abundant, and whose paleoenvironmental interpretation was restricted to shallow and warm environments (Ethington & Clark 1971; Fortey & Barnes 1977; Albanesi 1998). According to Pohler (1994), *Paroistodus* was a tolerant taxon, recovered from deposits of variable depth, otherwise Stouge (1984) indicated that it was typical of cold or deep waters.

Thus, the high proportion of *Colaptoconus* elements indicates shallow and warm environments. Otherwise, its decrease, followed by increasing number of *Paroistodus* elements (sample LSSJ O6), is related to a deepening event.

Associated lithology and environmental interpretation

The lithology consists of packstones (sample LSL 0) and wackestones (sample LSSJ O6) (Fig. 3). The comparison of biofacies and lithology from these strata supports a shallow and warm environment for the upper La Silla Formation (sample LSL 0). Whereas for sample LSSJ O6 a proximal-middle part

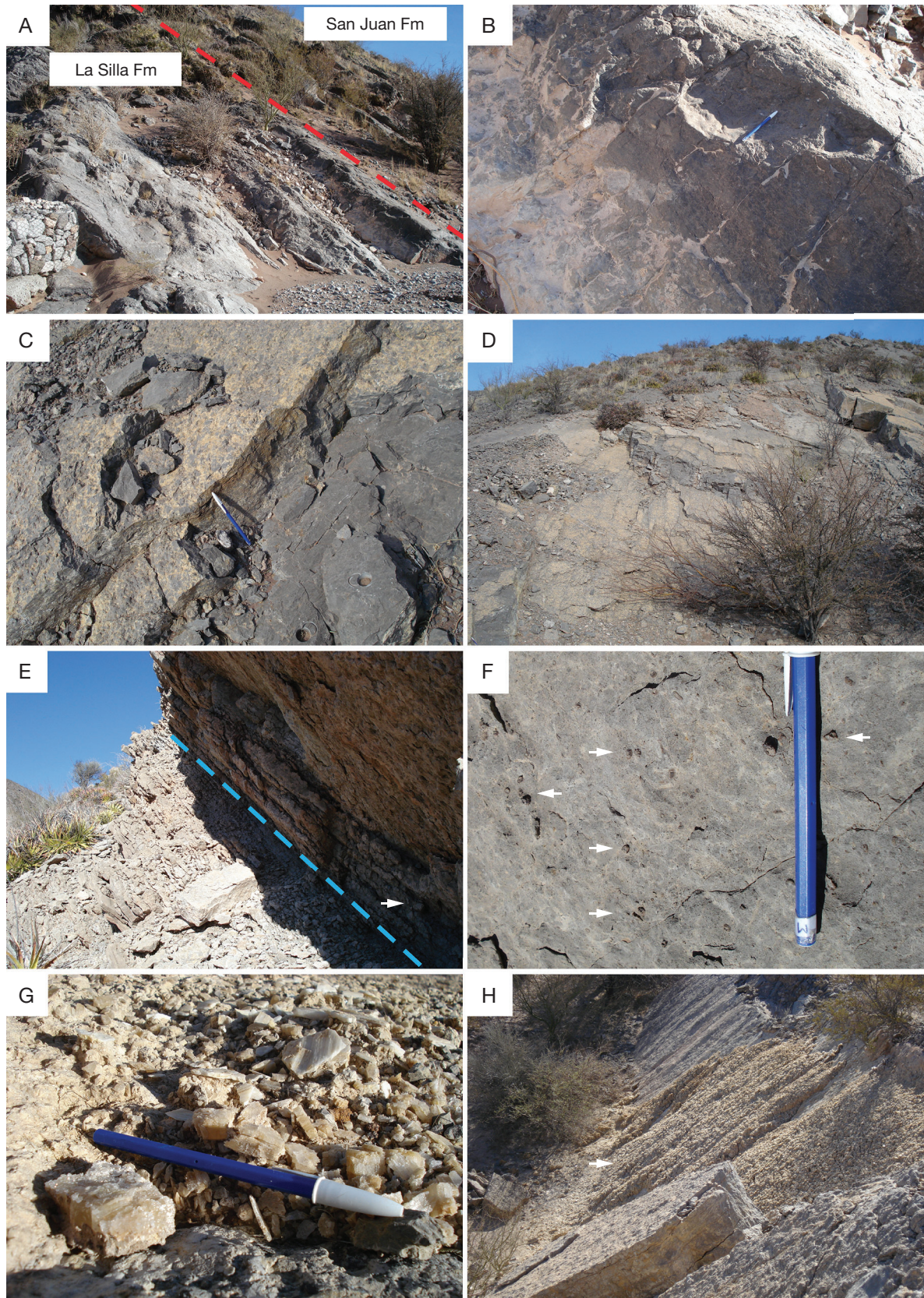


FIG. 2. — Photographs of the Cerro La Silla section: **A**, upper La Silla Formation (view to the SW); **B**, top stratum of the La Silla Formation (sample LSL5 0) (view to the SW); **C-H**, San Juan Formation: **C**, **D**, top of the lower reef, 12.6 m from the base of the formation (view to the E); **E**, base of the upper reef, 177.3 m from the base of the formation, indicated by the **arrow** (view to the SW); **F**, crinoid bases in living position, at the upper reef, indicated by the **arrows**; **G**, **H**, gypsum (**G**) and K-bentonite beds (indicated by the **arrow** in **H**) located in strata corresponding to the *Baltoniodus triangularis*-*Tripodus laevis* Zone (view to the NE).

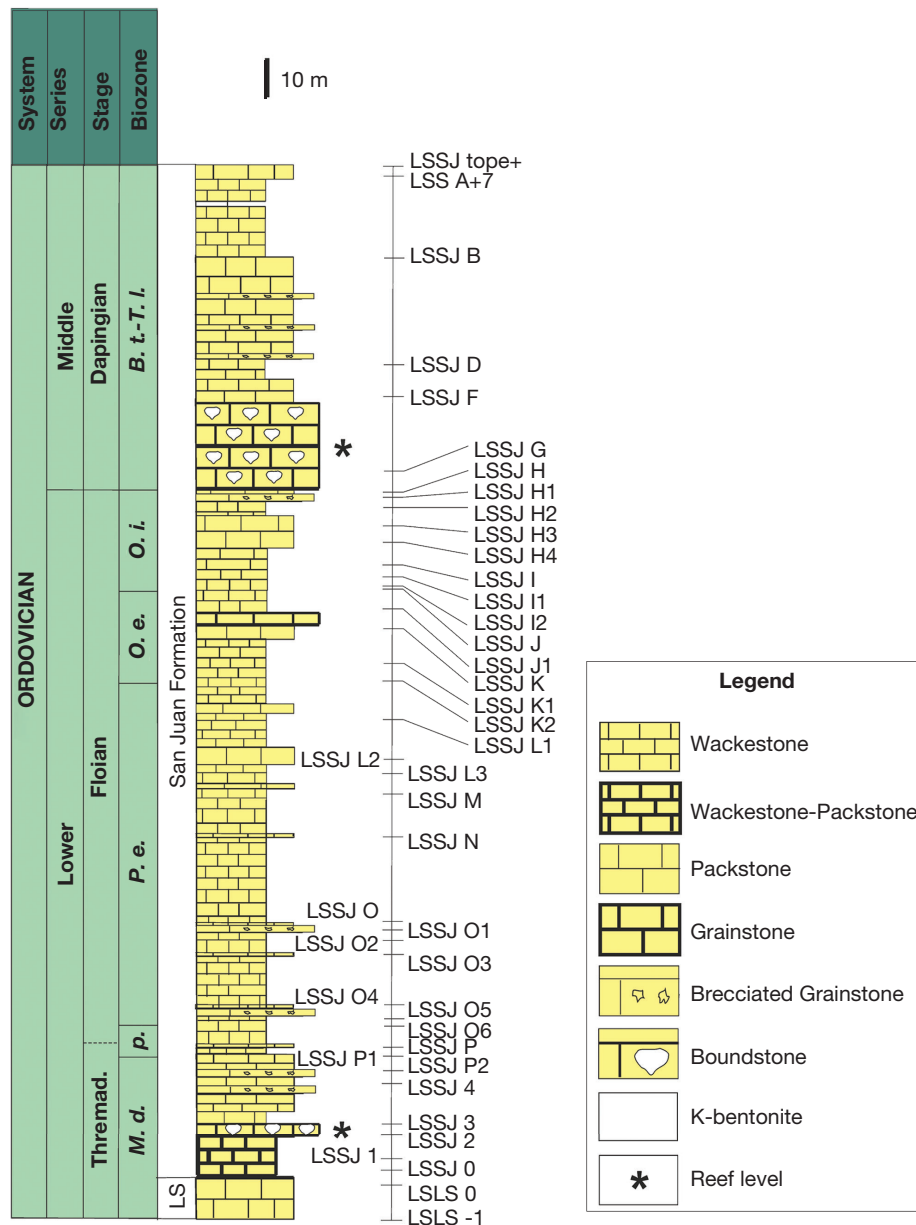


FIG. 3. — Stratigraphic column of the upper La Silla Formation and the San Juan Formation at the Cerro La Silla section. Abbreviations: **LS**, La Silla Formation; **M. d.**, *Macerodus diana* Zone; **p.**, *Paroistodus proteus* Zone; **P. e.**, *Prioniodus elegans* Zone; **O. e.**, *Oepikodus evae* Zone; **O. l.**, *Oepikodus intermedius* Zone; **B. t.-T. l.**, *Baltoniodus triangularis*-*Tripodus laevis* Zone.

of the middle ramp environment is interpreted. Thus, this biofacies settles in the inner and middle ramp environments.

TROPIDUS-REUTTERODUS BIOFACIES

Definition

This biofacies is defined by the most abundant genera per sample, which are *Tropodus* and *Reutterodus* (Fig. 9S-U, W-Y). The genera *Drepanodus*, *Protopanderodus*, *Paroistodus*, *Paltodus*, and *Oelandodus* occur in lower frequency.

Characteristics

The interval that comprises samples LSSJ O5 to LSSJ M (it is included), without sample LSSJ N, presents this biofacies (Figs 6; 8) (*Prioniodus elegans* Zone). The following genera

appear: *Reutterodus*, *Prioniodus*, *Paracordylodus*, *Rossodus*, *Bergstroemognathus*, *Oelandodus*, *Oistodus*, *Oepikodus*, *Parapaltodus*, *Periodon*, *Acodus*, *Jumudontus*, *Juanognathus*, *Tripodus*, *Semiacontiodus*, and *Parapanderodus*.

The total abundance and generic diversity (Figs 4; 5) of this interval are variable (40-1553 specimens per sample, 9-22 genera per sample).

Remarks

Tropodus was reported for inner to outer platform deposits in Newfoundland (Pohler 1994). Conversely, Wu *et al.* (2014) reported *Tropodus* as most abundant in shallow facies and warmer environments in the southern China platform, which can be related to the paleogeographic position of respective tectonic

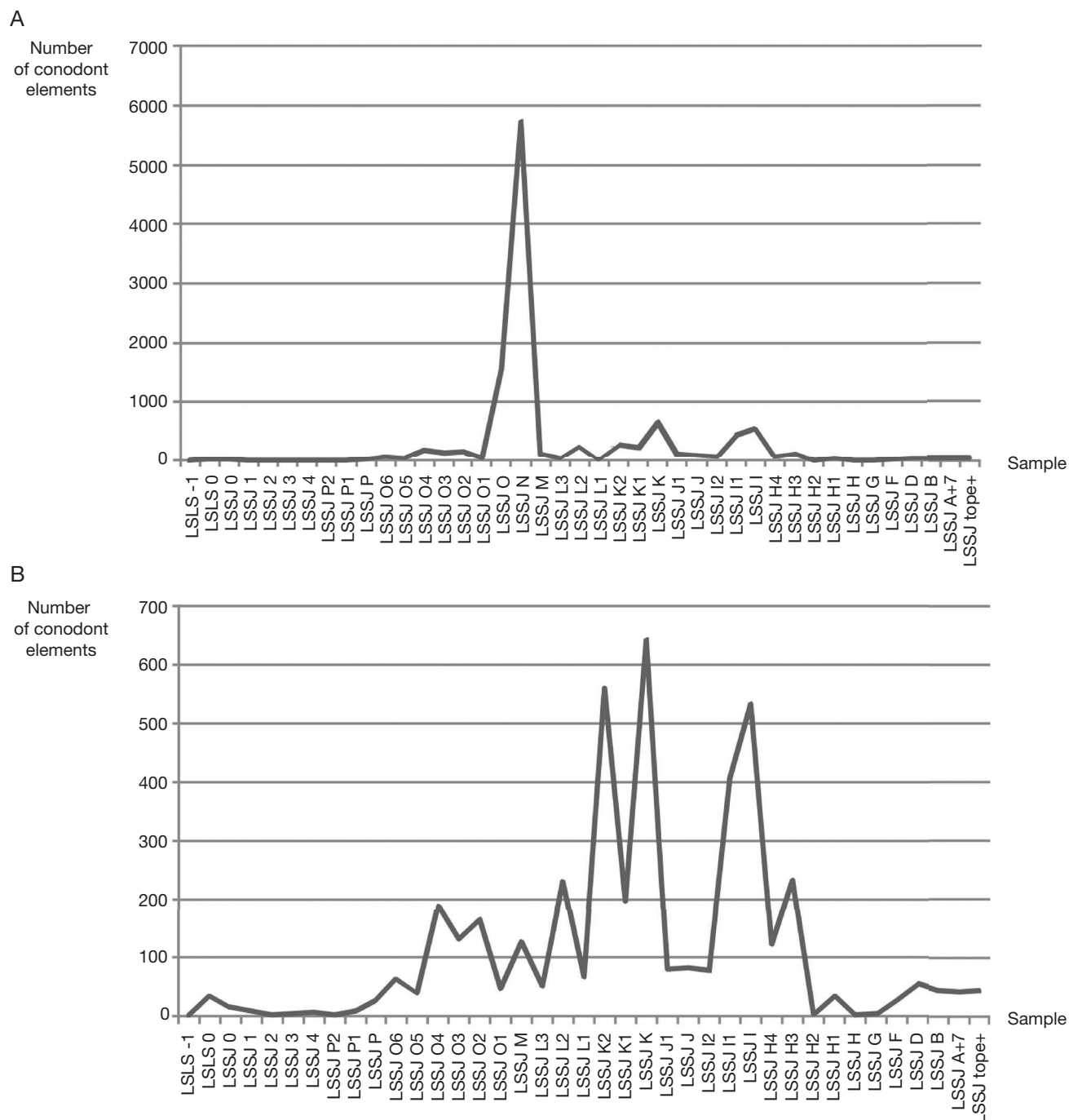


FIG. 4. — **A**, total abundance of conodonts per sample from the upper La Silla Formation and San Juan Formation, Cerro La Silla; **B**, total abundance of conodonts per sample excluding the more productive samples in conodont elements (LSSJ O and LSSJ N).

paleoplates. *Protopanderodus* was typical of facies from outer platform to slope, and *Paltodus* was found in facies ranging from inner platform to slope, though more abundant in inner to outer platform environments (Pohler 1994). Rasmussen & Stouge (2018) argued that *Protopanderodus* was typical within distal platform facies of cold-waters in the Baltoscandian Region, whereas *Drepanodus* was found from inner platform to slope. On the other hand, *Reutterodus* and *Tropodus* were found in middle to outer ramp facies in Argentina (Mango & Albanesi 2019).

This biofacies is typified by a number of genera adaptable to different sub-environments. In addition, *Protopanderodus* suggests a relatively deep sub-environment and cold-waters within the carbonate ramp for the levels studied.

Associated lithology and environmental interpretation

These strata are made up of wackestones, packstones, and brecciated grainstones in the lowermost part of this interval (Fig. 3). The combined characteristics from lithology and biofa-

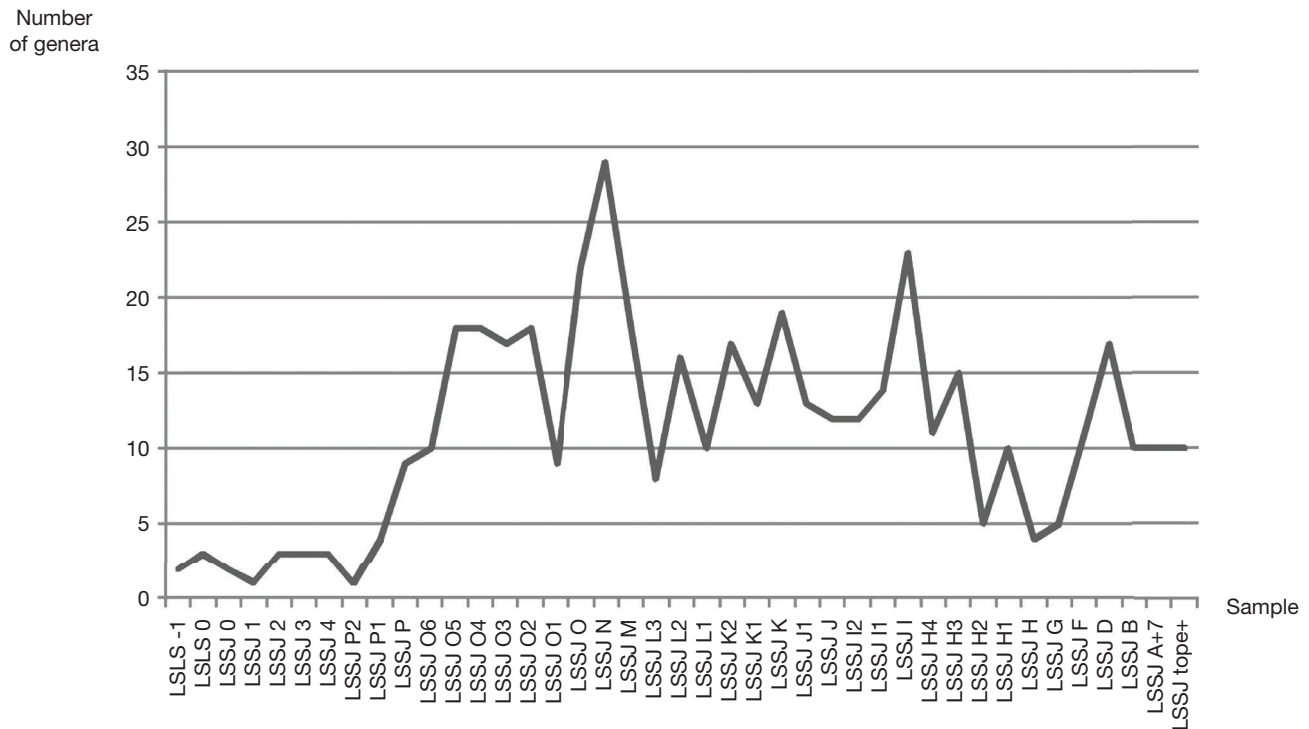


Fig. 5. — Generic diversity of conodonts per sample from the upper La Silla Formation and San Juan Formation, Cerro La Silla.

cies indicate a middle to outer ramp environment. Moreover, the occurrence of many new genera in this biofacies suggests a transgressive event.

OPEIKODUS-PRIONIODUS BIOFACIES

Definition

This biofacies is defined by the genera *Oepikodus* (3 444 elements of *Oepikodus communis* (Ethington & Clark, 1964)) and *Prioniodus* (637 elements), which are most abundant, being slightly more numerous than *Reutterodus* and *Paroistodus*.

Characteristics

The *Oepikodus-Prioniodus* Biofacies (Figs 6; 8) is recognized in sample LSSJ N (middle *Prioniodus elegans* Zone), where the first records of new, undescribed taxon and *Ansella* are found. At once, the genus *Acodus* has its latest occurrence.

The total abundance and generic diversity are high (5 748 specimens, 29 genera) (Figs 4; 5).

Remarks

In western Newfoundland, Pohler (1994) recorded the *Oepikodus communis* biofacies from the platform, the *Prioniodus-Textania* biofacies from the shelf edge, and the *Prioniodus-Paracordylodus* biofacies from the lower slope. Moreover, she observed that the abundance of *Oepikodus communis* was typical of shallow waters, while *Prioniodus* characterized the moderately deep to deep environments.

The combined occurrence of *Oepikodus communis* and *Prioniodus* together with less abundant *Reutterodus* and *Paroistodus* suggests an intermediate depth environment.

Associated lithology and environmental interpretation

The biofacies is restricted to a narrow packstone interval within the *Prioniodus elegans* Zone of the San Juan Formation (Fig. 3). Together, the lithology and biofacies indicate a middle ramp environment.

JUANOGNATHUS-BERGSTROEMOGNATHUS BIOFACIES

Definition

The eponymous genera of the biofacies are the most abundant in almost all samples (*Juanognathus* and *Bergstroemognathus*) (Fig. 9A-C, N-P), together with less abundant *Protopanderodus*. In this biofacies, *Juanognathus variabilis* Serpagli is the most abundant species of the genus.

Characteristics

This biofacies (Figs 6-8) is detected in samples LSSJ L3, LSSJ L2, LSSJ L1, LSSJ K1, LSSJ J1 and LSSJ J (i.e., upper *Prioniodus elegans* Zone, *Oepikodus evae* Zone and lower *Oepikodus intermedius* Zone). It presents the only record of the genus *Fahraeusodus*. In addition, the genera *Reutterodus* and *Kallidontus* have their latest occurrence.

The total abundance (Fig. 4) is variable (35-244 specimens per sample) and the generic diversity (Fig. 5) is low to medium (8-16 genera per sample).

Remarks

Juanognathus and *Bergstroemognathus* were referred as typical of the inner to outer platform by Pohler (1994), whereas, *Protopanderodus* was regarded as representative of the outer platform to slope facies. The genera *Juanognathus*, *Reutterodus*,

Bergstroemognathus, and *Diaphorodus* were considered typical of temperate waters by Bagnoli & Stouge (1991) and Albanesi & Bergström (2004). Wu *et al.* (2014) recorded an association of *Oepikodus*, *Paroistodus*, *Drepanoistodus*, *Protopanderodus*, *Juanognathus*, *Bergstroemognathus*, and *Diaphorodus* from a transgressive facies in China.

The presence of numerous *Juanognathus* and *Bergstroemognathus* elements, together with less abundant *Protopanderodus* suggest intermediate depth conditions.

Associated lithology and environmental interpretation

These strata are made up of wackestones and packstones (Fig. 3), whose conjunction with the biofacies refers to a middle ramp environment.

Similar biofacies in other areas

The *Juanognathus*-*Bergstroemognathus* Biofacies was also recognized at Cerro Viejo of Huaco (Mango & Albanesi 2019) and represents a middle ramp sub-environment in the lower San Juan Formation and middle to outer ramp sub-environment in its middle part, while at Cerro La Silla it represents a middle ramp sub-environment (Fig. 8). This difference is because the analysis was carried out to species level at Cerro Viejo of Huaco, while in this study it was carried out to genus level. Due to this, the *Juanognathus*-*Bergstroemognathus* Biofacies detected in the lower San Juan Formation at Cerro Viejo of Huaco has a similar genera association to the registered in this work; however, the same biofacies detected in the middle San Juan Formation at Cerro Viejo of Huaco has a different genera association, characterized by a greater number of elements of the genus *Oepikodus* in its upper part, which was adapted to middle to outer ramp sub-environments.

JUANOGNATHUS-OEPIKODUS-PROTOPANDERODUS BIOFACIES

Definition

The genera *Juanognathus* and *Oepikodus* (Fig. 9K-R) are the most abundant genera and they are used to define this biofacies, followed by *Protopanderodus*. The genus *Periodon* is abundant only in sample LSSJ K.

Characteristics

The *Juanognathus*-*Oepikodus*-*Protopanderodus* Biofacies is represented by samples LSSJ K2, LSSJ K and LSSJ I1 (Figs 7; 8) (i.e., *Oepikodus evae* Zone and lower *Oepikodus intermedius* Zone). It contains the only record of *Trapezognathus*. The earliest records of *Pteracantiodus* and *Texania* and the latest occurrence of *Prioniodus* are observed within this biofacies.

The total abundance is high (285-659 specimens per sample) and the generic diversity is medium (14-19 genera per sample) (Figs 4; 5).

Remarks

Pohler (1994) stated that *Juanognathus* inhabited inner to outer platform deposits, and *Oepikodus* was found in all the facies being more abundant in the platform facies. *Protopanderodus* characterized the outer platform to slope facies, and *Periodon* was found in slope and outer platform deposits, being more abun-

dant in the latter (Pohler 1994), with joint records of shallower environment species (Stouge 1984). According to Serra *et al.* (2017), the genus *Periodon* was frequent within outer platform deposits of the Precordillera. Rasmussen & Stouge (2018) demonstrated that in the Baltoscandian Region the *Protopanderodus* biofacies dominated the intermediate and distal platform areas facing colder waters, while the *Periodon* biofacies characterized the platform margin facing relatively warmer waters.

This biofacies is typified by a number of genera adapted to deep sub-environments. In addition, the abundance of *Oepikodus* elements (*O. evae* (Lindström, 1955) and *O. intermedius* (Serpagli, 1974)) suggests waters of equal or greater depth in relation to the *Juanognathus*-*Bergstroemognathus* Biofacies.

The *Evae* transgression is globally recognized (Barnes 1984) and it is associated to a shift positive in the $\delta^{13}\text{C}$ record in the Floian. Calner *et al.* (2014) analyzed samples of a Floian condensed succession from Öland, southern Sweden, and observed this shift positive in the $\delta^{13}\text{C}$ record. At Yangtze platform of China, Wu *et al.* (2020) detected a gradual positive $\delta^{13}\text{C}$ shift in the late Floian, ranging from the uppermost *Serratognathus diversus* Zone to the basal *Oepikodus evae* Zone. These zones are correlated with the upper *Prioniodus elegans* Zone to *Oepikodus evae* Zone in the Argentine Precordillera. In addition, Wu *et al.* (2020) made the correlation with the $\delta^{13}\text{C}$ curves of the Argentine Precordillera (Buggisch *et al.* 2003) and Ibex section, Utah, in North America (Edwards & Saltzman 2014).

Associated lithology and environmental interpretation

These strata consist of wackestones and packstones (Fig. 3). The combined lithological and biofacies characteristics indicate a middle to outer ramp paleoenvironment.

JUANOGNATHUS-PROTOPANDERODUS BIOFACIES

Definition

Juanognathus and *Protopanderodus* are the dominant genera and define the biofacies (Fig. 9K-P). In addition, *Oepikodus* and *Periodon* are common in sample LSSJ I.

Characteristics

This biofacies is detected in samples LSSJ I2, LSSJ I, LSSJ H4, and LSSJ H3 (Figs 7; 8) (*Oepikodus intermedius* Zone). The genera *Cooperignathus* and *Erraticodon* together with *Triangulodus* record their first appearance. Moreover, the uppermost records of *Bergstroemognathus*, *Colaptoconus*, *Texania*, *Jumudontus*, and *Paracordylodus* are reported.

The total abundance and the generic diversity are medium to high (63-542 specimens per sample, 11-23 genera per sample) (Figs 4; 5).

Remarks

Pohler (1994) recorded the genus *Juanognathus* within inner to outer platform deposits and *Protopanderodus* through outer platform to slope facies. According to Rasmussen & Stouge (2018), the *Protopanderodus* biofacies dominated the intermediate and distal platform areas facing colder waters.

The particular abundance of *Juanognathus* and *Protopanderodus* suggest cold waters in a moderate depth environment.

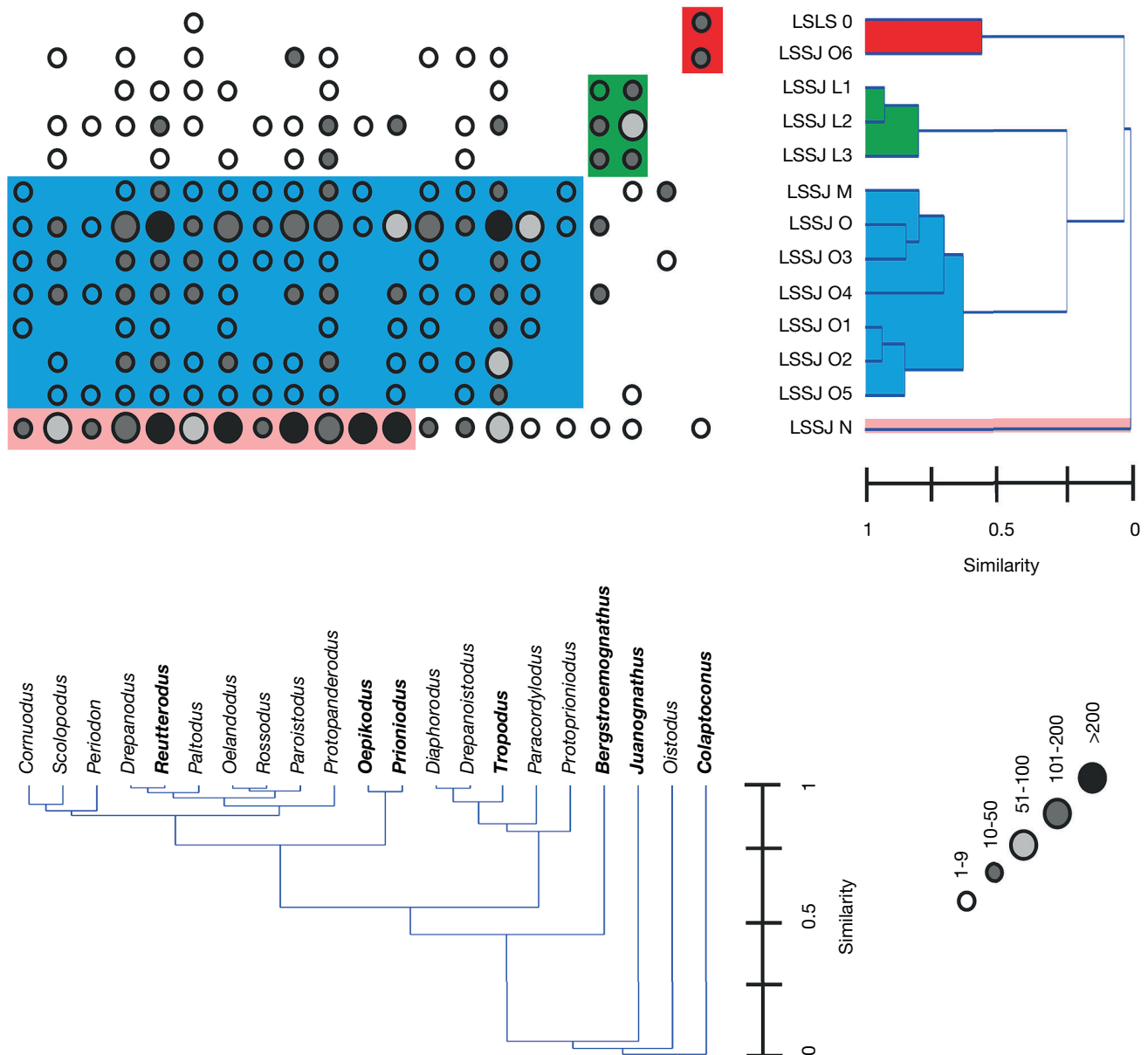


FIG. 6. — Two-way cluster analysis of conodont assemblages by use of the Morisita index of one conodont-bearing sample of the upper La Silla Formation and 12 of the San Juan Formation at the Cerro La Silla section (*Macerodus diana* to *Prioniodus elegans* zones). Limestone samples locate in Q-mode clustering order and conodont genera locate in R-mode clustering order (see Legendre & Legendre 1998, for a good explanation of Q-mode and R-mode analyses). Genera abundance expressed as graded series of dots. Colors: **red**, *Colaptoconus* Biofacies; **light blue**, *Tropodus-Reutterodus* Biofacies; **pink**, *Oepikodus-Prioniodus* Biofacies; **green**, *Juanognathus-Bergstroemognathus* Biofacies. **Bold**, significant conodont genera for biofacial determination.

Associated lithology and environmental interpretation

These strata are made up of wackestones and packstones (Fig. 3), and the combination of lithology and biofacies indicate the proximal-middle part of the middle ramp environment. In addition, the latest occurrence of several genera indicates an overall regressive phase during this part of the strata.

JUANOGNATHUS-SEMIACONTIODUS BIOFACIES

Definition

The most abundant genus is *Juanognathus*, whereas *Semiacontiodus* follows it (Fig. 9K-M, V). Both genera define the

biofacies. In the involved interval, *Juanognathus jaanussoni* Serpagli is the dominant species of the genus.

Characteristics

The *Juanognathus-Semiacontiodus* Biofacies occurs in the uppermost part of the studied section (Figs 7; 8), comprising samples LSSJ B, LSSJ A+7, and LSSJ tope+ (top stratum of the San Juan Formation) and was dated biostratigraphically to the *Baltoniodus triangularis-Tripodus laevis* Zone. The genus *Stolodus* is restricted to this biofacies and biozone in the studied section. A similar but not identical situation was reported from the Herram section of Norway by Rasmussen (2001),

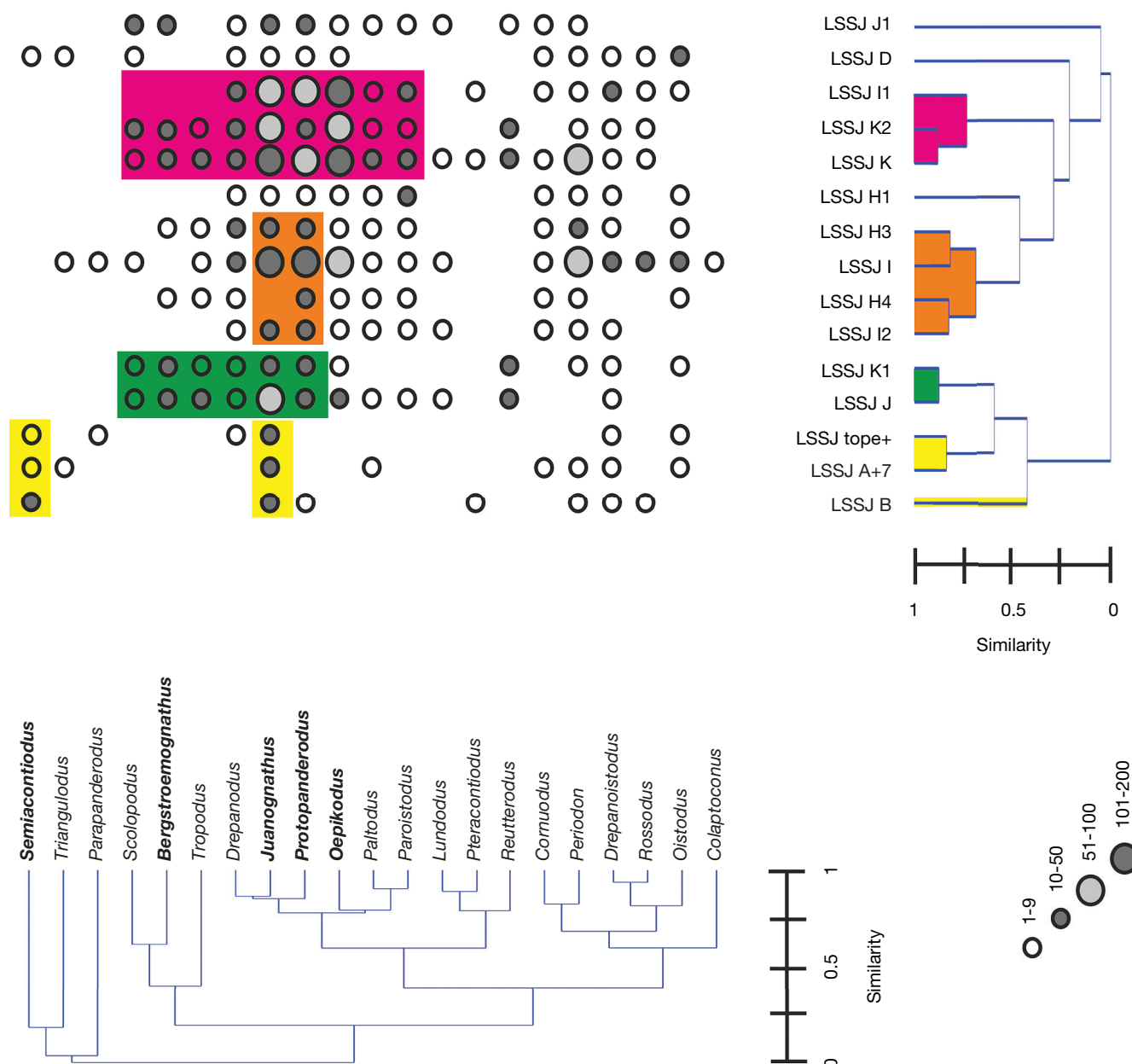


FIG. 7. — Two-way cluster analysis of conodont assemblages by use of the Morisita index of fifteen conodont-bearing samples of the San Juan Formation at the Cerro La Silla section (*Oepikodus evae* to *Baltoniodus triangularis*-*Tripodus laevis* zones). Limestone samples locate in Q-mode clustering order and conodont genera locate in R-mode clustering order (see Legendre & Legendre 1998, for a good explanation of Q-mode and R-mode analyses). Genera abundance expressed as graded series of dots. Colors: **green**, *Juanognathus*-*Bergstroemognathus* Biofacies; **fuchsia**, *Juanognathus*-*Oepikodus*-*Protopanderodus* Biofacies; **orange**, *Juanognathus*-*Protopanderodus* Biofacies; **yellow**, *Juanognathus*-*Semiacontiodus* Biofacies. **Bold**, significant conodont genera for biofacial determination.

where *Stolodus* was reported from the *Microzarkodina flabellum*-*Drepanoistodus forceps* Zone in an outer platform environment.

The total abundance and the generic diversity are low (43-45 specimens per sample, 10 genera per sample, respectively) (Figs 4; 5).

Remarks

Semiacontiodus has been documented from shallow to moderate depth environments (Pohler 1994; Rasmussen & Stouge 1995, 2018; Löfgren 1999; Carlorosi *et al.* 2019), meanwhile the contemporaneous *Juanognathus*, as previously mentioned,

typified inner to outer platform facies. Zeballo & Albanesi (2013) interpreted *Semiacontiodus* as a pelagic genus with tolerance and/or preference for low oxygenation conditions.

The association of *Juanognathus* and *Semiacontiodus* indicates shallow to moderate waters-depths, similar to the *Colaptoconus* Biofacies.

Associated lithology and environmental interpretation

These strata consist of wackestones and packstones (Fig. 3), whose lithology and biofacies refer to the proximal-middle part of the middle ramp environment.

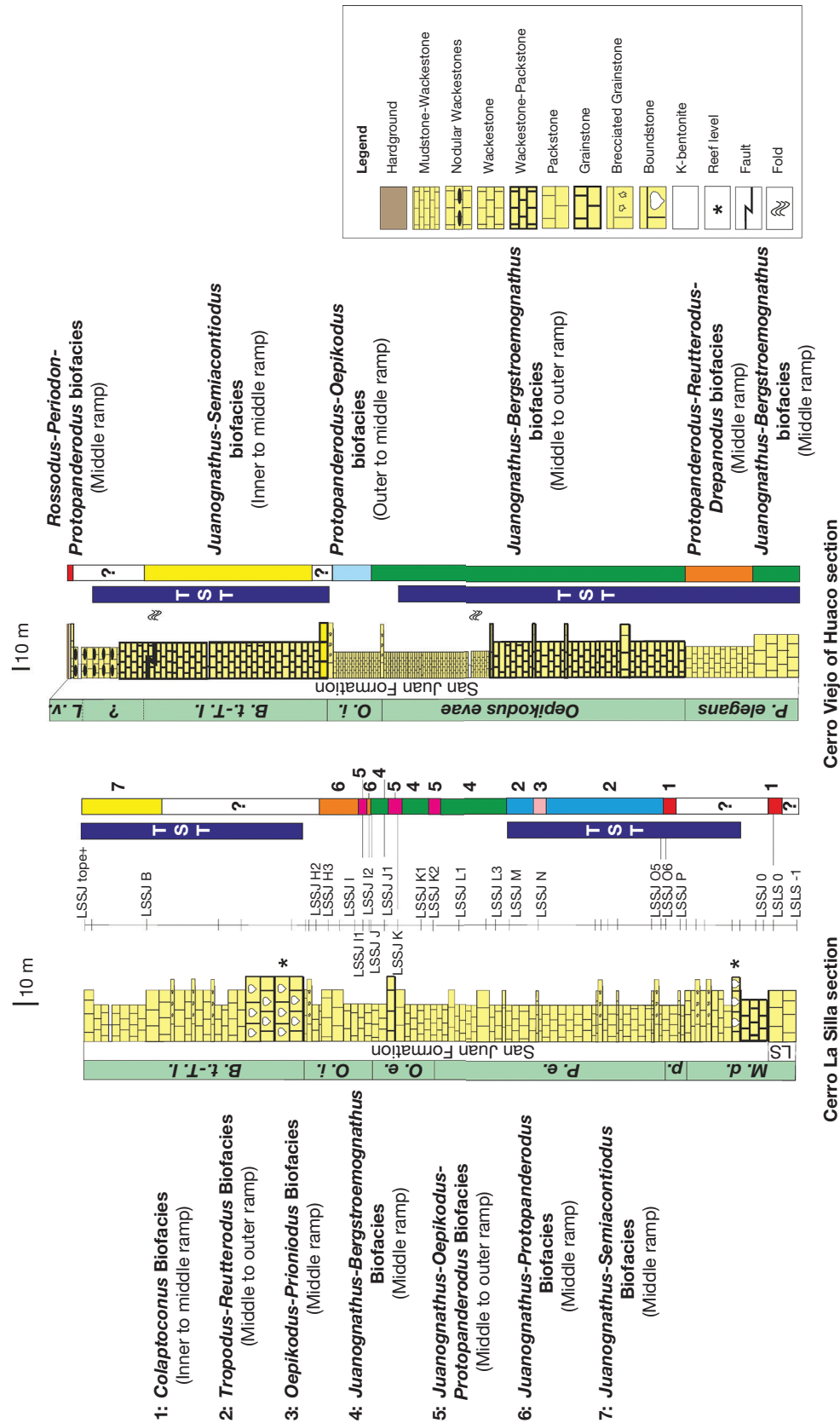


FIG. 8. — Stratigraphic columns of the upper La Silla Formation and the San Juan Formation at the Cerro La Silla section, and the San Juan Formation at the Cerro Viejo of Huaco section (modified from Mango & Albanesi 2020), with the conodont zones, conodont biofacies ranges, paleoenvironments and transgressive systems tracts. Abbreviations: **LS**, La Silla Formation; **M. d.**, *Macrodus diana* Zone; **p.**, *Paroistodus proteus* Zone; **P. e.**, *Prioniodus elegans* Zone; **O. e.**, *Oepikodus evae* Zone; **O. i.**, *Oepikodus intermedius* Zone; **B. t.-T. l.**, *Baltoniodus triangularis-Tripodus laevis* Zone; **L. v.**, *Lenodus variabilis* Zone; **D.**, *Darriwilian*.



FIG. 9. — Significant conodont species for biofacial determination from the upper La Silla Formation and San Juan Formation at Cerro La Silla: **A–C**, *Bergstroemognathus extensus* Serpagli, 1974: **A**, Sa element, sample LSSJ O4, CORD-MP 62193; **B**, Sc element, sample LSSJ O, CORD-MP 62194; **C**, P element, sample LSSJ K, CORD-MP 62195; **D, E**, *Colaptoconus priscus* (Ji & Barnes, 1994): **D**, a element, sample LSLs 0, CORD-MP 62379; **E**, f element, sample LSSJ 1, CORD-MP 62380; **F–J**, *Colaptoconus quadraplicatus* (Branson & Mehl, 1933): **F**, a element, sample LSLs 0, CORD-MP 62387; **G**, b element, sample LSLs 0, CORD-MP 62388; **H**, c element, sample LSLs 0, CORD-MP 62389; **I**, e element, sample LSLs 0, CORD-MP 62390; **J**, f element, sample LSLs 0, CORD-MP 62391; **K–M**, *Juanognathus jaanussoni* Serpagli, 1974: **K**, b element, sample LSSJ I, CORD-MP 63427; **L**, c element, sample LSSJ I, CORD-MP 63428; **M**, e element, sample LSSJ tope+, CORD-MP 63429; **N–P**, *Juanognathus variabilis* Serpagli, 1974: **N**, b element, sample LSSJ K, CORD-MP 63716; **O**, c element, sample LSSJ K, CORD-MP 63717; **P**, f element, sample LSSJ K, CORD-MP 63719; **Q, R**, *Oepikodus intermedius* (Serpagli, 1974): **Q**, Sb element, sample LSSJ I, CORD-MP 68400; **R**, Pa element, sample LSSJ I, CORD-MP 68403; **S, U**, *Reutterodus andinus* Serpagli, 1974: **S**, M element, sample LSSJ K, CORD-MP 71743; **T**, Sb element, sample LSSJ O, CORD-MP 71744; **U**, P element, sample LSSJ O, CORD-MP 71747; **V**, *Semiacontiodus potrerillensis* Albanesi, 1998, e element, sample LSSJ tope+, CORD-MP 72861; **W, Y**, *Tropodus sweeti* (Serpagli, 1974): **W**, M element, sample LSSJ O, CORD-MP 73091; **X**, Sb element, sample LSSJ O, CORD-MP 73092; **Y**, P element, sample LSSJ O, CORD-MP 73095. Scale bars: 100 µm.

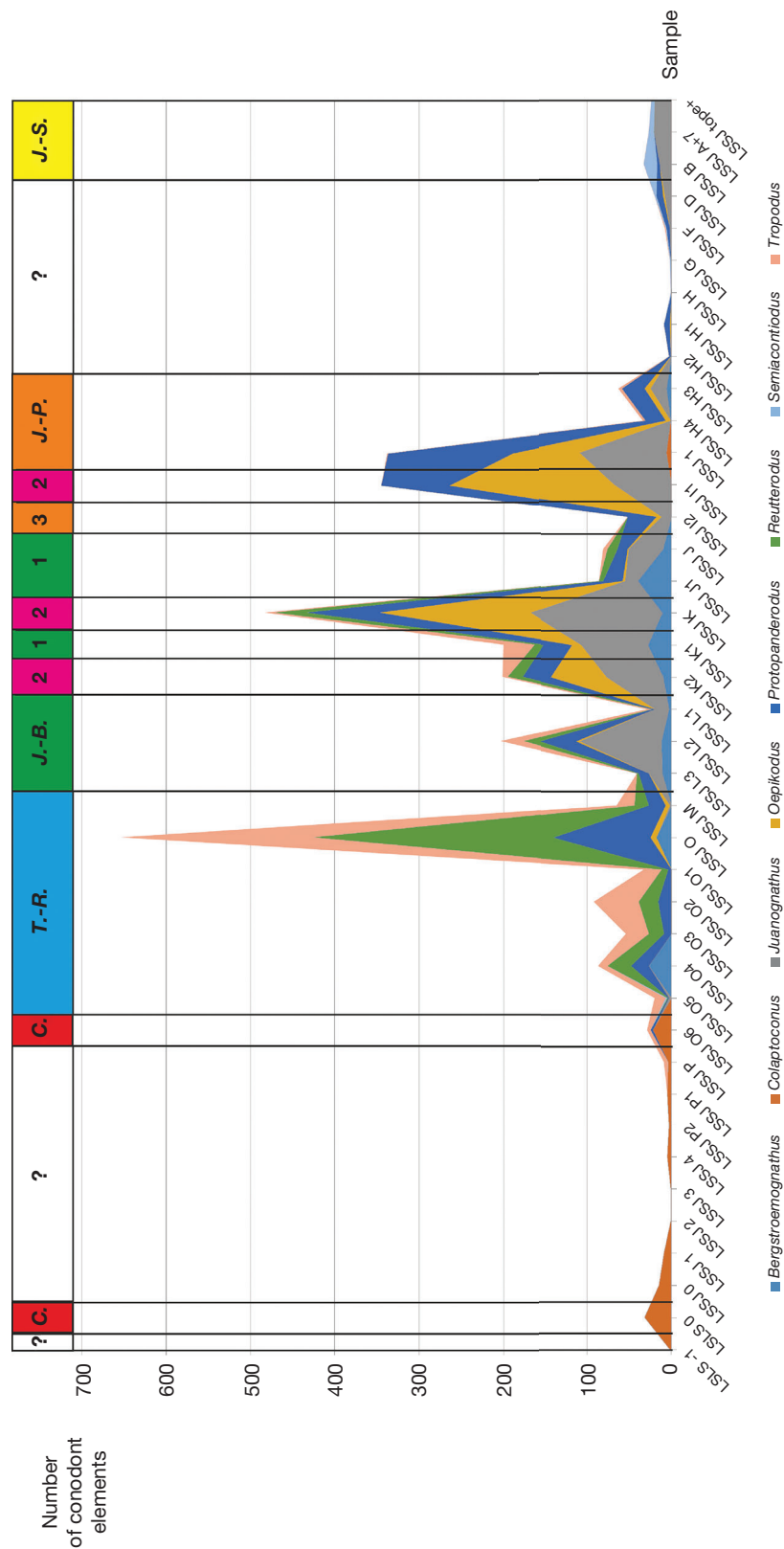


FIG. 10. — Total accumulated abundance of most significant genera from the upper La Silla Formation and the San Juan Formation, without most productive sample (LSSJ N-*Oepikodus-Prioniodus* Biofacies). Abbreviations: **C.**, *Colaptoconus* Biofacies; **T.-R.**, *Tropodus-Reutterodus* Biofacies; **J.-B.** and **1**, *Juanognathus-Bergstroemognathus* Biofacies; **2**, *Juanognathus-Oepikodus-Protopanderodus* Biofacies; **J.-P.** and **3**, *Juanognathus-Protopanderodus* Biofacies; **J.-S.**, *Juanognathus-Semiacontiodus* Biofacies.

Similar biofacies in other areas

The *Juanognathus-Semiacontiodus* Biofacies was also detected at Cerro Viejo of Huaco (Mango & Albanesi 2019). In this section, an inner to middle ramp sub-environment is interpreted, while at Cerro La Silla a middle ramp sub-environment (Fig. 8) is interpreted. At Cerro La Silla section there are not enough conodonts to identify a biofacies safely within the upper reef level, deposited in an inner ramp; notwithstanding that, the conodont association recorded in this part is similar to overlying levels.

SEA-LEVEL CHANGES

Conodont associations, similar to those described here, have been reported from several basins worldwide (Stouge 1984; Pohler 1994; Löfgren 1999; Albanesi *et al.* 2006; Zeballo & Albanesi 2013; Wu *et al.* 2014; Rasmussen & Stouge 2018; Carlorosi *et al.* 2019), which allow correlation of the recognized biofacies and sea-level changes.

Figure 10 shows the abundance of most significant genera of the upper La Silla Formation and exposed part of the San Juan Formation. However, in the most productive sample (LSSJ N) that belong to the *Oepikodus-Prioniodus* Biofacies, the genus *Oepikodus* displays such a strong peak that weakens or obliterates all the other genus curves. For this reason, the sample has been excluded from the figure.

The upper La Silla Formation (LSLS 0) is characterized by low to moderate abundance and low generic diversity (Figs 4; 5). It is dominated by packstones (Fig. 3) which contain conodonts of the *Colaptoconus* Biofacies (Figs 8; 10). This biofacies refers to a shallow-warm environment, as supported by the lithology as well.

The conodont abundance in the lowermost part of the San Juan Formation is, in most cases, too low to produce reliable biofacies results (Figs 8; 10). In this interval is situated a reef structure developed with boundstones of inner ramp (samples LSSJ 2 and LSSJ 3) (Fig. 3).

Sample LSSJ O6 is made up of wackestones with the *Colaptoconus* Biofacies. This litho/biofacial relationship refers to the proximal-middle part of a middle ramp, implying a depth increase from sample LSSJ 2.

In sample LSSJ O5, the lithology is similar but both conodont abundance and generic diversity are different in regard to sample LSSJ O6. The *Colaptoconus* Biofacies is replaced by the *Tropodus-Reutterodus* Biofacies (Figs 8; 10) and the total abundance increases towards sample LSSJ O4 (Fig. 4). In the upper interval of this biofacies, the lithology is composed mainly of wackestones (Fig. 3) which, together with the biofacies, indicates a deepening middle to outer ramp. Moreover, the occurrence of numerous new genera in the *Tropodus-Reutterodus* Biofacies is indicative of a transgressive event.

The total abundance and generic diversity (Figs 4; 5) reach a maximum peak in sample LSSJ N, where the *Tropodus-Reutterodus* Biofacies is replaced by the *Oepikodus-Prioniodus* Biofacies. Sample LSSJ N is the only that presents this particular middle ramp biofacies, which is followed by sample LSSJ M that repeats the *Tropodus-Reutterodus* Biofacies.

The total abundance and generic diversity decrease from sample LSSJ N towards sample LSSJ L3, where the *Tropodus-Reutterodus* Biofacies is replaced by the *Juanognathus-Bergstroemognathus* Biofacies (Fig. 10).

In the interval between samples LSSJ L3 and LSSJ L1 (*Juanognathus-Bergstroemognathus* Biofacies), the generic diversity is low to moderate (Fig. 5), while the total abundance is variable (Fig. 4). The lithology is composed of wackestones and packstones. This biofacies and particular lithology refer to a middle ramp and shallowing process given the conodont association and the increasing grain size of the sediments.

Above these levels, from sample LSSJ K2 to LSSJ I1, a biofacies overturn is recorded. Samples LSSJ K2, LSSJ K and LSSJ I1 represent the *Juanognathus-Oepikodus-Protopanderodus* Biofacies. It alternates with the *Juanognathus-Bergstroemognathus* Biofacies in the lower part (LSSJ K1, LSSJ J1 and LSSJ J) and the *Juanognathus-Protopanderodus* Biofacies in the upper part (LSSJ I2) (Figs 8; 10). The total abundance within the *Juanognathus-Oepikodus-Protopanderodus* Biofacies is high and the generic diversity is medium (Figs 4; 5). This biofacies is interpreted as indicative of middle to outer ramp deposits, though representing a deeper paleoenvironment than the *Juanognathus-Bergstroemognathus* Biofacies and the *Juanognathus-Protopanderodus* Biofacies. This is because the genus *Oepikodus* was most abundant in deeper environment than *Bergstroemognathus* and *Protopanderodus*.

The wackestone-packstone samples LSSJ I, LSSJ H4 and LSSJ H3 belong to the *Juanognathus-Protopanderodus* Biofacies, where the total abundance and generic diversity are medium to high. This biofacies, supported by the lithology, represents the proximal-middle part of the middle ramp, although shallower compared to the *Juanognathus-Oepikodus-Protopanderodus* Biofacies because the genus *Protopanderodus* was most abundant in shallower environment than *Oepikodus*. In addition, the latest occurrence of several genera in different samples indicates a shallowing process.

Buggisch *et al.* (2003) indicated a sequence boundary at the base of the upper reef (type 2 sequence boundary) of the San Juan Formation. It is followed by a thinning-upward succession (samples LSSJ G to LSSJ tope+).

Sample LSSJ G from the upper reef of the San Juan Formation (boundstones) contains to few conodont specimens to be safely assigned to a biofacies. This interval represents an inner ramp environment after a waning depth from the sample level LSSJ H.

The *Juanognathus-Semiacontiodus* Biofacies extends from sample LSSJ B up to the top of the San Juan Formation in the study section (sample LSSJ tope+). This biofacies is characterized by a low total abundance and generic diversity (Figs 4; 5), and occurs in wackestone and packstone-dominated deposits interbedding a K-bentonite stratum. This biofacies is interpreted as the proximal-middle part of the middle ramp.

Accordingly, the depth increases from the second level reef (LSSJ G) (Fig. 3) up to the top stratum (inner ramp to middle ramp environments) of the formation exposed in the study section (LSSJ tope+), representing a new transgressive event.

The general trend is an increase in the total abundance and the generic diversity from inner to outer ramp deposits. This may be related to several factors, such as the presence of a thicker water column for the habitat of conodonts on the outer ramp and less energy. These conditions promote a favorable habitat for the development of the conodont community, and/or less competition for food with other groups of organisms towards deeper sub-environments within the carbonate ramp.

Accordingly, two transgressive events are recognized in the limestone succession of the San Juan Formation at the Cerro La Silla section. The first one is detected from sample LSSJ 2 to LSSJ M (inner ramp to middle ramp and outer ramp environments). The second event is recorded from the second reef level (sample LSSJ G) to the top stratum of the San Juan Formation (sample LSSJ tope+) (inner ramp to middle ramp environments). The latter event can be related to a transgressive systems tract (TST) as recognized by Mango & Albanesi (2019) for Cerro Viejo of Huaco, and Cañas (1999) for other sections of the Central Precordillera of San Juan.

COMPARISON WITH BIOFACIES OF THE CERRO VIEJO OF HUACO SECTION

To the north of the Niquivil tectonic thrust, Mango & Albanesi (2019) studied biofacies of the San Juan Formation in the Cerro Viejo of Huaco section (Fig. 1), from the *Prioniodus elegans* Zone (lower Floian) to the *Lenodus variabilis* Zone (lower Darriwilian).

The *Juanognathus-Bergstroemognathus* Biofacies is recorded in Cerro Viejo of Huaco and Cerro La Silla (Fig. 8). However, in Cerro Viejo of Huaco it occurs in two intervals, the first one in the upper *P. elegans* Zone and the second one in the *O. evae* Zone and lower *O. intermedius* Zone; mediating between them the *Protopanderodus-Reutterodus-Drepanodus* biofacies. Whereas in Cerro La Silla it is observed in three successive intervals, the upper *P. elegans* Zone, the *O. evae* Zone, and the upper *O. evae* Zone and lower *O. intermedius* Zone; mediating the *Juanognathus-Oepikodus-Protopanderodus* Biofacies.

At Cerro Viejo of Huaco, Mango & Albanesi (2019) recorded the *Protopanderodus-Reutterodus-Drepanodus* biofacies (Fig. 8) that corresponds to the upper *Prioniodus elegans* Zone, with its upper boundary situated at the very top of the *P. elegans* Zone. It correlates stratigraphically partly with the *Juanognathus-Bergstroemognathus* Biofacies (Fig. 8) defined in this study. These biofacies represent more or less the same environment although they have different taxonomic compositions. The *Protopanderodus-Reutterodus-Drepanodus* biofacies described from the Cerro Viejo of Huaco section shows a greater abundance of genera adapted to the deepest environment within the middle ramp in relation to the biofacies of the Cerro La Silla section analyzed herein.

The *Juanognathus-Oepikodus-Protopanderodus* Biofacies is recognized in this study (Cerro La Silla) (Fig. 8). This biofacies is recorded in three levels of the upper *Oepikodus evae* Zone

and lower *Oepikodus intermedius* Zone, which can be correlated stratigraphically with the upper *Juanognathus-Bergstroemognathus* biofacies and the lower *Protopanderodus-Oepikodus* biofacies of Cerro Viejo of Huaco (Fig. 8) (Mango & Albanesi 2019). The *Juanognathus-Oepikodus-Protopanderodus* Biofacies shows a greater abundance of the genus *Oepikodus* adapted to deeper sub-environments within the carbonate ramp. This is also observed in the upper *Juanognathus-Bergstroemognathus* biofacies and the lower *Protopanderodus-Oepikodus* biofacies of Cerro Viejo of Huaco.

The *Protopanderodus-Oepikodus* biofacies at Cerro Viejo of Huaco (Fig. 8) (Mango & Albanesi 2019) can be partly correlated stratigraphically with the *Juanognathus-Protopanderodus* Biofacies of this study (Fig. 8). The *Protopanderodus-Oepikodus* biofacies ranges from the lower *O. intermedius* Zone to the boundary with the overlying zone in Cerro Viejo of Huaco, whereas in Cerro La Silla the conodont scarcity precludes the recognition of the biofacial development in the upper *O. intermedius* Zone. The biofacies recorded in Cerro Viejo of Huaco, in regard to Cerro La Silla, is characterized by a greater abundance of genera adapted to deeper sub-environments inside the carbonate ramp.

The *Juanognathus-Semiacontiodus* Biofacies was identified at Cerro Viejo of Huaco (Mango & Albanesi 2019) and also in the present (Fig. 8). Due to the restricted conodont recovery at both localities, the biofacies identification is scattered and difficult to establish in this part of the geological column. Its base is depicted in different levels just above the second reef level from the San Juan Formation.

Overall, Cerro Viejo of Huaco (Mango & Albanesi 2019) is characterized by similar biofacies to those analyzed in this study from the Cerro La Silla section, but it varies in taxonomic composition and stratigraphic extension. When comparing correlative levels, it is clear that differences are related to the occurrence of slightly deeper sub-environments through the northern Niquivil tectonic thrust, i.e., the Cerro Viejo of Huaco section.

CONCLUSIONS

At the Cerro La Silla section, the *Colaptoconus* Biofacies is recorded within the upper La Silla Formation, representing a shallow-warm environment.

The *Colaptoconus*, *Tropodus-Reutterodus*, *Oepikodus-Prioniodus*, *Juanognathus-Bergstroemognathus*, *Juanognathus-Oepikodus-Protopanderodus*, *Juanognathus-Protopanderodus*, and *Juanognathus-Semiacontiodus* biofacies are recorded for the San Juan Formation, representing middle and outer ramp environments.

A general increase in total abundance and generic diversity of conodonts from the inner to outer ramp deposits are related to various factors. The presence of a thicker water column for the conodont habitat on the outer ramp and less energy, promotes a favorable habitat for the development of conodont communities; and/or less competition for food with other organism groups to the deeper sub-environments within the ramp could reinforce this trend.

The analysis of biofacial and lithological relationships allows us to recognize two transgressive events in the San Juan Formation at the study succession, which would be related to transgressive systems tracts (TST) that occurred during the Early and Middle Ordovician, verifying stratigraphic sequences documented by Cañas (1999) and Mango & Albanesi (2019) for other sections of the Central Precordillera of San Juan.

The biofacies of the San Juan Formation identified in Cerro Viejo of Huaco and Cerro La Silla sections are similar, varying slightly in the biofacial compositions and developments. This variation is due to deeper sub-environments as confirmed in Cerro Viejo of Huaco, to the north of the Niquivil tectonic thrust.

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