Conodont biostratigraphy and correlation of the San Juan Formation at the Cerro La Silla section, middle Tremadocian-lower Dapingian, Central Precordillera, Argentina

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ABSTRACT: This study deals with the conodont biostratigraphy from the uppermost part of La Silla Formation (9.6 m) and the overlying San Juan Formation (264.7 m), at the Cerro La Silla section, Central Precordillera of San Juan, Argentina. The 41 samples of carbonate rocks that were digested for microfossils yielded 11,388 conodont elements corresponding to 78 species. The Paltodus deltifer deltifer Subzone of the Paltodus deltifer Zone from the Baltic biostratigraphic scheme is represented at the top stratum of the La Silla Formation and the basal part of the San Juan Formation (28.4 m), which correlates with the Macerodus dianae Zone (middle Tremadocian) of the Precordilleran and North American schemes. Following upwards, the Paroistodus proteus, Prioniodus elegans, Oepikodus evae, Oepikodus intermedius and Baltoniodus triangularis-Tripodus laevis zones (middle Tremadocian-lower Dapingian) are recorded in the San Juan Formation. The Baltoniodus triangularis-Tripodus laevis Zone is recognized from the second reef level (177.3 m from the base of the San Juan Formation) up to the top stratum in the section, in contrast to previous interpretations that assigned the referred interval to the Baltoniodus navis, Paroistodus originalis and Microzarkodina parva zones of the Baltic biostratigraphic scheme. The division of the Oepikodus evae Zone in subzones, according to its original definition for the Precordillera, is not applicable at the Cerro La Silla section due to the particular species distribution. The conodont elements show a brown alteration color (CAI 2-2.5), which indicates a burial paleotemperature of 60-155°C for the bearer strata.

Keywords: Biostratigraphy, Conodonts, San Juan Formation, Cerro La Silla, Ordovician, Precordillera.

RESUMEN. Bioestratigrafía de conodontes y correlación de la Formación San Juan en el cerro La Silla, Tremadociano medio-Dapingiano inferior, precordillera Central, Argentina. Este estudio presenta la bioestratigrafía de conodontes del tramo superior de la Formación La Silla (9,6 m) y la suprayacente Formación San Juan (264,7 m), en la sección del cerro La Silla, precordillera Central de San Juan, Argentina. Se procesaron 41 muestras de rocas carbonáticas para la obtención de microfósiles, las cuales proporcionaron 11.388 conodontes correspondientes a 78 especies. La subzona de Paltodus deltifer deltifer de la Zona de Paltodus deltifer del esquema bioestratigráfico de la región Baltoescandinava está representada en el techo de la Formación La Silla y en la parte basal de la Formación San Juan (28,4 m), correlacionándose con la Zona de Macerodus dianae (Tremadociano medio) de los esquemas de la Precordillera y Norteamérica. Las zonas suprayacentes de Paroistodus proteus, Prioniodus elegans, Oepikodus evae, Oepikodus intermedius y Baltoniodus triangularis-Tripodus laevis (Tremadociano medio-Dapingiano inferior) se registran en la Formación San Juan. La Zona de Baltoniodus triangularis-Tripodus laevis es reconocida desde el segundo nivel arrecifal (177,3 m desde la base de la Formación San Juan) hasta el tope aflorante en la sección, lo que difiere de interpretaciones previas que asignaban el intervalo referido a las zonas de Baltoniodus navis, Paroistodus originalis y Microzarkodina parva del esquema bioestratigráfico de la Región Baltoescandinava. La división de la Zona de Oepikodus evae en subzonas, según su definición original para la Precordillera, no es aplicable a la sección del cerro La Silla por su particular distribución de las especies. Los conodontes presentan una coloración parda (CAI 2-2,5), que indica una paleotemperatura de soterramiento de 60-155 °C para los estratos portadores.

Palabras clave: Bioestratigrafía, Conodontes, Formación San Juan, Cerro La Silla, Ordovícico, Precordillera.
1. Introduction

The Precordillera is located between 28°30ʹ and 33° S and 68°15ʹ and 69°45ʹ W, partly covering the La Rioja, San Juan and Mendoza provinces. This geological province includes extensive Paleozoic outcrops and, to a lesser extent, Mesozoic and Cenozoic rock units. On the basis of its stratigraphic and structural characteristics, the Precordillera is subdivided into three morphostructural units: Eastern (Ortiz and Zambrano, 1981), Central (Baldis and Chebli, 1969) and Western Precordillera (Baldis et al., 1982).

The Central Precordillera is composed mainly of carbonate platform deposits (Cerro Totora, La Flecha, La Silla, San Juan and Las Chacritas formations) that makes up a rock sequence of ca. 2,500 m thick. This represent an apparently continuous cycle (Baldis and Bordonaro, 1982) deposited under warm to temperate conditions, whose sedimentation began in the Cambrian and continued up to the Darriwilian.

The Cerro La Silla, in the Central Precordillera, is located 15 km southeast of Jáchal City (Figs. 1 and 2), San Juan Province. The study section can be accessed by vehicle through the National Route No. 40.
The section of the San Juan Formation at the Cerro La Silla (Fig. 1) is interesting to analyze due to the presence of two reefal structures in its lower and middle parts, where a stratigraphically continuous record of the conodont fauna is represented. The upper stratigraphic section, which occupies approximately one third of its actual thickness, is covered by alluvial sediments in this locality.

The conodont biostratigraphy of the San Juan Formation at Cerro La Silla was partly studied by Lehnert (1995) and Thalmeier (2014). The biostratigraphic analysis of the uppermost part of the La Silla Formation and of the overlying San Juan Formation, as well as an updating to the biostratigraphic scheme of the Precordillera (Albanesi and Ortega, 2016) motivated this work.

Accordingly, the objective of this work is to study the conodont fauna of the San Juan Formation exposed at the Cerro La Silla, including the transitional interval between this unit and the uppermost strata of the underlying La Silla Formation, in order to determine the characteristics and differences of the taxonomic record and to establish the conodont biostratigraphy following the updated biozonal scheme for the Precordillera (Albanesi and Ortega, 2016), as well as its regional and global correlation.

2. The San Juan Formation

The carbonate sequence of the San Juan Formation (Keller et al., 1994), approximately 330 m thick, is made up of skeletal micritic limestones deposited from the upper Tremadocian up to the middle Darriwilian on a ramp topography, recording two regressive-transgressive cycles (Cañas, 1995).

The boundary between the La Silla Formation and the overlying San Juan Formation marks a major change in the configuration of the carbonate platform, with the passage from subtidal to open platform facies in a carbonate ramp geometry (Pratt et al., 2012). This lithofacial change is accompanied by an important faunal change.

The limestones of the San Juan Formation start with a transgressive sequence at whose base a reef horizon consisting of calcimicrobials and sponges is developed (Cañas and Carrera, 2003).

Subsequently, high sea level sediments accumulate (mostly bioturbated skeletal wackestones) in a framework of environmental stability, which allows the development of rich subtidal communities dominated by suspension-feeding organisms, especially brachiopods and macluritacean gastropods (Cech and Carrera, 2002).
A second reef horizon that consists of microbialites, receptaculitids (Calathium) and mainly stromatoporoids (Zondarella) is located in the middle part of the San Juan Formation close to the base of the Middle Ordovician (Dapingian).

During the Darriwilian, as a consequence of a relative sea level increment that led to the drowning of the platform below the photic zone, the carbonate production is suffocated. Consequently, the carbonate cycle culminates, being followed by the deposition of calcareous-shaly facies towards a predominantly pelitic sequence (Baldis and Beresi, 1981; Baldis et al., 1984), known as the Gualcamayo and Los Azules formations in different localities of the Precordillera.

3. Framework of the conodont biostratigraphy at the study area

Lehnert (1995) studied the conodont biostratigraphy from the lower 130 m of the San Juan Formation at the Cerro La Silla section, proposing the Colaptoconus quadraplicatus-Parapanderodus striatus, Acodus? deltatus-Paroistodus proteus, Prioniodus elegans-Oepikodus communis, and Oepikodus evae association zones.

Subsequently, Thalmeier (2014) processed nineteen rock samples (16.5 kg) from San Juan Formation at the Cerro La Silla section, recovering 344 conodont elements. From this material, she recorded the Paroistodus proteus, Prioniodus elegans, Oepikodus evae, Oepikodus intermedius and Tripodus laevis zones of the biostratigraphic scheme of Albanesi et al. (1998). It should be noted that the samples from the basal strata (samples LS 8 and LS 7) were sterile, and the first productive level obtained by the author is located above the first reef level (sample LS 6).

4. Materials and methods

The field-work consisted in the recognition of the study area and the sampling of the stratigraphic profile corresponding to the San Juan Formation at the Cerro La Silla section. There 41 limestone samples were taken, with a variable weight between 2 and 4 kg, among intervals of interest for the accomplishment of the present study. Thus, 2 samples were taken from the upper part of the La Silla Formation (uppermost 9.6 m) and 39 samples throughout the San Juan Formation (Tables 1-4)

| TABLE 1. ABSOLUTE FREQUENCY OF CONODONT SPECIES FROM THE UPPER PART OF THE LA SILLA FORMATION AND THE SAN JUAN FORMATION (SAMPLES LSLS-1 TO LSSJ P) CERRO LA SILLA SECTION. |
|-----------------------------------------------|
| Species/Samples                              | LSLS-1 | LSLS-0 | LSSJ-0 | LSSJ-1 | LSSJ-2 | LSSJ-3 | LSSJ-4 | LSSJ P2 | LSSJ P1 | LSSJ P |
| Anodontus longus                             | 1      | -      | -      | -      | -      | -      | -      | -      | -      | -      |
| Colaptoconus priscus                         | -      | 1      | -      | 2      | 1      | -      | 2      | 1      | -      | -      |
| Colaptoconus quadraplicatus                  | 2      | 31     | 15     | 7      | -      | 1      | 5      | 1      | 4      | 4      |
| Cornodus longibasis                          | -      | -      | -      | -      | -      | -      | -      | -      | -      | -      |
| Drepanodus arcuatus                          | -      | -      | -      | -      | -      | 1      | 2      | -      | -      | -      |
| Drepanoistodus forceps                       | -      | -      | -      | -      | 1      | -      | -      | 5      | -      | -      |
| Kallidontus corbatoi                         | -      | -      | -      | -      | -      | -      | -      | -      | 3      | -      |
| Lundodus gladiatus                           | -      | -      | -      | -      | -      | -      | -      | -      | -      | 1      |
| Paltodus deltifer deltifer                   | -      | 1      | 2      | -      | 1      | 3      | 1      | -      | -      | -      |
| Paltodus perrii                              | -      | -      | -      | -      | -      | -      | -      | -      | -      | -      |
| Paltodus subaequalis                         | -      | 1      | -      | -      | -      | -      | -      | 1      | 5      |
| Paroistodus proteus                          | -      | -      | -      | -      | -      | -      | -      | -      | 1      | 4      |
| Protoprioniodus simplicissimus               | -      | -      | -      | -      | -      | -      | -      | -      | -      | 1      |
| Scandodus furnishi                           | -      | -      | -      | -      | -      | -      | -      | -      | -      | 1      |
| Tropodus comptus                             | -      | -      | -      | -      | -      | -      | -      | -      | 1      | -      |
| Tropodus sweeti                              | -      | -      | -      | -      | -      | -      | -      | -      | -      | 4      |
| Variabiloconus bassleri                     | -      | 2      | -      | -      | -      | -      | -      | -      | -      | -      |
| Total conodont elements per sample           | 3      | 36     | 17     | 9      | 3      | 5      | 8      | 3      | 10     | 28     |
| 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  |
| Insoluble material (g)                       | 0      | 0      | 0      | 0      | 0      | 140    | 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  |
### TABLE 2. ABSOLUTE FREQUENCY OF CONODONT SPECIES FROM THE SAN JUAN FORMATION (SAMPLES LSSJ O6 TO LSSJ L3), CERRO LA SILLA SECTION.

| Species/Samples                     | LSSJ O6 | LSSJ O5 | LSSJ O4 | LSSJ O3 | LSSJ O2 | LSSJ O1 | LSSJ O | LSSJ N | LSSJ M | LSSJ L3 |
|-------------------------------------|---------|---------|---------|---------|---------|---------|--------|--------|--------|---------|
| Acodus deltatus                     | -       | 1       | 2       | -       | 1       | 2       | 2      | 2      | -      | -       |
| Anodontus longus                    | 2       | -       | 1       | 2       | -       | 2       | -      | 2      | -      | -       |
| Ansella jemtlandica                 | -       | -       | -       | -       | -       | -       | 1      | -      | -      | -       |
| Bergstroemognathus extensus         | -       | -       | 27      | -       | -       | -       | 18     | 9      | -      | 11      |
| Colaptoconus priscus                | 1       | -       | -       | -       | -       | -       | 1      | 2      | -      | -       |
| Colaptoconus quadruplicatus         | 21      | -       | -       | -       | -       | -       | 2      | -      | -      | -       |
| Cornodus longibasis                 | -       | -       | 1       | 1       | -       | 2       | 5      | 18     | 4      | -       |
| Diaphorodus russoi                  | 3       | -       | 9       | 8       | 3       | 1       | 88     | 24     | 4      | -       |
| Diaphorodus tovei                   | -       | -       | -       | -       | -       | -       | 18     | 18     | -      | -       |
| Drepanodus arcuatus                 | 4       | 1       | 17      | 16      | 14      | 6       | 134    | 180    | 8      | -       |
| Drepanostodus forceps               | 2       | 2       | 4       | -       | 2       | -       | 49     | 14     | 1      | 2       |
| Gen. et sp. nov.                    | -       | -       | -       | -       | -       | -       | 1      | 2      | -      | -       |
| Juanognathus jaanussoni             | -       | 3       | -       | -       | -       | -       | -      | -      | -      | 1       |
| Juanognathus variabilis             | -       | -       | -       | -       | -       | -       | -      | 3      | 2      | 15      |
| Jamudontus gananda                  | -       | -       | -       | -       | -       | -       | 5      | 4      | -      | -       |
| Kallidontus corbatoi                | -       | -       | -       | 1       | -       | -       | 1      | -      | -      | -       |
| Kallidontus princeps                | -       | -       | -       | -       | -       | -       | 1      | -      | -      | -       |
| Kallidontus? lofgreni               | -       | -       | -       | -       | -       | -       | 1      | -      | -      | -       |
| Lundodus gladiatus                  | -       | 4       | -       | -       | -       | -       | -      | 4      | -      | -       |
| Oelandodus costatus                 | -       | 3       | -       | 6       | -       | 1       | 5      | 18     | 3      | 4       |
| Oelandodus costatus?                | -       | -       | -       | 1       | -       | -       | 4      | -      | -      | -       |
| Oelandodus elongatus                | -       | 1       | 9       | -       | 13      | -       | 159    | 233    | 4      | -       |
| Oepikodus communis                  | -       | -       | -       | -       | -       | -       | 7      | 3,444  | 5      | -       |
| Oistodus lanceolatus                | -       | -       | -       | -       | -       | -       | -      | 12     | -      | -       |
| Oistodus multiscorpiatus            | -       | -       | -       | 1       | -       | -       | -      | 1      | -      | -       |
| Paltoodus perrii                    | -       | -       | 3       | -       | -       | -       | 4      | 9      | -      | -       |
| Paltoodus subaequalis               | 4       | 1       | 8       | 14      | 2       | -       | 39     | 50     | 6      | -       |
| Paracordylodus gracilis             | -       | -       | 4       | 1       | -       | 1       | 70     | 1      | -      | -       |
| Parapaltodus simplicissimus          | -       | 1       | 1       | 4       | -       | -       | -      | 2      | -      | -       |
| Parapanderodus paracorniformis      | -       | -       | -       | 1       | -       | -       | -      | -      | -      | -       |
| Paroistodus originalis              | 13      | -       | -       | -       | -       | -       | -      | -      | -      | 1       |
| Paroistodus parallelus              | 1       | -       | -       | -       | -       | -       | 2      | 10     | 4      | -       |
| Paroistodus proteins                | -       | 2       | 14      | 9       | 8       | -       | 177    | 405    | 3      | -       |
| Periodon primus                     | -       | 2       | 1       | -       | -       | -       | 4      | 8      | -      | -       |
| Periodon selenopsis                 | -       | -       | -       | -       | -       | -       | -      | 4      | -      | -       |
| Prioniodus elegans                  | -       | 1       | 15      | -       | 6       | 4       | 84     | 637    | -      | -       |
| Protopanderodus elongatus           | 2       | 1       | -       | 1       | 4       | 4       | 14     | 11     | 6      | 2       |
Table 2 continued.

| Species/Samples                  | LSSJ O6 | LSSJ O5 | LSSJ O4 | LSSJ O3 | LSSJ O2 | LSSJ O1 | LSSJ O | LSSJ N | LSSJ M | LSSJ L3 |
|----------------------------------|---------|---------|---------|---------|---------|---------|--------|--------|--------|---------|
| Protopanderodus gradatus         | -       | -       | 3       | -       | -       | -       | -      | 47     | -      | -       |
| Protopanderodus leonardi          | 1       | -       | 14      | 7       | 12      | -       | 101    | 36     | 12     | 9       |
| Protopanderodus rectus            | -       | -       | 4       | 1       | -       | -       | -      | 40     | 2      | 1       |
| Protoprioniodus cowheadensis      | -       | -       | -       | -       | -       | -       | -      | 2      | -      | -       |
| Protoprioniodus simplicissimus    | -       | -       | -       | -       | -       | -       | -      | 8      | -      | 5       |
| Reutterodus andinus               | -       | 1       | 28      | 18      | 23      | 8       | 287    | 296    | 17     | 2       |
| Rossodus barnesi                   | -       | 1       | -       | 4       | 8       | -       | 28     | 49     | 1      | -       |
| Scandodus furnishi                | -       | -       | 1       | 1       | 1       | -       | 5      | 3      | -      | -       |
| Scolopodus krummi                 | 8       | 1       | 13      | 11      | 4       | -       | 11     | 57     | -      | 3       |
| Semiacontiodus potreriennis       | -       | 2       | -       | -       | -       | -       | -      | -      | -      | -       |
| Tripodus albanii                  | -       | -       | -       | -       | -       | -       | -      | -      | -      | -       |
| Tropodus australis                 | -       | 9       | -       | 5       | 1       | -       | 15     | 19     | 2      | -       |
| Tropodus comptus                  | -       | 3       | -       | 6       | 7       | -       | 13     | 46     | 1      | -       |
| Tropodus sweeti                    | 4       | 1       | 11      | 16      | 45      | 21      | 199    | 3      | 18     | -       |
| Venoistodus venustus               | -       | 1       | -       | -       | -       | -       | -      | -      | -      | -       |
| **Total conodont elements**       |         |         |         |         |         |         | 66     | 42     | 189    | 131     |
| per sample                        |         |         |         |         |         |         | 165    | 48     | 1,553  | 5,720   |
| **Amount of processed material (g)**| 2,025  | 2,090  | 2,005  | 2,100  | 2,225  | 2,090  | 2,375  | 2,005  | 2,105  | 2,520   |
| **Insoluble material (g)**        | 0       | 0       | 0       | 0       | 0       | 0       | 0      | 0      | 0      | 0       |
| **Soluble material (g)**          | 2,025  | 2,090  | 2,005  | 2,100  | 2,225  | 2,090  | 2,375  | 2,005  | 2,105  | 2,520   |

Table 3. Absolute frequency of conodont species from the San Juan Formation (samples LSSJ L2 to LSSJ I), Cerro La Silla section.

| Species/Samples                  | LSSJ L2 | LSSJ L1 | LSSJ K2 | LSSJ K1 | LSSJ K | LSSJ J1 | LSSJ J | LSSJ I2 | LSSJ I1 | LSSJ I |
|----------------------------------|---------|---------|---------|---------|--------|---------|--------|--------|--------|--------|
| Anodontus longus                 | -       | -       | -       | -       | -      | -       | -      | -      | -      | 1      |
| Ansellia jentlandica             | -       | -       | -       | -       | -      | -       | -      | -      | -      | -      |
| Bergstroemognathus extensus      | 12      | 3       | 10      | 28      | 11     | 40      | 10     | -      | -      | -      |
| Colaptoconus quadraplicatus      | -       | -       | -       | -       | -      | -       | -      | 6      |         |
| Cooperignathus aranda            | -       | -       | -       | -       | -      | -       | -      | 1      | -      | 2      |
| Cornodus longibasis              | -       | -       | -       | -       | -      | -       | -      | 1      | 1      | 7      |
| Diaphorodus russia               | -       | -       | 2       | -       | 3      | -       | 1      | -      | -      | -      |
| Drepanodus arcaustus             | 7       | 1       | 21      | 7       | 29     | 4       | 3      | 9      | 26     | 18     |
| Drepanoistodus basiivalis        | -       | -       | 1       | -       | -      | -       | -      | -      | -      | -      |
| Drepanoistodus forceps           | 2       | -       | 8       | -       | 4      | -       | 1      | 2      | 15     | 24     |
| Erraticodon patu                 | -       | -       | -       | -       | -      | -       | -      | -      | -      | -      |
| Fahraeusodus adentatus           | -       | 1       | -       | -       | -      | -       | -      | -      | -      | -      |
| Juanognathus jaanussoni          | -       | 1       | -       | -       | -      | -       | -      | 12     | 68     | 89     |
| Juanognathus n. sp. A            | -       | -       | -       | 2       | 18     | -       | -      | -      | -      | 11     |
| Juanognathus variabilis          | 97      | 16      | 67      | 77      | 139    | 15      | 37     | -      | -      | 3      |
Table 3 continued.

| Species/Samples                  | LSSJ L2 | LSSJ L1 | LSSJ K2 | LSSJ K1 | LSSJ K  | LSSJ J1 | LSSJ J2 | LSSJ J1 | LSSJ J  | LSSJ K  | LSSJ I2 | LSSJ I1 | LSSJ I  |
|----------------------------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| **Jumudontus gananda**           | -      | -      | -      | -      | 1      | -      | -      | -      | -      | -      | -      | -      | -      |
| **Kalidontus princeps**          | -      | -      | -      | 1      | -      | -      | -      | -      | -      | -      | -      | -      | -      |
| **Lundodus gladiatus**           | -      | -      | -      | 1      | 6      | 1      | -      | 1      | -      | 1      | -      | -      | -      |
| Gen. et sp. nov.                 | -      | -      | -      | 1      | -      | -      | -      | 1      | -      | -      | -      | -      | -      |
| **Oelandodus costatus**          | 1      | 1      | -      | 3      | -      | -      | -      | -      | 1      | -      | -      | -      | -      |
| **Oelandodus elongatus**         | 1      | 1      | -      | -      | -      | -      | -      | -      | -      | -      | -      | -      | -      |
| **Oepikodus communis**           | 4      | -      | 41     | -      | -      | -      | -      | -      | -      | -      | -      | -      | -      |
| **Oepikodus eave**               | -      | 25     | 10     | 136    | 3      | -      | -      | -      | -      | -      | -      | -      | -      |
| **Oepikodus intermedius**        | -      | -      | 1      | 43     | -      | 1      | 6      | 196    | 80     | -      | -      | -      | -      |
| **Oistodus lanceolatus**         | -      | -      | -      | -      | -      | 2      | -      | 7      | 39     | -      | -      | -      | -      |
| **Oistodus striolatus**          | -      | -      | -      | -      | -      | -      | -      | -      | 1      | -      | -      | -      | -      |
| **Paltoodus subaequalis**        | 1      | 1      | 2      | 3      | 19     | 4      | -      | 1      | 4      | 3      | -      | -      | -      |
| **Paltoodus? jomlandicus**       | -      | -      | -      | -      | -      | -      | -      | -      | -      | -      | -      | -      | -      |
| **Paracordylodus gracilis**      | -      | -      | -      | 1      | -      | -      | -      | -      | -      | -      | -      | -      | -      |
| **Parapanderodus simplicissimus**| 3      | 1      | -      | 1      | -      | -      | -      | -      | -      | -      | -      | -      | -      |
| **Parapanderodus paracornuformis**| -    | -      | -      | -      | -      | -      | -      | -      | -      | -      | -      | -      | -      |
| **Parapanderodus striatus**      | 3      | -      | -      | -      | -      | -      | -      | -      | -      | -      | -      | -      | -      |
| **Paroistodus cf. P. proteus**   | -      | -      | -      | -      | 29     | -      | -      | -      | 2      | -      | -      | -      | -      |
| **Paroistodus originalis**       | -      | -      | 2      | 7      | -      | -      | -      | 6      | 20     | 5      | -      | -      | -      |
| **Paroistodus parallelus**       | -      | -      | -      | 1      | 2      | 3      | -      | -      | -      | -      | -      | -      | -      |
| **Paroistodus proteus**          | 1      | -      | -      | -      | -      | -      | -      | -      | -      | -      | -      | -      | -      |
| **Periodon flabellum**           | -      | -      | 4      | -      | 31     | -      | 2      | 5      | 3      | 72     | -      | -      | -      |
| **Periodon primus**              | -      | -      | -      | 29     | -      | -      | -      | -      | -      | -      | -      | -      | -      |
| **Periodon selenopsis**          | 4      | -      | 1      | -      | -      | 2      | -      | -      | -      | -      | -      | -      | -      |
| **Prioniodus adami**             | -      | -      | -      | -      | -      | -      | -      | -      | -      | -      | -      | -      | -      |
| **Prioniodus elegans**           | 17     | -      | 2      | -      | -      | -      | -      | -      | -      | -      | -      | -      | -      |
| **Protopanderodus elongatus**    | 15     | 1      | -      | 7      | -      | -      | -      | -      | -      | -      | -      | -      | -      |
| **Protopanderodus gradatus**     | 3      | 1      | 15     | -      | 21     | 16     | -      | 7      | 9      | 94     | -      | -      | -      |
| **Protopanderodus leonardii**    | 23     | 1      | 3      | 14     | 16     | 7      | 4      | -      | -      | 14     | -      | -      | -      |
| **Protopanderodus rectus**       | 2      | -      | 16     | 13     | 50     | -      | 8      | 27     | 58     | 38     | -      | -      | -      |
| **Pteracontiodus cryptodens**    | -      | -      | -      | 8      | -      | -      | -      | -      | -      | -      | -      | -      | -      |
| **Reutterodus andinus**          | 20     | 1      | 18     | 11     | 39     | 5      | 12     | -      | -      | -      | -      | -      | -      |
| **Rassodus barnesi**             | 2      | -      | 8      | -      | 1      | -      | -      | 7      | 16     | -      | -      | -      | -      |
| **Scolopodus krummi**            | 1      | 1      | 27     | -      | 6      | 15     | 1      | -      | -      | -      | -      | -      | -      |
| **Scolopodus oldstockensis**     | -      | -      | 5      | 5      | 1      | 4      | 1      | -      | -      | -      | -      | -      | -      |
| **Texania heligma**              | -      | -      | 1      | -      | -      | -      | -      | -      | -      | -      | -      | -      | -      |
| **Trapezognathus diprion**       | -      | -      | -      | -      | -      | -      | -      | -      | -      | -      | -      | -      | -      |
| **Triangulodus brevibasis**      | -      | -      | -      | -      | -      | -      | -      | -      | -      | -      | -      | -      | -      |
| **Tropodus australis**           | 10     | -      | -      | -      | 1      | -      | -      | -      | -      | -      | -      | -      | -      |
| **Tropodus comptus**             | 1      | -      | 1      | 4      | -      | -      | -      | -      | -      | -      | -      | -      | -      |
| **Tropodus sweeti**              | 16     | 5      | 5      | 36     | 5      | -      | 5      | -      | -      | -      | -      | -      | -      |
| **Total conodont elements per sample** | 244 | 35 | 285 | 227 | 659 | 121 | 92 | 80 | 435 | 542 |
| **Amount of processed material (g)** | 1,975 | 2,075 | 2,140 | 2,155 | 2,080 | 2,120 | 2,055 | 2,010 | 2,105 | 2,175 |
| **Insoluble material (g)**        | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      |
| **Soluble material (g)**          | 1,975 | 2,075 | 2,140 | 2,155 | 2,080 | 2,120 | 2,055 | 2,010 | 2,105 | 2,175 | -      | -      | -      |
TABLE 4. ABSOLUTE FREQUENCY OF CONODONT SPECIES FROM THE SAN JUAN FORMATION (SAMPLES LSSJ H4 TO LSSJ TOPE+), CERRO LA SILLA SECTION.

| Species/Samples | LSSJ H4 | LSSJ H3 | LSSJ H2 | LSSJ H1 | LSSJ G | LSSJ F | LSSJ D | LSSJ B | LSSJ A+7 | LSSJ TOPE+ |
|-----------------|---------|---------|---------|---------|--------|--------|--------|--------|----------|-----------|
| Anodontus longus| -       | -       | -       | 1       | 1      | -      | 1      | 1      | -        | 1         |
| Anella jemtlandica| -     | -       | -       | -       | -      | 2      | -      | 2      | -        | -         |
| Bergestroemognathus extensus| 1     | 6       | -       | -       | -      | -      | -      | -      | -        | -         |
| Cornuodus longibasis| 1     | 4       | -       | 1       | -      | 2      | -      | 2      | -        | -         |
| Diaphorodus rusoii| -    | 1       | -       | -       | -      | -      | -      | 1      | -        | -         |
| Drepanodus arcuatus| 6     | 16      | -       | 7       | -      | -      | 1      | -      | -        | 1         |
| Drepanoistodus basiovalis| -    | -       | 1       | -       | -      | 1      | 2      | 1      | -        | 2         |
| Drepanoistodus costatus| -   | -       | -       | -       | -      | 1      | -      | -      | 2        | -         |
| Drepanoistodus forceps| -   | 1       | -       | 2       | -      | -      | -      | -      | -        | -         |
| Juanognathus jaanussoni| -  | 12      | 1       | 1       | -      | 1      | 2      | 8      | 14       | 18        |
| Juanognathus serratus| -   | -       | -       | -       | -      | -      | -      | -      | -        | 3         |
| Juanognathus variabilis| -  | 7       | -       | -       | -      | -      | -      | -      | -        | -         |
| Jumundontus gananda| -    | 1       | -       | -       | -      | -      | -      | -      | -        | -         |
| Lundodus gladiatus| -    | -       | -       | 1       | -      | 1      | -      | -      | -        | -         |
| Oelandodus elongatus| 2    | -       | -       | -       | 1      | -      | 1      | -      | -        | -         |
| Oepikodus intermedius| 6   | 7       | -       | 1       | -      | -      | 2      | -      | -        | -         |
| Oistodus lanceolatus| 6    | 1       | -       | 1       | -      | -      | 13     | -      | 1        | -         |
| Oistodus multicorrugatus| -  | 5       | -       | 3       | -      | -      | -      | -      | -        | -         |
| Oistodus striolatus| -    | -       | -       | -       | -      | -      | -      | -      | 3        | -         |
| Paltodus subaequalis| 3    | 4       | -       | 2       | -      | -      | -      | -      | -        | -         |
| Paltodus? jemtlandicus| -   | -       | -       | -       | -      | -      | -      | -      | -        | 1         |
| Parapaltodus simplicissimus| -  | 4       | -       | -       | -      | -      | 1      | -      | -        | 2         |
| Parapanderodus paracornuformis| -  | -       | -       | -       | -      | -      | -      | -      | -        | 8         |
| Paroistodus originalis| 6   | 5       | -       | 10      | -      | -      | -      | -      | -        | -         |
| Paroistodus parallelus| 3   | 2       | -       | -       | -      | -      | -      | -      | -        | -         |
| Periodon flabellum| 2    | 10      | -       | 2       | -      | -      | 1      | 2      | 1        | 1         |
| Periodon selenopsis| -    | 3       | -       | -       | -      | -      | -      | -      | -        | -         |
| Protopanderodus elongatus| -  | 7       | -       | -       | -      | -      | -      | -      | -        | -         |
| Protopanderodus gradatus| 15 | 7       | 1       | 5       | -      | -      | -      | -      | -        | -         |
| Protopanderodus rectus| 9   | 13      | 1       | 2       | -      | -      | 4      | 8      | 3        | -         |
| Pteracantiodus cryptodens| -  | -       | -       | -       | -      | -      | -      | -      | 2        | -         |
| Rossodus barnesi| -    | -       | 1       | -       | -      | -      | 9      | 1      | 4        | -         |
| Scalpellodus gracilis| -    | -       | -       | -       | -      | -      | 1      | -      | -        | -         |
| Scelopodus oldstockensis| -   | -       | -       | -       | -      | -      | 2      | -      | -        | -         |
| Scelopodus striatus| -    | -       | -       | -       | -      | -      | 1      | -      | -        | -         |
| Semiacantiodus potrerillensis| -  | -       | -       | -       | -      | -      | 1      | 1      | 2        | 16        |
| Stolodus stola| -    | -       | -       | -       | -      | -      | -      | -      | 2        | -         |
The laboratory work comprised the processing of rocks for the recovery of microfossils, following the method of Stone (1987) (10% formic acid). For each processed sample, insoluble residue was recovered varying in weight from 20 to 100 g, regarding the composition of the limestone. Over this residue, associated microfossils were picked up, including 11,388 conodont specimens, which correspond to 78 species (Tables 1-4), which were illustrated by conventional optical photomicrography. The conodonts are housed in the Museo de Paleontología, Universidad Nacional de Córdoba, under repository code CORD-MP.

5. Conodonts CAI

In the present study, the conodonts recovered from La Silla and San Juan formations present a color alteration index (CAI) around 2 to 2.5, which refers to burial temperatures of 60-155°C (Epstein et al., 1977). These values could be explained by the Niquivil tectonic thrust; that affected the easternmost part of the Central Precordillera (Voldman et al., 2010), as recorded for the San Juan Formation in the Cerro Potrerillo (Albanesi et al., 1998), Cerro Viejo of Huaco (Ortega et al., 2007; Mango and Albanesi, 2018a) and the Rio Las Chacritas exposures (Serra et al., 2015).

6. Conodont biostratigraphy and correlation

This work follows the conodont biostratigraphic scheme proposed by Albanesi et al. (1998, 2006, 2016) and Della Costa and Albanesi (2016), for the Argentine Precordillera, and subsequently updated by Albanesi and Ortega (2016) (Fig. 3).

6.1. Macerodus dianae Zone

This zone can be recorded from the lowest sample taken in the upper La Silla Formation, 9.6 m below the contact with the San Juan Formation (LSLS-1) (Fig. 4) to the sample LSSJ P1, where Paroistodus proteus (Lindström) appears in the record. These strata bear the index fossil Paltodus deltifer deltifer (Lindström) (Fig. 5) that allows to recognize the Paltodus deltifer Zone, Paltodus deltifer deltifer Subzone of the biostratigraphic scheme of Baltica, which correlates with the Macerodus dianae Zone of the scheme used in this work. In these samples, the record of Paltodus deltifer deltifer, Colaptoconus priscus (Ji and Barnes) and Colaptoconus quadruplicatus (Branson and Mehl) is frequent, and the record of Variabiloconus bassleri (Furnish) is scarce. The local thickness of this zone is ca. 38 m.

6.1.1. Regional correlation

Albanesi et al. (1998) reported the Paltodus deltifer Zone in the La Silla Formation at the Portezuelo Yanso section, and correlates its upper part with the Macerodus dianae Zone. Subsequently, Albanesi et al. (2016) studied the upper part of the La Silla Formation at the Cerro Viejo of San Roque, Central Precordillera of San Juan, and recognized the index fossils Macerodus dianae in the Umango section and Paltodus deltifer deltifer from the top stratum of the La Silla Formation in the Portezuelo Jáchal section. This work allowed to recognize the Macerodus dianae Zone.
Voldman et al. (2013a) analyzed the conodonts of the Santa Rosita Formation in the sections of Peña Blanca and San Felipe, Santa Victoria, Cordillera Oriental of northwestern Argentina, and recorded the upper *Paltodus deltifer* Zone (*P. deltifer* deltifer Subzone), which correlates with the *Macerodus dianae* Zone.

From the Alfarcito and Rupasca members of the Santa Rosita Formation at Nazareno, Giuliano et al. (2013) recognized the conodont fauna corresponding to the *P. deltifer* Zone; particularly, its upper part (the *Paltodus deltifer deltifer* Subzone) that correlates with the *Macerodus dianae* Zone.

In the San Jorge Formation, exposed in the central sector of the La Pampa Province, Albanesi et al. (2003) reported conodonts referred to the Baltoscandian upper *P. deltifer* Zone that correlates with the *Macerodus dianae* Zone.
FIG. 4. Stratigraphic column from the upper part of the La Silla and San Juan formations at the Cerro La Silla sections, showing the stratigraphic distribution of conodont species. (Abbreviations: LS: La Silla Formation; M.d.: Macerodus dianae; P.: Paroistodus proteus; P.e.: Prioniodus elegans; e.: Oepikodus evae; i.: Oepikodus intermedius; B.t.-T.l.: Baltoniodus triangularis-Tripodus laevis; reef level).
Conodont biostratigraphy and correlation of the San Juan Formation at the Cerro La Silla section...

**FIG. 5.** Conodonts from the upper La Silla Formation and the San Juan Formation at the Cerro La Silla section. 1-6. *Oepikodus communis* (Ethington and Clark); 1. M element, sample LSSJ N, CORD-MP 64714; 2. Sb element, sample LSSJ N, CORD-MP 64715; 3. Sc element, sample LSSJ N, CORD-MP 64716; 4. Sd element, sample LSSJ N, CORD-MP 64717; 5. Pa element, sample LSSJ O, CORD-MP 64718; 6. Pb element, sample LSSJ N, CORD-MP 64719. 7-12. *Oepikodus evae* (Lindström); 7. M element, sample LSSJ K, CORD-MP 68215; 8. Sb element, sample LSSJ K, CORD-MP 68216; 9. Sc element, sample LSSJ K, CORD-MP 68217; 10. Sd element, sample LSSJ K, CORD-MP 68218; 11. Pa element, sample LSSJ K, CORD-MP 68219; 12. Pb element, sample LSSJ K, CORD-MP 68220. 13-18. *Oepikodus intermedius* (Serpagli); 13. M element, sample LSSJ I, CORD-MP 68399; 14. Sb element, sample LSSJ I, CORD-MP 68400; 15. Sc element, sample LSSJ I, CORD-MP 68401; 16. Sd element, sample LSSJ I1, CORD-MP 68402; 17. Pa element, sample LSSJ I, CORD-MP 68403; 18. Pb element, sample LSSJ I, CORD-MP 68404. 19-21. *Osistodus striolatus* Serpagli; 19. Sa element, sample LSSJ tope+, CORD-MP 68824; 20. Sb element, sample LSSJ tope+, CORD-MP 68825; 21. Pb element, sample LSSJ tope+, CORD-MP 68826. 22-24. *Paltodus deltifer deltifer* (Lindström); 22. M element, sample LSLS 0, CORD-MP 68828; 23. Sb element, sample LSSJ 2, CORD-MP 68829; 24. Sb element, sample LSSJ 3, CORD-MP 68830. 25. *Paroistodus proteus* (Lindström), M element, sample LSSJ O, CORD-MP 69279. Scale bar: 100 μm.
6.1.2. Intercontinental correlation

The conodont associations from the Ceratopyge limestone (lower Oelandiano AIII Stage) of Västergötland and Öland, Sweden, would correspond to the \textit{Paltoodus deltifer} Zone (Lindström, 1955, 1971) that in turn correlates with the \textit{Macerodus dianae} Zone of the Precordillera.

Szaniański (1980) analyzed the chaledony layers from the Holy Cross Mountains at Poland, and divided the \textit{Paltoodus deltifer} Zone into two subzones, a lower or \textit{Paltoodus deltifer pristinus} Subzone, and an upper or \textit{Paltoodus deltifer deltifer} Subzone; later, Löfgren (1996) analyzed the biostratigraphy of the Örreholmen quarry in Västergötland, Sweden, recognizing this subdivision, where the upper subzone correlates with the \textit{Macerodus dianae} Zone.

The \textit{Prioniodus giberti} Zone defined by Stouge and Bagnoli (1988) for layer 8 of the Cow Head Group at Newfoundland would represent the discussed zone. A correlative interval has also been identified by Smith (1991) in Greenland, Küppers and Pohler (1992) in Montagne Noire, southern France, An et al. (1983) in northern China, and by Nicoll et al. (1993) from the units underlying the Emanuel Formation in the Canning Basin of Australia.

At the Honghuayuan Formation, Guizhou, southern China, Zhen et al. (2007) record an association of conodonts that compares with material from Sweden, concluding that the lower part of that association would correspond to the \textit{P. deltifer} Zone, that is partly the \textit{Macerodus dianae} Zone.

6.2. \textit{Paroistodus proteus} Zone

The index fossil \textit{Paroistodus proteus} (Figs. 5-6) is recorded between the samples LSSJ P1 and LSSJ O6 (Fig. 4), immediately below the occurrence of \textit{Prioniodus elegans} Pander. Its appearance in this stratigraphic interval allows the recognition of the \textit{Paroistodus proteus} Zone in this section. It shall be noted that it has not been possible to identify the subzones of this zone, because the index fossils that determine these intervals have not been found. The local thickness of this zone is 7.5 m.

The \textit{Paroistodus proteus} Zone records a low diversity of conodonts at the base, with \textit{Colaptoconus priscus} and \textit{C. quadruplicatus} as recurrent species, ranging from the underlying zone. The diversity increases upwards towards the upper section, with the appearances of \textit{Lundodus gladiatus} (Lindström), \textit{Tropodus comptus} (Branson and Mehl), \textit{Tropodus sweeti} (Serpagli), \textit{Cornuodus longibasis} (Lindström), \textit{Protoprioniodus simplicissimus} McTavish, \textit{Kallidontus corbatoi} (Serpagli), \textit{Diaphorodus russoi} (Serpagli), \textit{Paroistodus parallelus} (Pander), \textit{Protopanderodus leonardii} Serpagli, \textit{Protopanderodus elongatus} Serpagli, \textit{Paroistodus originalis} (Sergeeva), and \textit{Scolopodus krummi} (Lehnert).

6.2.1. Regional correlation

Hünicken and Mazzoni (1994) reported the \textit{Paroistodus proteus} Zone in the San Juan Formation from Guandacol River area of the northern Precordillera. In turn, Albanesi et al. (1998) determined the \textit{Paroistodus proteus} Zone from the top strata of the La Silla Formation and the basal part of the San Juan Formation at the Yanso Section, Central Precordillera.

Voldman et al. (2016) established the \textit{Acodus apex} Zone from the top stratum of the Santa Rosita Formation up to the basal part of the Acoite Formation, and the \textit{Acodus triangularis} Zone from the lower part of the Acoite Formation, at the Chulpíos Creek, Santa Victoria Range, Cordillera Oriental. The \textit{Paroistodus proteus} Zone of this study mostly correlates with the referred \textit{Acodus apex} and \textit{A. triangularis} zones.

6.2.2. Intercontinental correlation

Löfgren (1993) analyzed conodonts from Hunneberg, Sweden, and recognized four biostratigraphic intervals within of the \textit{Paroistodus proteus} Zone, increasing the resolution for this part of the Ordovician; later, Löfgren (1994) formalized them as subzones, including the \textit{Drepanoistodus} aff. \textit{D. amoenus}, \textit{Tripodus}, \textit{Paracordylodus gracilis} and \textit{Oelandodus elongatus/Acodus deltatus} subzones, from base to top, respectively.

At the Ledge Point of Head section, Cow Head Group, Newfoundland, Stouge and Bagnoli (1988) defined the \textit{Prioniodus oeipik} and \textit{Prioniodus adami} zones, which correlate with the upper part of the \textit{Paroistodus proteus} Zone.

The discussed zone correlates with the successive zones of \textit{Scalpellodus tarsus- Triangulodus} sp. aff. \textit{T. bifidus}, \textit{Serratognathus bilobatus} and \textit{Serratognathus extensus} described for northern China (An et al., 1983; An and Zheng, 1990; Zhen et al., 2015a, 2016; Wang et al., 2018).
Conodont biostratigraphy and correlation of the San Juan Formation at the Cerro La Silla section...

**FIG. 6.** Conodonts from the San Juan Formation at the Cerro La Silla section. 1-6. *Paroistodus proteus* (Lindström); 1. Sa element, sample LSSJ N, CORD-MP 69280; 2. Sb element, sample LSSJ O, CORD-MP 69281; 3. Sc element, sample LSSJ O, CORD-MP 69282; 4. Sd element, sample LSSJ O, CORD-MP 69283; 5. Pa element, sample LSSJ N, CORD-MP 69284; 6. Pb element, sample LSSJ O, CORD-MP 69285. 7-14. *Prioniodus elegans* Pander; 7. M element, sample LSSJ N, CORD-MP 70101; 8. Sa element, sample LSSJ N, CORD-MP 70102; 9. Sb element, sample LSSJ N, CORD-MP 70103; 10. Sc element, sample LSSJ N, CORD-MP 70104; 11. Sd element, sample LSSJ N, CORD-MP 70105; 12. Sd element, sample LSSJ N, CORD-MP 70106; 13. Pa element, sample LSSJ O, CORD-MP 70107; 14. Pb element, sample LSSJ N, CORD-MP 70108. 15-16. *Pteraconiodus cryptodens* (Mound); 15. Sd element, sample LSSJ 11, CORD-MP 71732; 16. P element, sample LSSJ B, CORD-MP 71733. 17-18. *Scolopodus oldstockensis* Stouge; 17. a element, sample LSSJ K, CORD-MP 72840; 18. e element, sample LSSJ J, CORD-MP 72841. 19-20. *Triangulodus brevibasis* (Sergeeva); 19. Sb element, sample LSSJ A+7, CORD-MP 72900; 20. P element, sample LSSJ A+7, CORD-MP 72901. 21-25. *Tripodus laevis* Bradshaw; 21. Sa element, sample LSSJ B, CORD-MP 72925; 22. Sb element, sample LSSJ D, CORD-MP 72923; 23. Sc element, sample LSSJ tope+, CORD-MP 72924; 24. Pa element, sample LSSJ tope+, CORD-MP 72926; 25. Pb element, sample LSSJ H, CORD-MP 72927. Scale bar: 100 μm.
At the Honghuayuan Formation, Guizhou, southern China, Zhen et al. (2007) recorded an association of conodonts that compared with material from Sweden, concluding that the upper part of that association would correspond to the P. proteus Zone, although they did not record the index species. At slope facies of the Shijiatou and Jingshan formations, southern China, Zhen et al. (2015b) recorded the Paroistiodus proteus, Triangularodus bifidus and Serratognathus diversus biozones, which correlate with the Paroistiodus proteus Zone of this study.

6.3. Prioniodus elegans Zone

The record of Prioniodus elegans (Fig. 6) below the first appearance of Oepikodus evae (Lindström), is verified between samples LSSJ O6 and LSSJ L1 (Fig. 4), allowing for the recognition of the homonymous zone for this interval, whereas its upper limit is demarked at the sample LSSJ K2 where the Oepikodus evae index fossil appears. The Prioniodus elegans-Tropodus sweeti Subzone is recognized from sample LSSJ O6 to LSSJ O1 by the record of Tropodus sweeti not associated with Oepikodus communis (Ethington and Clark). The Prioniodus elegans-Oepikodus communis Subzone is recognized from the sample LSSJ O through the occurrence of Oepikodus communis, to the sample LSSJ K2. The local thickness of this zone is 86.6 m.

These samples yield a high diversity and abundance of conodonts, with the record of Juanognathus jaanussoni Serpagli, Semiacodontiodus poterillensis Albanesi, Parapaltodus simplicissimus Stouge, Oelandodus elongatus (Lindström), Rossodus barnesi Albanesi, Reutterodus andinus Serpagli, Tropodus australis (Serpagli), Oelandodus costatus van Wamel, Bergstromognathus extensus Serpagli, Acodus deltatus (Lindström), Periodon primus Stouge and Bagnoli, Ansellajentlandica (Löfgren), Oistodus lanceolatus Pander, Parapanderodus paracornuformis (Ethington and Clark), Protopanderodus rectus (Lindström), Protopanderodus gradatus Serpagli, Paracordylodus gracilis Lindström, Oistodus multicorrugatus Harris, Periodon selenopsis (Serpagli), Jumudontus gananda Cooper, Parapanderodus striatus (Graves and Ellison) and Oepikodus communis.

6.3.1. Regional correlation

Serpagli (1974) suggested the existence of the Prioniodus elegans Zone in the San Juan Formation, Precordillera, and proposed its correspondence with the Fauna A of the Pachaco section, based on the species association, although not determining the nominal species. This species was firstly published by Hünicken and Sarmiento (1980) from the Guandacol section, and the zone was defined by Albanesi et al. (1998) in the Yanso section.

Lehnert (1993, 1995) defined the correlative Prioniodus elegans-Oepikodus communis Association Zone for the basal levels from the San Juan Formation at the Niquivil and Cerro La Silla sections, Precordillera of San Juan.

Mango et al. (2016) studied samples from the Huaco Anticline, San Juan Precordillera, and recognized the Prioniodus elegans Zone in strata of the lower part of the San Juan Formation, based on the occurrence of the nominal species at the Rio Huaco canyon.

6.3.2. Intercontinental correlation

Löfgren (1978, 1993, 1994, 1996) identified parts of this zone from different localities of Sweden. Layer 9 of the Cow Head Group contains conodonts assignable to the Prioniodus elegans Zone in different sections of Western Newfoundland (Fähræus and Nowlan, 1978; Stouge and Bagnoli, 1988; Pohler, 1994). It could also be correlated with the lower part of Fauna E proposed by Ethington and Clark (1971) for the North American biostratigraphic scheme, and with the Oepikodus communis Zone by Ethington and Repetski (1984).

The Protopanderodus inconstans-Scolopodus subrex Zone of shallow waters and Acodus delicatus-Acodus? primus Zone of deep water environments defined by Ji and Barnes (1994) for the Boat Harbour Formation, Saint George Group, Newfoundland, correlate with the lower Prioniodus elegans Zone. Its upper part corresponds to the lower Parapanderodus carlæ-Stultodontus ovatus Zone of shallow-water facies and to the Oepikodus communis-Protoprioniodus simplicissimus Zone of deep-water facies as defined for the Catoche Formation by the same authors.
Seo et al. (1994) defined the Paracordylodus gracilis and Triangulodus dumugolensis zones for the upper South Korean Dumugol Formation, which could be partially correlated with the Prioniodus elegans Zone. At slope facies of the Jingshan Formation, southern China, Zhen et al. (2015b) also recorded the Prioniodus elegans Biozone.

6.4. Oepikodus evae Zone

This zone is recognized from the sample LSSJ K2 by the occurrence of Oepikodus evae (Fig. 5) to the sample LSSJ J (Fig. 4), where Oepikodus intermedius (Serpagli) appears not associated to Oepikodus evae. In this section, the species Juanognathus variabilis Serpagli and Scolopodus oldstockensis Stouge are recorded throughout the zonal interval, though according to the reference biostratigraphic scheme by Albanesi and Ortega (2016) it would correspond to the Oepikodus evae-Scolopodus oldstockensis Subzone of Albanesi et al. (1998). The division of the zone will be discussed in detail under the discussion part. The local thickness of this zone is 23.9 m.

In this interval Periodon flabellum (Lindström), Drepanoistodus basiovalis (Sergeeva), Oepikodus intermedius, Scolopodus oldstockensis, Texania heligma Pohler, and Paroistodus cf. P. proteus appear in the record. Additionally, the last record of Tropodus compitus, Oepikodus communis, Prioniodus elegans and Periodon primus Stouge and Bagnoli is observed.

6.4.1. Regional correlation

Lehnert (1993, 1995) proposed the O. evae and O. evae/O. intermedius zones at the Niquivil section, which correlates with the O. evae Zone established by Albanesi et al. (1998). The later zone was recognized at the Los Gatos Creek, Cerro Viejo of Huaco, Precordilleran Central of San Juan, by Mango and Albanesi (2018a).

Mestre (2008) reviewed the conodont biostratigraphy of the uppermost San Juan Formation in the Buenaventura Luna Monument area, recognizing the Oepikodus evae Zone regardless previous studies by Lemos (1981). Subsequently, Mango et al. (2016) analyzed conodonts from the Huaco Anticline, recognizing conodonts of the O. evae Zone from the top stratum of the San Juan Formation, and the limestone dropstones that bear the basal strata of the unconformably overlying Guandacol Formation.

Species of the Trapezognathus diprion Zone are recognized in samples obtained from the Acoite Formation of the Cordillera Oriental, Northwest Argentina by Carlorosi and Heredia (2013), whose lower part correlates with the upper O. evae Zone of Albanesi et al. (1998).

Voldman et al. (2016) define the Gothodus andinus Zone, in the upper Acoite Formation at the Chulpios creek, Santa Victoria, Cordillera Oriental, Argentina. The upper section could be correlated with part of the O. evae Zone as used in this study. At the Suri Formation of the Famatina System (Lehnert et al., 1997; Albanesi and Astini, 2000) and the Niquivil section (Albanesi et al., 2006) the O. evae Zone is well documented.

6.4.2. Intercontinental correlation

The O. evae Zone can be correlated with the upper-middle part of the Oepikodus communis Zone in North American biostratigraphic schemes (Ethington and Repetski, 1984).

The index fossil has an important record in the formational units of Hubei Province in China (An, 1981; An et al., 1985), although Stouge and Bagnoli (1988) appreciate difficulty in correlation.

The Precordilleran O. evae Zone can be correlated with the O. evae Zone of Lindström (1971) and the O. evae Zone and the lower Trapezognathus diprion Zone of Bagnoli and Stouge (1997) from the Baltoscandian region.

In limestone blocks showing evidence of transport, contained in the Rosroe Formation, Lough Naforyo Area, Western Ireland, Stouge et al. (2015) recognize an association dominated by Oepikodus evae, Bergstroemognathus, Periodon and Protoperiodon.

6.5. Oepikodus intermedius Zone

The occurrence of Oepikodus intermedius (Fig. 5) not associated to Oepikodus evae and Tripodus laevis Bradshaw, allows to recognize the homonymous zone from the sample LSSJ J to the sample LSSJ H (Fig. 4), where Tripodus laevis appears in the record. The local thickness of this zone is 30.9 m.

These samples present the first record of Triangulodus brevibasis (Sergeeva) and Paltodus? jemtlandicus Löfgren. In addition, the last record of Colaptoconus quadruplicatus, Paltodus subaequalis Pander, Drepanoistodus forceps (Lindström), Scolopodus oldstockensis, Paroistodus parallelus,
Juanognathus variabilis Serpagli, Tropodus australis, Protopanderodus leonardii, P. elongatus, P. gradatus, Texitia heligma, Paracordylodus gracilis, Paraistodus originalis, Paraistodus cf. P. proteus, Bergstromogaphus extensus, Oistodus multicorrugatus, Juanognathus n. sp. A, Scolopodus krummi, Periodon selenopsis and Jumudontus gananda is reported.

6.5.1. Regional correlation

At the Yanso section (Albanesi et al., 1998) and the Niquivil section (Albanesi et al., 2006) the referred unit would be correlated with the O. intermedius Zone. According to their collection of conodonts, the latter authors demonstrate that the Fauna C of the San Juan Formation (Serpagli, 1974) would represent the O. intermedius Zone, but not the Baltoniodus navis Zone as interpreted by Serpagli. At the Los Gatos Creek, Cerro Viejo de Huaco, Precordillera Central of San Juan, Mango and Albanesi (2018a) record the Oepikodus intermedius Zone in the San Juan Formation.

Carlorosi and Heredia (2013) analyzed samples obtained from the Acoite Formation, Cordillera Oriental, Northwestern Argentina, and recorded the Trapezognathus diprion Zone, and also proposed the Baltoniodus cf. B. triangularis Zone above it, which correlates with the lower and upper O. intermedius Zone, respectively. In the Laguna Verde section, Zenta Range, Cordillera Oriental, Northwest Argentina, Voldman et al. (2013b) recovered Baltoniodus cf. triangularis, with similar conclusions as Carlorosi and Heredia (2013).

6.5.2. Intercontinental correlation

The O. intermedius Zone could be correlated with the O. communis Zone (Ethington and Repetski, 1984; cf. Smith, 1991; Ji and Barnes, 1994), and with the Protoprioniodus aranda-Juanognathus jaamussoni interval of Ethington and Clark (1981) for the middle Wah Wah Formation of the Pogonip Group at Ibex, Utah.

The O. intermedius Zone correlates with the uppermost part of the Oepikodus evae Biozone of southern China and with the Jumudontus ganada Biozone of northern China (Zhen et al., 2015a, 2016; Wang et al., 2018).

In the Baltic region, it can be correlated with the upper O. evae Zone (Lindström, 1971) and with the Microzarkodina sp. A Zone of Bagnoli and Stouge (1997). Lehner et al. (2013) studied the biostratigraphy of the Oslobreen Group in the Svalbard archipelago, and recognized in the Valhallfonna Formation, Olenidsletta Member, the Oepikodus intermedius Zone, which would correlate with the O. intermedius Zone and the base of the Baltoniodus triangularis-Tripodus laevis Zone of this work.

6.6. Baltoniodus triangularis-Tripodus laevis Zone

This zone is defined by the first appearance of Tripodus laevis (Fig. 6), without being associated with Baltoniodus navis (Lindström), between samples LSSJ H and LSSJ tope+ (Fig. 4), the latter corresponds to the top stratum of the San Juan Formation in the section. At these levels, Tripodus laevis, Drepanoistodus costatus, Stolodus stola (Lindström), Pieracodontus cryptodens (Mound), Scolopodus striatus Pander and Scalpellopus gracilis (Sergeeva) are recorded. The local thickness of this zone is at least 87.4 m.

6.6.1. Regional correlation

This unit has originally been defined to as Tripodus laevis Zone in the Portezuelo Yanso section of the Cerro Poterillo (Albanesi et al., 1998); although considering the presence of Baltoniodus triangularis (Lindström) at the same section and at Peña Sombria, Della Costa and Albanesi (2016) and Albanesi and Ortega (2016) emended the original definition by incorporating the latter taxon as composite name to the zone, for a broader reference. At the Niquivil section the referred biostratigraphic unit is correlated with the Tripodus laevis Zone (Albanesi et al., 2006) or Baltoniodus triangularis-Tripodus laevis (Mango and Albanesi, 2018b). At the Los Gatos Creek, Cerro Viejo de Huaco, Precordillera Central of San Juan, Mango and Albanesi (2018a) recorded the Baltoniodus triangularis-Tripodus laevis Zone in the San Juan Formation.

The conodont associations corresponding to Fauna D recorded at the Pachaco section on the San Juan River (Serpagli, 1974) could be assigned to the Baltoniodus triangularis-Tripodus laevis Zone.

6.6.2. Intercontinental correlation

This zone would correlate with the Baltoniodus triangularis and Microzarkodina flabellum zones of Bagnoli and Stouge (1997), and with the Baltoniodus triangularis Zone of Lindström (1971) and Tolmacheva (2001), from the Baltic biostratigraphic schemes.
In North America, it correlates with the Tripodus laevis Zone of Ross et al. (1997) and with the Microzarkodina flabellum-Tripodus laevis Zone of Ethington and Clark (1981). Ji and Barnes (1994) defined the Parapanderodus retractus Zone, for shallow-water environments, and the Pteracontiodus cryptodens Zone for deep-water environments in the Aguathuna Formation, Saint George Group, Newfoundland, correlatives of the Baltoniodus triangularis-Tripodus laevis Zone.

At the Huanghuachang section, China, it could be correlated with the Baltoniodus triangularis Zone (Wang et al., 2003). Lehner (1995) for the Baltic biostratigraphic scheme. However, the present records constrain the deposits located from the base of the second reef level to the top stratum of the San Juan Formation exposed in the section (87.4 m) to the Baltoniodus triangularis-Tripodus laevis Zone.

8. Conclusions

The San Juan Formation at the Cerro La Silla section presents a total thickness of 264.7 m. This result differs from published measurement that indicate a thickness of 320 m for the exposed strata of the formation, a significant difference possibly due to the field technique applied for measuring the thickness of this section. However, the thickness calculated from the base of the San Juan Formation up to the beginning of the Oepikodus evae Zone at this section is similar to the previously published data, as a reference for the middle part of the section.

The conodonts recovered from La Silla and San Juan formations present a color alteration index (CAI) varying from 2 to 2.5, which refers to burial temperatures of 60-155 °C compatible with the Niqquivil tectonic thrust, present in the easternmost belt of the Central Precordillera.

For the upper La Silla Formation and the lower part of the San Juan Formation at the Cerro La Silla, the Paltodus deltifer deltifer Subzone of the Paltodus deltifer Zone from the Baltic biostratigraphic scheme, which correlates with the Macerodus dianae Zone (middle Tremadocian) of the Precordillera and the North American schemes, is determined.

The San Juan Formation at the Cerro La Silla section records conodont species of the Macerodus dianae, Paroistodus proteus, Primiododus elegans, Oepikodus evae, Oepikodus intermedius and Baltoniodus triangularis-Tripodus laevis zones (middle Tremadocian-lower Dapingian). Recovering of Baltoniodus triangularis-Tripodus laevis Zone from the second reef level to the top stratum in the section contradicts previous interpretations that this interval correlates with the Baltoniodus navis, Paroistodus originalis and Microzarkodina parva zones of the Baltic biostratigraphic scheme.

At the Cerro La Silla section, Scolopodus oldstockensis is recorded from older strata of the Oepikodus evae Zone than at the Portezuelo Yanso section, Cerro Potrerillo, where this zone was defined for the Precordillera, either because of facies control or laboratory bias. This situation precludes the application of the zonal division in the study section.
Acknowledgments

The authors specially thank the CICTERRA (CONICET-UNC) and the CIGEA (FCEFYN, UNC) for infrastructure and equipment support. We are grateful to the CONICET and the Universidad Nacional de Córdoba, for the continuous funding to the study of conodonts. Comments and corrections by Editor W. Vivallo Sandoval and by the reviewer, Y.Y. Zhen, significantly improved our manuscript and are greatly appreciated. This contribution corresponds to part of the Doctoral Thesis in Geological Sciences of the first author.

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