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The Cambrian System in Northwestern Argentina: stratigraphical and palaeontological framework

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ABSTRACT

Cambrian sequences are widespread in the early Paleozoic of the Central Andean Basin. Siliciclastic sediments dominate these sequences although several minor occurrences of carbonates and volcanic rocks have been observed. The rocks assigned to the Cambrian System in NW Argentina are recognized in the Puna, Eastern Cordillera, Subandean Ranges and the Famatina System. This paper gives a general overview of the Cambrian formations outcropping in the northern provinces of Jujuy, Salta, Tucumán, Catamarca and La Rioja. Special emphasis has been given to the stratigraphical and biostratigraphical framework of the sequences. Late Precambrian-Early Cambrian thick sedimentary wackes dominate the basal Puncoviscana Formation (s.l.), characterized by a varied ichnofauna that includes the Precambrian-Cambrian transitional levels. Thick packages of sandstone facies characterize the overlying highly ichnofossiliferous Mesón Group. A rich shelly fauna included in sandstones, shales and volcaniclastics, dominate in the Cambrian-Ordovician transitional levels of the overlying Cambro-Ordovician Santa Victoria and Cachiyuyo Groups. Palaeogeographic aspects dealing with the position and development of Cambrian basins are discussed. Several synthetic biostratigraphic tables are presented displaying the known record for the Cambrian System, including the transitional levels to the lowermost Ordovician in the above-mentioned regions.

KEYWORDS **Cambrian. Northwestern Argentina. Lithostratigraphy. Biostratigraphy. Palaeogeography.**

INTRODUCTION

Widely distributed sedimentary rocks assigned to the Cambrian System are recorded in the early Paleozoic of the Central Andean Basin, cropping out from Southern Peru to northern Argentina. Thick sequences of over 7000 m are recognized in Jujuy, Salta, Tucumán, Catamarca and La Rioja provinces (Northern Argentina, Fig. 1). They were sedimented in large elongated marginal basins in the western border of Gondwana, connected to the north to other Bolivian, Peruvian, Paraguayan and Brazilian sedimentary systems.

The Cambrian sequences in northwestern Argentina display three clear depositional stages. The earlier one is recorded by the slates of the Puncoviscana Formation and equivalent units. The second stage resulted in the sedimentation of the Mesón Group (only represented in the Eastern Cordillera, Puna and Subandean Ranges). Finally, the third stage is represented by the lowermost part of the Santa Victoria (Puna, Eastern Cordillera and Subandean Ranges) and Cachiyuyo groups (Famatina System; Aceñolaza and Peralta, 2000). The first stage was developed during the Pampean Cycle of Aceñolaza and Toselli (1976), while the two others were deposited during the Famatinian Cycle (Aceñolaza et al., 2000; Fig. 2).

The Central Andean Basin is well known by its widespread Ordovician related economic deposits and fossiliferous content. Less attention has historically been given to the Cambrian sequences, as a consequence of their relative homogeneity and remarkable scarcity of fossiliferous shelly fauna.

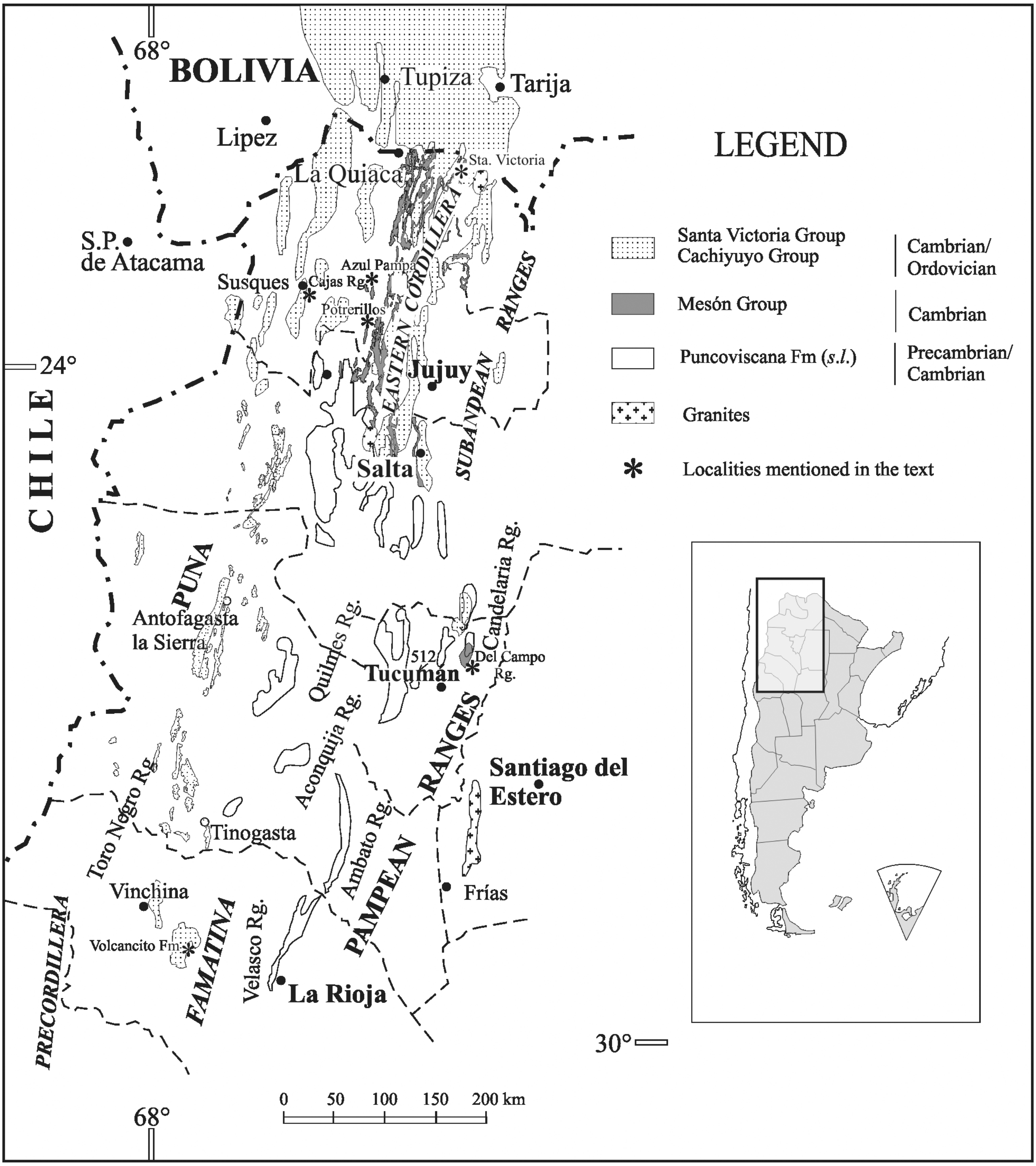

FIGURE 1 | **Location and distribution of Cambrian stratigraphic units (Precambrian-Cambrian Puncoviscana Formation (*s.l.*), the Cambrian Mesón Group and the Cambro-Ordovician Santa Victoria Group) in northwestern Argentina and location of significant outcrop zones mentioned in the text.**

The stratigraphy, biostratigraphy and fossiliferous distribution of the Cambrian sequences in northwestern Argentina, as well as some paleopalaeogeographic aspects, will be summarized in this paper.

GEOLOGICAL AND PALAEOGEOGRAPHICAL SETTING

Cambrian sequences display a large geographic distribution in northwestern Argentina, covering an area of over

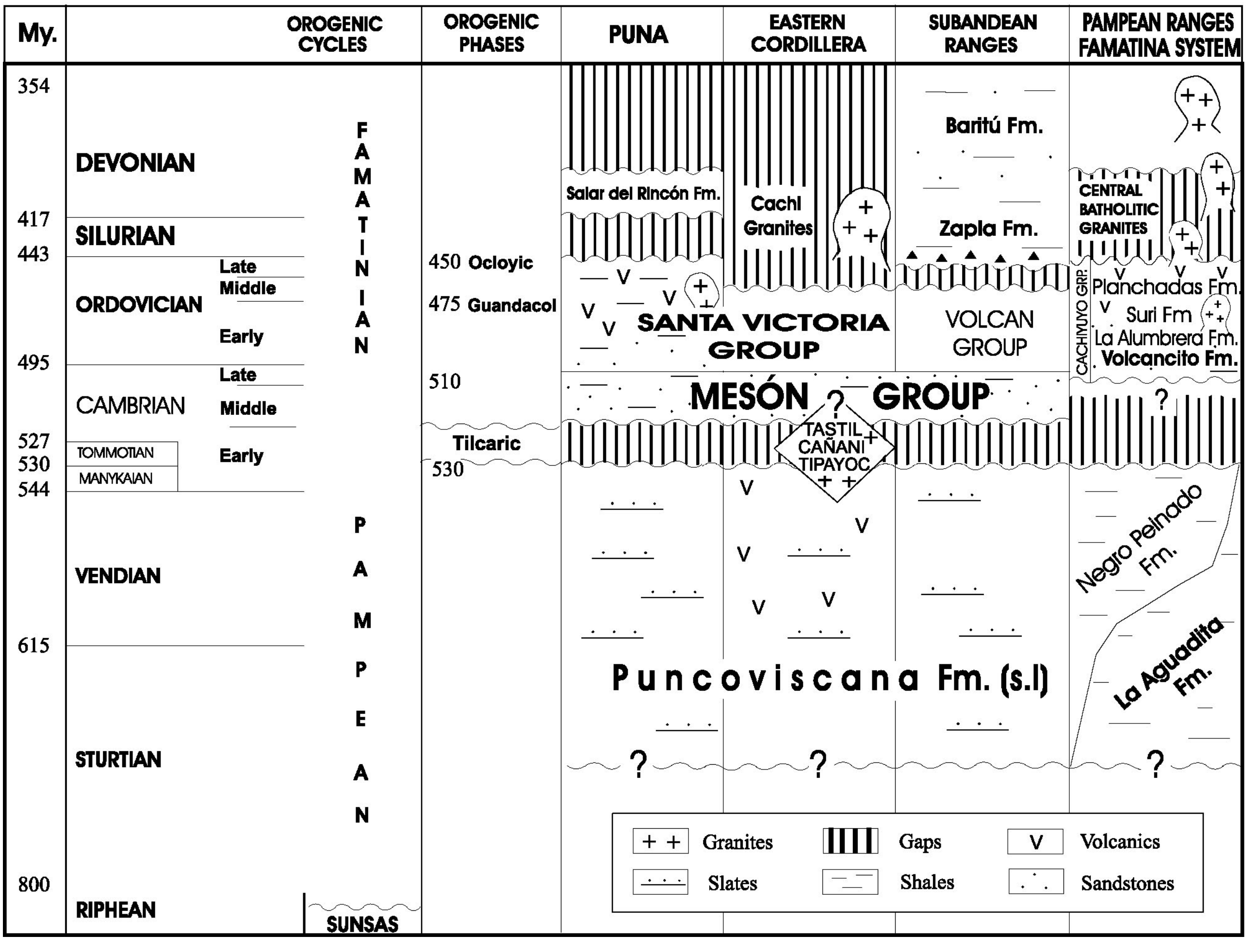

FIGURE 2 **Stratigraphic sketch for the Precambrian - Mid Paleozoic sequences in NW Argentina. The Puna, Eastern Cordillera, Subandean Ranges, and the Famatina System are considered (modified from Aceñolaza et al., 2000).**

400000 km^2. They are noticeable in many sectors of the Puna, most of the Cordillera Oriental, the Subandean Ranges and the Famatina System of Argentina, from the international boundary with Bolivia to La Rioja Province (Fig. 1). In addition, some successions, which are considered to be Cambrian in age, have been recorded to the east in well-cores of the Pampas, while to the west, an imprecise boundary is mentioned on the basis of subsurface strata (Aceñolaza and Toselli, 1981; Finney et al. in press; Bordonaro, 1992; González-Bonorino and Llambías, 1996; Sánchez and Salfity, 1999).

To the south of this area, an extended carbonate platform was developed in the Precordillera of Mendoza and San Juan, but a different geotectonic history has been given to this sector, assuming an allochthonous to parautochthonous origin for the latter (see Bordonaro, this volume; Aceñolaza and Tosselli, 2000).

The outcrops analyzed in this paper have a N-S orientation and record depositional processes which developed on the margin of Western Gondwana. On a broad outline, the sedimentary basins developed in this region had a border to the east with a more or less continuous belt of cratonic regions, which are regarded as the source areas for the basin infill. This palaeogeographic framework lasted, with only minor changes, from the Late Proterozoic to the early Silurian (Fig. 3A,B).

For the Puncoviscana Formation (s.l.), a rather long period of crustal stability resulted in very homogeneous sedimentary characteristics within a large area. A deep slope depositional setting, associated to large coalescent submarine fans, has been proposed for the facies assemblages included in this unit (Jezek et al., 1985; Jezek, 1990). Meanwhile, the deposition of The Mesón Group and of the lower part of the Santa Victoria Group took place mostly on shore lines, strongly influenced by the eustatic variations that characterised the Cambro-Ordovician transition.

Siliciclastic sediments dominate the sequences, while carbonates are scarce and occur mainly as local limestone successions, bioclastic beds and coquinas (Sánchez, 1994, 1999; Moya, 1988, 1998; Aceñolaza, 1996; Sánchez and Salfity, 1999).

LITHOSTRATIGRAPHY OF THE PRECAMBRIAN-EARLY ORDOVICIAN RECORD

The lithostratigraphic framework of the Early Paleozoic in the Eastern Cordillera, Puna, Subandean Ranges and the Famatina System is summarized in figure 2.

The Proterozoic-Early Cambrian Puncoviscana Formation (s.l.)

The precise lower boundary of the Cambrian System is not known in the provinces of northwestern Argentina (e.g., Durand, 1996). It has been considered that the boundary is included in the highly tectonised, dominantly clastic, thick sequences which are widely represented in the region. Different stratigraphic names such as Puncoviscana *s.l.* (Jujuy, Salta and Tucumán provinces), Suncho (Catamarca Province) and Aguaditas/Negro Peinado (Famatina System, La Rioja Province) have been used to refer to these sequences.

Lithologically, they are made up by over 2000 meters of shales, slates, sandstones and quartzites, with minor conglomerates, limestones and some interestratified basic lavas and tuffs. The sequence is highly deformed and fractured, with a general N-S alignment. Structural complexity obscures the stratigraphy of these sediments, without a single known undisturbed section. Distinctive structural styles characterize approximately parallel N-S zones within the outcrops of the Puncoviscana Formation (Mon and Hongn, 1991; Mon and Salfity, 1995).

Aceñolaza and Durand (1986) recognised the existence of a SW/NE oriented basin during the Vendian/Tommotian. This basin was developed by an expansion of the Gondwanan margin between the Río de la Plata Craton (SE) and the Arequipa Massif (NW), both of Rifean age (approximately 1000 My). The opening of the basin is interpreted to be related to a triple junction point placed in the centre of Bolivia. The southern branch of this rift corresponds to the early above-mentioned Puncoviscana basin (Fig. 3A).

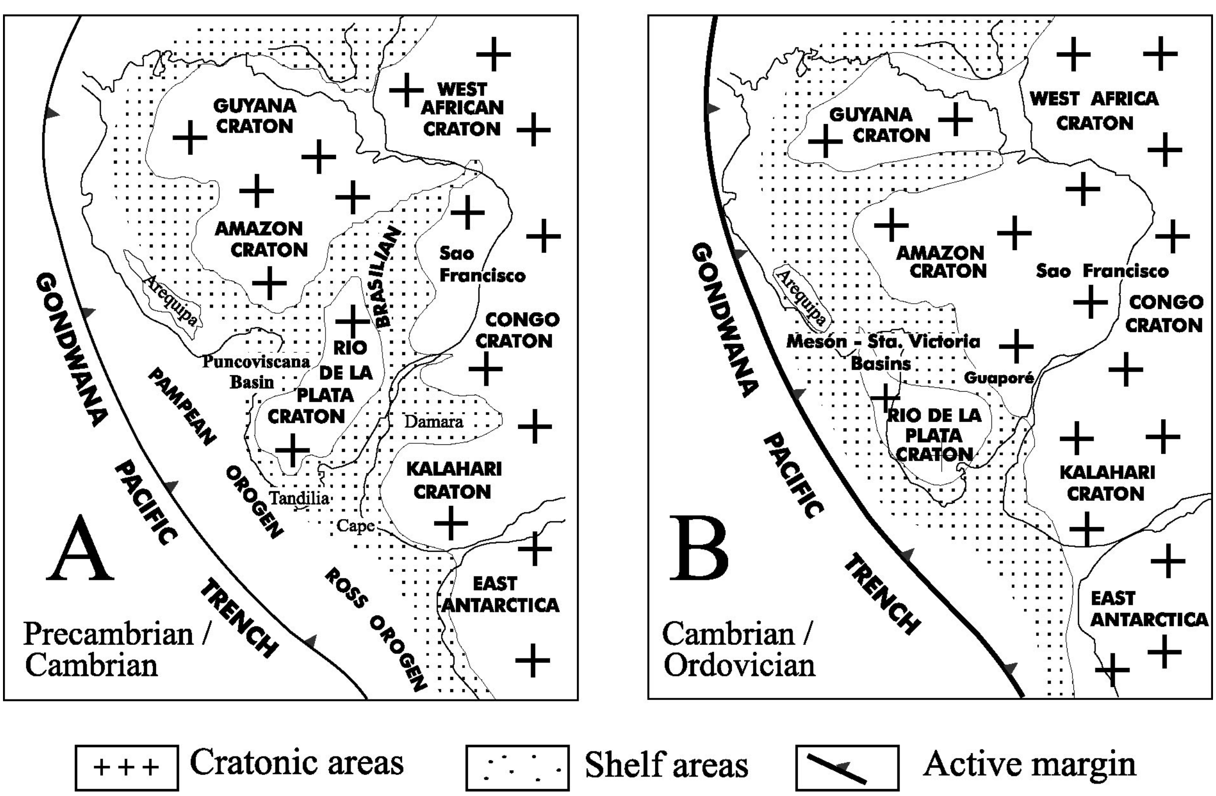

FIGURE 3 **Paleogeographic sketch of the Andean margin of South America for Precambrian-Cambrian and Cambro-Ordovician times. The Puncoviscana (Precambrian-Cambrian), Mesón (Cambrian) and Santa Victoria (Cambro-Ordovician) basins are shown related to the main structural elements in a Gondwanan framework**

This Early Paleozoic basin had smooth floor morphology with large, low- gradient submarine fans which spread towards the axis of the basin. Six facies have been distinguished within this fan system, ranging from proximal to distal submarine fan deposits, whose relationships are quite complex. (Aceñolaza et al., 1988; Jezek, 1990). Widespread turbidites are recorded within the sections (Baldis and Omarini, 1984; Durand and Spalletti, 1986; Spalletti and Durand, 1987; Jezek, 1990; Durand, 1990). In addition, near-shore sediments were unconformably deposited upon the cratons on the marginal sectors of the basin (Jezek et al., 1985).

The Puncoviscana sequence was intruded by Middle Cambrian (517 My) post-tectonic granites with important outcrops in Tastil and La Quesera localities (Salta Province). These episodes were related to an important deformation process, represented by the Lower Cambrian (?Atdabanian) "Tilcaric" unconformity (Turner, 1960). Jezek (1990) states that deformation affecting the Puncoviscana Formation had multiple phases: the strongest one occurred at the end of the Lower Cambrian (F1), the second during the Ordovician (F2), and lastly the third is represented by the Andean deformation (Cenozoic fracturation – F3).

Trace fossils were used as the only biostratigraphic marker to date the above- mentioned unit (Fig. 4). Among the recognizable Vendian traces are: *Nereites saltensis* ACEÑOLAZA and DURAND, *Tasmanadia* and probably *Sekwia*. Higher levels assigned to the Tommotian are characterised by: *Oldhamia radiata* FORBES, *O. flabellata* ACEÑOLAZA and DURAND, *O. antiqua* KINAHAN, *Diplichnites* and *Dimorphichnus* among others (Aceñolaza and Durand, 1986; Aceñolaza et al., 1999; Aceñolaza and Tortello, 2000; Buatois et al., 2000; Aceñolaza and Alonso, 2000, Aceñolaza and Tortello, this volume. See Appendix).

The Cambrian Mesón Group

After the "Tilcaric" orogenic phase, a new depositional setting developed in northwestern Argentina and southern Bolivia. Sediments associated to this basinal evolution are characterised by over 3000 m thick marine siliciclastic sequences. Outcrops of the Mesón Group are widely distributed in the northern provinces of Jujuy, Salta and Tucumán (Puna, Eastern Cordillera and Subandean Ranges; with the southernmost outcrop at about 27ºS; Fig. 1). In addition, thick packages of sandstones attributed to the group have been recorded to the east in cores from the provinces of Santiago del Estero (Árbol Blanco), Chaco (Charata) and Formosa (Mariano Boedo).

The Mesón basin was surrounded by the Río de La Plata and Arequipa cratons, and by some structural highs with a general SE/NW orientation ("Calchaquí Dorsal" *sensu* Auboin et al., 1973; or "Pampean Craton" *sensu*

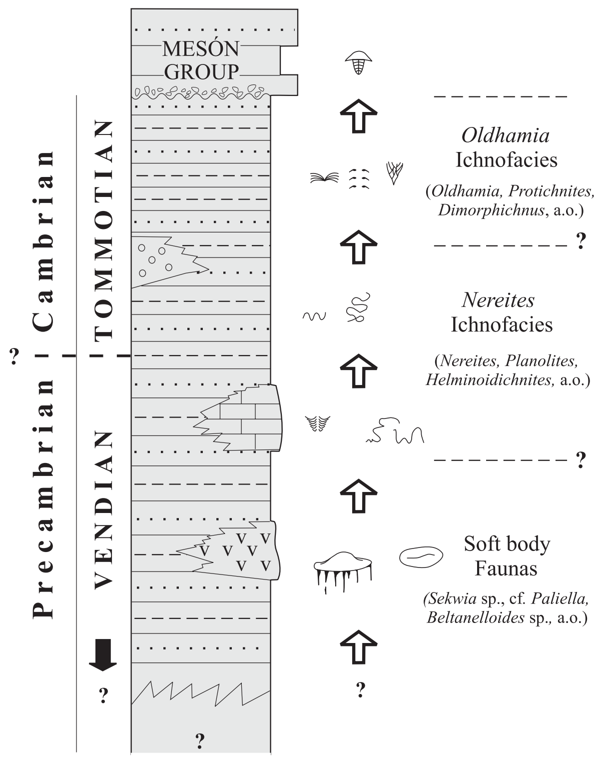

FIGURE 4 **Litho and biostratigraphic sketch of the Puncoviscana Formation (*s.l.*) with distribution of the different recognized ichnofacies (based on Durand and Aceñolaza, 1990b). See Figs. 1 and 2 for location, and Appendix.**

Bracaccini, 1960). The development of this basin was strongly related to the first marine flooding of the Proto-Andean border. A wide corridor that involved areas between the Arequipa Massif and the Guaporé Craton (SW margin of the Brazilian shield) seems to have been developed from the Lower to Upper Cambrian, connecting the southern Mesón Group basin northwards to other Bolivian, Peruvian and Brazilian contemporary basins (Fig. 3B).

The sequence is dominated in certain areas by thousands of meters of thick massive sandstones and quartzites (Santa Victoria Range in Salta, and Tarija region in southern Bolivia). These are correlated as a whole with thinner sequences that were deposited in some marginal sectors of the same basin. These rocks were named as Mesón Group by Turner (1960), which can be clearly split from bottom to top into three formations: Lizoite, Campanario and Chalhualmayoc (see Moya, 1998; Sánchez and Salfity, 1999) (Fig. 5).

Lizoite Formation

White, pinkish and grayish quartzites and sandstones characterize this Formation. The thickness of this unit

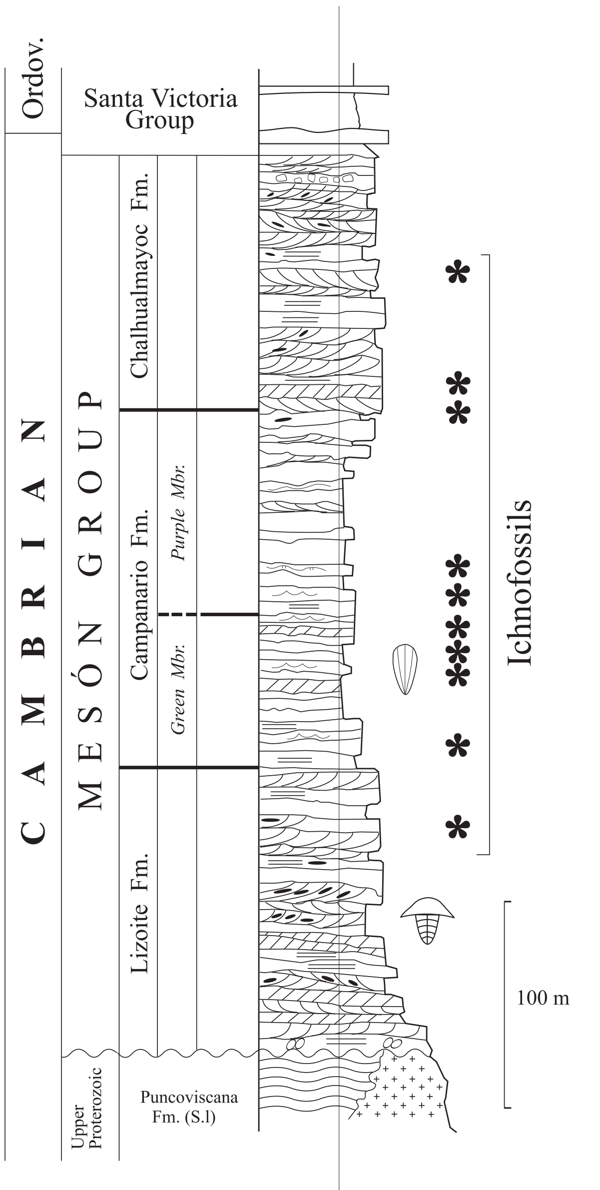

FIGURE 5 **Stratigraphic characterization of the Cambrian Mesón Group with its three-fold stratigraphic subdivision: Lizoite, Campanario and Chalhualmayoc formations. The relative distribution of fossils is displayed by the symbols (Brachiopoda and Trilobita) and asterisks (ichnofossils). Modified after Sánchez and Salfity, 1999. See Figs. 1 and 2 for location, and Appendix.**

ranges from 20 to 1100 m. The sequence starts after the Tilcarian unconformity with a conglomerate level. The successions of this unit show a fining upwards arrangement, and have been interpreted as intertidal and subtidal sandbars and channels (Moya, 1998; Sánchez, 1999; Sánchez and Salfity, 1999).

The only biostratigraphic markers for the Lizoite Fm. were recorded to the west, in the Puna Region (Potrerillos, Salta), where Aceñolaza (1973) and Aceñolaza and Bordonaro (1989) recognized fragmentary and poorly preserved trilobites (*Asaphiscus* sp.) and trace fossils (*Cruziana* isp.).

Campanario Formation

Two members have been differentiated within this unit: a lower "green member", characterized by medium grained sandstones and quartzites, and a upper "purple member" with fine grained sandstones and subordinated quartzites. This formation is 30 to 1100 meters thick. It has been interpreted as an intertidal flat sequence, which records sporadic storm events (Sánchez, 1999; Sánchez and Salfity, 1999).

Abundant trace fossils are recognised within this unit. Well defined "pipe rocks" with *Skolithos*, various types of *Rusophycus*, *Cruziana* and the Lower Cambrian *Syringomorpha nilssoni* (TORELL) are among the most remarkable ones (Ramos, 1973; Alonso and Marquillas, 1981; Aceñolaza et al., 1982; Manca, 1986; Sánchez, 1994; Moya, 1998). *Lingula* sp. and *Lingulepis* sp. are the only records of shelly fauna in the unit (Sánchez and Herrera, 1994 with references).

Chalhualmayoc Formation

The Chalhualmayoc Formation mostly consists of a fining upwards sequence of white to pinkish quartzites and subordinate sandstones with minor interbedded fine conglomerates. Abundant trace fossils and even *Skolithos* "pipe rock" are recorded in the sequence. This succession records deposition developed in relation to intertidal to subtidal sand bars, with migrating dune deposition (Sánchez, 1999; Sánchez and Salfity, 1999).

The age of the Mesón Group has been established on the basis of the scarce fossils yielded by the Chalhualmayoc Fm. It ranges between the Lower and Upper Cambrian. The Middle Cambrian trilobite *Asaphiscus* sp. has been mentioned for the basal Lizoite Formation, while with some temporal incongruity, the Lower Cambrian trace fossil *Syringomorpha nilssoni* (TORELL) was found in the middle Campanario Formation. Lastly, a single occurrence of the Cambro-Ordovician trilobite *Parabolina* (*N.*) *frequens argentina* (KAYSER) at the Azul Pampa locality, Jujuy Province is the only suitable biostratigraphic datum for the Group. The Mesón Group is overlain by the Cambro-Ordovician Santa Victoria Group.

The Cambro-Ordovician Santa Victoria Group

A few thousands of meters of Upper Cambrian to Lower Ordovician shales, sandstones, quartzites and some volcaniclastics make up this unit. The Santa Victoria Group comprises most of the sequences which overly the

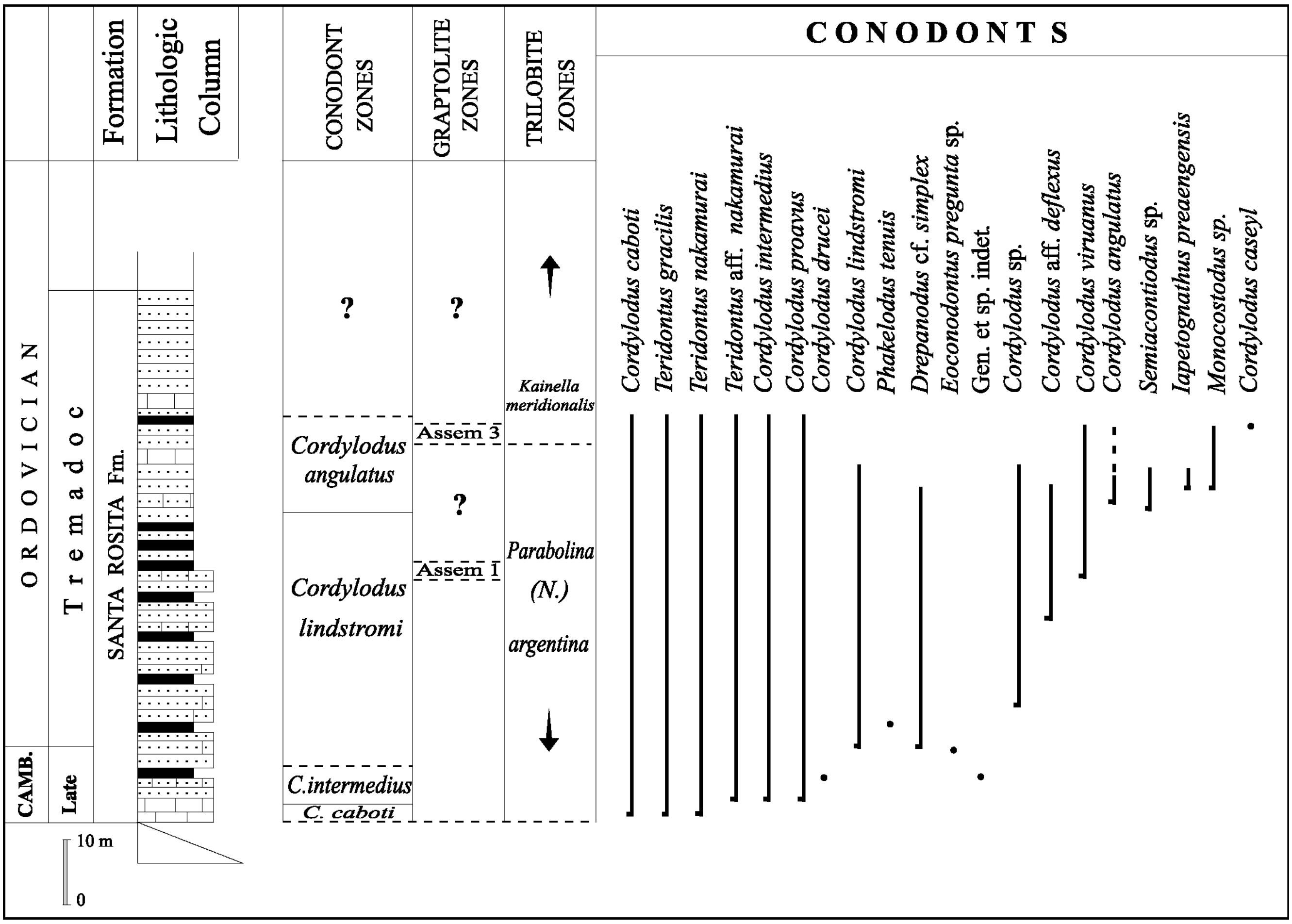

FIGURE 6 **Stratigraphic sketch and biostratigraphic framework for the Cambro-Ordovician transition in the study area (lower part of Santa Victoria Group). The stratotype for the Cambrian-Ordovician boundary at the Sierra de Cajas is shown (based in Rao and Hünicken, 1995b). See Figs. 1 and 2 for location, and Appendix.**

Mesón Group and crop out in a large area of the Puna, Eastern Cordillera and Subandean Ranges (Provinces of Jujuy and Salta; Aceñolaza, 1998).

The stratigraphic relation between the Mesón and Santa Victoria Group is a matter of discussion, due to the frequent occurrence of conglomerate beds in the transitional levels between both units within the uppermost part of the underlying Mesón Group. Some authors suggest an unconformable contact for the two groups (Turner and Méndez, 1975; Moya, 1988, 1998; Sánchez and Salfity, 1999). Nevertheless, the lithology mostly does not change below and above the conglomerates and quartzites and sandstones are dominant. Therefore, in this contribution the unconformity (named as “Tilcaric”) is considered earlier, and included in the underlying Chalhualmayoc Formation (Mesón Group).

These conglomerate layers have been interpreted as a channel fill within the platform, being related to the several eustatic episodes that characterised the Cambro-Ordovician transition (Aceñolaza and Aceñolaza, 1992; Aceñolaza, 1996).

The Santa Rosita Formation is the lower unit of the Santa Victoria Group and is composed of sandstones, shales and quartzites. The stratigraphic interval that includes the Cambrian-Ordovician transition reaches up to 900 m in thickness in the Santa Victoria Range (Salta Province), and is placed in the lower part of the Santa Rosita Formation (Figs. 6, 8).

The highly fossiliferous stratigraphic section cropping out at the Cajas Range has been proposed several times as the type section for the Cambrian – Ordovician transition in northwestern Argentina (Fig. 6).

The Cambro-Ordovician Volcancito Formation

To the south, in the Famatina System, neither the base nor the top of the Volcancito Formation is known. Esteban (1999) has recognized three members within the

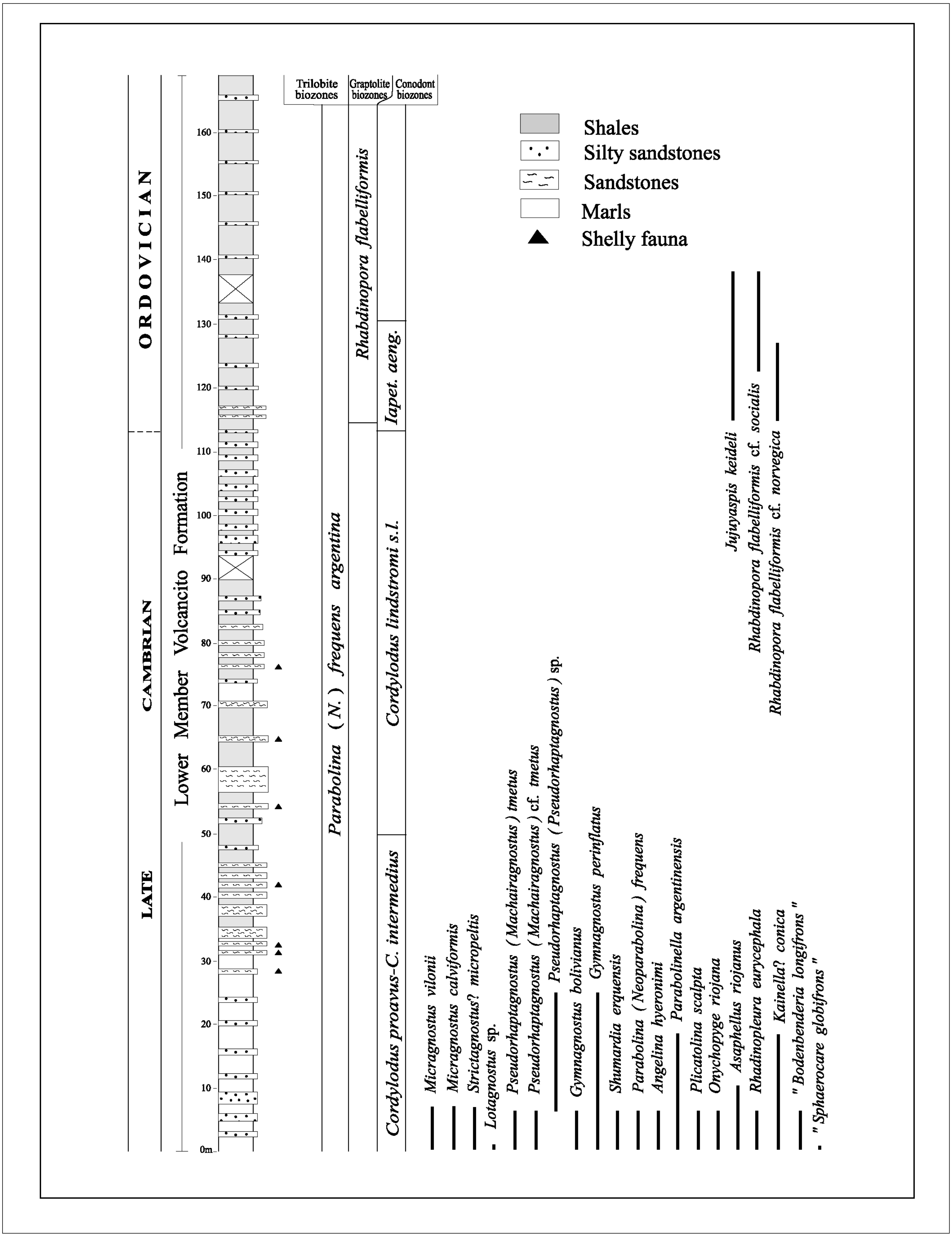

FIGURE 7 **Stratigraphic section and biostratigraphic framework for the Cambro-Ordovician transition in the Famatina System (Cachiyuyo Group, lower member of the Volcancito Formation). Volcancito River section, La Rioja Province (modified after Tortello and Esteban, 1999. See Figs. 1 and 2 for location , and Appendix.**

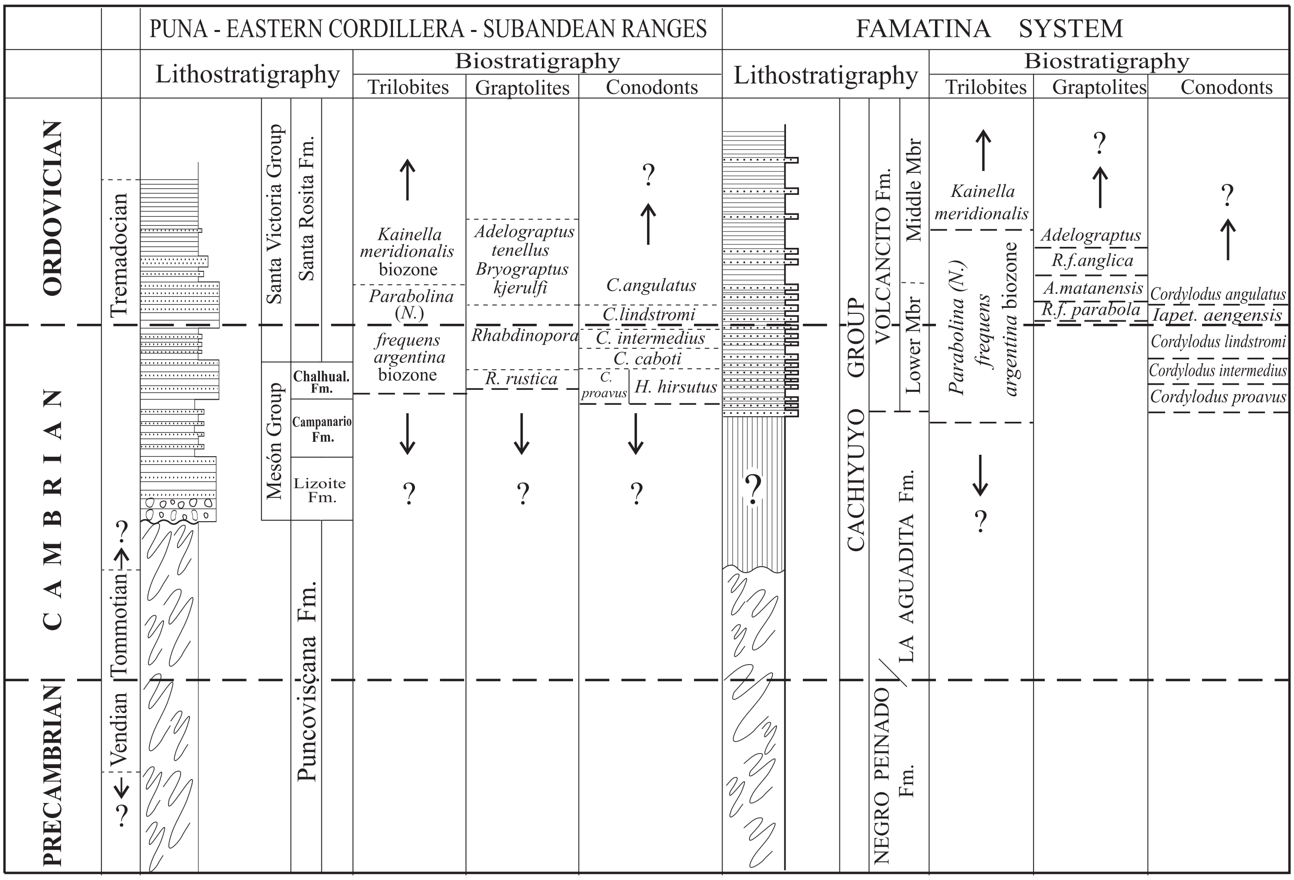

FIGURE 8 **Stratigraphical and biostratigraphical sketch for the Cambrian System in northwestern Argentina. The main fossiliferous groups have been integrated into a schematic stratigraphic section. See Figs. 5 to 7 and Appendix.**

unit: a lower Filo Azul Member, the mid Peña Negra Member and an upper Bordo Atravesado Member. The Cambrian- Ordovician boundary has been placed within the upper part of the 170 m thick Filo Azul Member (Fig. 7).

The formation is constituted by 430 meters of highly fossiliferous slates, black shales, sandstones and few limestones. These lithofacies yielded graptolites, trilobites, conodonts, brachiopods and filocariids (Harrington, 1938; Harrington and Leanza, 1957; Turner, 1959; Toselli, 1977; Aceñolaza and Durand, 1984; Esteban and Gutiérrez-Marco, 1997; Tortello and Esteban, 1997; Albanesi et al., 1999, 2000). The Filo Azul Member has been interpreted to be deposited on shore zones (inner and outer shelf settings), reaching to shoreface in the uppermost part (Esteban, 1999). The lowermost part of the Volcancito Formation in the type locality displays a tectonic contact with the underlying Negro Peinado Formation (equivalent to the Puncoviscana Formation s.l.), while upwards, is followed by La Alumbrera Formation and the Arenig shales, sandstones and volcaniclastics of the Suri Formation (Fig. 2).

THE CAMBRIAN BIOSTRATIGRAPHIC RECORD

The biostratigraphic record of the above described sedimentary succession, which spans throughout the Cambrian, is analyzed in this section (Fig. 8).

The Cambrian System in Northwestern Argentina lacks a good biostratigraphical zonation compared to its counterpart in the Precordillera. Palaeoecological conditions related to the palaeogeography are interpreted to be the main cause of this contrast. The only fairly good biostratigraphical data come from the transitional levels to the Ordovician, in the uppermost part of the Cambrian sequences (Fig. 8). A para-autochthonous or autochthonous origin for the highly fossiliferous Cambrian Precordilleran sequences in the Gondwanan margin has been widely discussed during the last decade (see Bordonaro in this volume; Pankhurst and Rapela, 1998; Aceñolaza and Toselli, 2000; Aceñolaza et al., 2000; Peralta, 2000 with references; Finney et al. in press).

In Northwestern Argentina, low-grade methamorphism affected the lower Puncoviscana Formation (*s.l.*) and equivalent units, dated only by means of trace fossils (Fig. 4). Quartzites and sandstones typify the Mesón Group, with remarkable good trace fossils but no significant shelly fauna (Fig. 5). Good biostratigraphic data can be obtained only from the shales and sandstones of the basal Santa Victoria and Cachiyuyo Groups, which includes the Cambrian-Ordovician transition, with graptolites, trilobites, conodonts, brachiopods, molluscs, echinoderms and ichnofossils among others.

For the Eastern Cordillera, Puna and Subandean Ranges, the Santa Rosita Formation (basal unit of the Santa Victoria Group) is the one that includes the Cambrian-Ordovician boundary (Fig. 6). This boundary is included in the Filo Azul Member of the Volcancito Formation (basal part of the Cachiyuyo Group) in the Famatina System of La Rioja Province (Fig. 7). Lithologically, both units are mainly characterized by shales and sandstones with a few quartzites of greyish, greenish and black colors, and displaying a mean thickness of a few hundred meters. The transition between the Cambrian and Ordovician is biostratigraphically well tied by graptolites (*Rhabdinopora flabelliformis* EICHWALD), conodonts (*Iapetognathus-Cordylodus*) and trilobites (*Jujuyaspis keideli* KOBAYASHI).

The tables provided in the Appendix to this paper show the known taxa for all the recorded palaeontological material yielded by the Precambrian-Cambrian Puncoviscana Formation, up to the Cambro-Ordovician Volcancito and Santa Rosita formations. The transitional levels to the Ordovician were also considered.

CONCLUDING REMARKS

The Cambrian sequences in the Andean margin of South America display a more or less shared, similar history. Nevertheless, the reduced biostratigraphic record does not provide sufficient insight into the studied sequences, to obtain a clear correlation with other Cambrian sequences and biostratigraphic records around the world.

The Cambrian biostratigraphic record displays a relatively low diversity in the Puna, Eastern Cordillera, Subandean Ranges and the Famatina System if compared to the record of the Precordillera terrane (see Bordonaro, in this volume). It is considered that the rather diverse palaeogeographic and palaeoenvironmental conditions under which both basins evolved during Cambrian account for the observed biostratigraphic record differences. While limestones are common in the western precordilleran sequences, siliciclastic rocks (sandstones, shales and conglomerates) are dominant in northwestern Argentina.

The transition from the Precambrian to the Lower Cambrian is located in the slightly metamorphosed, highly deformed Puncoviscana Formation. In spite of the scarcity of ichnofossil-bearing sections, the transition between the Precambrian and Cambrian is recognised by means of the trace fossils represented in the sequences.

The so called Cambrian explosion is recorded by means of the trace fossils represented in the slates of the Puncoviscana Formation (*s.l.*), with several ichnogenera as *Oldhamia*, *Protichnites*, *Nereites, Monomorphychnus, Dimorphichnus* and *Diplichnites* among others. During the deposition of the Mesón Group, little palaeontological information is displayed due to the special lithological characters (high-energy shelf quartzites and sandstones are dominant).

The Puncoviscana Formation is overlain by the almost barren, high-energy sandstones of the Mesón Group, which has delivered good palaeoichnological assemblages. The occurrence of the Middle Cambrian trilobite *Asaphiscus* sp. (which is associated to several other undetermined forms and brachiopods in the Lizoite Formation at the Locality of Potrerillos, Salta) causes some uncertainty into the dating of the unit. This occurrence also highlights the importance of the Mesón Group sections, which must be revisited for a better understanding of the Cambrian sequences in the region.

The second record of biodiversification in the study area is recognised in the finer sediments (shales and sandstones) of the lower part of the Cambro-Ordovician Santa Victoria Group, where most of the typical Early Paleozoic fossil groups are abundant. This transition to the Ordovician in the lower part of the Santa Victoria Group displays the most complete biostratigraphic data available in the studied sections. This "Cambro-Ordovician" biodiversification recorded in the Santa Victoria Group, may have started a short time before the flooding of the shelf during the early Tremadocian. This biodiversification is not well recorded because of the unfavorable lithology for fossil preservation (sandstone facies) that dominate the Mesón Group.

The number of taxa represented in the Puncoviscana Formation and Mesón Group is small compared to the material found in the transitional levels to the Ordovician in the Santa Victoria Group. Trace fossils are the most important elements within the older units, while a much more varied spectrum of taxa is represented in the younger ones (trilobites, graptolites, conodonts, brachiopods, and echinoderms, etc.).

Further biostratigraphic work is needed for a better understanding of the Cambrian System in Northwestern

Argentina. Research shall be focused in the fossiliferous levels of the Puncoviscana Formation (*s.l.*), and within marginal sectors of the Mesón basin, seeking softer environmental conditions that will help on a better fossil preservation within this high energy shallow Cambrian platform.

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APPENDIX

Biostratigraphic record of the Cambrian in NW Argentina

The taxa included in this appendix are considered significant for the definition of the Lower Paleozoic boundaries.

PHYLUM CONODONTA

The scheme given by Rao (1999) for the proposed Cambro-Ordovician stratotype in nortwestern Argentina is followed (Sierra de Cajas, Jujuy Province). Summarised data from Hünicken et al. (1985), Rao (1992, 1994, 1999), Rao et al. (1994), Rao and Hünicken (1995a, 1995b), Aceñolaza (1998) and Rao and Tortello (1998). Additional data from the Volcancito Formation by Albanesi et al. (1999, 2000) and Albanesi and Astini (2000). Asterisk indicates the first Ordovician taxa. See Figs. 7 to 8.

***Cordylodus proavus* Zone**
***Hirsutodontus hirsutus* Subzone (Late Cambrian)**

Cordylodus primitivus
C. proavus
Hertzina elongata
Eoconodontus notchpeakensis
Eoconodontus sp.
Phakelodus elongatus

Furnishina furnishi
F. gladiata
F. primitiva
Teridontus nakamurai

Ph. simplex
Ph. tenuis
Fryxellodontus sp.
Hirsutodontus aff. *hirsutus*

Teridontus sp.
Proconodontus posterocostatus
Prooneotodus gallatini
P. rotundatus
Gen. et sp. indet. 2

***Cordylodus caboti* Zone**
(Late Cambrian)

Cordylodus caboti
Teridontus gracilis
T. nakamurai

***Cordylodus intermedius* Zone**
(Late Cambrian)

Cordylodus intermedius
C. caboti
C. durcei
Teriodontus gracilis
T. nakamurai
Cordylodus proavus
Cordylodus sp.
Gen. et sp. indet.1

***Cordylodus lindstromi* Zone ***
(Base of Ordovician)

Cordylodus caboti
Cordylodus aff. *deflexus*
C. intermedius
C. lindstromi
Semiacontiodus sp.
Teridontus gracilis
Eoconodontus? sp.
C. proavus
C. viruanus
Cordylodus sp.
Drepanodus cf. *simplex*
T. nakamurai

***Iapetognathus aengensis* Zone ***
(Base of Ordovician)

Iapetognathus aengensis

CLASS GRAPTOLITHINA

Data from Harrington and Leanza (1957), Turner (1959, 1960, 1964), Toselli (1977), Aceñolaza and Durand (1984), Moya et al. (1994), Ortega and Rao (1995), Tortello et al. (1996), Esteban and Gutiérrez-Marco (1997), Aceñolaza (1998), Ortega et al. (1998).

Aspidograptus cf. *implicatus* *
Callograptus cf. *salteri* *
Rhabdinopora flabelliformis " rustica"
R. flabelliformis flabelliformis *
R. flabelliformis cf. *socialis* *
R. flabelliformis cf. *famatinense* *
R. flabelliformis cf. *norvegica* *
R. flabelliformis cf. *scitulun* *
R. flabelliformis parabola
R. flabelliformis anglica *
Bryograptus sp. aff. *kjerulfi* *
Bryograptus sp. *
Paradelograptus sp. *
Anisograptus cf. *richardsoni* *
Anisograptus cf. *flexuosus* *
Aspidograptus cf. *implicatus* *
Aspidograptus? cf. *minor* *
Rhabdinopora n. sp.1 *
Rhabdinopora n. sp. 2 *
R. flabelliformis "patula" *
Staurograptus sp. *
Aspidograptus? cf. *minor* *
Staurograptus cf. *dichotomus* *
Adelograptus tenellus *
Aspidograptus cf. *implicatus* *
Callograptus cf. *salteri* *

CLASS TRILOBITA

Data from Harrington and Leanza (1957), Aceñolaza (1973), Aceñolaza and Bordonaro (1989), Moya et al. (1993), Tortello and Aceñolaza (1993), Tortello and Esteban (1995, 1997, 1999), Koukharsky et al. (1996), Esteban (1996, 1999), Malanca (1996), Malanca et al. (1998), Tortello and Aceñolaza (1999), Tortello et al. (1999). Asterisk indicates the first Ordovician taxa). See Figs. 6 to 8.

Cambrian fauna

Asaphiscus sp.
Parabolina (N.) frequens argentina
Lotagnostus (Lotagnostus) sp.
Lotagnostus sp.
Lotagnostus (Semagnostus) zuninoi
Leiostegium douglasi
Shumardia alata
Micragnostus calviformis,
Asaphellus riojanus
Gymnagnostus bolivianus
Kainella? *conica*

Leiagnostus turgidulus
Micragnostus vilonii
Onychopyge riojana
Rhadinopleura eurycephala
Rossaspis sp.
Strictagnostus? *micropeltis*
Trilobagnostus chiushuensis
"Bodenbenderia longifrons"
"Sphaerocare globifrons"

Lower Ordovician *

Jujuyaspis keideli *
Parabolina (N.) frequens argentina
Parabolinella argentinensis
Anglagnostus? n. sp. A
Micragnostus sp.
Cyclopyge? sp.
Corrugatagnostus? sp.
Micragnostus sp.
Trilobagnostus chiushuensis
?*Gymnagnostus bolivianus*
"Geragnostus" sp.
Angelina hyeronimi
Anglagnostus? sp.
Kainella meridionalis *
Bienvillia tetragonalis *
Degamella famatinensis
Shumardia minutula *

Other trilobite taxa recorded for Cambrian - lowermost Ordovician strata

Shumardia alata
Shumardia sp.
Asaphellus catamarcencis
Pricyclopyge sp.
Pseudoperonopsis zuninoi
Rossaspis rossi
Bellaspidela sp
Ceratopyge forficuloides
Cyclopyge sp.
Micragnostus hoeki
Neoagnostus (Machairagnostus) tmetus
Notopeltis orthometopa
Orometopus pyrifrons
Parabolinella triarhroides
Basiliela carinata
Beltella ulrichi
Leptoplastides marianus
Hapalopleura clavata
Kainella? sp.
Leiagnostus turgidulus
Leiostegium sp.
Plicatolina scalpta
Acerocarina glaber
Apatokephalus serratus
Shumardia (Conophrys) erquensis
Shumardia (Conophrys) sulcatus
"Trinodus" jujuyensis

PHYLLUM BRACHIOPODA

Data from Sánchez and Herrera (1994, with references). Both samples come from the Cambrian Mesón Group. See Fig. 5.

Lingula sp.
Lingulepis sp.

PHYLLUM MOLLUSCA

Data from Sánchez (2000).

Ribeiria francae

PHYLUM ECHINODERMATA

Data from Aceñolaza (1986, 1999).

Macrocystella sp. *
Macrocystella? *durandi*

TRACE FOSSILS

Data from Ramos (1973), Aceñolaza (1978), Aceñolaza and Fernández (1978), Alonso and Marquillas (1981), Manca (1986), Aceñolaza and Durand (1987), Durand and Aceñolaza (1990a), Mángano et al. (1996), Aceñolaza et al. (1999, with references), Aceñolaza and Tortello (2000), Buatois et al. (2000), Mángano and Buatois (2000). Asterisk indicates the first Ordovician taxa. See Figs. 4 and 5.

Alcyonidiopsis pharmaceus *
Arenicolites isp.
Asaphoidichnus trifidus
Asaphoidichnus isp.
Bergaueria isp.
Cochlichnus isp.
Alcyonidiopsis pharmaceus *
Arenicolites isp.
Asaphoidichnus trifidus
Asaphoidichnus isp.
Bergaueria isp.
Cochlichnus isp.
Cochlichnus anguineus
Cruziana cf. *furcifera* *
Cruziana cf. *breadstoni* *
Cruziana goldfussi *
Cruziana omanica *
Cruziana problematica
Cruziana semiplicata
Cruziana isp.*
Didymaulichnus isp.
Dimorphichnus isp.
Diplichnites isp.
Diplocraterion isp.
Glockerichnus isp.
Gordia isp.
Helminthoidichnites tenuis
Helminthoidichnites isp.
Helminthopsis aff. *tenuis*
Helminthopsis tenuis
Helminthopsis isp.
Helminthorhape isp.
Helmintoida cf. *miocenica*
Helmintoida isp.
Laevicyclus isp.
Monocraterion isp.
Monomorphichnus bilinearis
Monomorphichnus lineatus
Monomorphichnus multilineatus
Monomorphichnus isp.
Multipodichnus isp.
Neonereites uniserialis
Neonereites isp.
Nereites saltensis
Nereites isp.
Oldhamia antiqua
Oldhamia flabellata
Oldhamia radiata
Palaeophycus tubularis
Palaeophycus isp.
Parahaentzschelinia isp.
*Phycodes pedum**
*Planocraterion carbajalis**
Planolites isp.
Protichnites isp.
Protovirgularia isp.
Rusophycus carbonarius
Rusophycus jenningsi
Rusophycus latus *
Rusophycus leifeirikssoni
Rusophycus isp. A
Rusophycus isp. B
Rusophycus isp. C
Rusophycus isp.
Scolicia isp.
Skolithos linearis
Syringomorpha nilssoni
Syringomorpha isp.
Tasmanadia cachii
Torrowangea isp.
Tomaculum problematicum *
Treptichnus isp.
cf. *Aulichnites* isp.
cf. *Phycodes*
cf. *Protopaleodictyon* isp.