East–West cross–section of the Precordillera: from San Juan City to Calingasta Valley throught the San Juan River Valley

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Introduction

The Precordillera Geological Province of the La Rioja, San Juan and Mendoza Provinces (Furque & Cuerda, 1979), stretches almost 400 km in length, and 110 km wide, at the Sierra de Villicum latitude. It is located in western Argentina, located between the Western Sierras Pampeanas to the east and Cordillera Frontal to the west, bounded by major tectonic features. From north to south the Precordillera extends from La Rioja Province, through the San Juan Province, ending on the southern margin of the Mendoza River. As a Geological Province, the Precordillera forms part of the composite Cuyania terrane (Ramos *et al.*, 1984, 1986), which also includes the Sanrafelino–Pampeana Geological Province (San Rafael and Las Mahuidas Blocks) (Criado Roque & Ibáñez, 1979), and the Angaco Belt (Vujovich & Ramos, 1994) from the Western Sierras Pampeanas. The Precordillera represents a high–level fold–and–thrust belt, formed during the Andean (Miocene) orogenesis that produced crustal shortening which affecting the whole pile of Paleozoic, Mesozoic and Cenozoic rocks, with neotectonic features, which demonstrate that Andean deformation is still active.

The structural style of the "thin skinned" thrust–and–fold belt of the Precordillera forms a N–S mountain chain, with a maximum elevation of 4340 m (Cerro Pircas) above sea level on the Sierra del Tontal. The Eastern Precordillera (Ortiz & Zambrano, 1981) is characterized by N–S striking imbricate faults with a westward vergence and thick skinned deformation in where, in general, limestone of the uppermost part of the San Juan Formation, form the base of the imbricates, resulting in a structural style similar to that of the Western Sierras Pampeanas.

The Central Precordillera (Baldis & Chebli, 1969) shows an eastward vergence, and the imbrications formed above a main décollement which truncates the more incompetent sandstones and siltstones of the Devonian and/or the Carboniferous (Von Gosen, 1992). Towards west, the dipping of the imbricate thrust surfaces increases, with the westernmost fault planes standing vertical or being overturned. This east to west steepening of the imbrications is explained by a progressive migration of already stacked western imbricates along the main décollement. This implies a ‘piggy–back’ mode in passively carrying earlier–formed imbricated thrust sheets above a basal décollement which propagated eastwards. Younger imbricate faults formed in front of the stack of imbricates, while the earlier–formed imbricates continued their movement along the pre–existing thrust faults which were steepened or overturned. Imbrications of Ordovician to Devonian strata also occur in the Central Precordillera where Tertiary sediments are preserved on the top of the Devonian.

The Western Precordillera (Baldis *et al.*, 1982) shows a general eastward vergence and thick skinned deformation. In this setting, Cambrian and Ordovician carbonate strata are absent, prevailing Ordovician siliciclastic strata that stand vertical or overturned. In the western flank of the Sierra del Tontal, the Late Paleozoic and Tertiary strata are gently folded, and slices of Cambrian?–Ordovician strata are back–thrusted onto a Permian sequence. Several authors have explained this structural styles as a result of the interaction of the Nazca plate subducting eastwards beneath the South America plate (Ramos *et al.*, 1984, 1986).

The ages of the individual thrusts could not be assessed. However, the pattern of imbricate faults verging eastward, together with the orientation of the flooring décollement, suggest that thrusting was initiated to the west areas and then gradually propagated towards the east. This is comparable with the situation observed in the Canadian Cordillera (Von Gosen, 1992). As there are no Cretaceous sediments, except for a Late Cretaceous sequence from the Huaco River section (Limarino *et al.*, 2000), preserved in the San Juan Precordillera, and onset of crustal shortening during Early Tertiary and/or Cretaceous times cannot be excluded. However, basalt dykes in the Cerro Morado anticline to the north of the Sierra de Villicum and their radiometric dating (Cuerda *et al.,* 1981, 1984) suggest that the Late Cretaceous times were dominated rather by crustal extension than by crustal shortening (Von Gosen, 1992). Few data are available to constrain the timing of thrust movements in the region. These are mainly derived from Tertiary clastics and volcanics (Leveratto, 1968, 1976; Contreras *et al*, 1990) which in eastern regions are affected by thrust tectonics. As these clastics received pebbles derived from the Frontal Cordillera in the west (e.g. rhyolites) it seems reasonable to suggest that a more or less peneplained surface may have existed before the onset of thrusting in the Precordillera (Von Gosen, 1992). Sedimentologic and magnetostratigraphic research at several localities in the Precordillera, combined with fission track dating of volcanic intercalations (Tabbut *et al*, 1987; Beer *et al.*, 1990; Jordan *et al.*, 1990), have shown that this landscape existed up to 10 Ma before present. In eastern belt of Central Precordillera, crustal extension with the generation of andesitic to dacite volcanics (Leveratto, 1976: K–Ar, amphibole, 47 ± 10 Ma; plagioclase, 16±2.9 Ma) pre–dates the onset of crustal shortening. Fission track dating of pyroclastic rocks along the eastern and northeastern parts of the Precordillera has show that the volcanic activity spanned a 10–4 Ma interval (Johnsson *et al.*, 1984).

From a stratigraphic point of view, Precordillera is composed mainly of a thick Early Paleozoic, Cambrian to Early Ordovician, carbonate bank, and Early Ordovician to Devonian siliciclastic marine deposits, all of them evolved as part of the Famatinian Geotectonic Cycle (Aceñolaza & Toselli, 1973). The Late Paleozoic continental and marine rocks, and Early Mesozoic rocks, belong to Gondwanan Geotectonic Cycle, which is separated from the Famatinian Cycle by the Chánica tectonic phase, expressed as an angular unconformity in Eastern and Western Precordillera, and an erosive unconformity in the Central Precordillera. The Jurassic and Cretaceous rocks are recognized only in few places of Eastern and Central Precordillera. The Neogene rocks were deposited in continental basins, and are widely distributed in piggy–back basins between Precordillera and Cordillera Frontal, in foreland basin within the Precordillera, and along the boundary between Precordillera and Western Sierras Pampeanas. These rocks have evolved during the Andean Tectonic Cycle, forming typical orogenic thickening–coarsening upward sequences.

In an E–W section of the Precordillera, Cambrian and Ordovician carbonate platform sequences crops out in the Quebrada de Zonda, at Sierra Chica de Zonda, in the Eastern Precordillera. In the Central Precordillera, across the San Juan River, Ordovician limestones and Silurian to Devonian marine siliciclastic sediments are well exposed in the Sassito, Sasso, Tambolar Pass and Pachaco sections. Upper Ordovician siliciclastic deposits, hosting an ophiolitic rock complex, are extensively exposed in the Western Precordillera. Along the San Juan River section, Upper Paleozoic rocks overlying paraconformably Early Paleozoic strata will be seen (see fig. 1, E 1). Triasic volcanic–clastic continental strata, which are part of the oil–productive Cuyana Basin, and Carboniferous to Lower Permian marine strata, are well exposed on the western belt of the Precordillera.

General features of the trip

In attention not only to scientific, but also to cultural features of this region of Argentine, stops have been scheduled seeking to satisfy both aspects. The San Juan Province is characterized, besides of its good wines and some times tremendous earthquakes (as in 1944 and 1977), by a diverse native cultures which thrived mainly along the western side of the Andean Cordillera, and to the east, on the Tulum Valley. Kaakanes and Huarpes are, among them, the more representative native groups, and most of them were mixed with the Spanish conquerors, but after also with Italian, Spanish and other immigrants from different parts of the world. They live around the San Juan River valley, surrounded by desert environment, and for a long time under the domain of the Inca Empire.

Previous to the first technical stop, the participants will be able to see eastwards a panoramic view of the Tulum Valley, where de San Juan City is emplaced, and the eastern slope of the Chica de Zonda range, with a spectacular view of the neotectonic features. The Chica de Zonda range is part of the north–south trending Villicum–Zonda–Pedernal structural arch (Baldis *et al.*, 1982), also called the "Zonda Swell" (Padula *et al.*, 1967) or "Zonda Arch" (González Bonorino, 1976). The arch forms part of the Eastern Precordillera morphostructural setting (Ortiz & Zambrano, 1981), with its western boundary marked by regional thrust, the " Regional Zonda Fault", which strikes N–S dipping steeply eastwards, and the eastern boundary is marked by a modern fault system, dipping to the east. In this frame, imbricate faults dipping to the east often displace Cambrian rocks. However, Silurian, Carboniferous and Tertiary siliciclastic deposits on top of the thrust sheets are also involved. In the Quebrada de Zonda, Cambrian rocks form the base of the imbricates, and, to the west, the dip of the imbricate thrust surfaces increases, with the westermost fault planes standing almost vertical. In the Villicum–Zonda–Pedernal structural arch, the regional faulting is responsible for range elevation, as well as for the whole Precordillera, where the main deformation and crustal shortening took place during the Late Tertiary

Field trip stops

Because this will be a long day of travel, we will not be able to make extended stops to study outcrops. Each stop has been programmed for short time, no more than 30’, to show the Ordovician rocks in particular thrusthed blocks, and other rocks integrating the stratigraphic succession as well. Stop 1and 2 are in the Eastern Precordillera, stops 3 until 7, in the Central Precordillera, stop 8 in the boundary between Central and Western Precordillera, and stop 9 to 11, in the Western Precordillera. During the travel, while we traverse through the Precordillera, impressive Quaternary landscapes of the San Juan River will be seen, such as enormous alluvial fans, neotectonic activity features, and fluvial gravel bars of braided river, among others.

Stop 1: Tulum Valley Landscape and neotectonic features on the eastern flank of the Sierra de Zonda

In this stop, the participants we will be able to have the panoramic view of the Tulum Valley, which separates Precordillera from the Western Sierras Pampeanas, and the eastern slope of the Chica de Zonda range, that forms part of the Eastern Precordillera morpho–structural setting, whose western boundary is marked by a regional thrust dipping steeply eastwards, and its eastern boundary is characterized by a modern, east depping fault system.

Stop 2: Dique Soldano (Soldano dam) in the Quebrada de Zonda (Zonda Gulch)

Inside the gulch, a thick marine carbonate succession, composed mainly of limestones and dolostones crops out (Figure 2), including several sandstone levels and interbedded black shales, related to shallow water environment. This Cambrian–Ordovician carbonate succession totalizes 2.500 m in thickness, and it is composed by the La Laja Formation (Lower to Middle Cambrian), the Zonda Formation, and the La Flecha Formation (Upper Cambrian), and typical fossiliferous limestones of the San Juan Formation (Early Ordovician), which belong to a continuous sedimentary cycle. The strata are dipping to the east, and tectonic deformation increases toward west. Along the eastern border of the Chica de Zonda rage, the Cambrian–Ordovician carbonate sediments are covered unconformably covered by continental red deposits Neogene of age, reach in fossil mammals.

The La Laja Formation (Borrello, 1962), 700 m thick in its type locality, is the oldest unit of the carbonate platform in the Quebrada de Zonda section, and it is distributed along the western flank of the Sierra de Villicum, Sierra Chica de Zonda and Cerro Pedernal. The name is derived from the Quebrada de la Laja (Borrello, 1962), where for the first time Cambrian faunas were described from the Precordillera (Harrington & Leanza, 1943). Its Type Section is located in the Quebrada de Zonda, from the western flank of the Chica de Zonda Range up to the Juan Pobre Creek (Borrello, 1962). Here, its lower boundary is unknown, because the La Laja Formation is always cut by thrust at the base. The upper boundary is drawn at the transition from limestones to dolomites of the Zonda Formation (Bordonaro, 1980). The best cross–section to look the sedimentary succession of the La Laja Formation, is displayed on the south margin of the Quebrada de Zonda, on the National Road N° 20, which runs from San Juan City to Calingasta Valley. For the first time Borrello (1962, 1963) discovered Cambrian trilobite fauna at the Villicum range, to the north of the Zonda range, where he separated the fossiliferous Cambrian rocks from the Ordovician limestones, introducing the name of "Formation Caliza La Laja". Later, Bordonaro (1986, 1989, 2003) described in detail the stratigraphy for the Lower and Middle Cambrian La Laja Formation (See Figure 3)

The La Laja Formation is a mixed carbonate–siliciclastic system, which in agree with Bordonaro (2003) consists of limestones, argillaceous limestones and marlstones or siltstones, forming staked, shallowing–upward cycles, arranged into four members (Baldis & Bordonaro, 1985): the El Estero Member, composed by grainstones and packstones, the Soldano Member, with sandstones and marls at the base; the Rivadavia Member, with oolitic grainstones, fossiliferous packstones, and marls in the middle part; the Juan Pobre Member, dominantly bioturbated mudstones and packstones at the top. Subtidal mudstones and wackestones indicating a shallow marine platform environment, constitute the typical deposits of the La

Laja Formation, including near–shore oolite shoals (packstones and grainstones), their distribution being related to sea level fluctuations. The sequence reveals six major shallowing upward cycles with basal marlstones–mud–wackestones, strongly bioturbated wacke to packstones and oolitic grainstone shoals (Bercowski *et al.*, 1990). On the basis of lithologic features, Bordonaro (1986, 2003) recognizes four members, which were defined from the base to upwards, as follows:

1. El Estero Member: is formed by black cherty limestones shales and quartzites, containing typical trilobite fauna of the *Ollenellus* Zone which indicates an Early Cambrian age. The lower boundary is unknown due to faulting, and no fossils have been found in the lowest levels, for this reason a Early Cambrian age is estimated.

2. Soldano Member: is composed of marls and mudstones, containing Antagmid trilobites together with chitinous–phosphatic brachiopods indicating the trilobite fauna a lower Cambrian age.

3. Rivadavia Member: is integrated by homogeneous set of black limestones, containing scarce trilobites and algal structures, indicating an Early Middle Cambrian age.

4. Juan Pobre Member: consists of oolitic limestones and black limestones to a lesser extent, bearing trilobites and brachipods in varied abundance, which extent through most of the Middle Cambrian.

Keller *et al.* (1998) suggest that an important unconformity, matched by a type–1 sequence boundary, occurs between the El Estero Member and the overlying the Soldano Member. The rocks beneath the sequence boundary are white quartz arenites and black shales of a shallow depositional environment. Above the unconformity, two trilobites zone seem to be absent, indicating an erosional event which could be correlative with the time–equivalent Hawke Bay event described from the Appalachian margin of Laurentia (Palmer & James, 1980).

The following biozones were determinate in La Laja Formation: *Bathyuriscus–Elrathina, Glossopleura, Albertela, Plagiura–Polliela* Zones in the lower Cambrian, algal structures (like stromatolites) are frequent. Formerly, 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. In agree with Bordonaro (1986, 1989, 2003) and Baldis & Bordonaro (1985), the age of the La Laja Formation range from the upper Lower Cambrian (*Olenellus* Zone) to upper Middle Cambrian (Marjuman Stage, *Bolaspidella* Zone). Baldis & Bordonaro (1985) recognize in the La Laja Formation, from the base to upwards, the following trilobites Biozones: *Olenellus* (Lower Cambrian), *Antagmus–Onchocephalus Zone* (topmost Lower Cambrian)*, Plagiura–Poliella* Zone (base of the Middle Cambrian), *Albertella* Zone, *Glossopleura* Zone and *Bathyriscus–Elrathina* Zone (Middle Cambrian) *, Bolaspidella* Zone icluding trilobites of the uppermost Middle Cambrian.

The Zonda Formation (Bordonaro, 1980), is widely distributed along the entire Eastern Precordillera and also at the Cerro La Silla in the Jáchal area (Bordonaro, 1980), overlaying conformably onto the La Laja Formation. Its name is derived from the Sierra Chica de Zonda, where its type locality has been established by the mentioned author. It is composed mainly of a succession of 300–350 m in thickness, of dolomitic limestones and dolomites with shallow–water sedimentary structures, especially microbial lamination and stromatolites, in which Arroqui Langer & Bordonaro (1996) have recognized hypersaline shallowing–upward cycles. The section in the Quebrada de Zonda shows an overwhelming majority of biolaminated deposits with only minor intercalations of dolomitized oolites, intraformational conglomerates and (dolo) mudstones with desiccation cracks or diagenetics evaporates. Stromatolites are rare and belong to the LLH–type (Logan *et al*., 1964). In this section, small mud mounds occur, now completely silicified, which are similar to those of the base of the La Flecha Formation in the Guandacol area (Keller *et* al., 1994). Here, the Zonda Formation is easily distinguished from the La Flecha Formation, and such distinction is made on lithology, color of the rocks and the differing content of stromatolites. However, sedimentologically, the lower part of the Zonda Formation is a continuation of the uppermost sequence of the La Laja Formation, which is indicated by the transition from oolites with herringbone cross–stratification, in the upper part of the La Laja Formation, to inter–and supratidal dolostones of the basal Zonda Formation. These rocks are abruptly overlain by dark subtidal mudstones at the base of another major shallowing–upward succession (Keller *et al*., 1998). The upper boundary of this cycle coincides with the boundary between the Zonda and La Flecha Formation.

Unfortunatelly, paleontological evidence for the age of the Zonda Formation, has not been provided up to date. Despite this, in the Zonda range the top of the underlying La Laja Formation, on the basis of its trilobite fauna, is dated as uppermost Middle Cambrian (Bordonaro, 1980, 1986; Baldis y Bordonaro, 1985). On the other side, in the Quebrada de La Flecha section, to the south of the Quebrada de Zonda, a significant trilobite fauna provided by strata of the La Flecha Formation, indicates a Franconian age. On the basis of the biostratigraphic contents of the La Laja and La Flecha Formations, the age of the Zonda Formation there seems to comprise the span between the Middle/Upper Cambrian boundary and the lower part of the Franconian, in this way, a Dresbachian/lower Franconian age of the Zonda Formation is most probable (Keller *et al*., 1994; 1998).

The La Flecha Formation (Baldis *et al*., 1981) is 400 m in thickness, and overlain conformably the Zonda Formation. Its name is derived from the type locality in the Quebrada de La Flecha, at the southern part of the Sierra Chica de Zonda, where the formation is widely distributed and its Type Section is located (Baldis *et al*., 1981). The lower boundary is marked by the first beds with abundant true stromatolites (LLH and SH types) and thrombolites, and the upper boundary is drawn, where the content of stromatolites rapidely decreases and limestones predominate over dolomitic lithologies. In other sections, the lower boundary is marked by the change from predominantly white dolomites towards yellow or brown dolomites and calcareous dolomite (Keller *et al*., 1994). In the type locality a varied trilobite fauna occurs indicating a Franconian to at least Late Trepeleauan age (*Saukia* Zone), whereas a Dresbachian age (*Crepicephalus* Zone) is recognized to the northern Precordillera (Vaccari, 1994). The facies and sedimentology of the La Flecha Formation were considered by Keller *et al.* (1989) in its type section. In the Quebrada de Zonda (Zonda gulch) La Flecha Formation exhibits a conspicuous lithostratigraphic sequence composed of two similar shallowing–upward sequences, but there is no well–defined boundary between them. In the lower cycle the abundance of calcrete horizons increases towards the top, but calcretes are absent above the presumed cycle boundary. A reversed pattern is visible in the distribution of thrombolites, which became less abundant towards the top of the cycle and are absent in the uppermost interval, but regain importance at the base of the next cycle. Both sequence boundaries within the La Flecha Formation either show signs of sub–aerial erosion, coarse detrital quartz, abundant evaporites, or concentrations of calcrete horizons just beneath the main surface. For this reason, each one of these sequence boundaries has to be regarded as a type–1 sequence boundary (Keller, 1997; Keller *et al*., 1998). It is presumed that these sequences plus the La Flecha Formation sequences were deposited during approximately 10 Ma, which qualifies them as third–order sequences (Keller, *et al*., 1989, 1998).

The age of the La Flecha Formation, early was suggested by Baldis *et al*. (1981) as Upper Cambrian–Lower Ordovician?, on the basis of the stratigraphic inference. Later, Keller *et al*. (1994) suggest that a (late?) Franconian to at least late Trempealeauan age (*Saukia* Zone) is probable for the La Flecha Formation, according to fossil record from the base of the overlying La Silla Formation at cerro La Silla section, which belongs to the uppermost Cambrian or earliest Tremdoc. Otherwise, trilobite faunas were found in the Quebrada de La Flecha (type section) and in the section of the Guandacol area. In the former, *Plethopeltis* cf. *saratogensis*, indicating a late Franconian age (Ludvigsen & Westrop, 1983) is recorded near the base of the La Flecha Formation (Keller *et al*., 1994). In the middle part of this unit, *Stenopilus convergens* (Raymond) appears, which indicate a late Trempealeau age (*Saukia* Zone) (Longacre, 1970; Ludvigsen *et al*., 1989). On the other side, in the La Angostura section, in Guandacol area, several trilobite faunas has been recorded, there, the earliest is composed of *Madarocephalus laetus* Rasetti, *Komaspidella laevis* Rasetti and *Crepicephalus* cf. *C. scilisis* Resser, together other new species, which indicate the *Crepicephalus* zone (Dresbachian). In this section, in the upper part of the La Flecha Formation, *Drytremacephalus strictus* Rasetti indicates the *Aphelaspis* zone (Westrop, 1992).

The La Silla Formation (Keller *et al*., 1994) constitutes the youngest Cambrian litho–stratigraphic unit for the Villicum–Zonda–Pedernal structural arch, continuing toward north, in the La Silla and Guandacol areas. This formation was defined at the Cerro La Silla section, 350 m in thickness, where paleontological material composed of trilobites and conodonts faunas indicate a Late Cambrian (uppermost Trempealeau) to uppermost Tremadoc (*deltifer* zone) age. A similar thickness to this unit is given at the Quebrada de Zonda section (Keller *et al*., 1994), where the calcareous deposits of the La Silla Formation display on the eastern side of the Zonda range, increasing thickness southwards, to the Quebrada de Las Lajas and Quebrada de La Flecha, respectively. This formation is predominantly a calcareous unit with dolomites displaying oftenly in biolaminated horizons. The succession is composed of an alternation of peloidal grainstones, intraclast grainstones and mudstones, with abundant bioturbation. Oolites deposits may show cross–bedding, wackestone deposits are significant, because yield diagnostic conodont faunas, showing typical association of nautioids and gastropods. No cycles or sedimentary rhythms could be demostrated to date (Keller *et al.,* 1994).

At Cerro Viejo de San Roque, to the southern of the Jáchal City, high–spired, conispiral gastropods, occurring in the upper part of the La Silla Formation, suggest a Early Ordovician age. However, no indicative macrofossil has been reported from the La Silla Formation in the Quebrada de Zonda range. On the other hand, at the type section of this unit, in the Cerro La Silla, trilobites of the *Saukia serotina* to the *Missiquoia depressa* subzone of Norh America, had been recorded (Keller *et al*., 1994), likewise, condonts of the *Clavohamulus hintzei* subzone of the *Cordylodus intermedius* Zone. In the upper part of the formation, the conodont fauna belongs to *Paltodus deltifer* Zone. It is noteworthy that the San Juan Formation not outcrops in the Quebrada de Zonda, although toward the south, in the Quebrada de Las Lajas, a part of this unit has been recognized by Beresi & Bordonaro (1984). There, the Ordovician limestones are overly in angular unconformity by Carboniferous continental deposits.

Stop 3: Embalse Punta Negra –Cerro Blanco (Punta Negra Dam–Blanco Hill)
(See Figure 4)

This stop is located in the eastern border of the Central Precordillera, where the thrust sheets show eastwards vergence. Towards north, on the northern margin of San Juan River, small outcrops of the San Juan Formation are sparsely distributed between the Neogene volcanic and volcanic clastic exposures. Silurian and Devonian sicliciclastic deposits are extensively exposed. The first one are referred to the Tambolar Formation (Heim, 1952), whose type locality is located to the west, in the Tambolar Pass, on the San Juan River transverse. It shows Graptolite are not recorded at present in the Silurian deposits of the San Juan River area. The base of this unit remains unknown due to tectonic and Neogene intrusion events. The Talacasto Formation conformably overlies the Tambolar Formation, and its top is affected by faulting. It shows shallowing upward arrangement, and it is composed by bioturbated greenish gray phosphate–rich mudstones, succeeded by siltstones and fine–grained sandstones, with HCS structures. Fossils are sparsely distributed in the whole formation, and faunal content is dominated by trilobites, brachiopods, gastropods, bivalves, corals and crinoids, among others. Brachiopod fauna is characterized mainly by the occurrence of *Australocoelia, Schellwienella, Austrolospirifer, Scaphiocoelia* and *Pleurothyrella* genera, among others.

In the Punta Negra Dam, crops out the type section of the Punta Negra Formation (Bracaccini, 1950; Padula *et al*., 1967), which according to recent biostratigraphic data (Peralta *et al*., 1995, Herrera and Bustos, 2001) span Lower to Middle? Devonian. This unit is composed of an over more 1000 m thick siliciclastic marine sequence dominated by mudstones, sandstones and shales, which bear abundant plant debris and trace fossils of the *Cruziana* Ichnofacies related to shallow–water environment. The paleocurrent data shows unimodal and bimodal low–scattered designs with a mean direction of approximately 270°, resulting in patterns transverse to the basin axis (González Bonorino, 1975; Bustos, 1996). This areal uniformity of the data for more than 100 km, suggest that turbidity currents have multiple point sources aligned longitudinally transporting sediments from the east to west. The lateral facies arrangement and architectural elements show multiple interdigitations between lobes and distributary channels. Scarce synsedimentary deformation together with the width and character of the channels, allow to infer a depositional substrate of very low gradient (less than 1°) (ramp–like) (Bustos, 1996).

The abundance of plant debris and thorough bioturbation along with the presence of wave reworking, might indicate sedimentary process operating in relative shallow waters, with depth of about 200 m at the most. Taking into account the thickening–upward sequence, as well the sandstones as the predominant lithology and showing the sedimentary structures and plant remains evidences of relatively shallow marine setting near to the shorline, a deltaic model progradding over a ramp margin has been suggested by Bustos (1996; Bustos & Astini, 1996) against the submarine fan model formerly proposed by González Bonorino (1975) and González Bonorino & Middleton (1976). The Punta Negra Formation is unconformably overlain by Miocene continental red deposits, intruded by a Miocene to Pliocene subvolcanic dacite–andesitie bodies, bearing some of them xenoliths of sedimentary and metamorphic rocks. This metamorphic xenoliths are though coming from the basement of the Precordillera, and in agree with isotopic dating a Grenvillian age is point out (Kay *et al*., 1996). Towards east, at the northern margin of San Juan river, Devonian rocks of the Punta Negra Formation are unconformably covered by continental and marine Carboniferous strata bounded by a basal erosional surface. They are composed of a light reddish arkosic sandstones and siltstones, which include some conglomerate levels.

Stop 4: Quebrada Río Sassito (Sassito River Creek)
(See Figures 5, 6)

The sedimentary succession exposed here is composed of fossiliferous limestones of the San Juan Formation (Lower–Middle Ordovician), the lower part of which has been eliminated by overthrus. Limestones are conformably overlain by calcareous and mixed, siliciclastic–calcareous deposits of the Sassito Formation (Astini & Cañas, 1995), of Upper Ordovician age (Lehnert, 1995), that shows at the upper part higher content of terrigenous material. This unit is in turn disconformably overlain by siliciclastic marine deposits of the Tambolar Formation, Silurian in age, which are interpreted as shallow water environment, bounded by an erosive surface at the base, and by paraconformity on top. This unit contains abundant trace fossils of the *Cruziana* Ichnofacies, and HCS structures evidencing storm–influenced environment. They are conformably overlain (paraconformity) by fossiliferous and bioturbated mudstones of the Talacasto Formation (Lower Devonian) showing a coarsening–thickening upward sequence arrangement. This unit, in turn, is conformably covered by a siliciclastic heterolitic sequence composed of dark greenish wackes and shales of the Punta Negra Formation, Lower to Middle? Devonian in age, that bears plant remains and trace fossils of the *Cruziana* Ichnofacies. The younger deposits that crops out in this area, are represented by Carboniferous continental sediments (fluvial, glacial and deltaic deposits, with coal– bearing strata), that includes several fossiliferous marine levels, bounded by erosive surface at the base. Stratigraphic arrangement in the Sassito Creek is as follow:

The San Juan Formation is the older unit recognized in this area, and it is bounded by the Sassito thrust at the base, and at the top is overlaid by the basal conglomerate of the Sassito Formation. This unit crops out sparsely on the western margin of the Sassito Creek, as isolated blocks distributed southward and towards the north of the San Juan River. It is composed mainly of fossiliferous limestones which exhibit in the upper part dissolution phenomena. On the basis of its paleontological content this unit is assigned to Arenig.

In accordance with Astini & Cañas (1995), the carbonate succession of the Sassito Formation, 24.5 m in thickness, is Upper Ordovician (Caradoc–Lower Ashgill) carbonate succession. It is a thinly stratified thinckening–upward and strongly episodic unit outcropping in the Sassito thrust in the Central Precordillera, on the southern margin of the San Juan River. This unit represents the youngest carbonate succession described in the Lower Paleozoic of the Precordillera. Formerly, it has been considered as part of the San Juan Formation but recent surveys allowed to determine the existence of an important erosive and nondepositional gap between them, as show by a thin horizon of chert and limestone conglomerates and coarse calclithites which cover the San Juan Formation. The conglomerates are succeeded by 5.5 m of condensed black shaly mudstones. Several lithofacies are identified within the Sassito Formation: a) black calcilutites (shaly mudstones), b) coarse fossiliferous calcarenites (calclithites), seldom graded, c) thin–bedded calcarenite/calcisiltite rhythmites with variable degree of bioturbation, and d) laminated (with frequent low angle corss–laminations) fine–grained calcarenites (Astini & Cañas, 1995).

The upper part of the Sassito Formation represents the episodic sedimentation of a storm–dominated carbonate shallowing–upward succession deposited on a shallow carbonate ramp, mostly between the storm wave base and the fair weather wave base. A gradual stratofabric change from tabular to lenticular allow to interpret a progradational arrangement from mid–ramp to lower shoreface. In the mid–ramp a better preservation of trace fossils allows to differentiate pre and post event burrowing. In the shoreface some isolated gutter casts were described, whereas hummocky cross–stratification and swaley cross–stratification dominate the lenticular pattern. The aspect ratios as well as the sizes of hummocks and swales are lower than average, and in plan view out of phase (discordant) pyramidal oscillatory megaripples are present. Because of its erosive boundaries and shallowing–upward arrangement, the Sassito Formation is interpreted to involve part of a transgressive system tract and a highstand succession, in which the transgressive surface is coincident with the basal sequence boundary. An earlier (Early–Middle Ordovician) relative sea–level drop is evidenced by a chert and fossiliferous limestone conglomerate and red dolomitized breccia, which caps the San Juan Formation locally. The onlapping black calcilutites can be regarded as a highstand condensed deposit (Astini & Cañas, 1995).

The peculiarity of the Sassito River section is that this is the only locality where authochthonous Upper Ordovician limestones are exposed in the Precordillera. The top of the San Juan Formation is overlain by a thin chert pebble conglomerate (0.45 m thick) with *Cruziana* traces and fragments of brachipods of, presumably Llanvirnian age (Lehnert, 1995a). This indicates a first erosion event on the top of the San Juan platform. The conglomeratic layer is covered by dark shales, bioturbated greenish siltstones and calcareous sandstones with chert clasts, bryozoans and solitary corals. The first grainstone horizons yielded *Ansella nevadensis* (Ethington and Schuhmacher), *Panderodus* aff. *bergstroemi* Sweet, *Dapsilodus mutatus* (Branson and Mehl), *Plectodina* sp., recrystallized *Belodina* sp. and reworked *Histiodella* fragments possibly of *H. holodentata* and very thin and fragile (?juvenile) elements of aff.*Plegagnathus nelsoni* Ethington and Frunish. From a horizon 2.85 m below the top of this unit elements of *Apheolognathus politus* (Hinde), aff. *P. nelsoni, A. nevadensisk* and reworked material (*H. holodentata* and *Histiodella*? sp.) were obtained. The correlation of the distinct conodont associations mainly is based on the comparison with zonations and composite range charts of Sweet (*e.g.,* 1984) and was discussed in detail by Lehnert (1995b). The condensed succession might bear a hiatus as reflected by reworked faunal elements. The evolution of the platform began presumably during Late Llanvirnian times and at least persisted to the Middle Caradoc, perhaps even into the Ashgill based on the occurrence of *A. politus* (Lehnert, 1995a). The Sassito Formation probably correlates with part of the Empozada Formation, from southern Precordillera, and the Trapiche Formation, from northern Precordillera, where late forms of the *Amorphognathus* conodont genus have been recorded (Heredia *et al.*, 1990; Albanesi *et al.*, 1995).

The Tambolar Formation (Heim, 1952), 150 m thick, is Silurian in age, and the oldest siliciclastic unit exposed in this area, being characterized by a thickening–upward succession. It unconformably overlies (erosional surface) the Sassito Formation, and at the top it underlies paraconformably (paraconcordance) the Lower Devonian fossiliferous mudstones of the Talacasto Formation. The succession starts with a basal cherty pebbly tabular conglomerate, 30 cm thick, which is succeeded by a thin, over 80 cm, argillite succession, continuing upward phosphate rich mudstones, 50 m thick, thin bedded wackestone and mudstones, 50 m thick, and the upper part it is dominated by thin to medium bedded wackestone and scarce intercalations of mudstones. The whole succession contains abundant trace fossils of the *Cruziana* Ichnofacies (Aceñolaza & Peralta, 1991) evidencing a shallowing upward trend.

The Talacasto Formation, 270 m thick, is Lower Devonian in age, exhibiting also thickening–upward siliciclastic arrangement. It paraconformably overlies the Tambolar Formation, and at the top underlies the basal muddy succession of the Punta Negra Formation. The Talacasto Formation is composed mainly of bioturbated phosphate rich mudstones at the lower part, bearing shelly fauna (brachipods, bryozoans, corals, bivalves, ostracods, and trilobites) and trace fossils of the *Cruziana* Ichnofacies (Baldis & Peralta, 1999). From a sedimentological point of view, this unit has been interpreted by Astini (1991) as a muddy shelf environment. Shelly fauna appears distributed in the whole sequence and it is characterized by the occurrence of brachiopod remains such as *Australocoelia tourtelotti*, *Schellwienella inca, Australospirifer antarcticus,* and *A. kayserianus,* among others (Baldis, 1975; Herrera, 1990).

The Punta Negra Formation, over 1000 m thick measured in this locality, between the Sassito and Sasso creeks, by Peralta & Ruzycki (1990), is Lower–Middle? Devonian in age (Peralta *et al.,*1995; Herrera & Bustos, 2001). As the underlying Talacasto Formation, this unit exhibits a thickening–upward sequence, and it is composed mainly in the lower part of reddish and greenish shales and bioturbated mudstones, which are succeeded by greenish siltstones bearing trace fossils of the *Cruziana* Ichnofacies (Baldis & Peralta, 1999). Towards the upper part the succession is dominated by interbedded graywackes, shales and siltstones including in places, plant remains. This unit underlies unconformably (erosional surface) the continental and marine–continental Carboniferous deposits. The mentioned unconformity is related to the Chánica tectonic phase which marks the upper boundary of the Famatinian Geotectonic Cycle in Argentina.

Stop 5: Río Sasso (Sasso River)

This stop is no more than 5 km westward of the Sassito creek, for this reason, both sections show stratigraphic similarities among them. In this place the Los Caracoles dam is being built, as part of the Los Caracoles–Tambolar hidroelectric complex. Here, the succession starts with the limestones of the San Juan Formation, which is overlain unconformably by basal sandstones (wackes) of the Tambolar Formation (Silurian). This unit is made up by yellowish and greenish mudstones, siltstones and waquestones, which show a thickening–coarsening upward sequence, containing abundant trace fossils of the *Cruziana* Ichnofacies. It is noteworthy the lack of the cherty basal conglomerate present in the Sassito creek section. At the top, the Tambolar Formation is conformably overlain by fossiliferous basal mudstones of the Talacasto Formation (Lower Devonian, Lochkovian–Pragian until Emsian), which in turn is also conformably overlain by fossiliferous mudstones and siltstones passing upward to wackes of the Punta Negra Formation (Lower Devonian, Emsian, until Midd? Devonian). This unit also is characterized by thickening–coarsening upward sequence, bearing abundant trace fossils of the*Cruziana* Ichnofacies (Peralta & Ruzycki, 1990; Baldis & Peralta, 1999), and HCS (hummocky cross stratification) structures, indicating shallow water environment. At the top, this unit is unconformably (erosional unconformity) covered by continental and mixed deposits of Upper Carboniferous age, and this unconformity is related to Chánica tectonic phase, which separates both the Famatinian and Gondwanan Geotectonic Cycles, and show widespread distribution overall Argentina and neighboring countries. The main difference between the Sasso and the Sassito sections is the absence in the former of the limestnes of the Sassito Formation, owing to subsequent erosive events (Base of the Tambolar Formation) that actuated in the Sasso Creek section.

Stop 6: Portezuelo del Tambolar (Tambolar Pass)
(See Figure 7)

This stop is placed in the highest point on the road from the San Juan city to Calingasta Valley, in the southern margin of the San Juan River. The sedimentary succession is similar to that of the Sasso Creek. The oldest unit exposed in this section is the San Juan Formation, composed mainly of fossiliferous limestones including in the upper part several bentonite levels. This Ordovician limestones form the base of the thrust verging to the east. For this reason, the base of the San Juan Formation remains unknown, and the top is unconformably overlain by siliciclastic marine deposits of the Tambolar Formation.

The Tambolar Formation (Heim, 1952), 74 m thick (Peralta & Carter, 1990), is Silurian in age. It unconformably overlies the limestones of the San Juan Formation, and in turn is unconformably (paraconcordance) overlain by the Lower Devonian Talacasto Formation. Shallowing–upward succession of the Tambolar Formation can be observed in detail in this section, which is the type locality of this unit. According to Peralta & Carter (1990), thin, normally graded sandstones interbedded with bioturbated mudstones characterize this unit. In places, the laterally extensive sandstones, which are in sharp contact with the mudstones, are capped by hummocky cross–stratification (HCS). In addition, the bases of some sandstones contain accumulations of fossils such as articulated brachipods, and in the mudstones, trace fossils of the *Cruziana* Ichnofacies (Peralta & León, 1997). The association of the HCS with the graded sandstones, and the fossils indicate a platform environment, below the fair–weather wave base. The sands were probably transported by turbidity currents generated by liquefaction of shoreface deposits during storms. Subsequent reworking of the graded sands below the fair–weather wave base by wave and currents produced the HCS. The overall coarsening upward nature of the formation and the change from a high diversified to a low diversified ichnoguild, evolved within of the *Cruziana* Ichnofacies, implies a seaward migration of the platform deposits (Peralta & Carter, 1990; Aceñolaza & Peralta, 1991).

It is noteworthy that the stratigraphic correlation of the basal cherty pebbly conglomerate of the Tambolar and La Chilca formation is based both in lithological and biostratigraphic data. A Late Ashgillian (Hirnantian) age has been recognized for that basal level, towards the north, in the Los Baños de Talacasto section (Cuerda *et al.,* 1988), which underlain a thin mudstone level bearing graptolites of the *persculptus* Zone, and associated palynomorphs (acritarchs and chitinozoans) (Melendi &Volkheimer, 1982). On the other side, the basal conglomerate level of the Tambolar Formation is overlain by a thin bioturbated mudstone level bearing a palynologic assemblage dominated by forms of acritarchs and prascinoficeas indicating a Late Llandovery to Early Wenlock age (Peralta *et al.,* 1997). The Silurian age of the Tambolar Formation is well constrained on the basis of its brachipod fauna composed by*Australina jachalensis,* *Salopina* cf. *missendenensis*, *Isorthis* sp., and *Clarkeia tambolarensis*, among others (Castellaro, 1959; Benedetto *et al*., 1996; Benedetto and Franciosi, 1998).

The Talacasto Formation, almost 180 m thick, is Lower Devonian in age. It paraconformably overlies the Tambolar Formation and, in turn is paraconformably overlain by the Punta Negra Formation. The lower part of the unit is mainly composed by bioturbated fossiliferous greenish and yellowish phosphate rich mudstones, bearing abundant coral remains formerly assigned to "*Favosites*" genera (Baldis, 1975). This deposits are succeeded upward by laminated siltstones with abundant articulated and inarticulated brachipods, bivalves, crinoids, bryozoans, and in the upper part a conspicuous sandstone level, no more than 1 m thick, exhibiting water escape structures, is interbedded in the siltstones. The Lower Devonian fauna on this unit is mainly characterized by the occurrence of *Australocoelia tourtelotti*, *Schellewienella inca, Australospirifer antarcticus, A. kayserianus,* among others.

The Punta Negra Formation crops out towards west, from this area up to the Pachaco locality. It is composed of siliciclastic deposits that are widely distributed forming most of the exposures, in several imbricates along the San Juan River. This unit overlies conformably the uppermost sandstones of the Talacasto Formation, and at the top is disconformably (erosional surface) overlain by Upper Carboniferous continental and mixed (marine and continental) deposits, which in part include fossiliferous marine levels. However, in some places due to tectonic effect, the Devonian succession is repeated by thrusting. The erosional surface between both Carboniferous and Devonian deposits is though evolved as a result of the Chánica tectonic phase, which developed an angular unconformity whether in the Eastern as well as in the Western Precordillera. It is noteworthy that in this place occurs the last outcrop of the Talacasto Formation which lacks in the Early Paleozoic stratigraphic framework in the western section of the Precordillera.

Stop 7: Pachaco Checking Point (Control de Pachaco)
(See Figure 8)

In this locality, the Lower Paleozoic succession was formerly considered by Beresi (1980) who mentioned the finding of Silurian ferriferous levels. Here, the thicker carbonate sequence of the Lower–Middle Ordovician San Juan Formation forms the base of two east–directed imbricate sheets, indicating a deeper position of the main décollement. They are doubled by an imbricate fault, and the western carbonates are unconformably overlain by Silurian to Devonian deposits (Von Gosen, 1992). In this scenario, the more conspicuous thrust is represented by the limestone block named as Cerro Blanco de Pachaco, which is bounded on the east side by thrust fault verging eastwards.

The stratigraphic succession initiates with fossiliferous limestones of the San Juan Formation, composed by yellowish and grayish dolomite and calcite laminated thin beds. At the upper part this unit shows a thicker carbonate sequence dominated by dolomite and calcite banks, with thin yellowish K–bentonite level interbedded, and at the top is formed by argillaceous limestones interbedded with thin calcareous shales. The base of this carbonate succession remains unknown because its lower part is affected by the overthrust, and at the top is unconformably underlain by the Silurian basal conglomerate horizon. The age of the limestone is Arenig to Lower Llanvirn according to the conodont record by Serpagli (1974) and Lehnert (1995).

Silurian deposits are represented by greenish and reddish muddy shelf facies named as the "Pachaco Facies of the Tambolar Formation" (Peralta & León, 1993), made up of greenish (lower Member) and reddish (upper Member) bioturbated mudstones and siltstones, which in the upper part includes thin fossiliferous storm–sandstone–beds. They are conformably overlain by siliciclastic marine deposits of the Punta Negra Formation (Lower–Middle? Devonian). It is noteworthy that the Talacasto Formation is not exposed in this area, and the hiatus between the Tambolar and the Punta Negra formations is longer in this section. From a paleobiological point of view, Silurian deposits informally called "Pachaco Facies", are characterized by the occurrence of trace fossils of *Zoophycos* (Peralta & León, 1993), and the *Cruziana* Ichnofacies (Peralta *et al*., 1997), and brachipods indicating a Wenlock age (Benedetto & Franciosi, 1998). However, based on palynological data (Pöthe de Baldis, personal communication) and regional correlations, a Ludlowian age is also suggested for the upper part of this unit. The age of the lower Member and the basal conglomerate at present remains unknown due to the lack of fossil record (See Figure 9 for correlations).

Westwards, the Silurian deposits are succeeded by siliciclastic marine deposits of the Punta Negra Formation, made up of greenish and gray–greenish graywackes and pelites dominating the lower part, succeeding upward thin sandstones beds interbedded with mudstones and shales. To the upper part medium to thick sandstone beds interlayered with pelites prevail. A conspicuous feature of these deposits is the occurrence of channel–fill conglomerates, in the lower part of the unit, which are composed mainly of clasts sourced mainly from the underlying Lower Devonian Talacasto Formation, but also from the Silurian Tambolar Formation and limestones from the Ordovician San Juan Formation. In this place, in the lower part of the Punta Negra Formation Peralta *et al.* (1995) registered the occurrence of shelly fauna similar to that of the upper part of the underlying Talacasto Formation. On base of this finding, the mentioned authors assigned a Lower–Middle Devonian age to the lower part of the Punta Negra Formation. From an ichnological point of view, trace fossils such as Pa*leohelmintoidea, Paleophycus, Arenicolites, Planolites, Didymaulichnus,*among other, of the *Cruziana* Ichnofacies, are widely distributed in the whole sequence of the formation.

In the El Palque creek , a thick Neogene volcaniclastic continental sequence of the Pachaco Formation, which in accordance to Milana *et al.* (1993) is Miocene until Early Pliocene age, crops out forming an asymmetric synclinal. The Neogene deposits are made–up of lacustrine (lower part) yielding rests of palynomorphs, which pass upward to eolian(middle part) and fluvial–alluvial (upper part) deposits. The typical coarsening–thickening upward arrangement of the Pachaco Formation, agrees with the orogenic origin of the Andean Neogene basins (Strelkov & Alvarez, 1984), due to the uplift of the Andes Cordillera, in the western Argentina, since the Miocene. It is noteworthy that this sequence was formerly considered as probably Triassic in age for the lack of fossil records, up to the mentioned palynologic finding by Milana *et al.* (1993).

Stop 8: Quebrada de los Ratones (De los Ratones creek)
(See Figure 10)

This creek is placed in the boundary between the Central and Western Precordillera settings. To the east, sedimentary rocks of the Late Ordovician (Hirnantian) age belonging to Alcaparrosa Formation crop out, composed mainly of graptolite–rich black shales, varied type of sandstones and conglomerates, associated with mafic and ultramafic rocks, forming sills and pillow lava structures, related to oceanic crust accretion processes (Kay *et al*., 1984; Haller & Ramos, 1984, among others). Sedimentary rocks have been interpreted as deep–water deposits, and the channel–fill conglomerates contain varied kind of sedimentary and igneous clasts. In this place, Hirnantian rocks lie in tectonic contact with siliciclastic marine deposits of the Punta Negra Formation (Lower–Middle? Devonian), and also with limestones of the San Juan Formation. Westwards, allochthonous blocks of Cambrian limestones and conglomerates, appear in tectonic contact with deep–sea deposits of the Alcaparrosa Formation (see Figure 10).

In the Los Ratones Creek, allochthonous Cambrian carbonate–siliciclastic sediments crops out, in which siliciclastic lithology prevails. Exposures have a maximum of 1,5 km in length and about 250 m in thickness, and they were included into the Los Sombreros Formation (Banchig & Bordonaro, 1994). The sedimentary sequence is characterized by three autochthonous lithofacies: A) Sandstone: Presented in facies of turbiditic Tb–c and Tb–e and conglomerates channel fill distributed in the olistostromic sequence with sandstones lenses, boulders of limestones, involved by green shales; B) Shales: The shales are represented as term Te–d of turbidite cycles, as well as heterolithic deposits integrating the matrix in the olistrostrome that contains olistoliths and boulders; C) Conglomerates: represent channel–fill normally graded passing up to coarse–grained sandstones. Clasts and boulders lithologies indicate a metamorphic source with marked roundly and allochthonous provenance: D) Olistoliths and boulders: boulders of different sizes (2 to 10 m) floating into a dark green siltstone–sandstone deposit, without internal sedimentary structures. In addition a huge olistolith that bears Middle Cambrian trilobites (*Pachyaspis aff. Deborra, Kootenia and Glossopleura*) are present. It is composed by hemipelagic limestones (mudstones–wackestones/black shales) and orthoquartzite sandstones.

Due to the scarcity of fossil content in the siliciclastic sequence, is not possible to know the real age of the outcrop in this locality, but a correlation according to similar depositional paleoenvironment interpreted to the Ojos de Agua section situated 10 km to south, it is possible to be done. Lithofacial distribution indicates mass flow and debris flow zone, where the sandstone/shale couple suffered deformation under the gravity stress and indicating initial state of the mass movement. Isolated lenses bodies of conglomerates, (composed by rounded metamorfic clasts), and allochthonous boulders and olistoliths composed by hemipelagic limestones, (with fossiliferous content from Middle Cambrian age: corresponding to *Pachyaspis aff. Deborra, Kootenia* and *Glossopleura)*, floating into a dark green shale and sandstone matrix, indicating a topographic gradient favorable to erosional process (as conglomerates fill erosional channels) and mass movement in the south and central part of outcrops (olistoliths). The sequence pass from olistostrome facies (Lithofacies A, B in sandstone lenses and D), to sandstone facies in turbidite Tb–c and Tb–d cycles, indicating at least the passing from mass flow zone or debris flow, towards the apron slope or turbiditic fan to the north of outcrop.

According to Shanmugam et al. (1985), this scheme would characterize submarine canyon depositional system with channels distributed next to levee zone.

Stop 9: Quebrada de Alcaparrosa, km 114 (Alcaparrosa Creek)
(See Figure 11, 12)

This creek is outlined by the El Tontal Fault, which strikes N–S, and it is traceable by hundreds of kilometers, being characterized by impressive neotectonic features. From a regional point of view, the El Tontal–Tigre fault conforms a steeply inclined back thrust zone, on the western boundary of the Tontal and El Tigre ranges. The Paleozoic strata are pervasively deformed, and Ordovician rocks of the Alcaparrosa Formation overthrust onto Permian rocks. On the western flank of the Sierra del Tontal, Late Ordovician (Hirnantian) strata of the Alcaparrosa Formation crops out, which is unconformably overlain by marine and continental deposits of the El Planchón Formation, Carboniferous in age, and also by Permian deposits of the El Salto Formation. Towards west, a heterolithic sequence composed of dark greenish sandstones and shales of the Don Polo Formation is exposed, which lies towards east, in tectonic contact with Carboniferous deposits of the El Planchón, Codo and the El Ratón formations.

The Don Polo Formation is widely exposed from the western flank of the Sierra del Tontal up to the Santa Elena Creek, and it is fault–bounded whether at the base and top. It is composed mainly of gray–greenish graywackes and interbedded pelites, thought as marine in origin. The age of this unit is not well constrained, but in agree with regional interpretations, some authors assigned it to the Cambrian–Early Ordovician, taking into account its stratigraphic emplacement, which is thought to be below of the Late Ordovician Alcaparrosa Formation (Quartino *et al*., 1971). From a sedimentary point of view, Don Polo Formation is similar to the early Late Ordovician Portezuelo del Tontal Formation that crops out further to the south. The main difference among them is the occurrence of mafic and ultramafic rocks in the later, which are absent in the Don Polo Formation. However, marine trace fossils are common in both.

The Portezuelo del Tontal Formation is exposed to the west in the Los Ratones Creek. It lies in tectonic contact with the olistostrome of the Los Sombreros Formation to the east, and with the Hirnantian Alcaparrosa Formation to the west. It is noteworthy that more extensive exposures of the Portezuelo del Tontal Formation crop out further south of the San Juan River, in the Sierra del Tontal. This unit is composed of siliciclastic marine rocks bearing graptolites of the *gracilis* Zone (Cuerda *et al*., 1986; Schauer *et al*., 1987; Peralta *et al*., 2003), associated with mafic and ultramafic rocks, which according to dating by Gerbi *et al*. (2002) dating in possibly equivalent rocks from the Bonilla–Cortadera areas, indicate a Silurian age (429 Ma). The sedimentary sequence of the Portezuelo del Tontal Formation has been interpreted by Spalletti *et al*. (1989) as result of a turbidity system. Alternatively, a storm–dominated shelf environment has been proposed by Basilici *et al*. (2003a, b). From a lithostratigraphic point of view, this formation is mainly composed of greenish graywackes interbedded with siltstones and mudstones, scarce black shales and channel–fill conglomerates. Graptolites appear concentrated at the base of the massive sandstones beds, as well as in laminated sandstones, and in black shales, while trace fossils are common in sandstone and siltstone beds. In the sedimentary conglomerate, mafic and ultramfic clasts are predominant;

among them, fossiliferous limestone clasts from the San Juan Formation occur as conspicuous component.

The Alcaparrosa Formation, over 1.000 m thick, is Hirnantian in age (Brussa *et al.*, 1999), forms the largest exposures of the Sierra del Tontal on the San Juan River transect and is represented by a sedimentary complex, fault–bounded at the base and top, characterized by the occurrence of graptolite–rich black shales, immature sandstones and siltstones, interbedded channel–fill conglomerates that include limestone clasts from the San Juan Formation. The presence of dykes and sills of mafic and ultramafic rocks is related to an extensional event (Borrello, 1969; Ramos *et al.,* 1984; Haller & Ramos, 1984; Kay *et al.*, 1984; Ramos *et al.*, 1986). Its basal boundary is a tectonic contact with the Portezuelo del Tontal Formation to the east, and is unconformably overlain by marine and mixed Upper Paleozoic deposits. Close to the east, the Tontal fault zone can be traced on hundred kilometers, striking parallel along the western flank of the Sierra del Tontal, which is interpreted as a result of strike–slip mechanism. Impressive neotectonic features are developed on the trace of this fault, mainly towards north of the San Juan River, on the western flank of the Sierra del Tigre.

Stop 10: Calingasta checking point (Control Policial de Calingasta)
(See Figures 12, 13)

This stop, located on the southern margin of the San Juan River, is scheduled for Hirnantian graptolites of the *extraordinarius* Zone, described by Brussa *et al.* (1999). Graptolite–rich shales crops out in an old quarry. Formerly, this graptolite assemblage was recorded by Aparicio & Cuerda (1976) who assigned it to Upper Ordovician *gracilis* Zone. Since then, this formation has been assigned to the Caradoc, and all geologic interpretation was based on such age. However, from Brussa *et al.* (1999) revision, a new spotlight on the Precordillera paleogeography has been introduced, taking into account its connection with western Gondwana in the Late Ordovician (Mitchell *et al.,* 1997). The graptolite fauna of the *extraordinarius* Zone described by Brussa *et al.* (1999) includes *Normalograptus* sp. cf. *N. normalis*, *Climacograptus tubuliferus*, *Dicellograptus* sp. cf. *D. flexuosus*, *Dicellograptus ornatus*, *Normalograptus* n. sp.,*Normalograptus miserabilis*, *Normalograptus extraordinarius*, *Dicellograptus* sp. cf. *D. complanatus*, and *Amplexograptus* sp. cf. *A. latus.* The occurrence of this zone is particularly important because it reveals the basal strata of the Hirnantian Stage are preserved in the Alcaparrosa Formation, Western Precordillera. On the other side, it confirms a younger age than previously assigned, at least for part of this unit, and suggests that less studied equivalents in the Western Precordillera could extend into the uppermost Ordovician (Brussa *et al.*, 1999). The mafic and ultramafic rocks intruding the whole sequence of the Alcaparrosa Formation, and associated tholeitic pillow basalts have been thought as part of an extensive ophiolite belt along the western margin of Precordillera. It continues to the south in the eastern side of the Cordillera Frontal, in the Andes, which might be originated as a result of an oceanic rifting in the Upper Ordovician (Borrello, 1969; Ramos *et al.*, 1984; Haller & Ramos, 1984; Kay *et al.*, 1984).

Step 11: Villa de Calingasta (Calingasta Village)
(See Figures 12, 13)

This place is located in the Calingasta valley, at the contact zone between the San Juan Precordillera and Frontal Cordillera. This boundary is obscured by Quaternary sediments infilling the valley. The stratigraphic section is mainly formed mainly by deposits of the Alcaparrosa Formation, which is widely exposed in the western part of the Western Precordillera, San Juan Province.Beside the road we can see the most impressive pillow lava structures, interbedded in the siliciclastic deposits of the Alcaparrosa Formation (Figure 12). Towards west, crossing the Los Patos River, this unit is unconformably overlain by Upper Carboniferous siliciclastic marine deposits of the La Capilla Formation, bearing abundant shelly fauna that indicates a shallow–water environment. Towards the south siliciclastic marine deposits of the Calingasta Formation crop out, likely Ordovician in age in agree with the interpretation suggested by Stephen *et al.* (1995) and Nullo and Stephen (1996), besides of regional considerations. This unit is composed mainly of reddish and greenish shales and scarce siltstones, and fine–grained sandstones interbedded, and it is unconformably overlain, angular unconformity, by Triasic lacustrine deposits that evolved as part of the oil–producer Cuyania Basin. It contains abundant rest of plants (*Dicroidium* Flora), which are widely exposed towards south, as part of the Mendoza Precordillera, and further to the south of the Mendoza River, as a principal component of the Cuyana Basin. To the west, in front of Precordillera, an impressive landscape of the snowed Cordillera de los Andes will be seen. The highest elevation is represented by the Mercedario Hill in the San Juan Province, but towards south, in the Mendoza Province, is the Aconcagüa Hill, the highest pick overall America.

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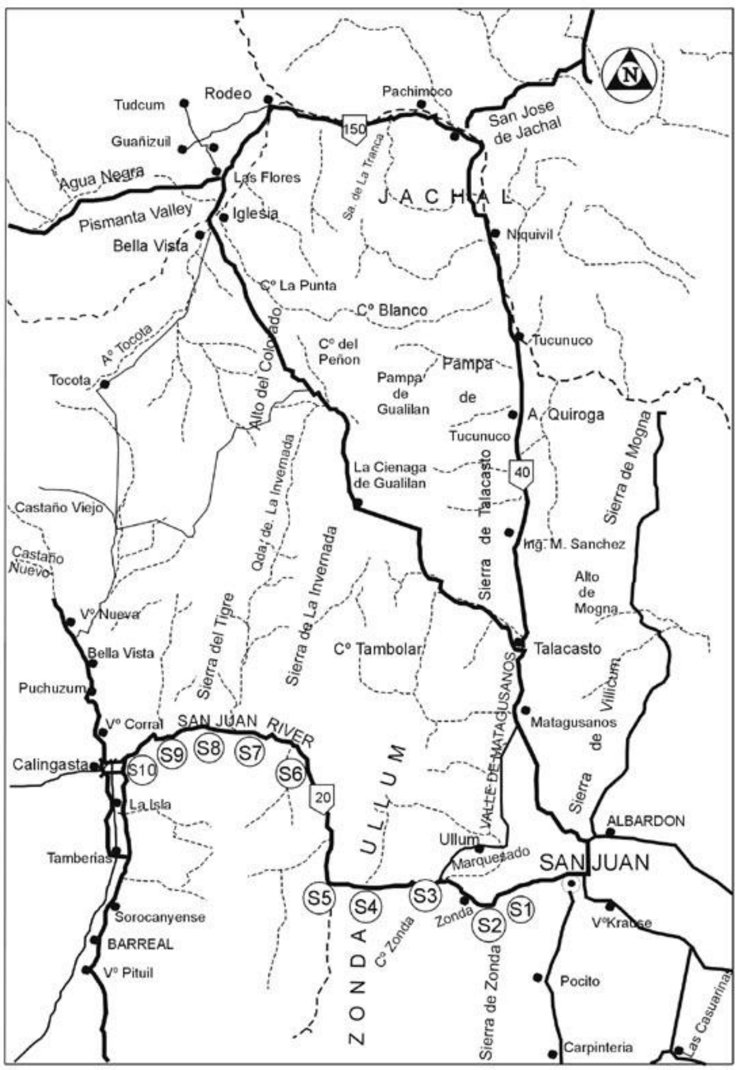

Figure 1. Map showing programmed stops for the field trip through the San Juan River.

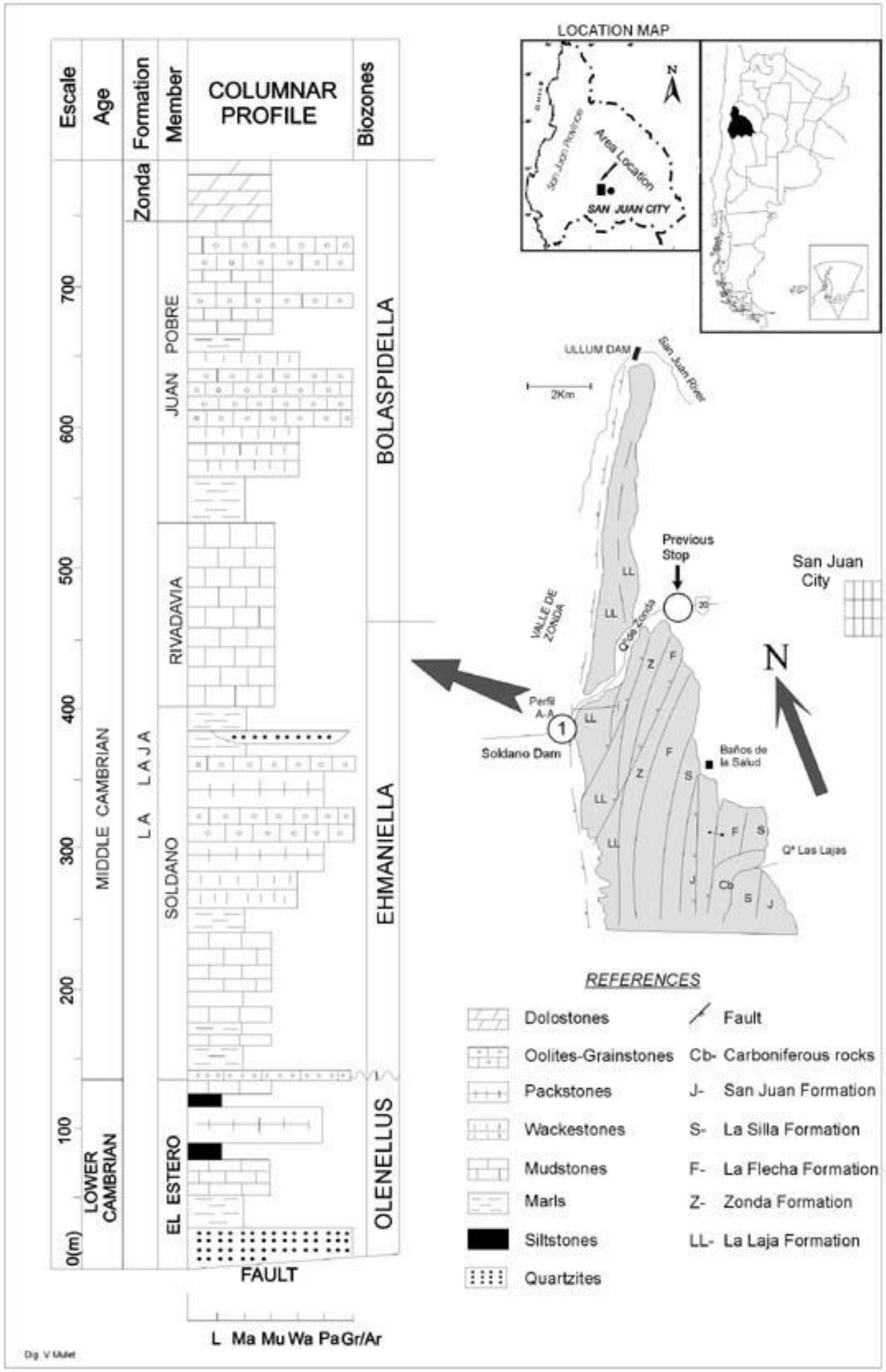

Figure 2. Geology of the Zonda Gulch, in Chica de Zonda Range at Eastern Precordillera.

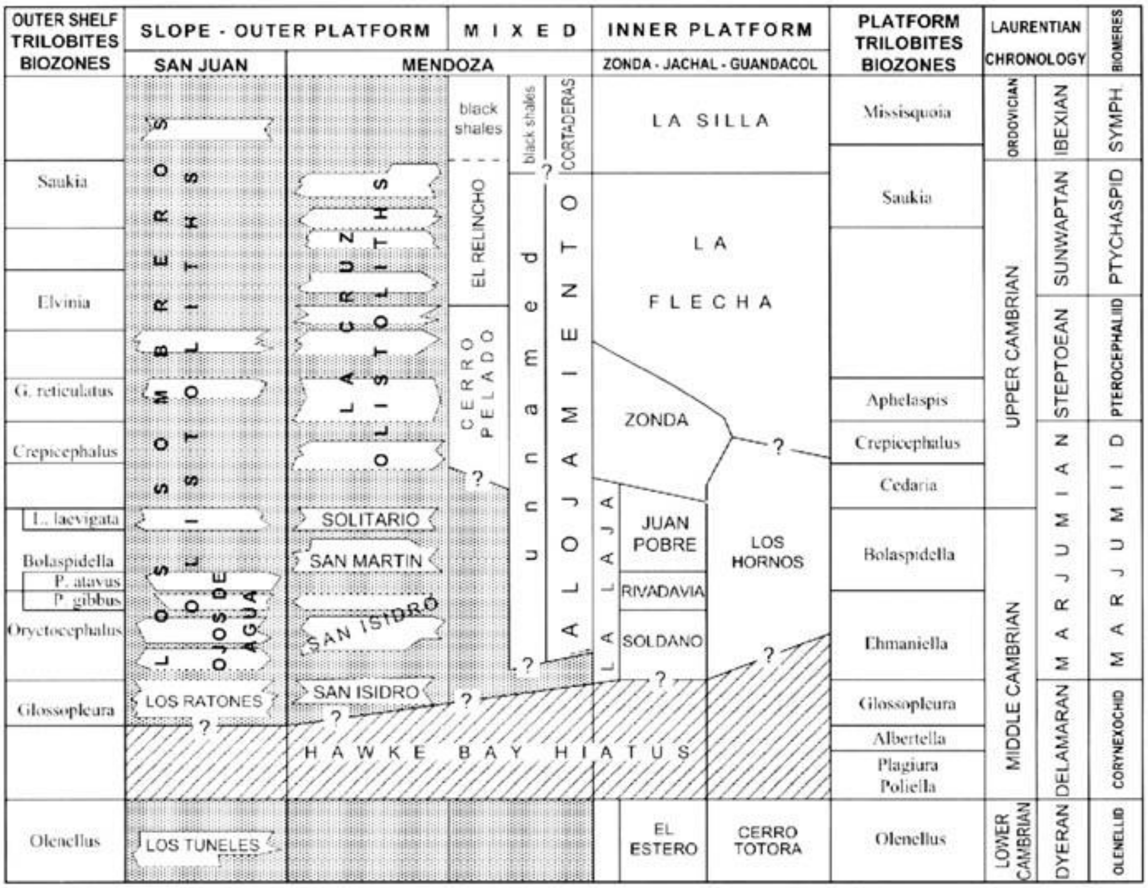

Figure 3. Stratigraphic correlation of the Cambrian of Precordillera. After Bordonaro (2003)

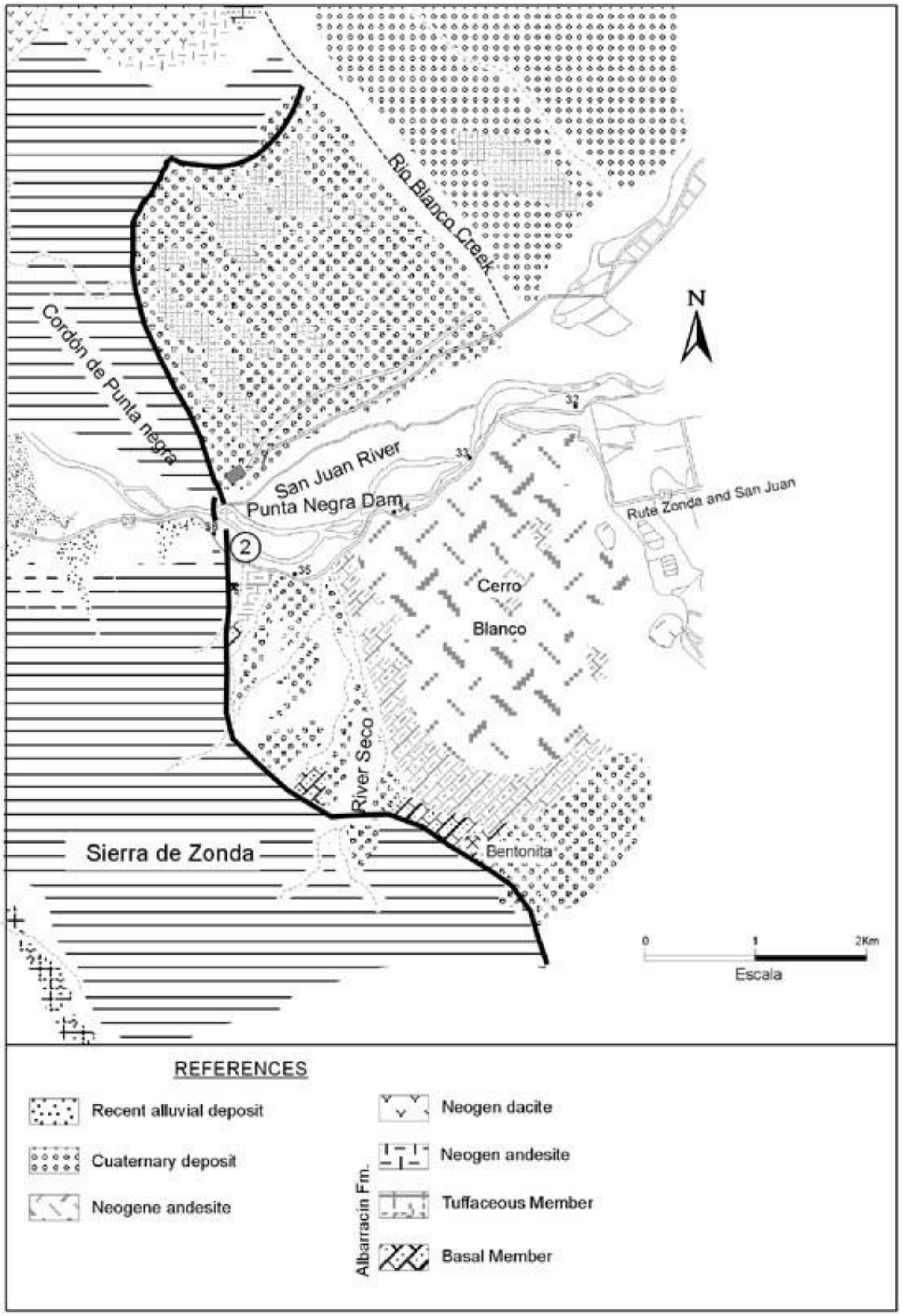

Figure 4. Geology of the Cerro Blanco (Blanco Hill) and Punta Negra Dam areas at Central Precordillera. After Leveratto (1968).

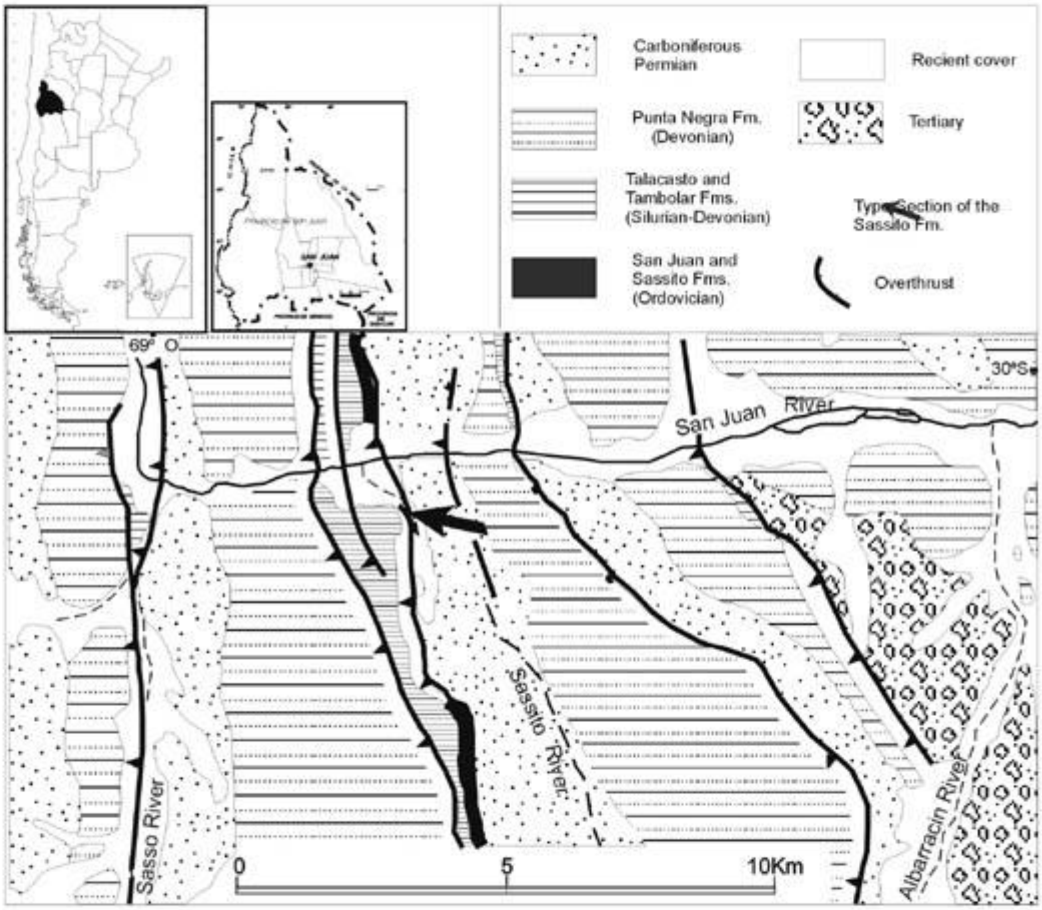

Figure 5. Geology of the Sassito Creek at Central Precordillera. After Astini & Cañas (1995)

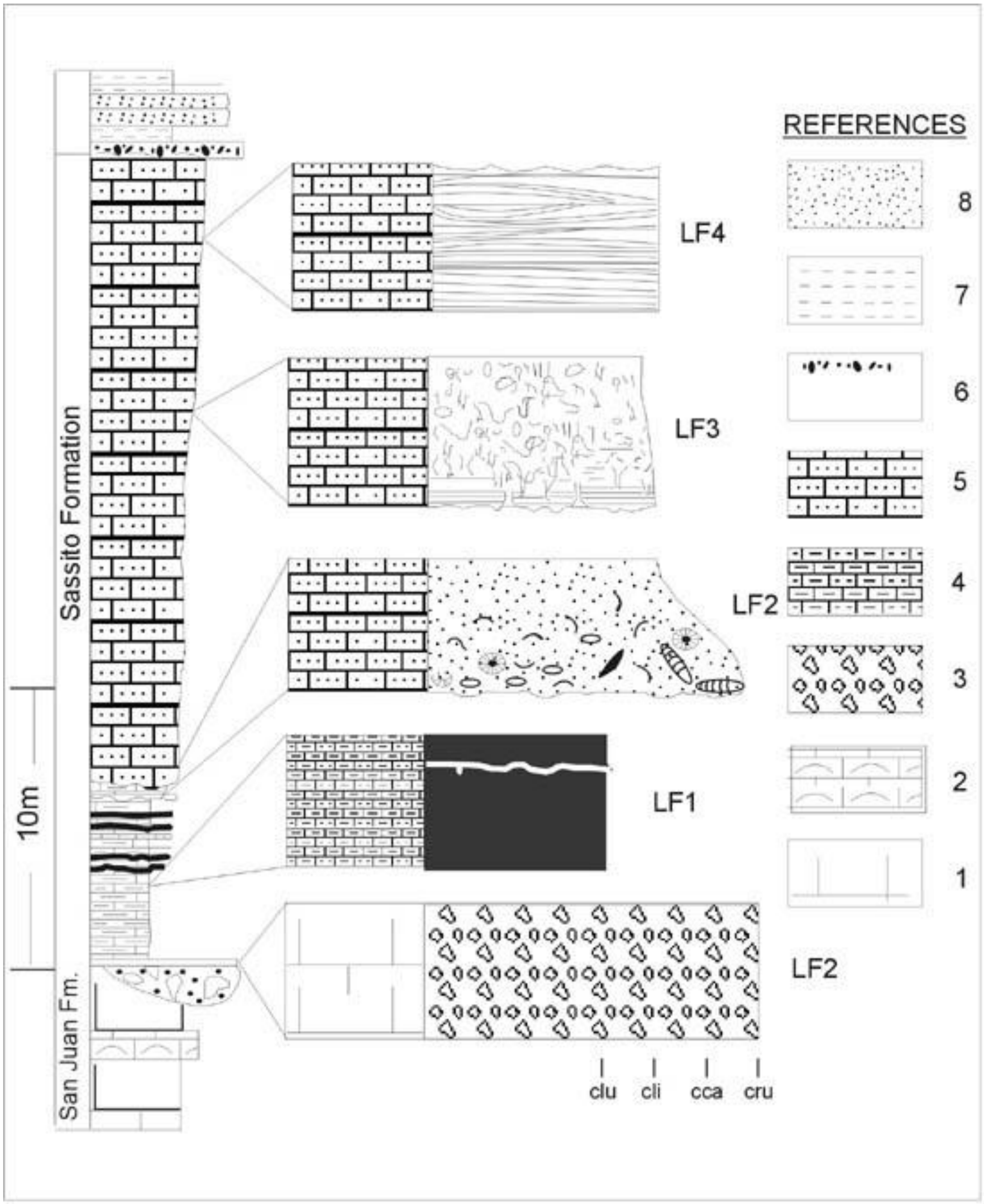

Figure 6: Sedimentary log of the type section of the Sassito Formation and lithofacies details. LF1: Laminated calcilutites, LF2:calcirudites and coarse graded calcarenites, LF3: bioturbated calcilistones, LF4: laminated fine-grained hybrid calcarenites. 1:wakestones and packtones, 2:stromatoporoid levels, 3 calcareous conglomerates, 4: black calcilutites, 5: calcarenites, 6:chert conglomerates, 7:siltstones, 8: fine-grained sandstones (From Astini & Cañas, 1995).

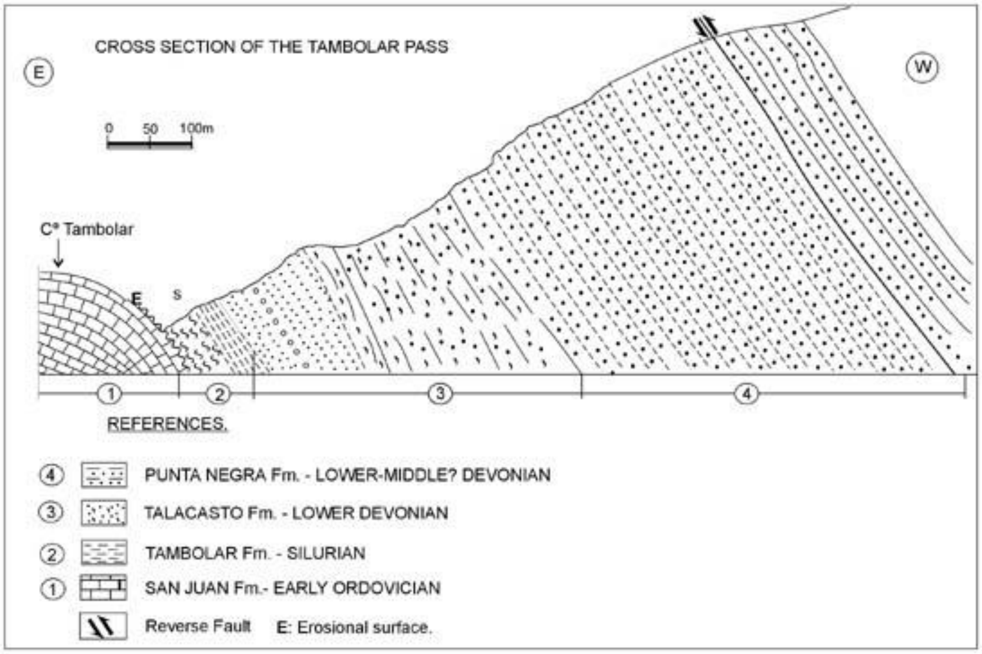

Figure 7. Stratigraphic section of the Lower Paleozoic at the Tambolar Pass, Central Precordillera. Modified from Heim (1948)

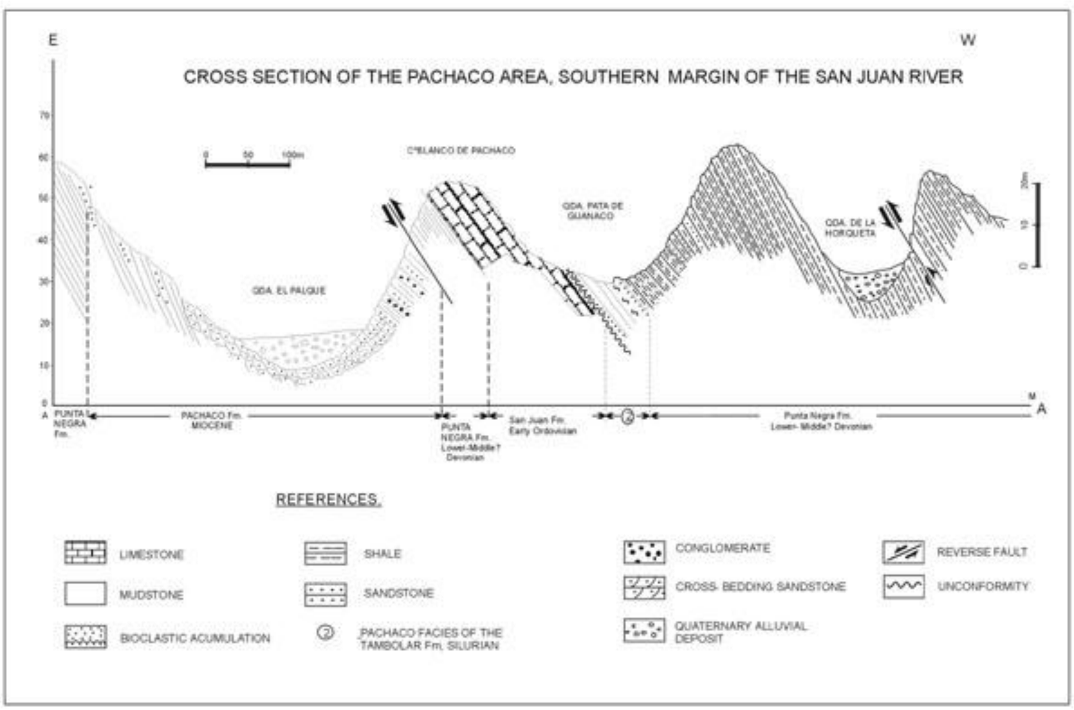

Figure 8. Stratigraphic section of the Lower Paleozoic and Neogene at the Pachaco locality. Modified from Peralta et al. (1995)

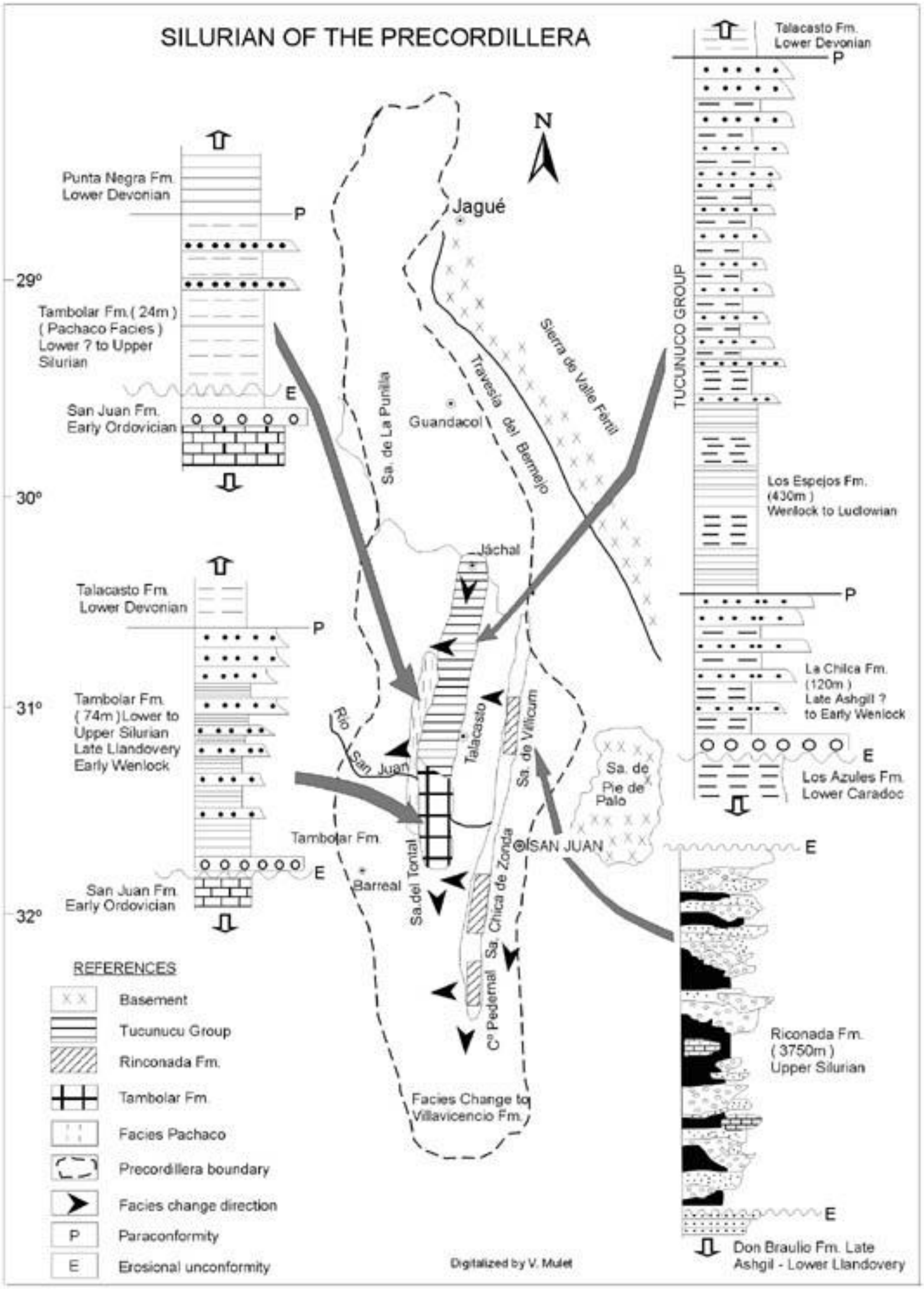

Figure 9. Geologic map showing stratigraphy and distribution of the Silurian units at Eastern and Central Precordillera. Modified from Peralta (1990).

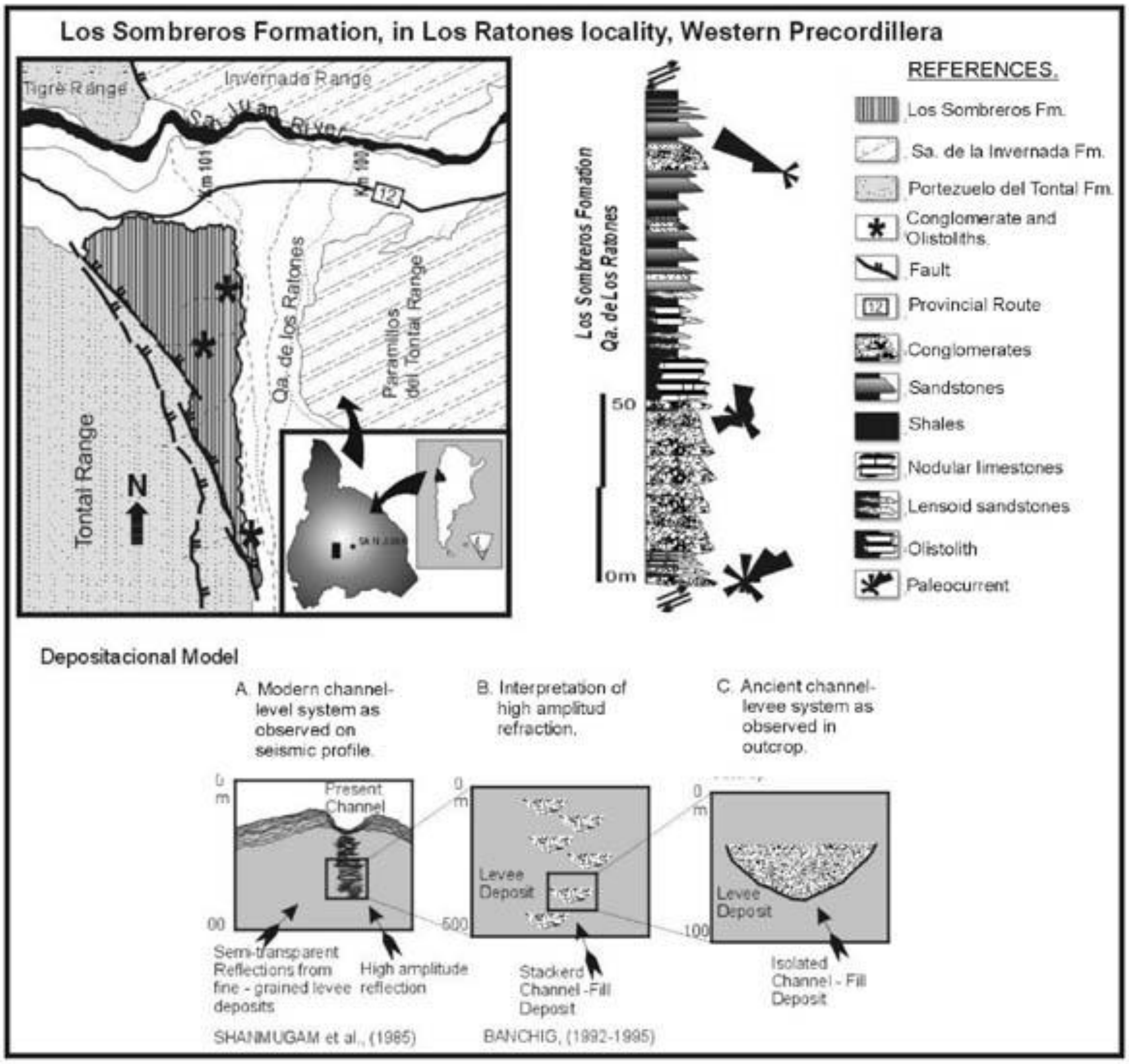

Figure 10. Geology and stratigraphy of the Ordovician Los Sombreros Formation in the Los Ratones Creek, at the eastern border of the Western Precordillera. After Banchig (1992, 1995).

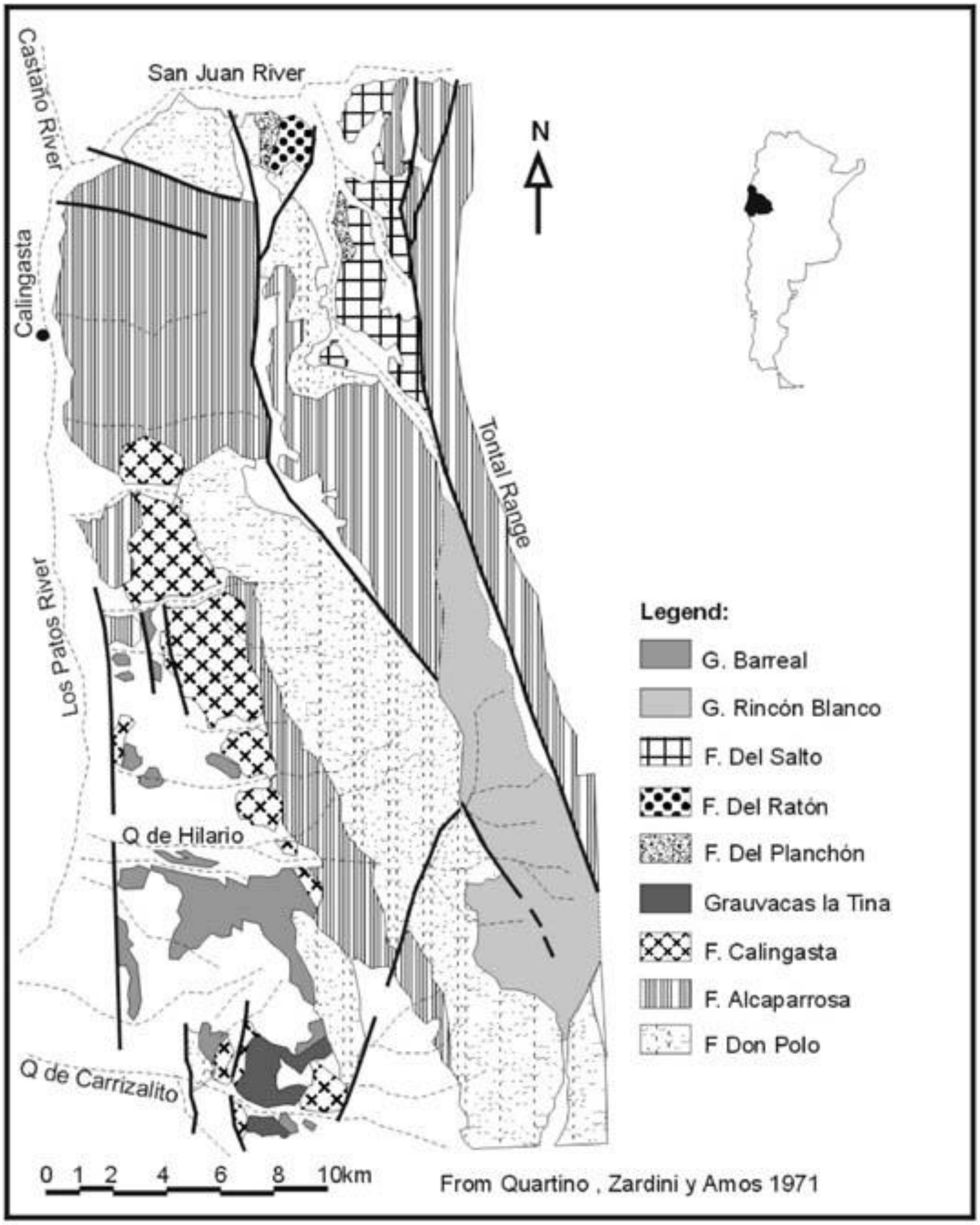

Figure 11. Geology and stratigraphy of the Lower and Upper Paleozoic, and Triassic, on the western belt of the Western Precordillera, to the south of the San Juan River. After Quartino et al. (1971).

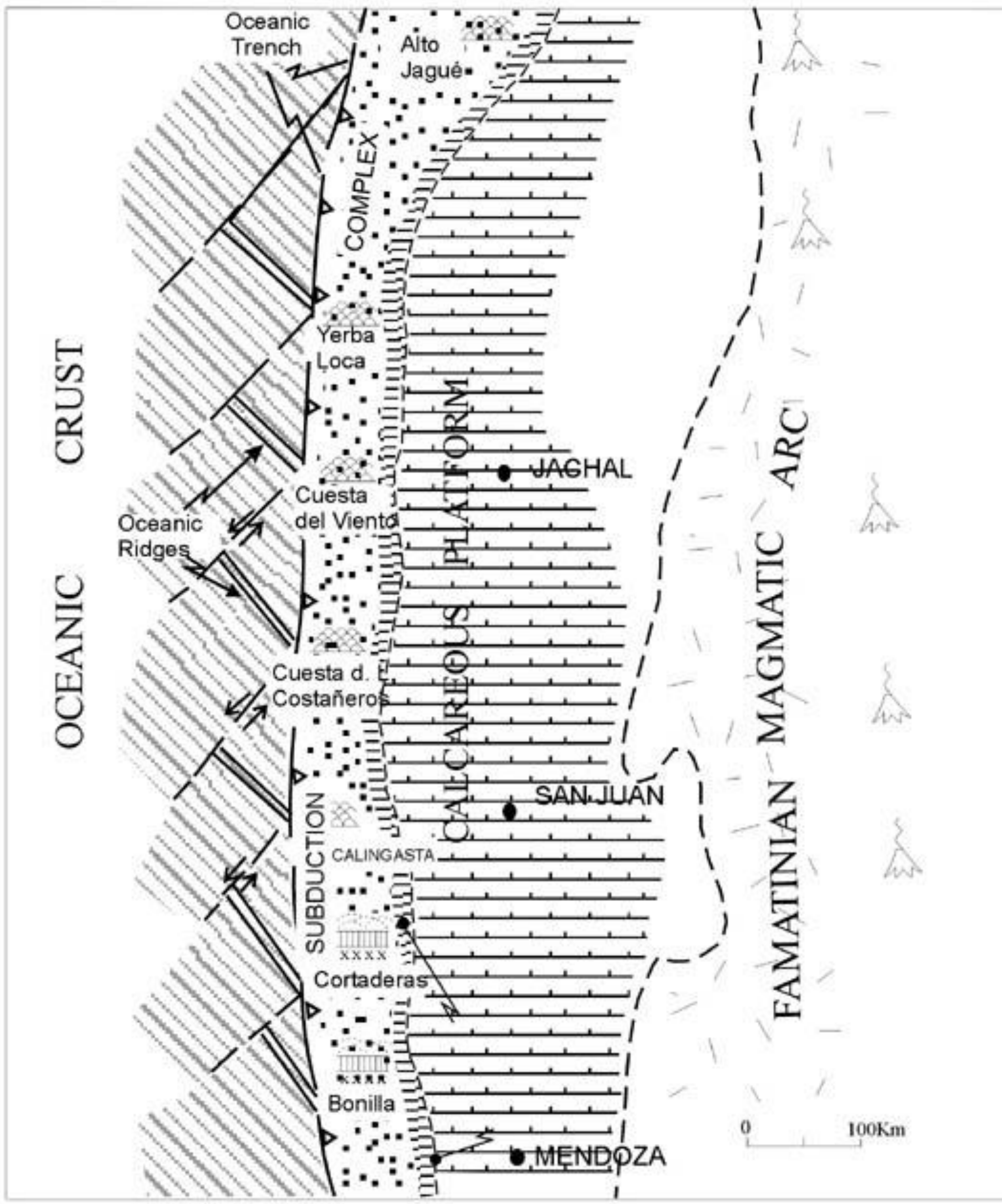

Figure 12. Geologic map of the San Juan River area, westward from the Sierra del Tontal, mainly showing the Upper Ordovician (Hirnantian) Alcaparrosa Formation outcrops and associated pillow lavas (Quartino et al., 1971). Paleogeographic and geotectonic setting of Western Precordillera, after Haller & Ramos (1984).

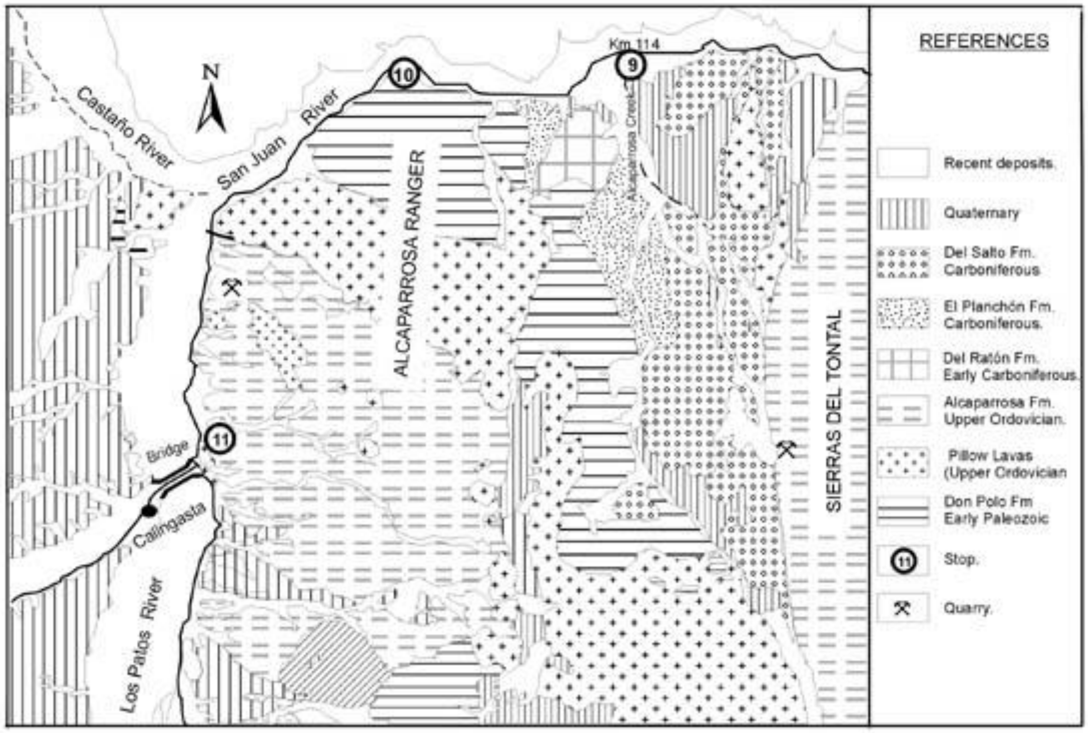

Figure 13. Distribution of the ophiolite complex along the western border of the Precordillera, from Bonilla–Cortadera area (south) in Mendoza Province, to Alto Jagüé (north) in La Rioja Province. After Quartino et al. (1971).