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# Review of the Cambrian Stratigraphy of the Argentine Precordillera

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## ABSTRACT

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The Cambrian rocks of the Argentine Precordillera are analyzed and updated providing a new stratigraphic interpretation. The lithostratigraphic assemblages provide evidence that the Precordilleran Cambrian Basin was a rimmed platform. The lithostratigraphy record enables to distinguish three large areas corresponding to an inner platform, an outer platform to slope environment and a mixed zone where both platforms and the rim interfinger. The biostratigraphic proposal based on trilobites include restricted shelf biozones to the East, characterized by sparse, endemic and low diversity polymeroid faunules. Moreover, to the West outer shelf biozones are characterized by widespread, high diversity, mixed endemic and cosmopolitan polymeroid and agnostoid faunas. The lithostratigraphic and biostratigraphic data prove the existence of an important hiatus near the Lower-Middle Cambrian boundary, which is correlated to the Hawke Bay regressive event recorded along the eastern margin of Laurentia. The *Olenellus* Zone assemblage trilobites underlies the *Glossopleura* or the *Ehmaniella* Zone. The early Middle Cambrian zones (from *Plagiura-Poliella* to *Albertella*) are lacking in the whole Precordillera.

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**KEYWORDS** | Cambrian. Lithostratigraphy. Biostratigraphy. Precordillera Argentina.

## INTRODUCTION

The presence of Cambrian rocks in the Argentine Precordillera has been known since the last century and they have been the object of numerous studies from the stratigraphic, paleontologic, sedimentologic as well as geodynamic viewpoints. The last decade has seen publication of several interpretative reference proposals in terms of the origin of the Precordillera terrane, linking it to a Laurentian origin, with the subsequent drift and collision against Gondwana. Also during recent years, there have been many contributions yielding new data for the regional stratigraphic interpretation.

This paper is a summarized update of what is known about the Cambrian stratigraphy in the Precordillera, and mainly analyzes the lithostratigraphic units and trilobites biozones assembled in a rimmed platform palaeogeographic model.

## GEOLOGICAL SETTING

The Precordillera is a morphostructural province in the central western pre-Andes of Argentina, placed between the Western Sierras Pampeanas to the east and the Cordillera Frontal to the west, with extended longitudinal valleys between them both. The Cambrian rocks of the Precordillera are distributed over 400 km from N to S and, having a maximum E-W extension of 66 km; They extend from the southern part of the province of La Rioja, across the center of the province of San Juan and to the northern part of the province of Mendoza (Fig. 1). Within this belt, it is possible to differentiate inner platform facies in its eastern part (Precordillera Oriental and Central) close to the Sierras Pampeanas, while the outer platform rocks are located in its western part (Precordillera Occidental) close to the Cordillera Frontal (Bordonaro, 1992). The southern end is named Precordillera Mendocina, where mixed out-

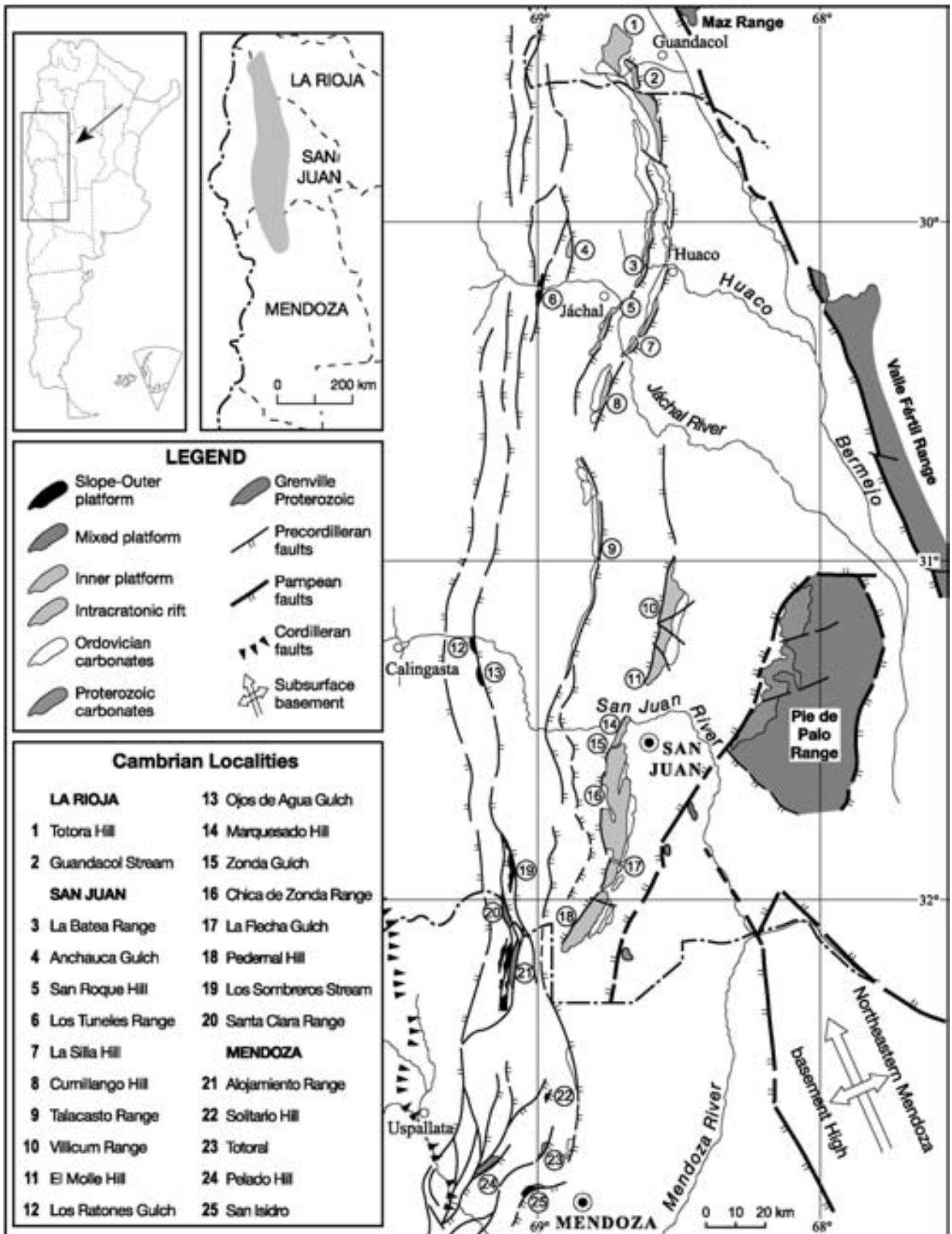


FIGURE 1 | Distribution of Cambrian outcrops in the Argentine Precordillera, differentiated into inner platform, outer platform and mixed outer and inner platform. The Precambrian basement is also indicated.

crops of inner and outer platform and rim facies exist (Banchig and Bordonaro, 1997). Figure 1 shows the location of 25 outcrops with critical sections or paleontological localities essential to the assemblage of the regional framework of the Precordilleran Cambrian stratigraphy. Figure 2 shows an updated synthesis of the Cambrian stratigraphy, using the chronostratigraphy of North America as proposed by Palmer (1998).

Similarities between the Cambrian carbonate lithofacies and faunas of both the Appalachian and the Precordillera suggest that the Precordillera was an allochthonous terrane accreted to Gondwana during the Ordovician (Astini et al., 1996).

## CAMBRIAN LITHOSTRATIGRAPHIC UNITS

### Autochthonous Units

These units are distributed within the Precordillera Oriental and Central as inner platform facies, except in the Precordillera Mendocina, where the facies belong to the inner-platform and rim and outer platform types (Fig. 1). This complete stratigraphic succession, predominantly carbonates, ranges from the upper Lower Cambrian to the Lower Ordovician, (Fig. 2). Below follows a brief synthesis of the characteristics of each unit.

#### *Cerro Totorá Formation*

This unit crops out at the Totorá Hill (1 in Fig. 1), west of Guandacol, in the La Rioja Precordillera (Astini and Vaccari, 1996). The unit is composed of shales, red sandstones, siltstones, laminated gypsum, calcareous dolomites, claystones and cyclically laminated sandstones. Toward the top, the formation contains olenellids (*Arcuolenellus megafrontalis* VACCARI) belonging to the *Olenellus* Zone of the late Lower Cambrian (Vaccari, 1988).

#### *La Laja Formation*

This formation is distributed along the western flank of the Villicum, Chica de Zonda and Pedernal Ranges (Borrello, 1962, emended Bordonaro, 1980; 10, 16 and 18 in Fig. 1). It consists of limestones, argillaceous limestones and marlstones or siltstones arranged in four members, reaching a thickness of almost 700 m. These members were named by Baldis and Bordonaro (1981) as El Estero, Soldano, Rivadavia and Juan Pobre (Fig. 2). Originally the depositional record of this unit was considered to be continuous from the late Early Cambrian to the late Middle Cambrian. However, Bordonaro (1999) has reported a major hiatus during the early Middle Cambrian between the El Estero and Soldano Members (Fig. 2). Bercowski et al. (1990) reported shallowing-upward cycles which stack up in this formation.

#### *Los Hornos Formation*

This unit has been informally defined at the locality of Totorá Hill, west of Guandacol, La Rioja (Astini and Vaccari, 1996; 1 in Fig. 1). The formation is formed by massive dolomites corresponding to deposits of a shallow hypersaline platform. It could be of Middle Cambrian age, owing to the fact it overlies paraconformably the Cerro Totorá Formation, even though lithologically it could be correlated to the Zonda Formation which is of Upper Cambrian age.

#### *Zonda Formation*

This formation is distributed along the entire Precordillera Oriental and also at the La Silla Hill in Jáchal (Bordonaro, 1980; 7, 10, 11, 14, 15, 16, 17 and 18 in Fig. 1). It is composed of a succession of 300 m of dolomitic limestones and dolomites with shallow-water sedimentary structures, especially microbial lamination and stromatolites. Arroqui Langer and Bordonaro (1996) recognized hypersaline shallowing-upward cycles in this unit. At present, no fossils have been found that would allow dating, but because of its stratigraphic position it is assigned to the early Late Cambrian.

#### *La Flecha Formation*

This unit crops out mostly in the Precordillera Oriental and Central of San Juan and La Rioja (Baldis et al., 1981; 2, 3, 5, 7 to 11 and 14 to 18 in Fig. 1). With an average thickness of 500 m, it is characterized by a shallowing-upward, cyclic alternation of cherty limestones and dolomites, with abundant stromatolitic and thrombolitic patch reefs with diverse forms (Keller et al., 1989; Armella, 1994). The age of this formation varies within the Late Cambrian, with trilobites indicating Steptoean and Sunwaptan age (Keller et al., 1994).

#### *La Silla Formation*

This unit is largely found in the Precordillera Oriental and Central of San Juan and La Rioja, from Guandacol to the Pedernal Hill (Keller et al., 1994; 2 and 18 in Fig. 1). It is composed of 400 m of dark-gray limestones with intercalations of laminated dolomite, peloidal grainstones, intraclastic grainstones and lime mudstones, with abundant bioturbation. The base of the formation contains trilobites from the *Saukia* Zone of the Upper Cambrian and the remainder of the unit contains conodonts from the Lower Ibxian (Keller et al., 1994).

#### *Alojamiento Formation*

This unit crops out at the Alojamiento and Santa Clara Ranges between San Juan and Mendoza (Harrington, 1971; emended by Banchig and Bordonaro, 1997; 20 and 21 in Fig. 1). It is composed of limestones and dolomites,

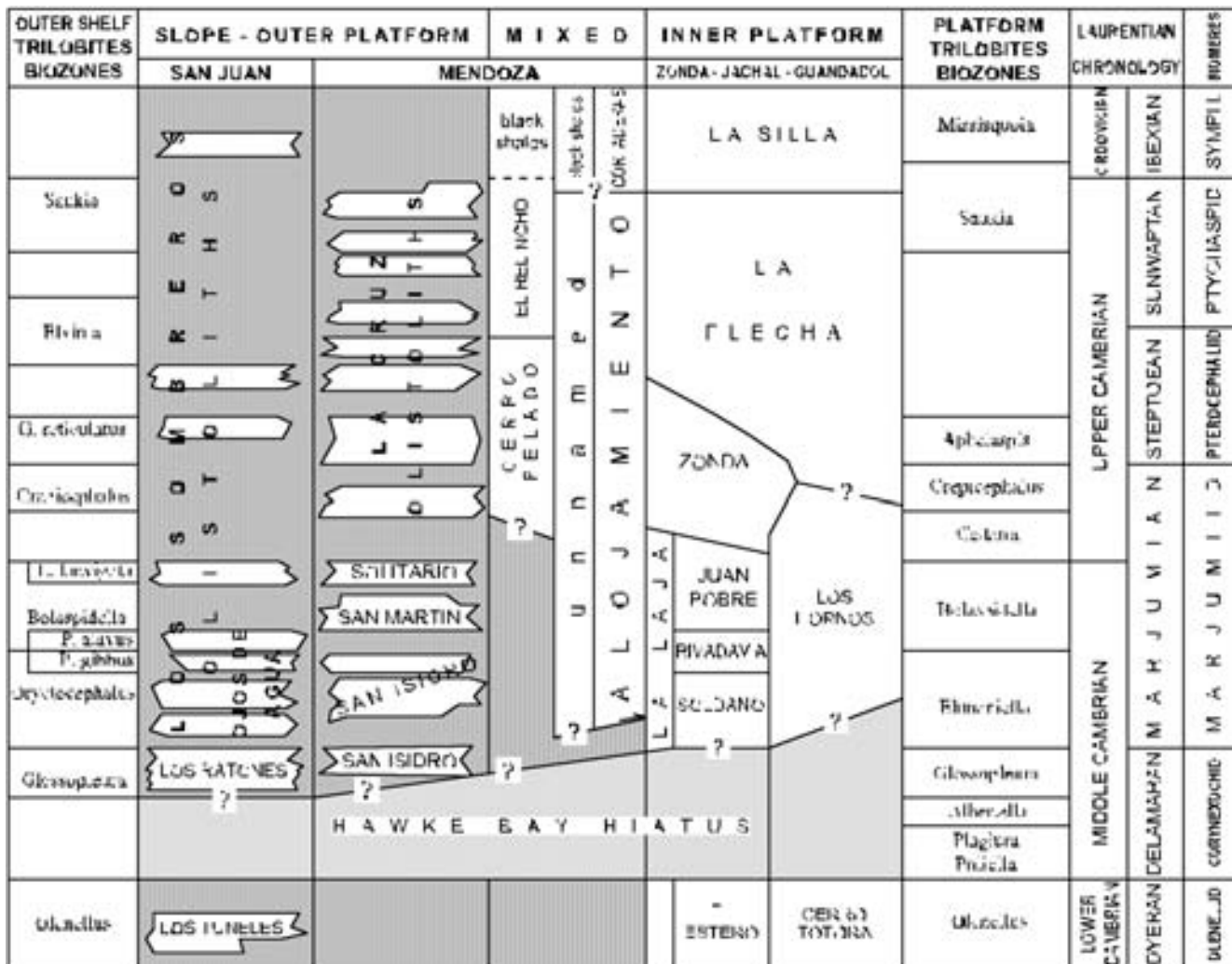


FIGURE 2 | Cambrian stratigraphic record of the Argentine Precordillera grouping the stratigraphic successions into an inner platform, slope - outer platform and mixed zones. The names of the olistoliths correspond to the localities where they are found. Laurentian chronology is after Palmer (1998).

with intercalations of sandstone, shales and calcareous breccias, indicating outer platform environments near the base, with inner platform and rim settings in the rest of the unit. The Middle Cambrian age of the base is shown by a trilobite fauna belonging to the *Ptychagnostus gibbus* and *Oryctocephalus* zones.

**Cerro Pelado Formation**

This unit stretches along the ridge of the Pelado Hill west of the city of Mendoza (Heredia, 1996; 24 in Fig. 1). Toward the base, it contains conglomerates and sandstones, bioturbated wackestones and packstones. In the middle part there are thrombolitic boundstones with chert, and the upper part contains bioturbated wackestones-packstones. The top is of late Steptoean- early Fraconian age with trilobites from the *Elvinia* Zone, while the age of the base is unknown.

**El Relincho Formation**

This formation crops out at the Pelado Hill (Heredia, 1996; 24 in Fig. 1) and is characterized by dark, laminated lime mudstones alternating with dark shales. The age of the basal beds is latest Cambrian, as shown by *Proconodontus tenuiserratus* Zone (Heredia, 1996) and by trilobites of the *Saukia* Zone (Shergold et al., 1995). The age of the shales at the top is unknown.

**Unnamed Formation**

This is a newly recognized unit by Bordonaro et al. (1999), cropping out at Totoral to the northwest of Mendoza city (23 in Fig. 1). It contains massive limestones of shallow platform origin in the lower part, black lime mudstones and calcareous shales of an outer platform and upper slope environment in the middle part, and black

shales at the top. At the base of the unit species of *Bathyriscus* and *Bathyriscidella* trilobites, representing the Middle Cambrian *Oryctocephalus* Zone, are found.

### Allochthonous Units (Olistoliths)

A number of allochthonous blocks (olistoliths) are located along the Precordillera Occidental of San Juan and in the Precordillera Mendocina at numerous localities (Fig. 2). They are composed mainly of limestones and are enclosed in Middle and Upper Ordovician olistostromes of the Los Sombreros and Empozada formations (Bordonaro et al., 1999; see also Beresi in this volume). Many of these olistoliths are small, ranging from a few centimeters to a few meters in size. Others, have sizes ranging from several tens of meters to several hundreds of meters.

#### *Ancaucha Olistolith*

This is an olistolith located at the Ancaucha gulch, north of the Jáchal River (Astini and Thomas, 1999a; 4 in Fig. 1). It is composed of sandstones and shales, with beds of bioclastic grainstones containing olenellid and *Salterella* faunas of late Early Cambrian age.

#### *San Martín Olistolith*

This body is a resedimented megablock in the Empozada Formation cropping out in the San Isidro area, near Mendoza city (Bordonaro et al., 1993; 25 in Fig. 1). It is composed of alternating limestones, marlstones and black shales deposited as periplatform carbonate muds and contains agnostoids from the late Middle Cambrian.

#### *San Isidro Olistoliths*

These are several medium-sized olistolithic blocks, enclosed in the Empozada Formation, and cropping out in the San Isidro area, Mendoza (Bordonaro et al., 1993; 25 in Fig. 1). They are composed of marlstones and oncolitic limestones. Some of these blocks contain trilobites from the *Glossopleura* Zone, and others ones from the *Oryctocephalus* Zone.

#### *La Cruz Olistoliths*

This is a set of small and medium-sized carbonate olistoliths within the Empozada Formation, outcropping at San Isidro (Bordonaro, 1992; 25 in Fig. 1). They contain trilobites from the Upper Cambrian, belonging to the *Saukia*, *Elvinia*, *Glyptagnostus reticulatus* and *Crepicephalus* zones.

#### *Los Sombreros Olistoliths*

This is a set of large olistoliths within the Los Sombreros Formation and located at the Los Sombreros

stream, Tontal Range (Bordonaro and Banchig, 1996; 19 in Fig. 1). They are composed of dark limestones and contain trilobites from the Middle Cambrian (*Tonkinella stephensis* KOBAYASHI, *Bathyriscus* aff. *rotundatus* RASETTI); and the Upper Cambrian (*Glyptagnostus reticulatus*, ANGELIN). These olistoliths also contain Ibexian conodonts of the *Cordylodus proavus* Zone (Lehnert, 1994).

#### *Ojos de Agua Olistoliths*

This is a group of small and medium-sized blocks within the Los Sombreros Formation. These olistoliths crop out at the Ojos de Agua section, of the eastern flank of the Tontal Range (Bordonaro and Banchig, 1996; 13 in Fig. 1). These blocks belong to the outer platform facies and contain trilobites such as *Tonkinella stephensis* KOBAYASHI, *Bathyriscus* aff. *rotundatus* RASETTI and *Glossopleura* aff. *leona* LOCHMAN, from the Middle Cambrian and *Pseudagnostus idalis* OPIK, from the Upper Cambrian also occurs.

#### *Los Ratones Olistoliths*

These olistoliths form a set of small blocks within the Los Sombreros Formation and are exposed at the northern end of the Tontal Range, in the Los Ratones gulch (Bordonaro and Banchig, 1996; 12 in Fig. 1). They are composed of shales and calcareous shales from the platform margin, containing middle Cambrian trilobites such as *Kootenia* sp. and *Glossopleura* sp.

#### *Los Túneles Olistoliths*

These olistoliths are located within the Los Sombreros Formation and are exposed at the Los Túneles Range along the Jáchal River (Bordonaro and Banchig, 1996; 6 in Fig. 1). They are two large carbonate olistoliths from the outer platform facies (Benedetto and Vacari, 1992). The first one contains a fauna of *Olenellus* sp. and *Sombrerella argentina* VACCARI and BORDONARO, from the late Lower Cambrian, and the second one *Chilometopus tunelensis* VACCARI and BORDONARO, and *Ptychagnostus praecurrens* WESTERGARD, from the Middle Cambrian (Vaccari and Bordonaro, 1993).

#### *Solitario Olistolith*

This olistolith crops out in Solitario Hill, North of Mendoza city (Bordonaro and Banchig, 1996; 22 in Fig. 1). It is considered that this unit has the characteristics of an olistolithic body owing to its dimensions and syndimentary deformation, although it is impossible to observe its relationship with the host rock; its position could also be caused by tectonic emplacement. It consists of black limestones, intercalated with dark calcare-

ous shales from the deeper periplatform setting. It contains agnostoid trilobites from the late Middle Cambrian *Lejopyge laevigata* Zone.

## CAMBRIAN BIOSTRATIGRAPHIC UNITS

The biostratigraphic units recognized throughout the entire Precordillera are defined on the basis of either polymeroid or agnostoid trilobites. In the stratigraphic chart (Fig. 2), the units are grouped in inner platform biozones, defined by Laurentian endemic polymeroids, and outer platform biozones, defined by both endemic and cosmopolitan agnostoids and polymeroids.

### Inner Platform Biozones

#### *Olenellus* Zone (Lower Cambrian)

Borrello (1963, 1964) documented the presence of the Lower Cambrian with *Fremontella inopinata* BORRELLO, found at the southwestern extreme of the Villicum Range and northeast of the Chica of Zonda Range. Later Borrello (1971) assigned it to the upper *Olenellus* Zone, limited to the basal part of the La Laja Formation. The original elements mentioned by Borrello in this biozone are: *Pagetides? dubius* HUPE, *Laudonia* sp., *Olenellus* aff. *brachycephalus* (EMMONS), *Fremontella inopinata* BORRELLO, *Eoptychoparia acuminata* HUPE, *Villicumia borrelloii* HUPE, *Zacanthoides* sp., *Paedeumias? sp.* and *Kootenia* sp. Bordonaro (1986) recognized the *Bonnia-Olenellus* Zone in the El Estero Member through findings of *Olenellus zondaensis* BORDONARO, *Bonnia villicumica* BORDONARO, *Antagmus argentinus*, BORDONARO and *Bristolia* sp. Astini and Vaccari (1996) recognized *Arcuolenellus megafrontalis* VACCARI, characteristic of the upper part of the *Olenellus* Zone in the Cerro Totorá Formation, La Rioja. Bordonaro and Banchig (1996) demonstrated that the *Olenellus* Zone can be recognized in the entire late Lower Cambrian of the San Juan and La Rioja Precordillera after the concept of Palmer and Repina (1993).

#### *Ehmaniella* Zone (Middle Cambrian)

This biozone was established in the Precordillera by Bordonaro and Banchig (1996), in agreement with the concepts of Sundberg (1994), to replace the *Bathyriscus – Elvathina* Zone adopted by Borrello (1971). This biozone is present in most of the Soldano Member of the La Laja Formation, and is identified by a variety of taxa belonging to Ehmaniellidae (Bordonaro, 1999).

#### *Bolaspidella* Zone (Middle Cambrian)

At the Zonda gulch, this biozone was recognized in the upper part of the La Laja Formation with elements of

*Modocia* sp. and *Asaphiscus* sp. (Baldís and Bordonaro, 1981).

#### *Cedaria* Zone (Upper Cambrian)

Borrello (1965) reported this biozone from El Totoral, Mendoza Precordillera. It was defined by the presence of remains of *Cedarina* sp., *Blountia* sp., *Olenoides* sp. and *Maryvillia? sp.* Borrello (1971) also mentioned it (questionably) in San Isidro, Mendoza, on the basis of the presence of *Blountia? sp.* and *Tricrepicephalus anarusconi* RUSCONI.

#### *Crepicephalus* Zone (Upper Cambrian)

Keller et al. (1994) recognized this biozone in the La Flecha Formation, close to Guandacol, La Rioja, due to the presence of *Madaroccephalus laetus* RASETTI, *Komaspidella laevis* RASETTI and *Crepicephalus* cf. *C. scillisis* RESSER.

#### *Aphelaspis* Zone (Upper Cambrian)

These zone was identified by Keller et al. (1994) at the base of the La Flecha Formation, in La Angostura, near Guandacol, La Rioja through the presence of *Dytremacephalus strictus* RASETTI.

#### *Saukia* Zone (Upper Cambrian)

Keller et al. (1994) identified this biozone in the La Flecha Formation, at the La Flecha gulch, San Juan, based on the presence of *Stenopilus convergens* (RAYMOND), and in Guandacol, La Rioja, due to *Plethopeltis* cf. *P. armatus* BILLINGS. It was also recognized at the base of the La Sila Formation in its type section, with the occurrence of *Plethopeltis obtusus* ( RASETTI).

### Outer Platform Biozones

#### *Olenellus* Zone (Lower Cambrian)

Identified by Vaccari and Bordonaro (1993) in the Los Túneles olistolith with *Olenellus* sp., *Prozacanthoides* sp., and *Sombrerella argentina* VACCARI and BORDONARO.

#### *Glossopleura* Zone (Middle Cambrian)

Identified by Poulsen (1958) at San Isidro, Mendoza, based on the presence of *Glossopleura* sp., *Chilometopus parabolicus* RUSCONI, *Asperocare argentinum* POULSEN, *Alokistocare elongatum* POULSEN, *Alokistocare australe* POULSEN, *Kistocare mendozanum* ( RUSCONI), among others. Bordonaro and Banchig (1990) described *Glossopleura* aff. *leona* LOCHMAN in the Ojos de Agua olistoliths in

the Tontal Range, San Juan. *Glossopleura* sp. was also observed in the Los Ratones olistoliths (Bordonaro and Banchig, 1996).

#### ***Oryctocephalus* Zone (Middle Cambrian)**

This biozone was first recognized in the Precordillera of Mendoza and San Juan in facies from the outer platform (Bordonaro, 1992). Later, Bordonaro and Banchig (1995) identified it in the olistoliths from San Isidro and Los Sombreros through the presence of *Oryctocephalus burgessensis* RESSER, *Bathyriscus elegans* (WALCOTT), *Parkaspis endecamera* RASETTI, *Elrathia kingii*, (MEEK), *Tonkinella stephensis* KOBAYASHI and *Athabasquia anax* (WALCOTT). It is also reported from the Alojamiento Formation by Banchig and Bordonaro (1997) with *Tonkinella* sp., *Bathyriscus* sp., and *Peronopsis* sp.

#### ***Bolaspidella* Zone (Middle Cambrian)**

This biozone is reported at the Solitario Hill near Mendoza, as defined by the presence of by *Williamsina* sp., *Talbotinella communis* POULSEN, *Bolaspidella lucieae* POULSEN, *Canotaspis aliena* POULSEN and *Goycoia brevicaudata* POULSEN, among others (Poulsen, 1960).

#### ***Ptychagnostus gibbus* Zone (Middle Cambrian)**

This biozone is reported at the Alojamiento Formation because of the presence of *Ptychagnostus intermedius* ROBISON, Banchig and Bordonaro (1997).

#### ***Ptychagnostus atavus* Zone (Middle Cambrian)**

Tortello and Bordonaro (1997) recognized this biozone in olistoliths at San Isidro by the presence of *Hypagnostus parvifrons* (LINNARSSON) and *Ptychagnostus cuyanus* (RUSCONI).

#### ***Ptychagnostus punctuosus* Zone (Middle Cambrian)**

This biozone occurs in the San Isidro olistoliths with *Homagnostus pehuenchensis* RUSCONI, *Ptychagnostus cuyanus* (RUSCONI) and *Tomagnostella exsculpta* (ANGELIN), (Tortello and Bordonaro, 1997).

#### ***Lejopyge laevigata* Zone (Middle Cambrian)**

Bordonaro and Liñán (1994) detected this biozone in the limestones of the Solitario Hill, Mendoza, and in olistoliths at Los Sombreros. The accompanying agnostoids are *Agnostus exsulatus* POULSEN, *Clavagnostus canotensis* (RUSCONI), *Oedorhachis australis* POULSEN, *Kormagnostus seclusus* (WALCOTT), *Peronopsis tenuis* (ILLING), *Tomagnostella exsculpta* (ANGELIN), and *Ptychagnostus aculeatus* (ANGELIN). Tortello and Bordonaro (1997) also

recognized *Lejopyge laevigata* (DALMAN) at the Solitario Hill.

#### ***Crepicephalus* Zone (Upper Cambrian)**

Borrello (1965) mentioned this biozone at San Isidro, Mendoza, based on the presence of *Tricrepicephalus* sp., *Modocia* sp., and *Coosia* sp. In addition, Bordonaro and Banchig (1996) recognized it in one of the La Cruz olistoliths in San Isidro, as indicated by the presence of *Tricrepicephalus texanus* (SHUMARD) and *Cedaria selwyni* PRATT.

#### ***Glyptagnostus reticulatus* Zone (Upper Cambrian)**

This biozone is represented in the Los Sombreros olistoliths of the Tontal Range, San Juan, by *Glyptagnostus reticulatus* (ANGELIN), (Shergold et al., 1995). This species was also reported in some of the La Cruz olistoliths, in the San Isidro area, near Mendoza (Bordonaro and Banchig, 1996).

#### ***Elvinia* Zone (Upper Cambrian)**

The occurrence of *Elvinia oblicuoensis* RUSCONI, and *Irvingella jorusconi* RUSCONI, indicates the presence of this biozone in San Isidro, Mendoza. (Borrello, 1971). Bordonaro and Banchig (1996) confirmed this biozone in the La Cruz olistoliths of San Isidro, based on the presence of *Elvinia roemeri* (SHUMARD) and *Irvingella major* ULRICH and RESSER. Bordonaro et al. (1999) also mentioned the *Elvinia* Zone in the El Relincho Formation at the Cerro Pelado, Mendoza, with elements of *Elvinia* sp. and *Irvingella* sp.

#### ***Saukia* Zone (Upper Cambrian)**

This biozone was recognized in the limestones of the La Cruz olistoliths in San Isidro, Mendoza by Borrello (1971), who noted the occurrence of *Lotagnostus* sp., *Bienvillia* sp., *Parabolinella peladoensis* BORRELLO, *Hungaiia puelchana* RUSCONI, and *Rasettia* sp., among others. The *Saukia* zone in San Isidro is represented by olistoliths of La Cruz bearing *Lotagnostus (L.) peladensis* (RUSCONI), *Lotagnostus trisectus* (SALTER), and *Bienvillia corax* (BILLINGS), (Shergold et al., 1995). Bordonaro et al. (1999) also identified this zone in the El Relincho Formation of Mendoza, based on the presence of *Hungaiia* sp. and *Saukia* sp.

### **THE HAWKE BAY HIATUS**

A faunistic and stratigraphic hiatus, recorded in the entire Precordillera occurs at the boundary between the Lower and the Middle Cambrian.

In the restricted platform (Fig. 2) the hiatus is found between the top of the El Estero Member and the base of the Soldano Member (Bordonaro, 1999), where Keller (1999) recognized a type 1 sequence boundary. This bounding surface separates mixed siliciclastic-carbonate platform sediments from entirely calcareous deposits. Trilobites of the *Olenellus* Zone are present in the El Estero Member, with species of *Olenellus*, *Antagmus*, *Bonnina*, *Fremontella*, *Bristolia* and pagetiids, frequently associated with *Hyolithes* and *Salterella*. These species are diagnostic of the middle part of the *Olenellus* Zone in Laurentia (Palmer and Repina, 1993). At the base of the Soldano Member, there are 2 m of glauconitic grainstones marking a change from the preceding mixed siliciclastic-carbonate sedimentation towards some 20 m of marlstones with thin cyclic intercalations of mudstones, fossiliferous wackestones and grainstones. The first trilobites recorded in this new sequence are ehmaniellids, which are typical representatives of the *Ehmaniella* Zone (sensu Sundberg, 1994) that characterizes the lower part of Marjumiid Biome of the late Middle Cambrian. In this basal 2 m of glauconitic grainstones level it has not been possible to find early Middle Cambrian trilobites typical of the Corynexochid Biome, which contains the *Plagiura-Poliella*, *Albertella* and *Glossopleura* zones.

On the other hand, Cañas (1988) described a hardground with an erosional unconformity at the base of the Los Hornos Formation carbonates, resting on the siliciclastic and carbonate deposits of the Cerro Totorá Formation. Astini and Thomas (1999b), showed an erosional unconformity between the red clastic rocks and evaporites of the Cerro Totorá Formation and the overlying dolomitic carbonate-shelf succession of the Los Hornos Formation. At the base of the Los Hornos Formation, there are also 2 m of glauconitic sandstones (Astini and Thomas, 1999b) overlaying a green shale with *Olenellus* of the Cerro Totorá Formation.

These glauconitic levels probably represent the regressive Hawke Bay event, manifested as a condensed interval with formation of glauconite. It is correlated with the Hawke Bay Formation from western Newfoundland and equivalent units from the Appalachian, which contain fossils from the *Olenellus* Zone at the base, and fossils from the later Middle Cambrian at the top (Palmer and James, 1984).

Even though work is still being done on this subject, it is estimated that in the inner platform the Hawke Bay Event lasted from the upper part of the *Olenellus* Zone of the late Lower Cambrian through the early Middle Cambrian *Plagiura-Poliella*, *Albertella* and *Glossopleura* Zones.

On the outer platform, and in spite of the fact that there is no continuous sedimentary record, no trilobites representative of the *Plagiura-Poliella* and *Albertella*

zones have been found. However, there are elements of the *Glossopleura* Zone such as *Glossopleura* aff. *leona* in the Ojos de Agua olistolith and *Glossopleura* sp. in the Los Ratones and San Isidro olistoliths. Also an *Olenellus* sp. and *Sombrerella argentina* (VACCARI and BORDONARO, 1993) association is recorded at the Los Túneles olistolith, which indicates the middle part of the *Olenellus* Zone. Astini and Vaccari (1996) recognized *Arcuolenellus megafontalis* as representative of the base of the upper *Olenellus* Zone in the Cerro Totorá Formation. Astini and Thomas (1999a) mentioned the finding of olenellids and *Salterella* in the Anchauca Olistolith.

The faunistic and stratigraphic evidence found until now indicates that the Hawke Bay Event had a greater duration on the inner platform than on the outer platform (Fig. 2). This fact suggests the formation of an onlap-type structure caused by the Middle Cambrian transgression succeeding the Hawke Bay regression. This transgression affected first (during the *Glossopleura* Zone) the outer platform in the western Precordillera, and later, during the *Ehmaniella* Zone, flooded the inner platform toward the eastern Precordillera.

The Hawke Bay Hiatus appears to be a nearly worldwide regressive event. It is widely represented in the Appalachians, where it marks the boundaries of Sauk I and Sauk II sequences (Palmer, 1981), and has also been recognized in Baltoscandia and the Iberian Peninsula (Ahlberg, 1998; Liñán and Gámez-Vintaned, 1993).

## CAMBRIAN – ORDOVICIAN BOUNDARY

In the basal 15 m of the La Silla Formation, in its type locality at La Silla Hill (Fig. 1), Keller et al. (1994) found *Plethopeltis obtusus*, which range from the *Saukia serotina* Subzone of the later Upper Cambrian up to the *Missisquoia depressa* Subzone of the early Lower Ibexian in North America (Ludvigsen, 1982). At 70 m above the base there appear conodonts from the *Cordylodus hintzei* Subzone, belonging to the *Cordylodus intermedius* Zone (Miller, 1988), of the Canadian Stage (or Tremadocian) are present at a distance of 70 m over the base of the formation. Based on the position of the trilobites in the succession, it can be inferred that the Cambrian-Ordovician boundary is located in the lower 15 m of the La Silla Formation.

In the Precordillera Occidental of San Juan, at the Los Sombreros stream (Fig. 1), the Los Sombreros Formation consists of shaly olistostromic deposits of Middle and Upper Ordovician age. The youngest olistolith found was a block of limestone and calcareous shale containing *Cordylodus proavus* (Lehnert, 1994). Possibly, the Cambrian-Ordovician boundary is located within this olistolith, within outer platform facies, as *Cordylodus proavus*



has a range between the late Upper Cambrian and the early Ibexian.

In the Alojamiento Range (Fig. 1), above the Cambrian carbonates of the Alojamiento Formation there is an apparently conformable sandy-pelitic siliciclastic succession (Cortaderas Formation, Fig. 2) which yields abundant traces of *Tommaculum problematicum* and *Didymaulichnus* isp. (Durand et al., 1997) of Ordovician age. The Cambrian-Ordovician boundary may be present in this unit, but diagnostic fossils are absent.

At Cerro Pelado (Fig. 1), the upper levels of El Relincho Formation, which contain trilobites from the *Saukia* Zone, are overlaid by black shales that yielded undeterminable graptolites (Fig. 2). This sequence potentially records the Cambrian-Ordovician boundary in deeper basinal facies.

## CONCLUDING REMARKS

The complete and updated lithostratigraphic as well as biostratigraphic data, which are shown in this summarized overview, provide evidences to confirm that the Precordillera basin was a rimmed platform.

The lithostratigraphic and biostratigraphic data allow the detection of an important hiatus in the Precordillera near the Lower-Middle Cambrian boundary, which is proposed to be correlated with the Hawke Bay regressive event in the Appalachian area of North America. This hiatus shows a greater longer duration on the inner platform than on the outer platform. This fact is interpreted as a consequence of the onlap of successive units, which was produced by the Middle Cambrian transgression succeeding the Hawke Bay regression.

## ACKNOWLEDGEMENTS

I gratefully acknowledge to the Consejo Nacional de Investigaciones Científicas y Técnicas of Argentina and to the Universidad Nacional de San Juan, for their financial support. I also thank María Elena Soler for help with the english text and Brian Pratt for the comments about the text. Special thanks to Lluís Cabrera and Martin Keller for the revision of this paper.

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**Manuscript received October 2001;  
revision accepted July 2002.**