FIELD GUIDE ON THE ORDOVICIAN OF THE SIERRA PINTADA, SAN RAFAEL BLOCK, MENDOZA.

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Field trip abstract

First day: Departure from San Juan City by bus, at 8 AM. Arrival at San Rafael City (about 370 km towards the South) in Mendoza Province at lunch time. During the trip by the plain road we can see the Eastern Precordillera and Frontal Cordillera sides and the Cuyo oil basin. This region is also famous for its vineyards and with a nice production of several wines. After accommodation at the hotel we will depart to **Cerro Bola region** (about 25 km towards the East of San Rafael City). The **stop** will be at Baños Cerro Bola (ancient spring baths) to see the more complete section of the siliciclastic sequence know as Pavón Formation. Graptolites from the Lower Caradoc age are common in black shales of this section. We can observe the sedimentary characteristics and structural style of the sequence. At about 7 PM we will return to the hotel at San Rafael City for dinner and sleeping.

Second day: Departure from San Rafael City at 8.30 AM (with luggage) and we will go to the South-East side of the San Rafael Block known Ponón Trehue locality (about 70 km).
The **first stop** will be at Ponón Trehue creek, where we can see the Precambrian basement (grenvillian crust) and the contact with Ordovician units from Tremadoc and Arenig carbonate rocks and Llanvirn-Llandeilo to Lower Caradoc clastic-carbonate sediments.

The biostratigraphy of these Ordovician outcrops has been based on Conodont assemblages. The sedimentological and stratigraphical studies suggest that these units are megablocks, blocks and megaconglomerates and could be allochtonous deposits associated with an extensional regime well described in the Precordillera Terrane. After a field lunch we will go to the **second stop** at the Tortuga section, where the outcrops of the Ponón Trehue Formation represent the *Pygodus serra* Zone, *Eoplacognathus robustus* subzone and *Eoplacognathus linstroemi* subzone, and *Pygodus anserinus* Zone, *Sagittodontina kielcensis*subzone. We will observe the sedimentological characteristics of the sequences. At 5 PM we will return to Mendoza City. Arrival to Mendoza City at about 8 PM, location at the hotel and dinner. The field trip is finished.

Key words: Ordovician. San Rafael block, Mendoza.

Palabras claves: Ordovícico. Bloque San Rafael, Mendoza

INTRODUCTION

The purpose of this field guide is to provide an introduction to the Ordovician geology of the San Rafael Block, Mendoza Province, Argentina (Fig. 1). Understanding the "pre-Carboniferous" geological framework of the San Rafael or Sierra Pintada Block is essential to current models related to the origin and evolution of the Precordillera, Cuyania or Occidentalia Terrane in the western side of the proto-Andean Gondwana margin. Geotectonic models were presented to explain the evolution of the Lower Paleozoic of this region and have been the target of international cooperation projects during the last ten years. Strong emphasis focused on the origin and evolution of the Precordillera crustal fragment with a consensus that could be exotic to western Gondwana (Ramos, et al. 1984; Dalla Salda et al., 1992; Dalziel et al., 1994; Astini et al., 1995; Pankhurst and Rapela, 1998; Keller, 1999).

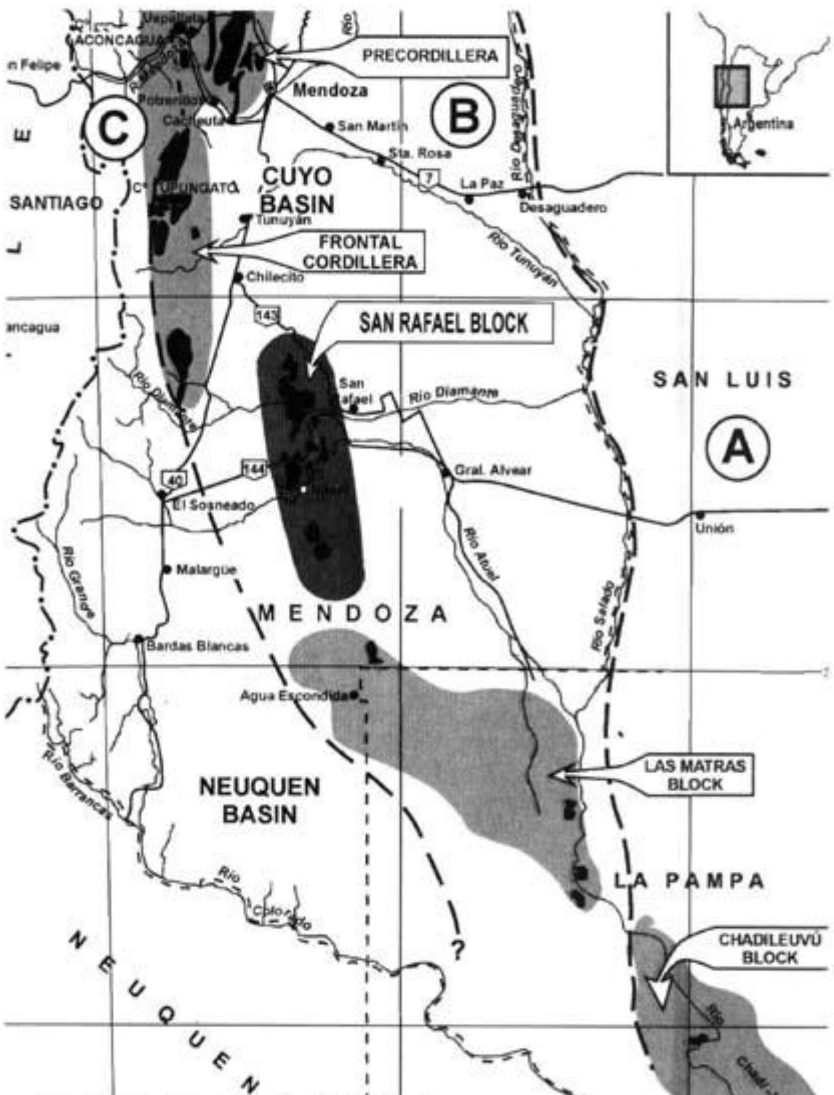

Figura 1. Location of the San Rafael block.

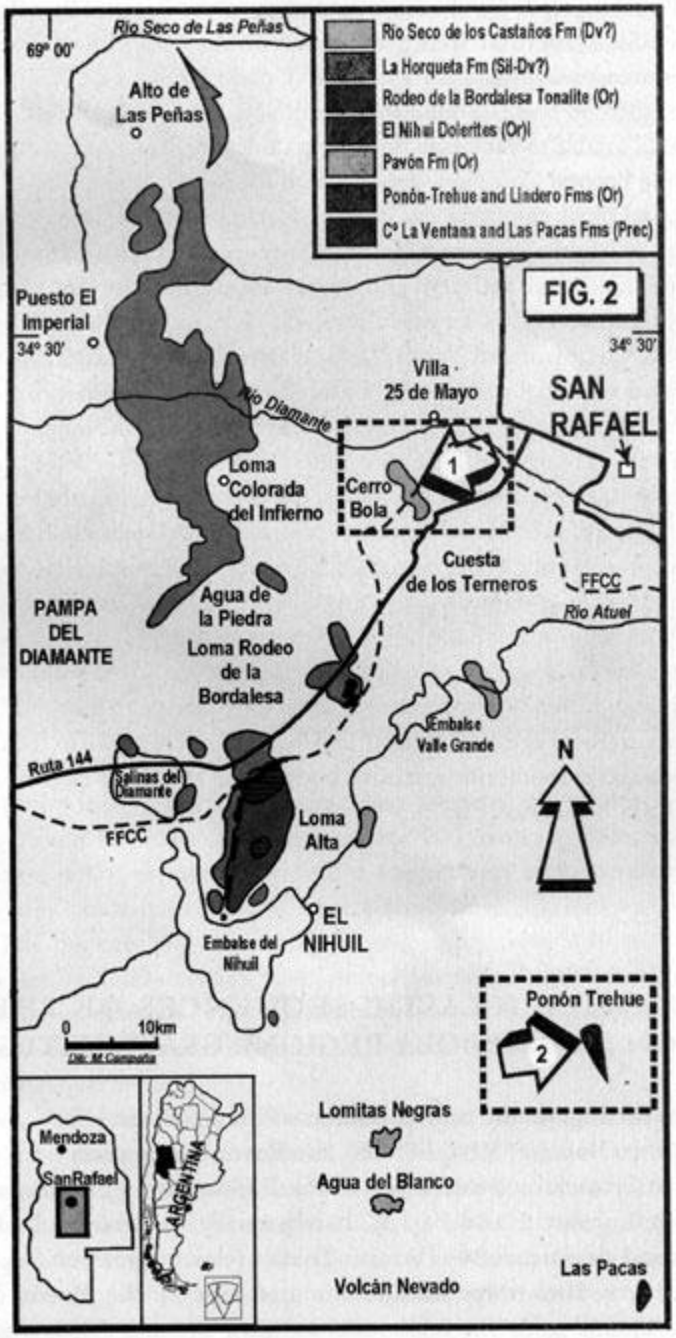

Figura. Distribution of the Pre-Carboniff rous units in the San Rafael Block.
1. Cerro Bola. Pavón Section. 2. Ponón Trehué section.

The San Rafael Block as the southern extension of the Precordillera Terrane (Fig. 1) shows NNW-SSE structural trend, extended about 200 km southwards of the Precordillera outcrops in Mendoza Province (Criado Roqué and Ibañez, 1979). The Cuyo and Neuquén oil basins bound the North and South respectively. Eastwards the San Rafael Block grades to the plains vanishing under the Cenozoic sedimentary cover.

To the West, the Frontal Cordillera defines the boundary.

The San Rafael Block shows diverse igneous-metamorphic and sedimentary sequences of Precambrian to Middle Paleozoic age, known generally as "pre-Carboniferous units" (Fig. 2) due to their clear differentiation from the Carboniferous beds by regional unconformity (Nuñez, 1979; González Díaz, 1981). A Greenville-type basement (Ramos et al., 1996; Cingolani and Varela, 1999) is present in the eastern part of the San Rafael Block and is partially covered (Ponón Trehué zone) by carbonatic-siliciclastic sedimentary rocks bearing Ordovician macro and microfossils (Nuñez, 1979; Heredia, 1982, 1996, 1998, 2001; Bordonaro et al, 1996; Lehnert et al., 1999). A siliciclastic Ordovician sequence is present at Cerro Bola region (Pavón Formation) with graptolites of the Lower Caradoc. In isolated outcrops were recognized siliciclastic turbidites with low metamorphic grade known as Horqueta Formation (Dessanti, 1956) with uncertain stratigraphic age. Shallow water sequences bearing trace fossils and acritarcs of Silurian to Devonian (?) age (González Díaz, 1981; Rubinstein, 1997; Poiré et al., 2002) were separated from the later and mapped as Rio Seco de los Castaños Formation. It is important to mention that this unit contains limestones clastic pebbles with Ordovician fossils. Ordovician (K-Ar ages) dolerite MORB-type dykes crops out in the Nihuil region, and a small tonalitic-granodioritic intrusive body in the Horqueta Formation is present at the Rodeo de la Bordalesa (Fig. 2).

1. CARADOC SILICICLASTIC SEQUENCES OF THE PAVÓN FORMATION (CERRO BOLA REGION). GRAPTOLITES FAUNA.

Geological setting: In the central portion of the San Rafael Block, at the eastern slope of the Cerro Bola (68º30'W-34º35'S), the **Pavón Formation** is cropping out as folded sedimentary rocks and developed of the 3,5 km long a maximum wide of 1,2 km (see Fig. 2, Locality 1 and Fig. 3). It is partially covered by Lower Permian volcaniclastics and was intruded by Permian-Triassic felsic magmatism (e.g. Cerro Bola).

Stratigraphy, sedimentary conditions and age of the Pavón Formation:

Holmberg (1948) was study the region and assigned the unit ("Estratos del Arroyo Pavón") to a Carboniferous time. Also was mapped as a part of the regional geological chart (Hoja 27c Cerro Diamante) and designed as "Serie de la Horqueta" by Dessanti (1956) from Precambrian to Lower Paleozoic age (?). Marquat and Menéndez (1985) recognized the unit bearing graptolites in the black shales. Cuerda and Cingolani (1998); Cuerda et al. (1998); Cingolani et al. (1999); Manassero et al. (2000) have summarized

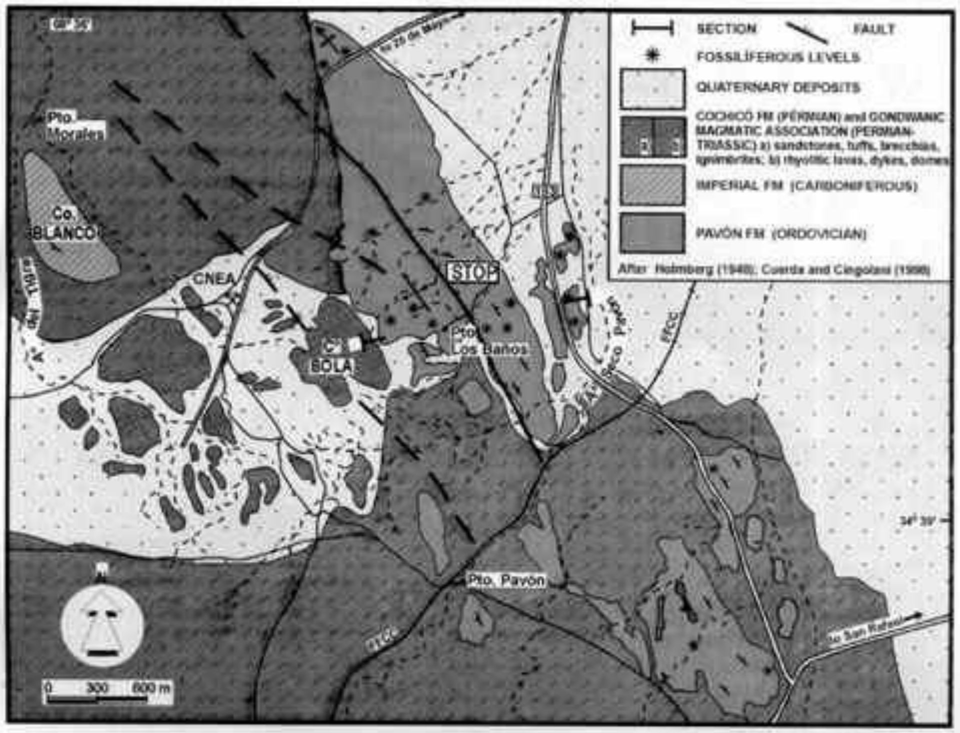

Figura 3. Geological sketch map of Cerro-Bola-Arroyo Pavón locality.

the stratigraphy of this Ordovician sedimentary succession and proposed the new nomination as Pavón Formation. The base of the 700 m stratigraphic column of the Pavón Formation is not exposed. The unit is made up by an association of massive green-reddish-grey sandstones, wackes, quartz-sandstones, siltstones and interbedded black shales. The thickness of the sandstone strata vary from 0.40 to 1 m. The illite crystallinity values by XRD in shales have been obtained and shows anchimetamorphic grade. Deformations affected some clasts and produce a cleavage, as well as siliceous recrystallization. The sequence is intruded by rhyolitic dykes of about 2-3 m thick and thin hydrothermal quartz veins.

The following sedimentological features have been recognized within the Pavón Formation: good sorting, sand dominated facies, regular tabular bedding with sharp contacts and abundant graptolites in fine sediments; on the other hand, there are scarce flow and load casts at the base of the beds, and also scarce channels and syndepositional deformation structures. All these sedimentological features suggest gravity flows in a relatively deep marine sedimentary environment. Petrographical and geochemical analysis of sandstones and paleocurrent data point to a recycled orogen and/or continental block as a source area to the east of the study region. The development of cleavage, siliceous recrystallization and illite crystallinity data suggest deep burial diagenetic conditions.

The proposed depositional model for this unit is that of a turbidite sand-rich ramp.

According to Cuerda and Cingolani (1998) a rich Ordovician graptolite fauna composed of 23 taxa (families Glossograptidae, Nemagraptidae, Dicranograptidae,

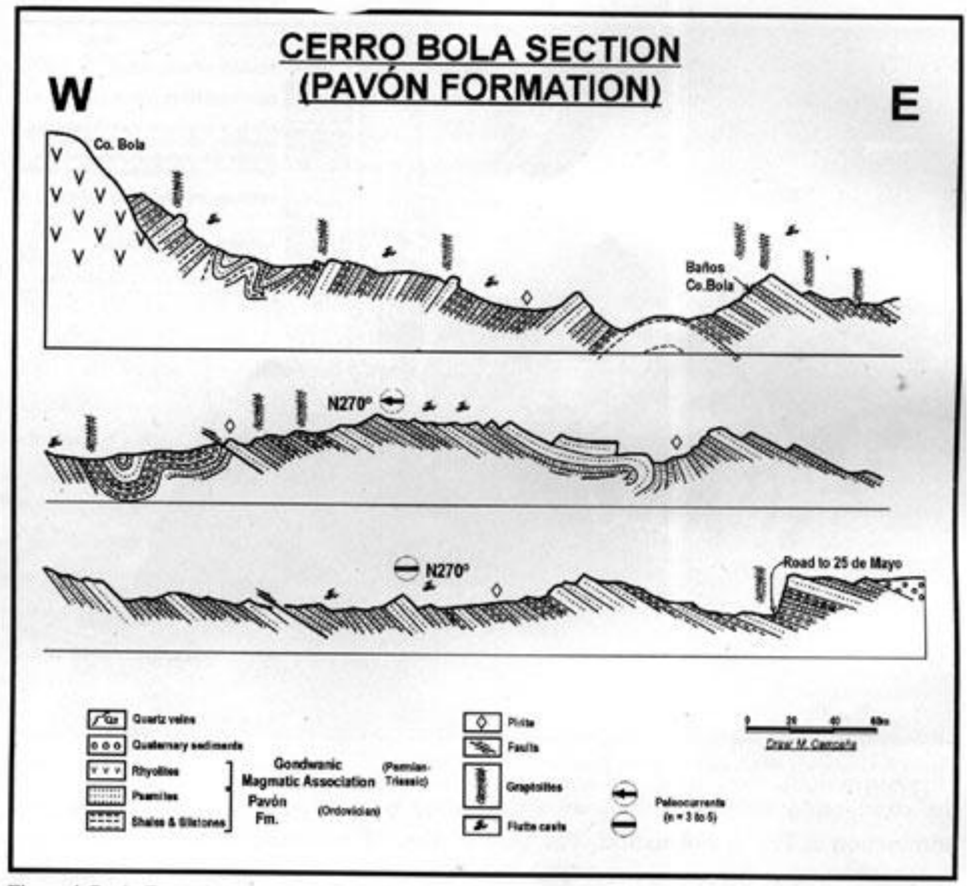

Figura 4. Pavón Formation sections at "Baños Cerro Bola".

Diplograptidae, Orthograptidae, Lasiograptidae and Retiolitidae) has been found in several levels (Fig. 5). The presence of *C. bicornis* and *C. tridentatus* allow considering that the age of the sequence is Lower Caradoc (*Climacograptus bicornis* Biozone). With these graptolite assemblages the Pavón Formation may be correlated with equivalents Precordilleran units (e.g. Empozada, Sierra de la Invernada and Alcaparrosa Formations).

2. LIMESTONES AND CLASTICS TREMADOC-ARENIGLLANVIRN TO LOWER CARADOC DEPOSITS OF PONÓN TREHUE FORMATION. CONODONT BIOZONES. CONTACT WITH BASEMENT ROCKS.

Geological setting: In the Ponón Trehué area (see Fig. 2, Locality 2), have been recognized the Grenvillian igneous-metamorphic basement, Carboniferous sedimentary rocks, Tertiary basalt rocks, and isolated Ordovician strata (Fig. 6). Ordovician strata

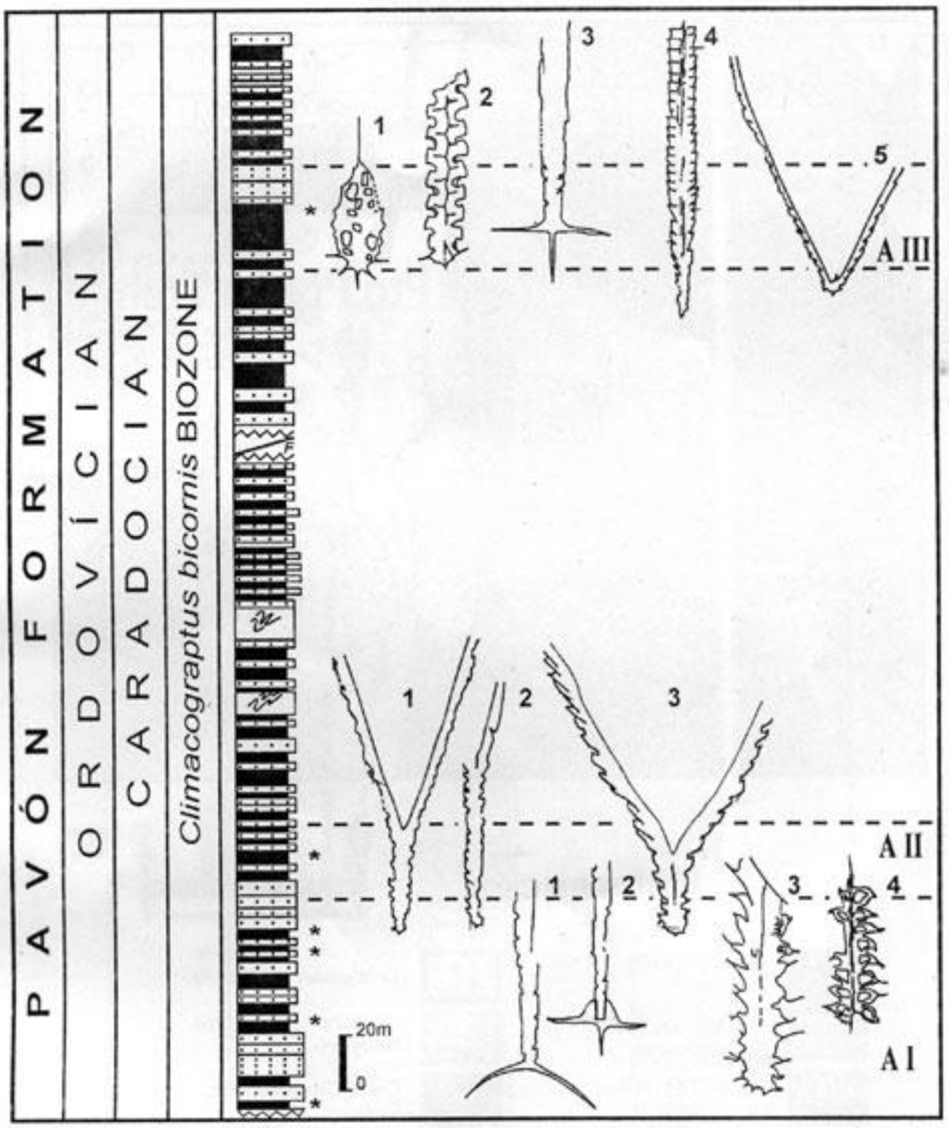

Figura 5. Graptolites assemblages. Position of the fossiliferous levels and distribution of the recognized graptolite assemblages (AI, AII, AIII). AI: 1- Climacograptus bicornis; 2- Climacograptus tridentatus; 3- Lasiograptus costatus; 4- Orthoretiolites sp. AII: 1- Dicranograptus ramosus ramosus; 2- Dicranograptus ramosus cf. longicaulis; 3-Dicranograptus nicholsoni. AIII: 1- Cryptograptus tricornis insectiformis; 2- Pseudoclimacraptus scharenbergi; 3- Climacograptus tridentatus; 4- Orthograptus aff. apiculatus y 5- Dicellograptus salopiensis.

composed by limestones, conglomerates, sandstones and shales, were named as **Ponón Trehué Formation** (Criado Roque and Ibáñez, 1979), and **Lindero Formation** (Núñez, 1979). Bordonaro *et al.* (1996) and Lehnert, *et al.* (1997, 1998) redefined these units, restricting the Ponón Trehué Formation to Tremadoc and Arenig carbonate sediments and the Lindero Formation to Llanvirn-Llandeilo clastic-carbonate sediments. In this

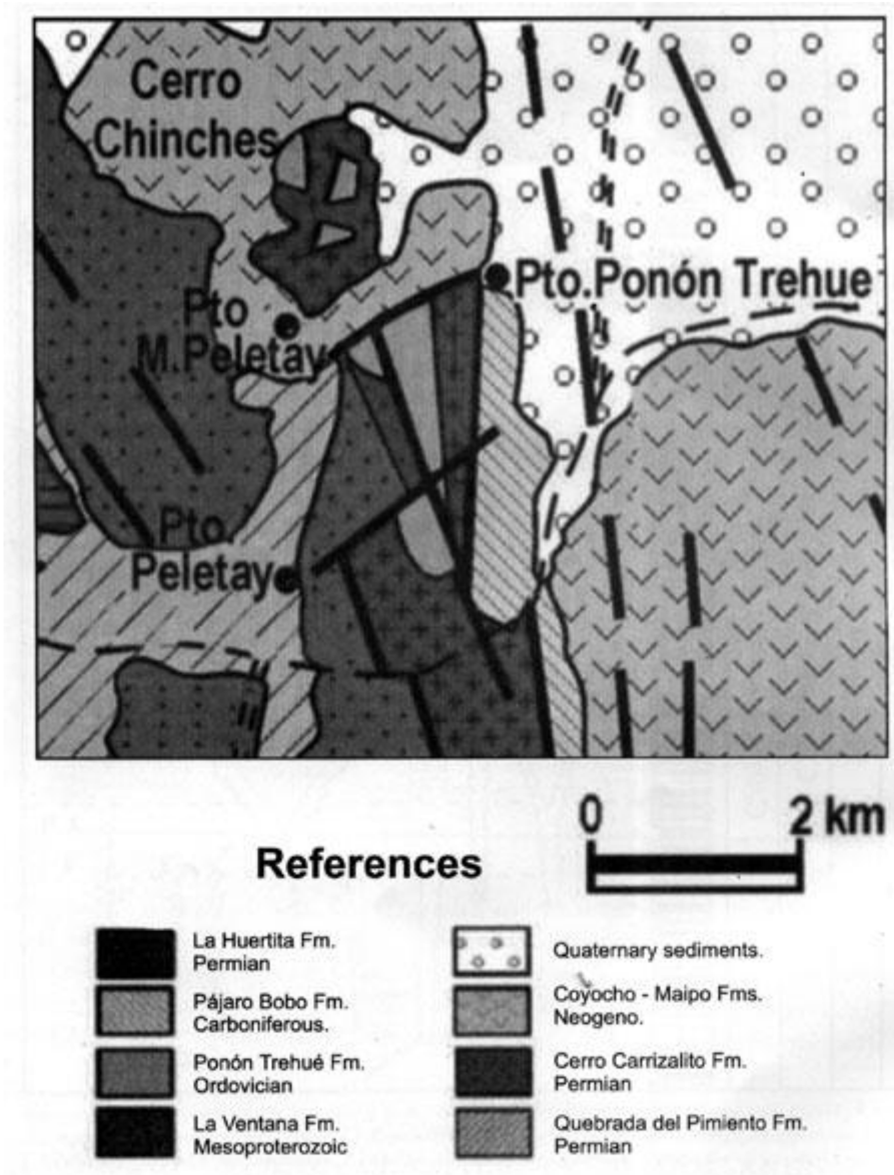

Figura 6. Geological sketch map of the Ponón Trehué region

study the previous nomenclature (sensu Criado, Roqué, 1979) is retained for outcrops northward and to the south of the Ponón Trehué Creek.

Stratigraphy and sedimentary conditions: The biostratigraphy of these Ordovician outcrops has been based only by conodont assemblages (Fig. 7). On the southern sector (Figure 6) of these outcrops Heredia (1982) identified the Pygodus anserinus

		PONON TREHUE FORMATION		
		CONODONT ZONATION		CONODONT ASSOCIATION
ORDOVICIAN	CARADOCIAN			
		Pygodus anserinus / Cahabagnathus sweeti	A. inaequalis	Pygodus anserinus. Cahabagnathus sweeti Eoplacognathus lindstroemi Baltoniodus variabilis
	LLANVIRN	Pygodus anserinus	S. kielcensis	Pygodus anserinus. Pygodus serra
		Pygodus serra	E. lindstroemi	Pygodus serra. E. lindstroemi. B. prevat-variah. t.
			E. robustus	Pygodus serra. E. robustus. B. prevariabilis
			E. reclinatus	

Figura 7. Conodont zonation for the Ponón Trehué Formation (after Heredia, 2001).

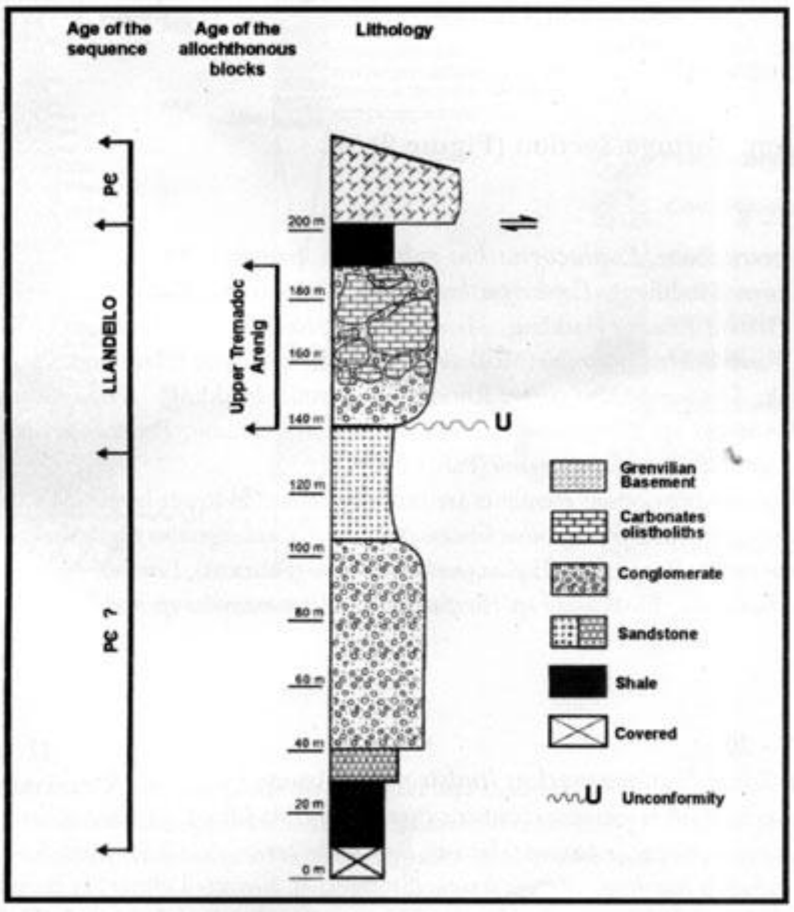

Figure 8. The Cantera section, Tremadoc and Arenig sampling limestones

Zone and Bordonaro *et al*. (1996) and Heredia (1996) recognized the *Pygodus serra* Zone.

Recently, Leslie and Lehnert (1999) and Lehnert *et al.* (1999) pointed out the presence of *Cahabagnathus sweeti* (Bergström) and attributed the lowest Caradoc age for the top of the Ponón Trehué Formation.

First Stop: Arroyo Ponón Trehué

.- Greenville-type basement : the basement is composed of siliciclastic metasediments, gneisses and granitoids called Cerro La Ventana Formation. It is overlain (unconformity) by siliciclastic rocks of the Middle to Late Ordovician.

.- La Cantera Section: (Figure 8) In the northern sector Bordonaro *et al.* (1996) identified elements of *Parapanderodus striatus* (Graves et Ellison) and conodonts of the associations of the *Oepikodus comunis/Prioniodus elegans* and *Oepikodus evae* Zones. This indicates both the Tremadoc and Arenig are represented. Heredia (1998) suggested that these deposits are megablocks, blocks and megaconglomerates occurring in the northern and central parts of the strip-form outcrops. These allochtonous deposits could be associated with the accretion or extension in the exotic-to-Gondwana Precordillera Terrane (*sensu* Astini, 1999).

Second Stop: Tortuga Section (Figure 9)

Samples 3 - 8

The P. serra Zone, Eoplacognathus robustus subzone *Pygodus serra* (Hadding), *Eoplacognathus robustus* Bergström, *Baltoniodus prevariabilis* (Fåhræus), *Periodon aculeatus* Hadding, *Ansella sinuosa* Stouge, *Ansella biserrata* Lehnert et Bergström, *Pseudooneotodus mitratus* (Moskalenko), *Spinodus spinatus* (Hadding),*Phragmodus polonicus* Dzik, *Strachanognathus parvus* Rhodes, *D. robustus* Hadding, *Drepanoistodus* aff. *suberectus*, *Erismodus* sp, *Erraticodon* sp., Panderodus aff. *sulcatus*, *Protopanderodus rectus* (Lindström) and *Walliserodus ethingtoni* (Fåhræus).

The redeposited conodont elements are more abundant in lower levels (M 4 to M 5) and they are identified as *Eoplacognathus foliaceus* (Fåhræus), *Eoplacognathus pseudoplanus* (Viira), *Eoplacognathus suecicus* Bergström, *Eoplacognathus reclinatus* (Fåhræus), *Lenodus*? sp, *Dapsilodus* sp., *Microzarkodina* sp., *Histiodella* ? sp.*Parapaltodus* sp, *Parapanderodus* sp. and *Protopanderodus* sp.

Samples 9 - 10

P. serra Zone, Eoplacognathus lindstroemi subzone

The next conodont association contains *Pygodus serra* (Hadding), *Eoplacognathus robustus* Bergström, *Eoplacognathus lindstroemi* (Hamar), *Baltoniodus prevariabilis* (Fåhræus), *Baltoniodus prevariabilis-variabilis transition, Ansella sinuosa* (Stouge), *A. biserrata* Lehnert et Bergström, *Walliserodus ethingtoni* (Fåhræus),*Strachanognathus parvus* Rhodes, *Periodon aculeatus* Hadding, *Erraticodon* sp, *Drepanodus robustus* Hadding, *Phragmodus* ? sp. and *Panderodus* sp.

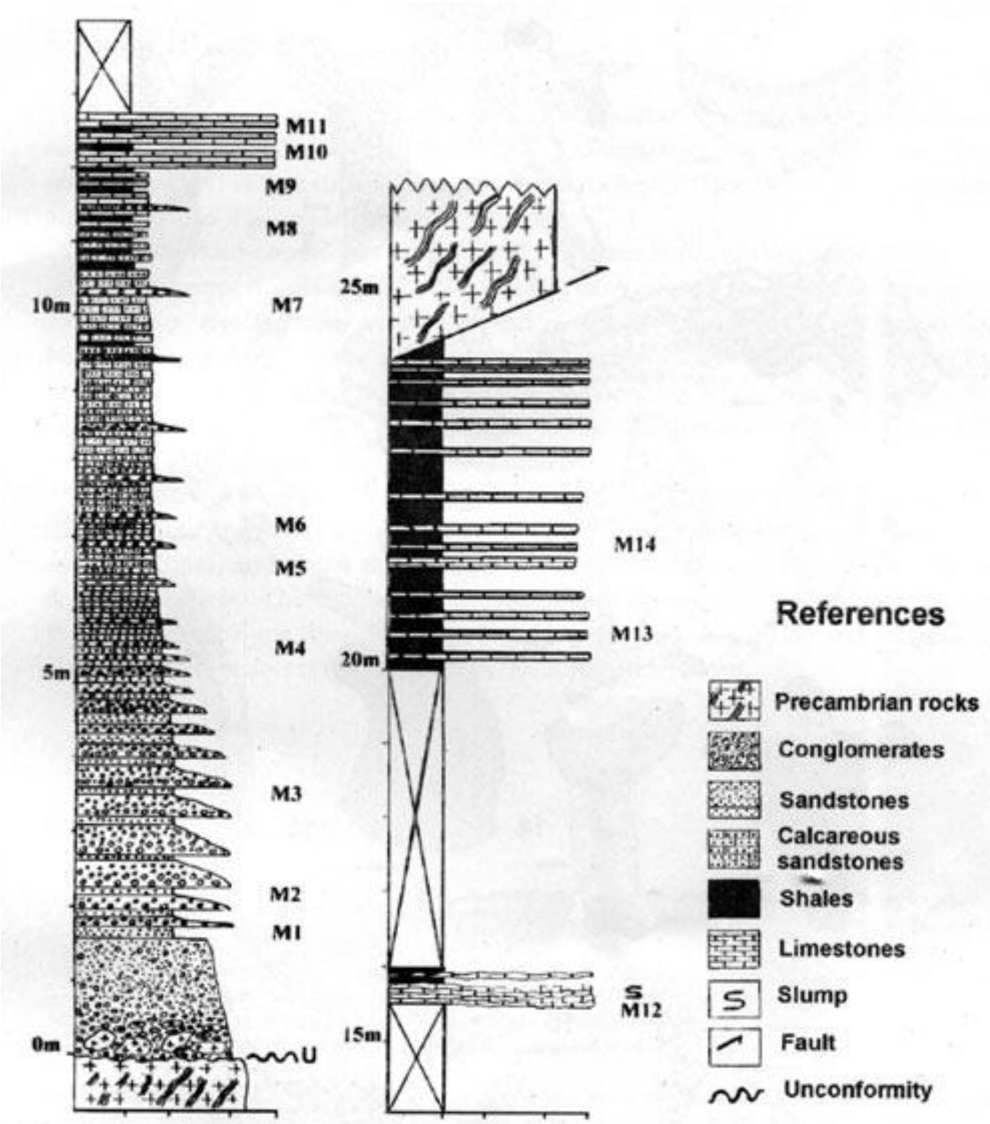

Figure 9. Tortuga section with sampling levels

Sample 11

P. anserinus Zone, Sagittodontina kielcensis subzone *Pygodus anserinus* Lamont *et* Lindström, *Pygodus serra* (Hadding), *Baltoniodus prevariabilisvariabilis* transition, *Strachanognathus parvus* Rhodes and *Periodon aculeatus* Hadding.

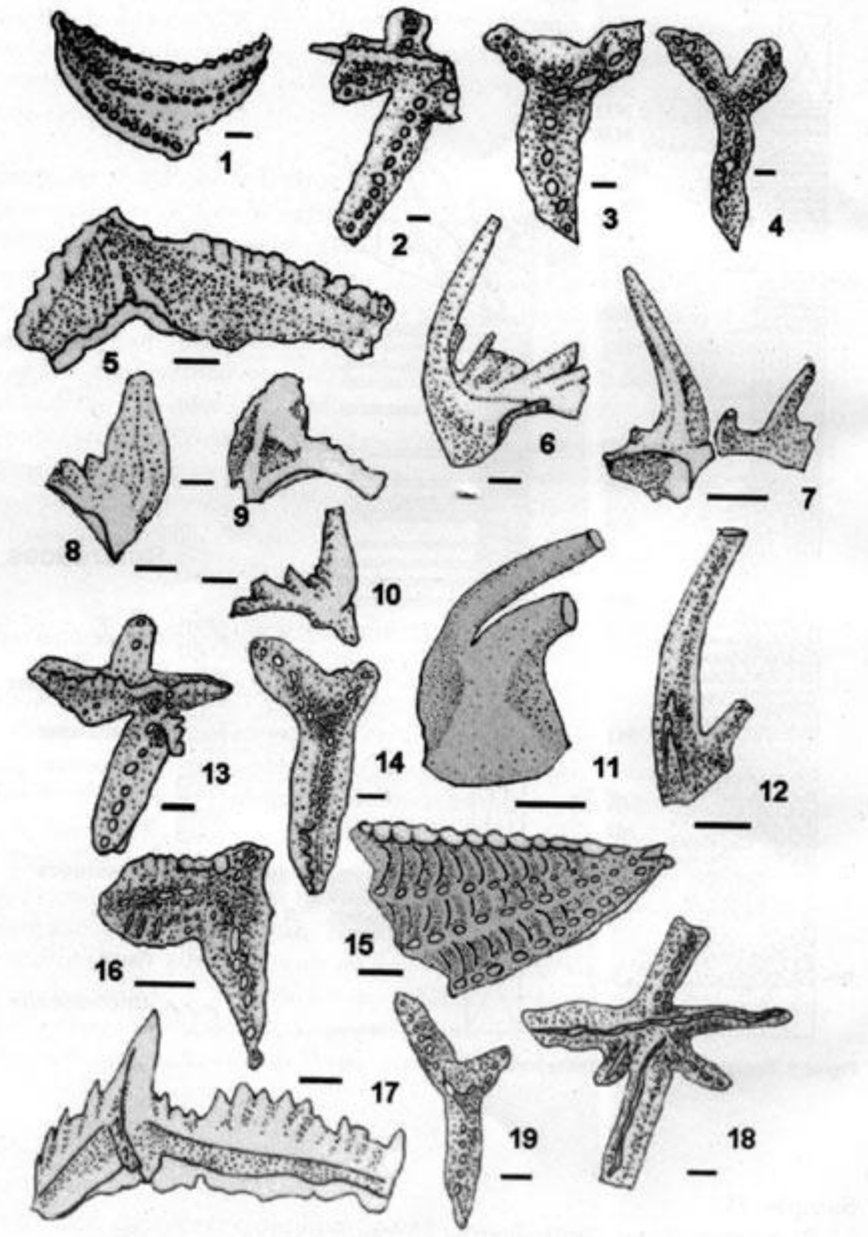

Figure 10. Diagnostic conodonts for Ponón Trehué Formation. Illustrated elements represent the following species (Scale bar: 0,1 mm): 1.- *Pygodus serra* (Hadding); 2 - 4.- *Eoplacognathus robustus* Bergström; 5.- *Baltoniodus prevariabilis* (Fahraeus); 6.- *Periodon aculeatus* Hadding; 7.- *Erismodus* sp., 8 – 10.- *Phragmodus polonicus* Dzik; 11.- *Strachanognathus parvus* Rhodes; 12.- *Erraticodon* sp. ; 13- 14.- *Eoplacognathus lindstroemi* (Hamar)(early form) ; 15.- *Pygodus anserinus* Lamont et Lindström ; 16.- *Cahabagnathus sweeti* (Bergström) ; 17.- *Baltoniodus variabilis* Bergström ; 18 – 19.- *Eoplacognathus lindstroemi* (Hamar)(later form).

Samples 11' - 15

P. anserinus Zone, *Amorphognathus inaequalis* subzone

Pygodus anserinus Lamont *et* Lindström, *Cahabagnathus sweeti* (Bergström), *Baltoniodus variabilis* (Fåhræus), *Periodon aculeatus* Hadding, *Strachanognathus parvus* Rhodes, *Ansella* *biserrata* Lehnert et Bergström, *Drepanoistodus* aff. s*uberectus* (Branson et Mehl), *Panderodus* aff. *sulcatus* and *Walliserodus ethingtoni* (Fåhræus).

Reworked conodonts are of mixed provenance due to deposition in this facies (gravity influence deposits). The conodont age determination based on species such as *Lenodus* ? sp., *Eoplacognathus pseudoplanus* and *E. suecicus* suggest similar deposition times both in the north and in the south of the Precordillera basin. These conodonts have been previously identified in the northern Precordillera at the top of the San Juan Formation (Sarmiento, 1987; Albanesi *et al.*, 1998). The coeval strata are not exposed in the Sierra Pintada range (Phantom Formations).

Bordonaro et al. (1996) mentioned Ordovician outcrops near Ponón Trehué Creek, without specifying places or sampled sections. They identified *Pygodus serra* and *Pygodus anserinus* Zones, and noted the *Eoplacognathus reclinatus* Subzone older than subzones documented here. These authors proposed a hiatus between the *Pygodus serra* Zone and *Pygodus anserinus* Zone, based on the alleged absence of *E. robustus* and *E. lindstroemi* Subzones. Such hiatus is not apparent in the lithological record.

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