Talacasto, La Invernada, and Jáchal River sections, Precordillera of San Juan Province

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Introduction

The purpose of this field guide is to provide an introduction to the geology and paleontology of the lower Paleozoic of the Precordillera Geological Province (Furque & Cuerda, 1979). Central and Western Precordillera settings at Talacasto, La Invernada, and Jáchal River sections, located at the central and northern part of the San Juan Province, are considered. The approximate distance of the cited sections from San Juan City is as follows: Talacasto, 70 km; La Invernada, 110 km, and Jáchal River, 170 km, respectively. The most significant sections run across the Jáchal River and Talacasto Creek, exposing a thick pile of lower Paleozoic siliciclastic marine rocks.

Stratigraphic Framework

In the Eastern and Central Precordillera, the lower Paleozoic succession is made up of a Cambrian to Middle Ordovician carbonate platform succession, which is conformably overlain by thick clastic wedges ranging from the Middle Ordovician up to probably Middle Devonian. Isolated Middle to Late Ordovician carbonate and mixed deposits occur in this succession. In these settings, three main unconformities are present, the first one, which correspond to the Guandacol phase, occurs at the base of upper Middle – lower Upper Ordovician deposits (Las Vacas and La Cantera formations, and equivalents), the second one at the base of upper Asghill (Hirnantian) deposits (La Chilca and Don Braulio formations, and correlatives), and the third one attributed to the Chánica tectonic phase, at the base of Carboniferous strata overlying Lower–Middle Devonian or older Lower Paleozoic deposits. In this scenario, important paraconformities are recognized between the San Juan (Arenig to lower Llanvirn) and Gualcamayo (Llanvirn) formations (and correlatives), between the La Chilca (upper Ashgill – upper Llandovery – lower Wenlock) and Los Espejos (Wenlock – Pridoli to Lochkov?) formations, as well as between the Los Espejos and Talacasto (Lochkov to Emsian) formations, and the Talacasto and Punta Negra formations (Lower–Middle Devonian).

From a stratigraphic viewpoint, the Sierras de Talacasto and La Invernada belong to the Central Precordillera setting, as defined by Baldis & Chebli (1969), and the Sierras del Tigre and Yerba Loca to the Western Precordillera (Baldis *et al*., 1982). Following Astini (1991a; 1992a) the eastern tectofacies is composed of mainly carbonates and shallow marine clastics of shelfal and restricted environments, whereas the western tectofacies consists of deep–marine, resedimented, mainly siliciclastic open–marine deposits, with some basic dykes and mafic lava flows affected by a very low–grade metamorphism.

In the Talacasto area we will look at the regional unconformity developed at the top of the Ordovician San Juan limestones. In this area we will also visit type localities for the Silurian and Devonian Malvinokaffric successions, as well as Gondwanan Carboniferous glacial deposits. At Sierra de La Invernada, we will see an impressive sedimentary mélange, in which huge carbonate blocks from the San Juan Formation are included into a Silurian–Devonian? clastic framework. Besides, siliciclastic graptolite–rich facies of the Sierra de La Invernada Formation are well exposed. Along the Jáchal River transect, located to the west of Jáchal City, Ordovician, Silurian and Devonian clastics and Tertiary Andean foreland deposits will be seen.

Stop 1: Cambrian of the Villicum Range
(See Figure 1 for location)

On the way to the northern San Juan Precordillera, on the National Road Nº 40 approximately between the Km 10 and Km 55 from San Juan city, the Villicum Range crops out. This range, together with the Zonda Range, conforms what is known on a morphostructural basis as the west–vergent Eastern Precordillera (Ortiz & Zambrano, 1981) In this thrust, a complete Cambrian to Ordovician carbonate stratigraphy together with Ordovician clastics of the Eastern Precordillera are exposed. At the base of the main thrust (dipping east) the Lower Cambrian La Laja Formation is well exposed, which includes the typical Ollenelids trilobite fauna.

The La Laja Formation (Borello, 1962) is restricted to the Eastern Precordillera belts and its name is derived from the Quebrada La Laja (Sierra Chica de Zonda), where Cambrian faunas were described from the Precordillera (Harrington & Leanza 1943), for the first time. Its age ranges from the upper Lower Cambrian (*Olenellus* Zone) to the upper Middle Cambrian (Marjuman Stage) (*Bolaspidella* Zone). The lower boundary is unknown. The upper boundary is drawn at the transition from limestones to the dolomites of the Zonda Formation. Its thickness is about 500 m. On lithological basis several members were recognized according to different authors. Predominant sediments are subtidal mudstones and wackestones characteristic of a shallow marine platform. Oolite–barrier (packstones and grainstones) systems are related to relative sea–level fluctuations in a nearshore environment. The sequence reveals six major shallowing upward cycles with basal marlstone–mudwackestones, strongly bioturbated wacke–packstones and oolitic grainstones shoals (Bercowski *et al.,* 1990).

The name of the Zonda Formation (Bordonaro, 1980) is derived from the Sierra Chica de Zonda, where the formation is widely distributed. The lower boundary is given by the transition to the La Laja Fortmation and its upper boundary by a sudden occurrence of abundant stromatolites at the base of the La Flecha Formation. No fossils have been obtained from this unit. A lower Upper Cambrian age is estimated in relation to the bounding units. Its thickness is of approximately 350 m in its type section. The Zonda Formation is composed mostly of dolostones (early diagenetic origin) with abundant biolaminated deposits (rare LLH–type stromatolites) and minor intercalations of dolomitized oolites, intraformational conglomerates and (dolo) mudstones with desiccation cracks and evaporites. Small silicified mud mounds also occur. This association is interpreted as peritidal in origin.

The La Flecha Formation (Baldis *et al.*, 1981) is about 400 m thick in its type section at the La Flecha Creek (South of Sierra Chica de Zonda). Its lower boundary is marked by the first beds with abundant stromatolites (LLH and SH types) and trombolites. In many sections the boundary is also marked by the change from predominant dolomites to yellow or brown dolomites and calcareous dolomites. In the Type section, its upper boundary is drawn, where the content of stromatolites rapidly decreases and limestones predominate over dolomitc lithologies. Based on a diverse trilobite fauna a Franconian to at least Late Trempeleauan age (*Saukia* Zone) is suggested in the type area, whereas a Dresbachian age (*Crepicephalus* Zone) is given in the northern Precordillera (Vaccari, 1994). The La Flecha Formation is almost entirely made up of samll–scale shallowing upward cycles (1–5 m), which exhibit a great variety of stromatolites, trombolites and cryptalgal laminites, together with subtidal to supratidal lithologies, characteristic of arid tidal flats (Cañas, 1986, 1990; Keller *et al.*, 1989). Chert and chalcedony seldom replaces the biogenic structures as well as oolite beds. The shallowing upward cycles are of peritidal origin and conform small scale stacked successions.

The type locality of the La Silla Formation (Keller *et al.*, 1994) is at Cerro La Silla (southeast of Jáchal), which is located in the northern Precordillera of San Juan. In the type section its thickness is 350 m and is distinguished from under – and overlying formations by thick–bedded, dark gray to bluish gray limestones. Its lower boundary is drawn at the level where the coarse sparitic dolomites abruptly change towards thick–bedded limestones. The upper boundary is given by limestones with the appearance of an abundant open marine fauna of brachiopods, trilobites, echinoids, and sponges typical of the San Juan Formation. The age of this unit is assigned on basis of trilobites and conodonts to the lower Ibexian (*M. depressa* Subzone up to P. *deltifer* Zone) (Vaccari, 1994; Lehnert, 1995a,b; Albanesi *et al.*, 1998). The *Plethopeltis* biofacies was recognized in the lower levels of this unit (Vaccari, 1994). The La Silla Formation is traceable from sections near Guandacol in the Province of La Rioja to the southernmost sections in the Sierra Chica de Zonda, Province of San Juan. The La Silla Formation is predominantly calcareous, with dolomites occuring mainly in sparse biolaminated horizons. It is mainly composed of an alternation of peloidal grainstones and mudstones, often with abundant bioturbation. Conodont yielding wackestones with nautililoids, gastropods, and cross bedded oolite shoals are scattered. Distribution of facies seems to be random. The La Silla Formation (which includes the Cambro–Ordovician boundary) shows evidences of restricted subtidal rimmed shelf (Keller *et al.*, 1994, Cañas, 1995a).

Stop 2: Baños de Talacasto (Talacasto Baths)

This locality is one of the best areas in the Central Precordillera to watch lower Ordovician carbonate succession of the San Juan Formation, and the overlying upper Ashgill–Silurian deposits of the Tucunuco Group, mainly of the lower La Chilca Formation. In fact, this section is significant because it includes the Ordovician–Silurian boundary. The erosional unconformity at the base of the La Chilca Formation, results from diastrophic, glaci–eustatic and eustatic events through the Late Ordovician (Rolleri, 1947; Baldis *et al.,* 1984; Astini, 1991a, 1992b; Peralta, 1994) in this locality. The Talacasto Canyon offers a spectacular outcrop of an east–vergent anticline with a complex folded core affecting the San Juan limestones (see Figures 1 and 2 for location).

San Juan Formation (Kobayashi, 1937; Keller *et al.,* 1994)

The name of San Juan Formation is derived from the Province of San Juan and was originally used for the whole succession of platform carbonates. Its type section is exposed in the Cerro La Silla where a thickness of approximately 350 m was determined (Keller *et al*., 1994). The lower boundary is marked by the appearance of abundant open marine fauna, whereas the upper boundary is given by an alternation of black shales and platy marlstones or by graptolitic black shales, the Gualcamayo or Los Azules Formations, respectively. Abundant fossils can be recovered from this unit, among which sponges, brachiopods, echinoids, trilobites, gastropods, bryozoans and nautiloids are the most frequent. Its age ranges from the latest Tremadoc (mid–upper Ibexian) to early Llanvirn (early Whiterockian), although its upper boundary is regionally diachronous, being late Arenig in the northern Precordillera and early Llanvirn in the southern–central Precordillera as determined by conodonts (Hünicken, 1985; Lehnert, 1995a; Albanesi *et al*., 1998).

Lithologically it is mainly composed of limestones (wackestones and packstones) and minor marlstones near the top. Yellowish to brownish dolomites are almost absent, being related to pressure solution or burrow fillings. A dramatic change in widespread muddy fossiliferous carbonates is represented in the Precordillera by the lower section of the San Juan Formation of late Tremadoc and early Arenig age, which is composed by open shelf subtidal limestones of thin– to medium–bedded burrowed skeletal wackestones and packstones with thin intebeddings of coarse–grained storm deposits and widespread metazoan buildups (sponges, receptaculitid *Calathium*, *Girvanella*, and microbial structures) associated with grainstones (Carrera, 1991; Cañas & Keller, 1993; Cañas & Carrera, 1993). By then, the Precordillera platform had many of the attributes of an epeiric sea (*sensu* Shaw, 1964). The massive limestones of the middle part of the San Juan Formation, which comprises the *Monorthis* Zone (Herrera & Benedetto, 1991) with scarce fauna, are capped by stromatoporid and sponge–algal–stromatoporoid reefs, typical of shallow warm waters (Cañas & Keller, 1993). The upper stylo–nodular wackestones contain characteristic platform faunas of the San Juan Formation (*Ahtiella* Zone, Herrera & Benedetto, 1991). Kolata *et al*. (1994) and Huff *et al*. (1995) have discovered horizons of K–bentonites for an interval of several meters through the top of this unit, in several sections of the Precordillera.

Imbricated thrusts of the San Juan limestones show excellent outcrops of the fossiliferous upper levels of the San Juan Formation (*Ahtiella* Zone) and the Silurian Tucunuco Group (La Chilca and Los Espejos formations), which bear the typical *Clarkeia* fauna (a classical locality for fossil collection). Sponges include: *Patellispongia argentina, P. occulata, Archaeoscyphia tenuis, A. Anulata, A. Typicalis, A. Minfanensis, Hudsonospongia cyclostoma, Anthaspidella? Annulata Rhopalocoelia clarkei,* among others (Carrera, 1994a, b; Beresi & Rigby, 1993). Brachiopods include: *Paralenothis talacastensis, Petroria rugosa elevata, Ahtiella argentina, Sajuanella* sp., *Camarella* sp., *Idiostrophia* n. sp., *Rugostrophia* sp., among others. Trilobites include: *Annamitella forteyi, Basillicus (Basiliella)* n.sp., *Illaemus* ssp. *Ampyx* sp., Acanthoparyphinae gen. et sp. indet. Rostroconchids as *Talacastella herrerai*, and abundant gastropods, nautiloids, and bryozoans (*Hallopora* sp. and *Amplexopora* sp., Carrera, 1994a).

Nearby Ancha Creek the highly fossiliferous upper part of the San Juan Formation (lower Llanvirn) crops out. On the road between the Talacasto Baths and the Ancha Creek a block of the San Juan Formation, about 40 m thick, intercalates K–bentonites. Same block records the first appearance of*Protoprioniodus aranda* Cooper and *Texania heligma* Pohler, which are key species to define the Lower – Middle Ordovician Series boundary, as it is proposed for the

Niquivil section, Precordillera of San Juan (Albanesi *et al.,* 2003). These data and the presence of K–bentonites, which allow for the radiometric dating of these levels (Baldo *et al.,* 2003), make the profile feasible as auxiliary section for the referred boundary. In these strata, the oldest known scolecodonts from South America were recorded (Eriksson et al., 2002).

Outcrops showing the unconformity that separates Lower Ordovician limestones and the uppermost Ordovician and Silurian clastics of the La Chilca Formation are located to the east of the Talacasto anticline. Cuerda *et al.* (1988) recognized three assemblages: The *Glyptograptus persculptus* Zone (0.55 m above the conglomerate): *Climacograptus angustus, Glyptograptus persultus, Pseudoclimacrograptus robustus, Climacograptus* cf. *medius and C. normalis.* A suspected *Parakidograptus acuminatus* Zone (0.60 to 1.60 m from the bottom): *Climacograptus angustus, C. robustus, C.* cf. *medius, C. normales, C. acceptus, C. rectangularis,? Glyptograptus maderni,* and *Rhaphidograptus* sp. An interval that probably corresponds to the *Atavograptus atavus* Zone (1.60 m to 3.70 m) includes the following taxa: *Climacograptus angustus*, *C.* cf. *medius, C. normalis*, *C. rectangularis, Lagarograptus praeacinaces*, *Paraclimacograptus?* sp. nov., *?Cystograptus* sp.,*Clinoclimacograptus* sp. and *Talacastograptus leanza* (See Figures, 4, 13).

Ancha Creek

The unconformable contact of the San Juan Formation with Silurian deposits (La Chilca Formation) is well–exposed to about 5 km south of road, on the eastern margin of Ancha Creek. Aside the road we will visit outcrops of the middle and upper part of the Los Espejos Formation. The siliciclastic Silurian sequence is interrupted by a thrust of the San Juan Formation. In the basal part of the Silurian platform deposits it is possible to identify the *Nereites* ichnofacies and a poorly diversified brachiopod fauna (*Harringtonina acutiplicata* and *Australina jachalensis*) related to low oxygen contents in the basin (Sánchez *et al.,* 1993). The interbedded coquinas in the middle–upper part of these outcrops yield a diverse fauna of brachiopods, gastropods, trilobites, tentaculitids, conodonts, ostracods, and graptolites. *Monograptus uncinatus notouncinatus* Cuerda and *Saetograptus argentinus* (Cuerda) (see Figures 5, 12) are the only graptolites registered at present, which were referred to an early Ludlow age by Cuerda (1969, 1971). The finding of conodonts from the *Kokelella variabilis variabilis* Zone verifies this age for the bearer levels (Albanesi, in progress; *cf.,* Hünicken and Sarmiento, 1988). The conodont fauna consists of*Kokelella v. variabilis* Walliser, *Pseudooneotodus beckmanni* Bischoff & Sannemann, *Panderodus unicostatus* Branson & Mehl, *Oulodus siluricus* (Branson & Mehl), *Ozarkodina confluence* (Branson & Mehl), *Ozarkodina excavata excavata* (Branson & Mehl), and *Coryssognathus dubius* (Rhodes), restricted to the Gorstian Stage of the Ludlow Series (*K. v. variabilis* Zone of Sardinia, Italy, by Corradini & Serpagli, 1999) (see Figure 11).

Stop 3: Scop Quarry

The objetive of this stop is to visit the Silurian and Devonian platform deposits, of the Tucunuco and Gualilán groups, respectively. They form a sedimentary cycle, unconformity–bounded, which starts in the Late Ashgill (Hirnantian) to end in the Middle Devonian, according to the biostragraphic record. Each group consists of two formations, which show shallowing upward trends. The Tucunuco Group (Late Ashgillian – Silurian) (Cuerda, 1969) includes the Silurian units outcropping in the Central Precordillera, ranging in age from the late

Ashgill (Hirnantian) until Pridoli to Lochkovian (see Figure 5). From bottom to top it includes the La Chilca and the Los Espejos Formation, both yielding important Malvinokaffric faunas. The La Chilca Formation is sand dominated, whereas the Los Espejos is mixed to mud dominated (Astini, 1991b; Astini & Piovano, 1992). Toward the south, this unit receives the name of Tambolar Formation in the San Juan River outcrops, where it has only around 67 m thick in its type locality, at Portezuelo del Tambolar Pass, with similar shallowing upward trend.

The La Chilca Formation (Cuerda, 1969) is composed mainly by yellowish sandstones with thorough low–angle cross–stratification and frequently amalgamated beds. Siltstone partings and minor fossil concentrations are present is some localities. The type section of this unit is located in the Cerro La Chilca, where it overlies the Don Braulio Formation (Upper Ordovician) and is conformably overlain by the Los Espejos Formation. Its thickness varies from 25 to 85 m in different localities. Everywhere, a basal chert conglomerate seldom mixed with a rich graptolite fauna develops immediately on top, where *Normalograptus persculptus* has been found, indicating a latest Ordovician age for this basal part. In the Talacasto area, Cuerda *et al.* (1988) recognized the *G. persculptus,* and probably the *Parakidograptus acuminatus* and *Atavograptus atavus* zones. In the western flank of Cerro del Fuerte, graptolite assemblages indicate the *N. persculptus* Zone and other association that is referred to the *atavus* to *triangulatus* zones inclusive (Rickards *et al.*, 1996). Facies arrangement and upward–thickening trends indicate an increasing shallowing toward the top, with significant influence of storms modelling the bottom substrate.

The name of the Los Espejos Formation (Cuerda, 1969) is derived from the shiny surfaces of fine–grained sandstones embedded in olive green silstones of this unit. It is characterized by a rich brachiopod content, which is commonly concentrated in coquinas (Sánchez *et al.*, 1991). Its thickness varies from approximately 280 m in the area of Talacasto to more than 500 m in the area of Cerro del Fuerte near Jáchal. This unit is Ludlow to Pridoli in age based on brachiopods, graptolites and achritarchs. In the region of Cerro del Fuerte, it passes in transition into the lowermost Devonian (Benedetto *et al.*, 1992). This unit exhibits frequent symmetric ripple marks and hummocky surfaces toward the top and abundant trace fossils. Increasing bed thickness, as well as higher energy structures and trace fossils demonstrate upward shallowing trends. In the Los Espejos Formation three associations characterize the following environments: muddly shelf with no influence of wave action, inner shelf under storm activity, and storm–dominated shoreface to offshore transition (Astini & Piovano, 1992). In the Silurian *Clarkeia* fauna, the following brachiopods are common: *Australina jachalensis, Harringtonina acutiplicata, Leangella (Leangella) mutabilis, Dedzetina? silurica, Amosina* sp.*, Leptaena spp., Coelospira* sp.*, Clarkeia* sp.*, Isorthis* sp. *Castellaroina fascifer* (Benedetto *et al.*, 1992). *Nereites, Zoophycos* and *Cruziana* ichnofacies are present in the Silurian beds.

The Gualilán Group (Devonian) (Baldis, 1975) takes its name from the type locality in the Central Precordillera (the Gualilán depression). It includes the Talacasto and the Punta Negra formations, both of them siliciclastic and Devonian in age. These units are characterized by their content of typical Malvinokaffric faunas and incarbonated plant fossil remains. Very rich micas, specially moscovites, and stable and unstable heavy minerals show an increasing influence of their provenance from metamorphic rocks. The Poblete Creek is the type section of the Gualilán Group (Talacasto and Punta Negra formations), which is considered a good fossil locality for the Lower Devonian with typical Malvinokafric faunas.

The Talacasto Creek is the type locality for the Talacasto Formation (Padula *et al.*, 1967). This unit mostly crops out between the Jáchal River area and the River San Juan area, in the Central Precordillera setting, with variable thickness, and is characterized by its pale greenish to gray colors. Toward the south, its thickness is about 100 m, whereas to the north it is more than 700 m. The gap that separates this unit from the Silurian rocks dramatically decreases toward the northeast. Moreover, in the Cerro del Fuerte locality (to the southeast of Jáchal) it overlies the Silurian strata, where it starts with a thin basal conglomerate that consists of iron oolites and phosphate nodules. It is mainly composed of muddy bioturbated sandstone and silstones with minor thin–bedded graded and laminated sandstone layers with wave reworking on tops. Brachiopod and trilobite fossil remains are common especially in marly nodules which occur in the middle to upper section. Trilobites include: *Parabouleia eldredgei, Tormesiscus hildae, Tarijactinoides jarcaensis, Francovichia* sp., *Harpidella* sp., *Burmesteria (Burmesteria) hercheli.* Brachiopods include: *Babinia* cf. *B. parvula, Pacificocoelia* cf. *nunezi, Metaplasi baldisi, Sanjuanetes andina, Australospirifer antarticus, Australocoelia tourteloti, Protoleptostrophia cocinna, Orbiculoidea callis, Spinoplasia pobletensis,* among others. These are associated with abundant bivalves, conulariids, hyolitids, and plant fragments.

Among the composite ichnofabrics *Zoophycos, Arenicolites, Chondrites, Phycosiphon, Scalarituba,* and *Paleophycus*, among others, are the more common and diagnostic traces. Its important brachiopod faunas allow assigning the Talacasto Formation to the Lower Devonian and to the Malvinokaffric realm (Herrera, 1993). This unit has been interpreted as a muddy shelf sequence (Astini, 1991b) with periodically influences of storm events. Facies trends closely resemble across–shelf trends on modern shelves supplied by muddy rivers, suggesting that the processes were similar. The general trend shows a gradual shallowing to the middle part and an increase of depth toward the top, where a condensed section separates it from the overlying Punta Negra Formation.

The Punta Negra Formation (Bracaccini, 1950) is characterized by its great thickness (more than 700 m) and coarse grain, graded sandstones with profuse current marks and trace fossils of the *Cruziana* Ichnofacies at their bases. Thick–bedded, coarse to medium grain sandstone beds show upward thickening and thinning trends of 5 to 10 m thick, which are interbedded with finely laminated siltstones and sandstones with ripple marks. These are interpreted as channel and lobe sequences, and interlobe fines, respectively. This unit transitionally overlies the Talacasto Formation. To the top is covered through a regional erosive unconformity by upper Paleozoic glacial rocks and red beds. Very few fossils have been found up to date, except for the plant remains and scarce inarticulate and articulate brachiopod remains which do not show much difference with those found in the Talacasto Formation. Its age is tentatively established as mid Devonian. According to their facies, the Punta Negra Formation could represent either turbidite fan deposits or prograding deltaic systems developed on a wide ramp margin. Because of its continuity with the Talacasto Formation, the second alternative is more probable. Glacial paleovalley carved into the Devonian (Punta Negra Fm.), which are represented by resedimented glaciolacustrine coarse conglomerates and pebbly sandstones with minor rippled sandstones with dropstones (Martinez & Astini, 1992). We will observe the erosive contacts to both sides of the glacial trough and the onlapping relationships of the Carboniferous beds onto the Devonian paleorelief.

Stop 4: Sierra de la Invernada (La Invernada Range)

This stop will be done close of the Menfis Quarry, in which calcareous olistolith blocks provide ornamental rocks. The Lower Paleozoic stratigraphic framework of the western part of Central Precordillera and Western Precordillera (Western Tectofacies, Astini, 1991a, 1992a) exhibit several differences respect to the Eastern Precordillera and eastern part of the Central Precordillera, although the complex structure and the very low–grade metamorphism complicates the general framework mainly in the Western Precordillera (see Figures 1, 6, for location).

The Sierra de la Invernada Formation (Furque, 1983) is similar to the Yerba Loca Formation, although it shows several layers with wave reworking and micro–hummocks, which resemble siliciclastic shelf environments more than deep marine turbidites. Its main outcrops are those in the La Invernada Range, located to the west of the Gualilán depression. Brussa (1994, 1995, 1997a, b) recognized the *Paraglossograptus tentaculatus* Zone; the graptolite assemblages show variations in their vertical distribution. The lower part of the *Paraglossograptus tentaculatus* Zone includes: *Ptilograptus geinitzianus*, *P.* cf.*delicatulus*, *Didymograptus* (*Expansograptus*)? sp., *Pseudophyllograptus* sp., *Tetragraptus bigsbyi*, *T. quadribrachiatus*, *T. reclinatus toerniquisti*, *Tetragraptus* sp. A and B., *Holmograptus* n. sp., *Paraglossograptus tentaculatus, P. tricornis, Cryptograptus antennarius*, *C.? inutilus, Isograptus victoriae cf. divergens, I. caduceus caduceaus, I. c. australis, Isograptus caduceus cf. gibberulus, Arienigraptus zhejiangensis, Pseudisograptus* sp*., Xiphograptus svalbardensis, Undulograptus austrodentatus, U. sinicus*, rests of sinograptids, sigmagraptines and dendroids indeterminated. According to the mentioned author, this association suggests an early Darrwilian age (Da1). The upper part of the *Paraglossograptus tentaculatus* Zone comprises: *Ptilograptus geinitzianus*, *Cryptograptus antennarius*, *Holmograptus spinosus*, *Pseudotrigonograptus ensiformis, Paraglossograptus tentaculatus, Undulograptus austrodentatus, Undulograptus* sp. and fragments of glossograptids and isograptids. In these levels conodonts of the*Leonudus variabilis* and *Eoplacognathus suecicus* zones were recognized (*Paroistodus horridus, Periodon aculeatus*, and *Protopanderodus rectus,* among others) (Astini *et al*., 1995; Brussa, 1997a,b). The graptolite–conodont association indicates a Darriwilian age (Da2–Da3) (see Figures 14, 15).

In these levels, conodonts of the *Lenodus variabilis* and *Eoplacognathus suecicus* zones (lower Llanvirn) were recognized (Albanesi, unpubl. coll.). Recently, Brussa (1999) described two species of *Holmograptus* genus for this unit; *H. serpens* Brussa is recorded in the lower part of the formation, and *H. spinosus*(Ruedemann) in the uppermost levels. The latter species suggest a Darriwilian Da3 age for the upper part of the Sierra de La Invernada Formation. The studied graptolite assemblages indicate that *Undulograptus austrodentatus* (Da1), *U. dentatus* (Da2), *Holmograptus lentus* (Da2–Da3) and probably*Nicholsonograptus fasciculatus* (Da3) zones could be present in terms of a more refined biozonal scheme (Figure 15).

Stop 5: Cuesta del Viento section on the Jáchal River Transect
(See Figure 7)

The stratigraphy in the Western Precordillera is much simpler (Astini, 1991a, 1992a) although the complex structure and the very low–grade metamorphism complicate the general framework. The three main units from bottom to top are the Los Sombreros, Yerba Loca, and the Alcaparrosa formations, for which several names are common. An equivalent for the Yerba Loca Fm. in the central Precordillera is the Sierra de La Invernada Formation. The thin–skinned thrust belt that characterizes the Precordillera can be appreciated along the Jáchal

River canyon. Its main characteristic is the exposure of Lower Paleozoic rocks involving Ordovician, Silurian, and Devonian clastics, separated by longitudinal narrow valleys, which in turn are filled with Tertiary foreland deposits and Quaternary alluviums. The Ordovician clastics show the complete stratigraphy of the western tectofacies in a slope to basinal setting.

Four to six major west dipping Cenozoic thrusts account for the great shortening observed in this region (90 to 95 km according to Allmendinger *et al.,* 1990). The important Neogene to Quaternary deformation in the Precordillera is superimposed to the Paleozoic tectonism. This can be observed in the Jáchal River, particularly in the western tectofacies. Evidences in favour of a Mid Ordovician tectonism are mainly sedimentological and are given by the olistoliths represented in the Lower Ordovician Los Sombreros Fm., the thick turbidite succession of the Middle Ordovician Yerba Loca Fm., and the mafic lava flows preserved in the Upper Ordovician Alcaparrosa Fm. By contrast, the age of the metamorphism that affected the western tectofacies has been dated as Silurian to early Devonian (Buggisch & von Gosen, 1994).

The Los Sombreros Formation (Cuerda *et al.,* 1983) (Figure 9) is a sedimentary mélange with abundant carbonate allochthonous blocks and debris flows with mixed Cambrian to Lower Ordovician (up to Arenig) blocks in a fine–grained siliciclastic matrix with well developed slaty cleavage. This unit, about 400 m thick, includes olistoliths over 1 km length, and is affected by a very low–grade metamorphism (conodont CAI 5). According to the autochthonous faunal content (graptolites and conodonts) its age is restricted to the late Arenig–early Llanvirn interval (Ortega *et al.,* 1991; Benedetto & Vaccari, 1992, Albanesi, unpubl. coll.). The basal olistostrome of the Los Sombreros Formation is composed of a variety of carbonate blocks ranging in age from Lower Cambrian to Lower Ordovician (Benedetto *et al*., 1986, Benedetto & Vaccari, 1992) embedded in a muddy matrix that is affected by slaty cleavaje and very low grade metamorphism. It constitutes the olistostrome levels and breccias observed in the basal part of the Los Sombreros Fm. outcropping in the Jáchal River section. Resedimented quartz conglomerates, chert pebbles, subfeldespathic and quartzose turbidites, shales, and hemipelagites, together with the olistostromes, are the dominant lithologies.

The so–called "Los Túneles" olistolith is a huge carbonate slab in the Los Sombreros Formation with Middle Cambrian trilobites, which is conformably overlain by resedimented carbonates with early Middle Ordovician conodonts (*Paraistodus originalis* and *Pteracontiodus cryptodens*, among others) (Benedetto & Vaccari, 1992; Albanesi, unpubl. coll.). Faulted contact with the Yerba Loca Fm. with graptolites of the *Paraglossograptus tentaculatus* Zone and hybrid arenites with microfossils like *Nuia* sp. (common in the upper section of the San Juan Fm.) indicating a Llanvirn or early Whiterock age. The carbonate slab is composed of mostly dark hemipelagic fine–grained evenly–stratified limestones, typical of outer platform to slope environments. They contain a well preserved trilobite fauna (Vaccari & Bordonaro, 1993) (see Figure 9).

A west vergent folded succession of the Yerba Loca Formation (Furque, 1963) can be observed on the left margin of the Jáchal River. It is a typical turbidite succession (Astini, 1988a,b) of over 1000 m thick, intruded by mafic–ultramafic sills and dikes. Although affected by very low–grade metamorphism, intense cleavage and kinking, original sedimentary features can be recognized in several sections. The lithologic association is composed by fine–grained turbidites, coarse–grained turbidites and subordinated conglomerates, and hemipelagites.

Facies sequences characterize sandy turbidite lobes, shallow distributary channel systems and interlobe deposits. The sandstone textures are predominantly subwackes and arenites of sublithic to subfeldespatic composition, falling into the sublithic to lithic field in ternary diagrams. Petrofacies analysis (Astini, 1991a) indicates a recycled orogen provenance and, to a lesser extent, dissected arc and continental block provenances (75% Qz, 10% Fd., 15 % Lithics, 0.05% volcanics, 9% sedimentary, 3% metamorphics, and 3% polycristaline quartz). An important feature of this unit is the presence of mafic pillow lavas and ultramafic columnar jointed sills, which outcrop in the westernmost Precordillera. The rock assemblage has been interpreted as part of an ophiolite complex by Ramos *et al.* (1984, 1986).

The age of this formation ranges from the late Arenig to the early Caradoc (Ortega *et al.,* 1991; Albanesi *et al*., 1995). A preliminary conodont zonation considers the *Lenodus variabilis, Eoplacognatus suecicus,* and *Pygodus serra* zones for the eastern section (Ancaucha and Cerro Alto de Mayo). A graptolite assemblage suggesting the *Undulograptus austrodentatus – Undulograptus dentatus* zones (*Paraglossograptus tentaculatus* Zone *sensu* Ortega *et al.,* 1991) comprise *Ptilograptus* sp., *Cryptograptus antennarius, Isograptus caduceus caduceus, Tetragraptus* sp., *Undulograptus* sp. cf. *U. dentatus*, and *Holmograptus serpens* (see Figure 16).The green phyllites of the upper part of the formation (western section) contain scarce and poorly preserved graptolites of the *Nemagraptus gracilis* fauna in the Cuesta del Viento locality (Blasco and Ramos, 1976). Bearer strata are referred to an early Caradoc age; however, it is not possible to recognize which of both, the *Nemagraptus gracilis* or the *Climacograptus bicornis* Zone is present.

A new graptolite association includes *Corynoides calicularis, Corynites?* sp., *Cryptograptus insectiformis, Dicellograptus flexuosus, Phormograptus sooneri, Climacograptus caudatus, Orthograpthus* sp. cf. *O. quadrimucronatus, Rectograptus* sp. cf. *R. amplexicaulis, Orthoretiolites* sp. cf. *O. hami robustus*, among others, was mentioned for the Yerba Loca Formation exposures at El Tigre Range (Brussa, 1995; Brussa et al., 1999). It could be equivalent to the *Dicranograptus clingani* and *Pleurograptus linearis* zones of Scotland, and *Climacograptus spiniferous* and *Glyptograptus pigmaeus* zones of North America (Eastonian, Ea2 – Ea3 of the Australian scheme).

Lower Upper Ordovician graptolitic black and gray shales with mafic and ultramafic sills, exposed in the Cuesta del Viento section, have been referred by Astini *et al.* (1995) to the Alcaparrosa Formation (Harrington, 1957), which are included in this Field Guide in the Yerba Loca Formation. A west vergent folded of this succession can be observed on the left margin of the Jáchal River. We will see several flows with pillow lavas and columnar jointed sills. Graptolites in black shales represent to the *Nemagraptus gracilis* Zone (Blasco & Ramos, 1976). The rock assemablage has been interpreted as part of an ophiolite complex by Ramos *et al.* (1984, 1986). This formation is composed mainly of alternating dark gray to black graptolitic shales, minor lithic graywackes, and quartzose sandstone bodies. An important feature of this unit is the presence of mafic pillow lavas and ultramafic sills, which outcrop in the westernmost Precordillera. According to the graptolite fauna the age of this unit could be assigned to the early Late Ordovician due to the presence of *Nemagraptus gracilis* (Blasco & Ramos, 1976). New findings by Ortega et al. (1991) and Brussa (1994) recently moved its age up to the mid Late Ordovician.

Last stop will be the Pachimoco area (Figure 10) where folded Silurian strata of the Los Espejos Formation will be seen. This is a classical fossiliferous locality for the Silurian of the Central Precordillera. It is noteworthy the absence of the La Chilca Formation in this locality.

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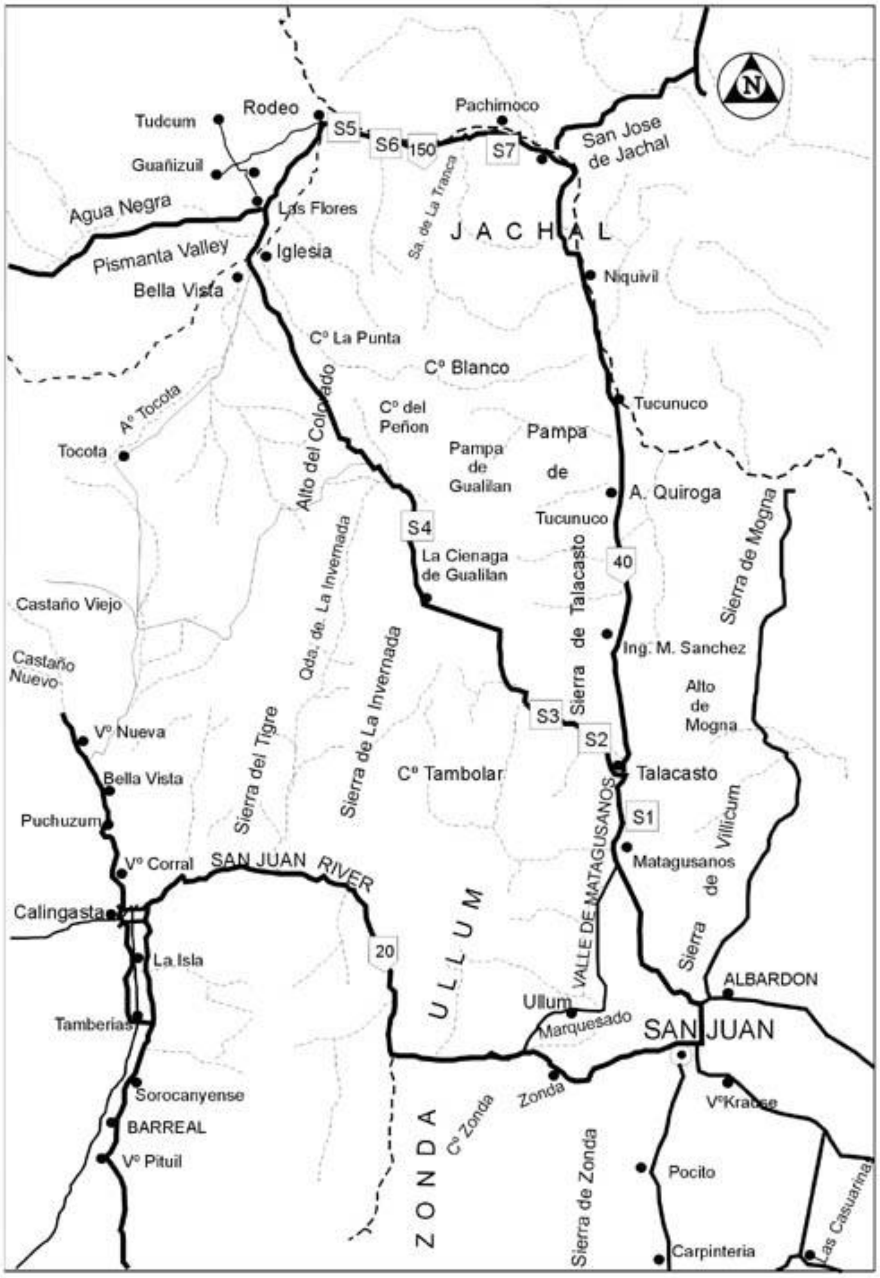


Figure 1. Map showing programmed stops for the Talacasto–La Invernada–Jáchal River field trip.

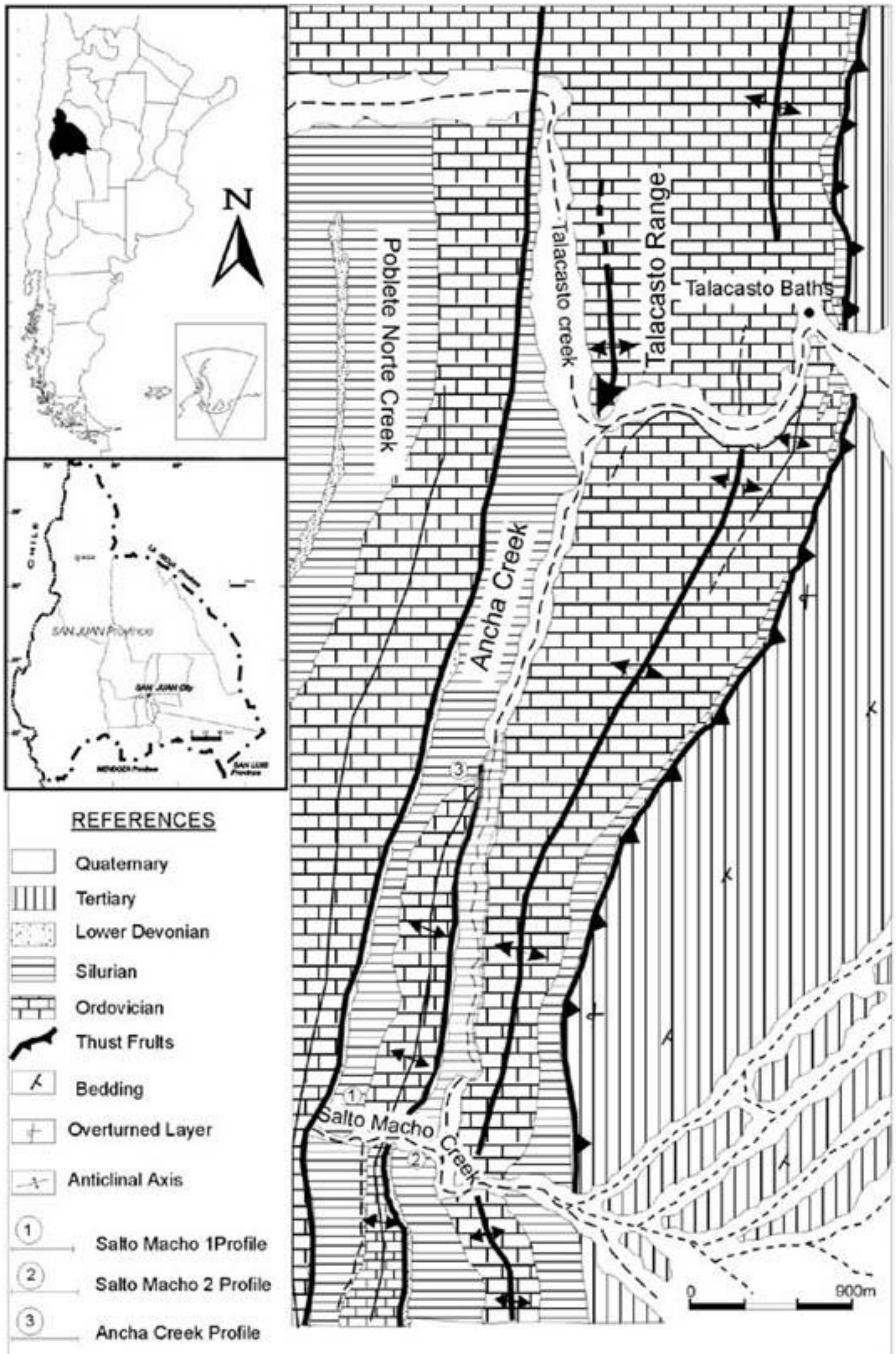


Figure 2. Map showing the geology of the Talacasto Creek. After Baldis et al. (1984).

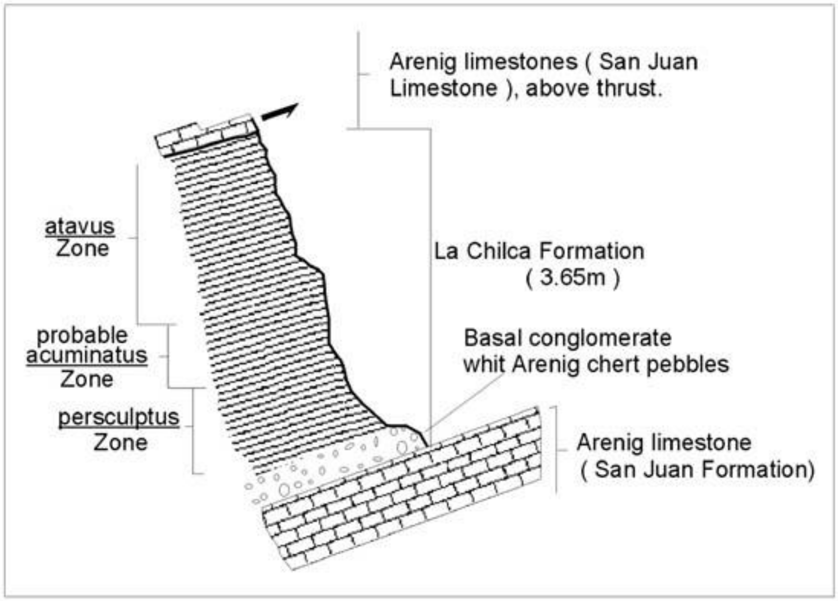


Figure 3. Stratigraphic column showing the Ordovician–Silurian boundary from the lower part of the La Chilca Formation at the Los Baños section.

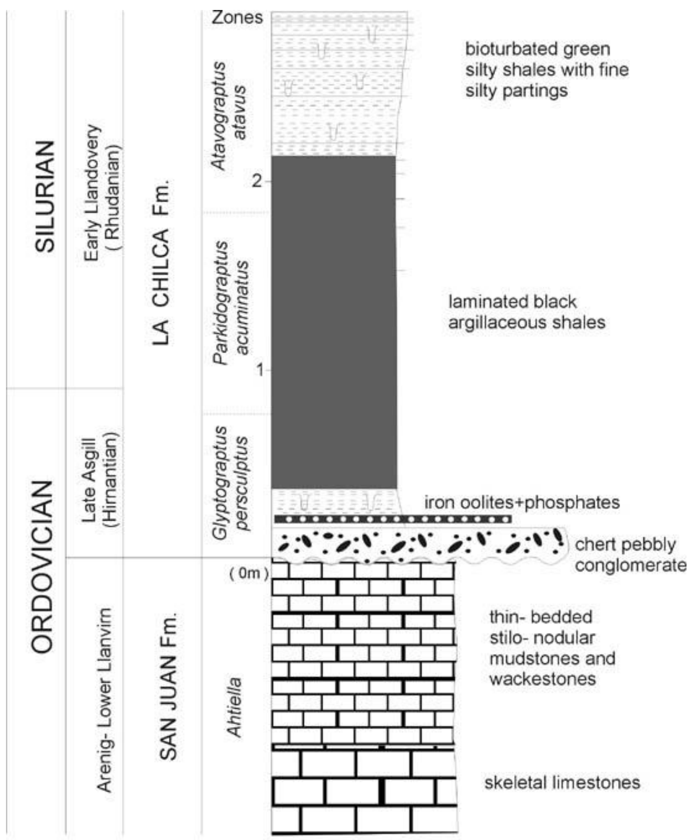


Figure 4. Type section of the Ordovician -Silurian boundary in Talacasto Bath, Precordillera of San Juan, Argentina. Brachiopod zonation from Herrera & Benedetto (1991), graptolite zonation according to Cuerda *et al.*, 1988.

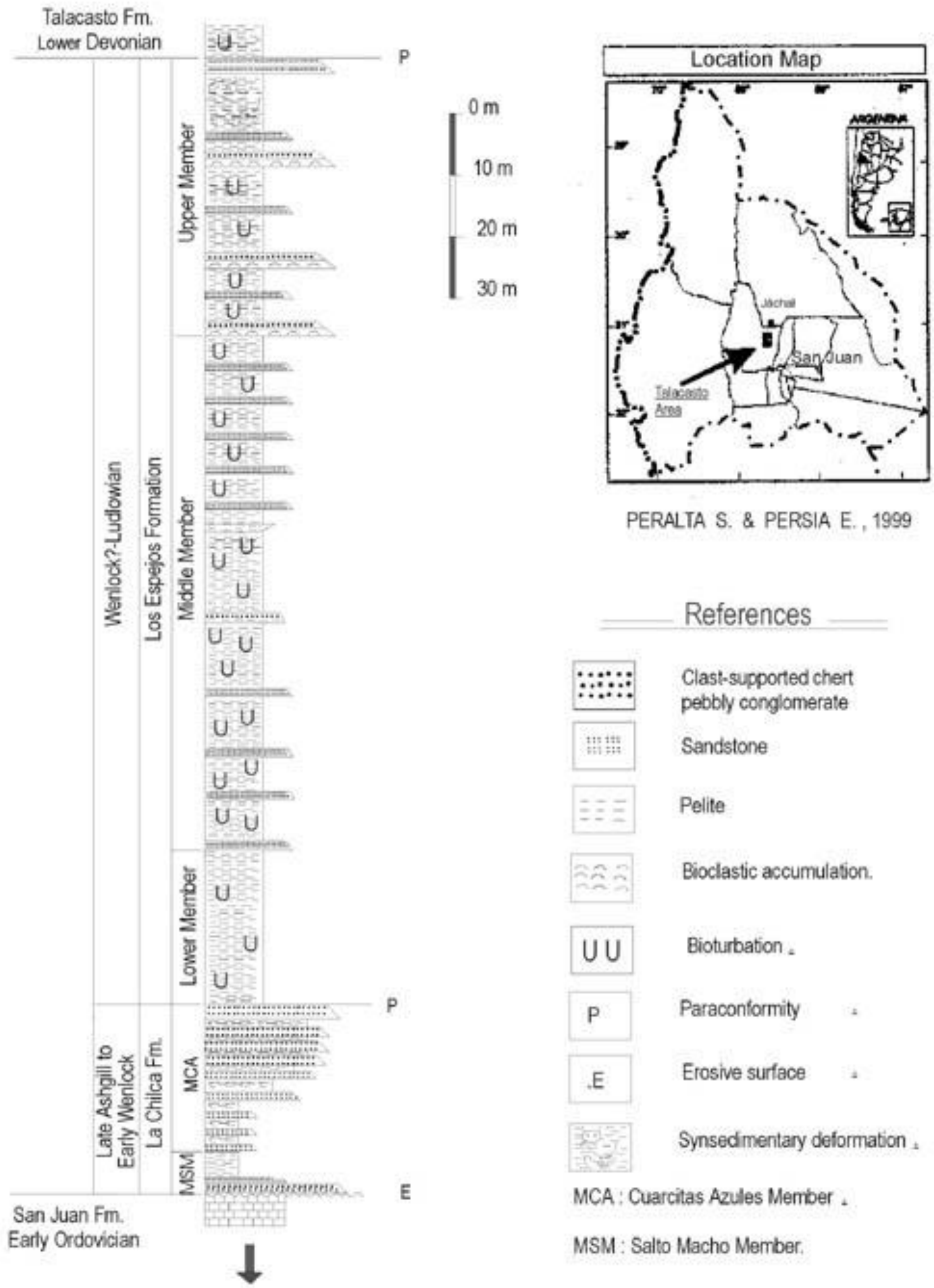


Figure 5 : Compose stratigraphic column of the Tucunuco Group, La Chilca and Los Espejos formations, in the Quebrada Ancha and Scop Quarry, at Talacasto area.

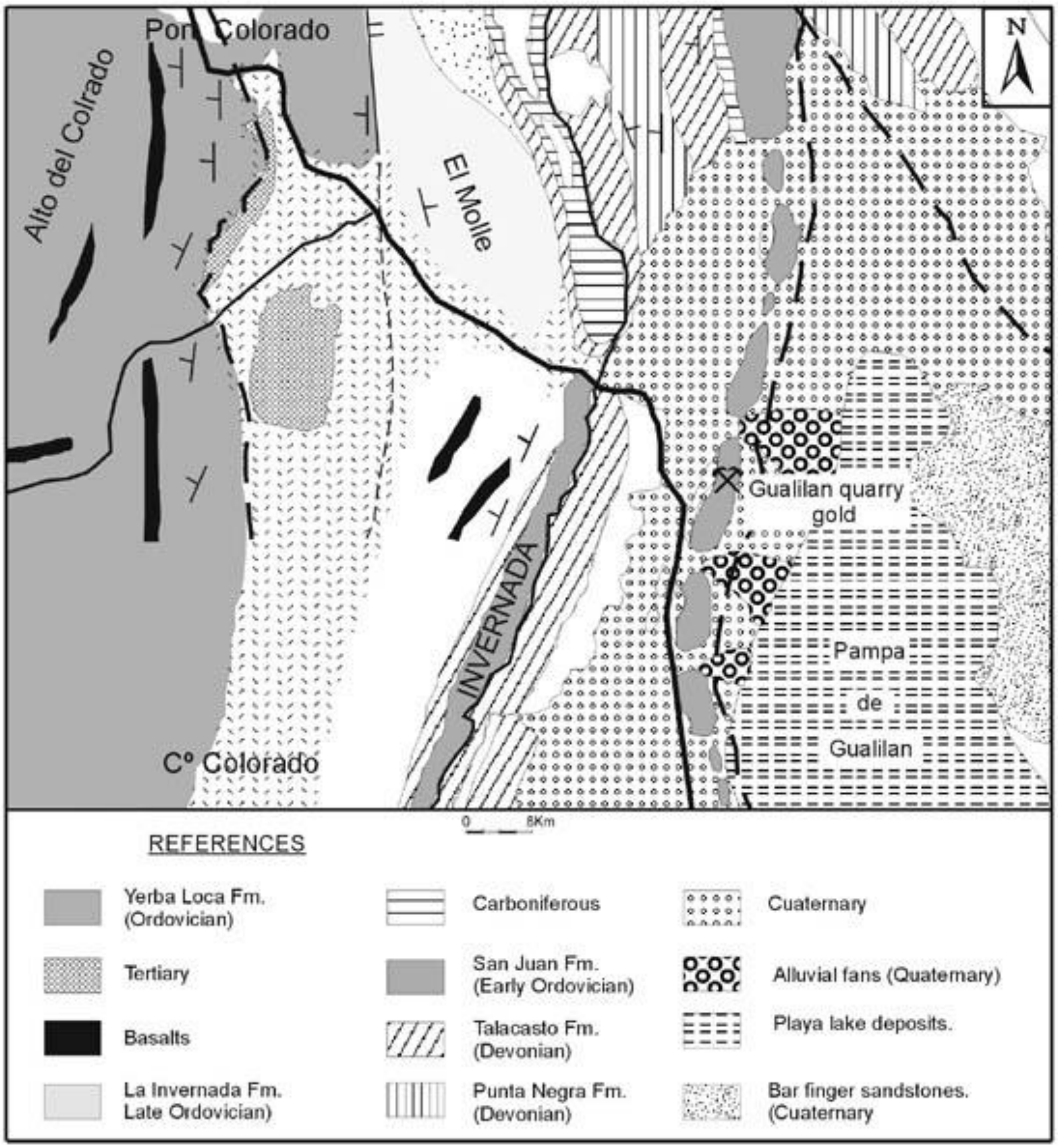


Figure 6. Map showing the geology around the stop of the Sierra de La Invernada Formation.

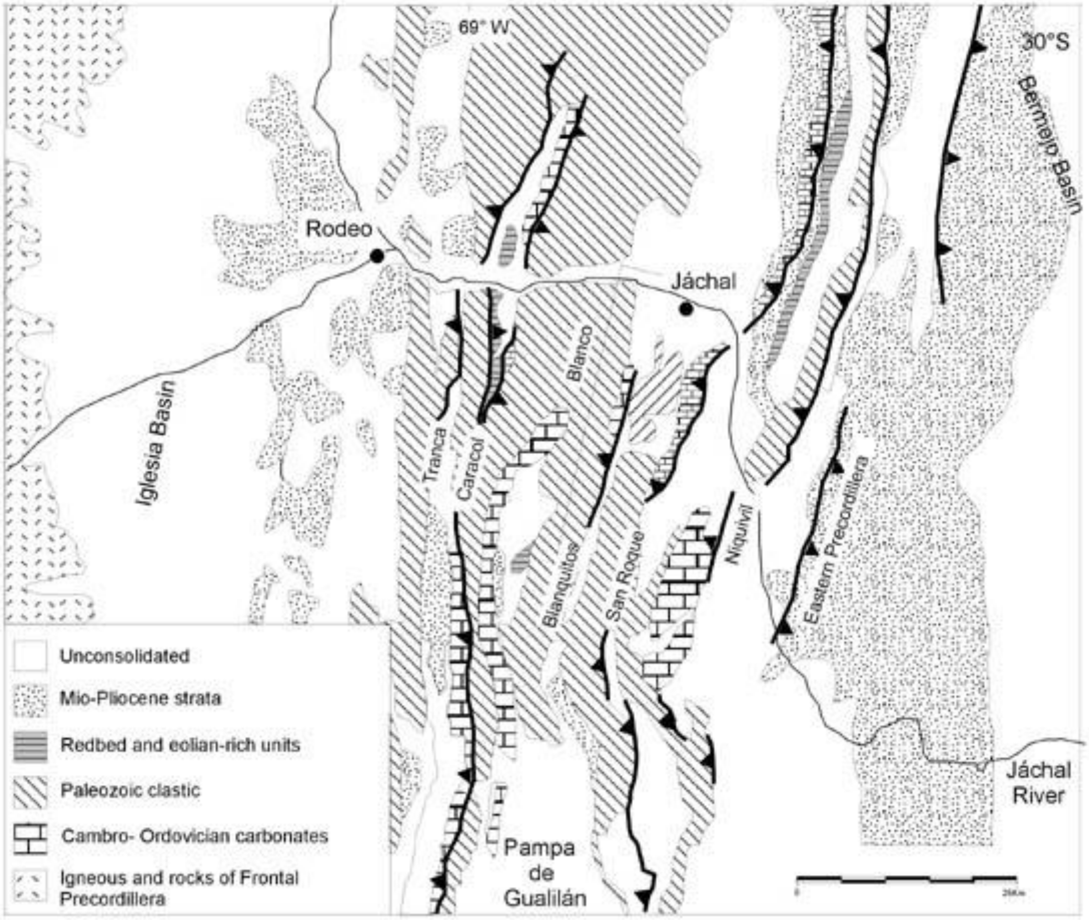


Figure 7. Map showing the geology of the Jáchal River section. After Jordan et al. (1993)

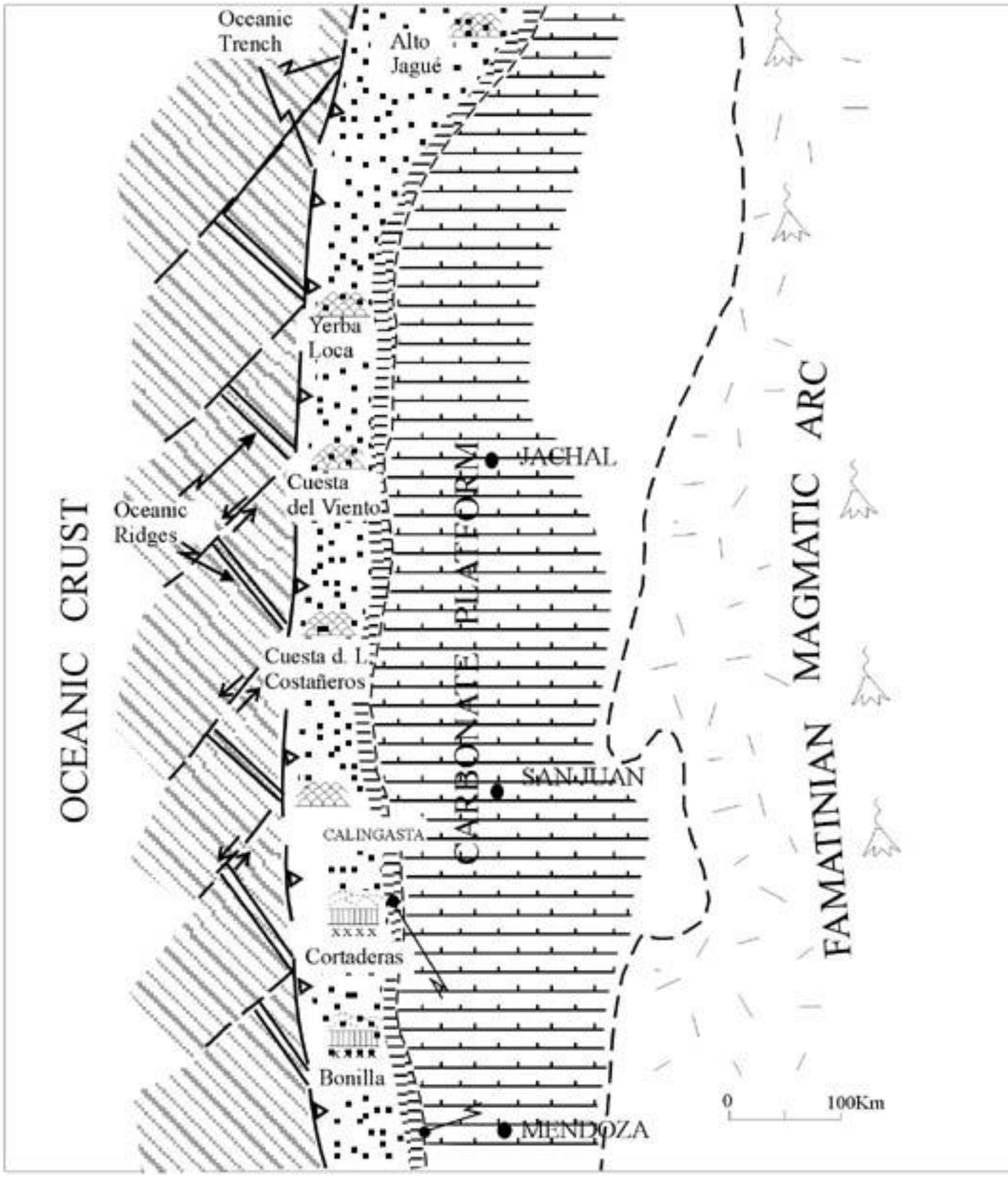


Figure 8. Geology of the Hirnantian Alcaparrosa Formation and associated pillow lavas in the Cuesta del Viento section. Paleogeographic and geotectonic setting of Western Precordillera. After Haller & Ramos (1984).

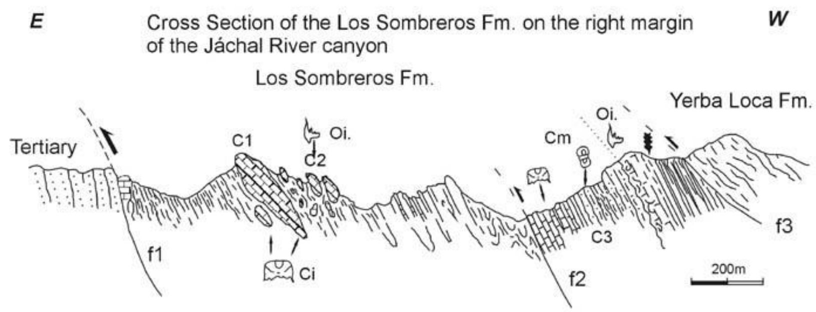


Figure 9. Schematic cross section of the Los Sombreros Fm. on the right margin of the Río Jáchal (Sierra de Yerba Loca) showing its boundaries, main facies, and fossil findings. LC: Lower Cambrian; MC: Mid Cambrian; LO: Lower Ordovician (from Benedetto & Vaccari, 1993; Vaccari & Bordonaro, 1993).
C1:-block in basal olistostrome: Olenillids indet. *Prozacanthoides* n.sp;*Sombrerella argentina*, *Wimmanella catulus*, Bicia sp, Hyolitids.
C2:-block in basal olistotrome: *Periodon flabellum, Protopanderodus* sp. *Oistodus seudoramis, Depranoistodus* sp. *Cornodus* sp.
C3:- Los Túneles olistolith: *Olenoides* sp. *Zacanthiodes* sp. *Kootenia* sp. *Chilomenthopus? tunelensis Pentagnosthus praecurrens*, ptychoparids indent.= Middle Cambrian.
Pteracontiodus criptodens, Paroistodus originalis, Drepanodus arcuatus, Cornodus longibasis, Lenodus sp. and *Crytograptus*, cf. *antemarius, Isograptus caduceus* cf. *caduceus Undulograptus austrodentatus americanus (P. tentaculatus* Zone *)* = Lower Ordovician.

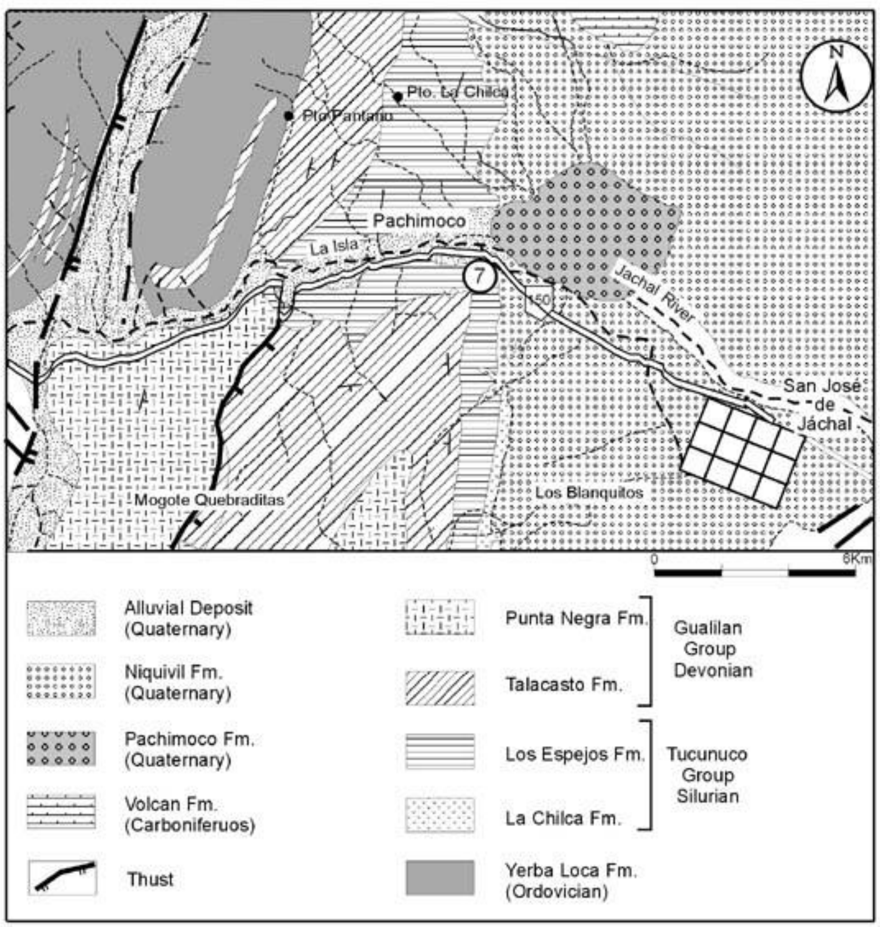


Figure 10. Map showing the geology of the Pachimoco area. After Furque (1979).

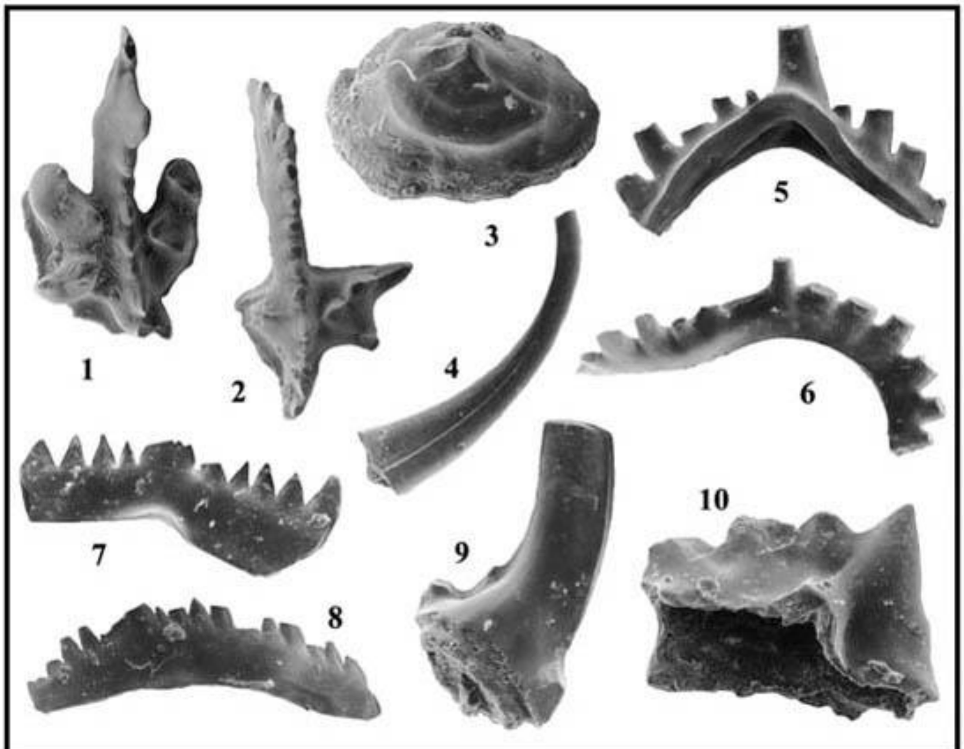


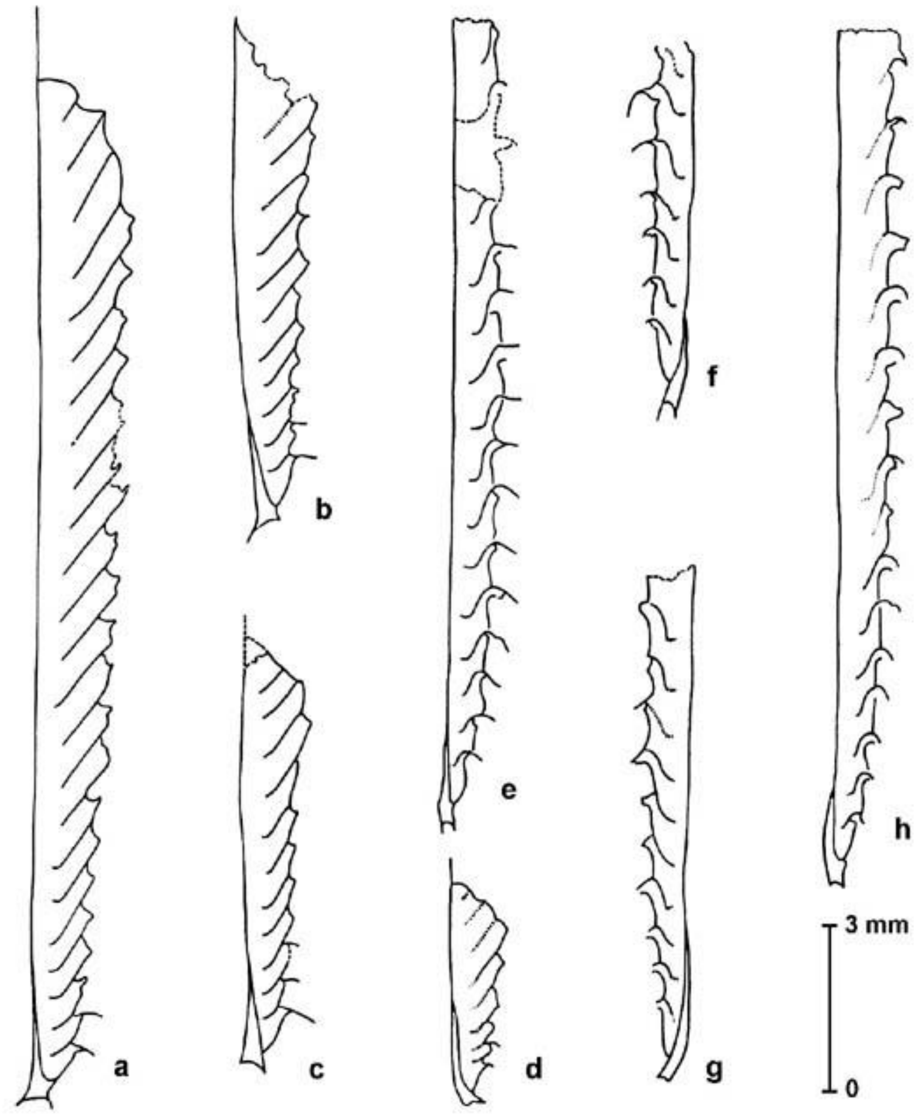
Plate references

1) *Kokelella variabilis variabilis* Walliser, 1957. Pa element, upper view (adult specimen). Sample LEB, CORD-MP 10048, x160.
2) *Kokelella variabilis variabilis* Walliser, 1957. Pa element, upper view (juvenile specimen). Sample LEB, CORD-MP 10049, x180.
3) *Pseudooneotodus beckmanni* Bischoff and Sannemann, 1958. Upper view. Sample LEB, CORD-MP 10050, x260.
4) *Panderodus unicostatus* Branson and Mehl, 1933. Lateral view. Sample LEC, CORD-MP 10051, x180.
5) *Oulodus siluricus* (Branson and Mehl, 1933). Pa element, posterior view. Sample LEB, CORD-MP 10052, x120.
6) *Oulodus siluricus* (Branson and Mehl, 1933). Pb element, anterior view. Sample LEB, CORD-MP 10053, x120.
7) *Ozarkodina confluence* (Branson and Mehl, 1933). Pa element, lateral view. SampleLD, CORD-MP 10054, x200.
8) *Ozarkodina excavata excavata* (Branson and Mehl, 1933). Pa element, lateral view. Sample LEB, CORD-MP 10055, x150.
9) *Coryssognathus dubius* (Rhodes, 1953). Pc element, postero-lateral view. Sample LEB, CORD-MP 10056, x220.
10) *Coryssognathus dubius* (Rhodes, 1953). Pa element, lateral view. Sample LEB, CORD-MP 10057, x180.

All figured specimens are SEM photographs.

Conodont species from the middle part of the Los Espejos Formation at Ancha Creek, Talacasto locality of Central Precordillera, San Juan Province (Albanesi, in progress).
The conodont association represents the *Kokelella variabilis variabilis* Zone of the new scheme proposed by Corradini and Serpagli (1999) for Sardinia, Italia, and global correlatives. This biozone is constrained to the lower Ludlow Series (Gorstian Stage) of the Upper Silurian.

Figure 11. Conodont assemblage from the middle part of the Los Espejos Formation, at Ancha Creek, Talacasto area.



References

Early Ludlow graptolites from the Los Espejos Formation, Precordillera of San Juan. **a, e**, *Saetograptus argentinus* (Cuerda); **f, h**, *Monograptus uncinatus notouncinatus* Cuerda. Scale bar: 1 mm.
After Cuerda (1969)

Fig. 12

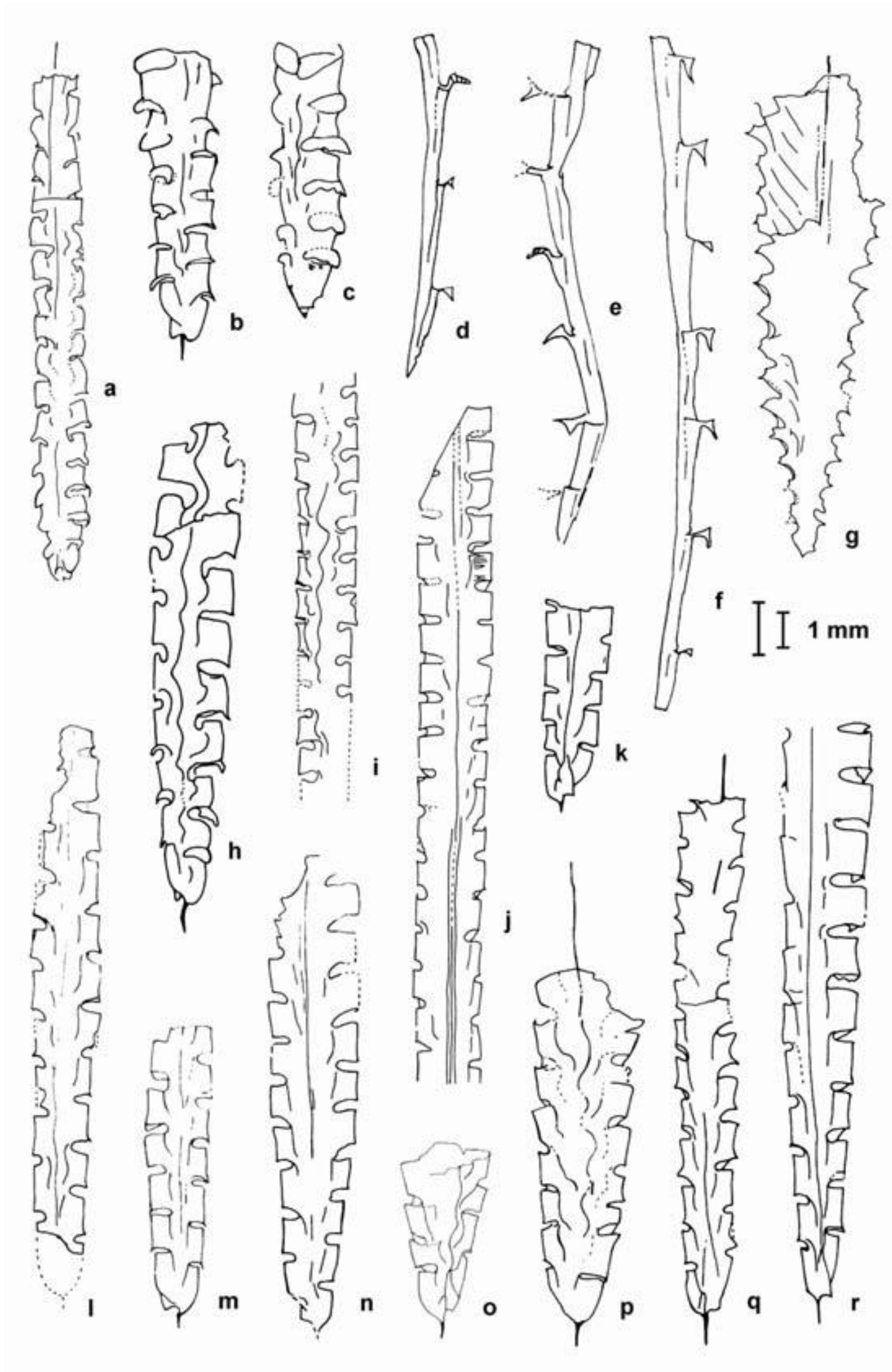


Figure 13. Late Ashgill – early Llandovery graptolite fauna from the lower part of the La Chilca Formation (Normalograptus persculptus Zone, probable Parakidograptus acuminatus and Atavograptus atavus zones), Talacasto locality, Precordillera of San Juan.
a, b, c, Talacastograptus leanzai Cuerda, Rickards & Cingolani, a, b DPI 21883; c, DPI 21879; d, e, f, Lagarograptus praeacinaces Cuerda, Rickards & Cingolani, d, DPI 21900, e, DIP 21902,

c, DIP 21903; g, Paraclimacograptus sp., DIP 21893; h, i, Pseudoclimacograptus robustus Cuerda, Rickards & Cingolani, h, DPI 21909, i, DPI 21910; j, k, Normalograptus medius (Törnquist), j, DPI 21921, k, DPI 21920; l, m, Normalograptus angustus (Perner), l, DPI 21914, m, DPI 21913; n, Normalograptus normalis (Lapworth), DPI 21918; o, p, Normalograptus persculptus (Salter), o, DPI 21896, p, DPI 21895; q, Normalograptus acceptus (Koren' & Mikhaylova), DPI 21919; r, Climacograptus rectangularis McCoy, DPI 21916. All figures x7,5 except for a, g, j x5,0. Scale bar: 1 mm.
After Cuerda, Rickards & Cingolani (1988).

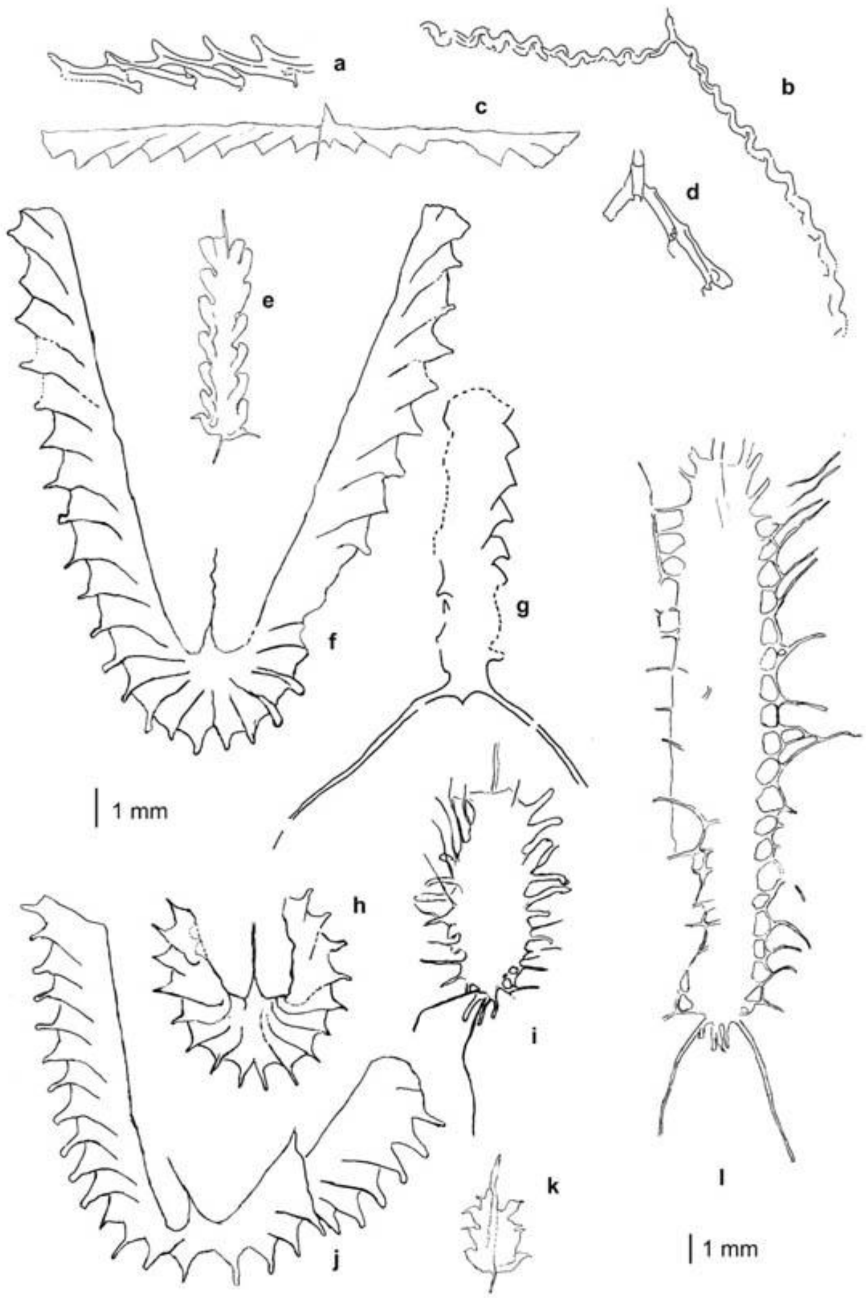


Figure 14. Darriwilian graptolites from the Sierra de La Invernada Formation, San Juan Precordillera. a, d, Holmograptus spinosus (Ruedemann); a, CEGH–UNC 872, d, CEGH–UNC 868 (after Brussa, 1999); b, Holmograptus serpens Brussa, CEGH–UNC 868 (after Brussa, 1999); c, Xiphograptus lofuensis (Lee), CORD–PZ 22757; e, Undulograptus austrodentatus (Harris & Keble), CORD–PZ 22757; f, Isograptus caduceus caduceus (Salter), CORD–PZ 22757; g, Cryptograptus antennarius (Hall), CEGH–UNC 3080 (after Brussa, 1997b); h, Arienigraptus zhejiangensis Yu & Fang, CORD–PZ 22757; i, Paraglossograptus? sp., CORD–PZ 22756 B; j, Tetragraptus sp., CORD–PZ 22756 B; k, Undulograptus sinicus (Mu & Lee); l, Paraglossograptus tentaculatus (Hall), CORD–PZ 22757; all specimens x6, except for l, which is x5. Scale bar: 1 mm.

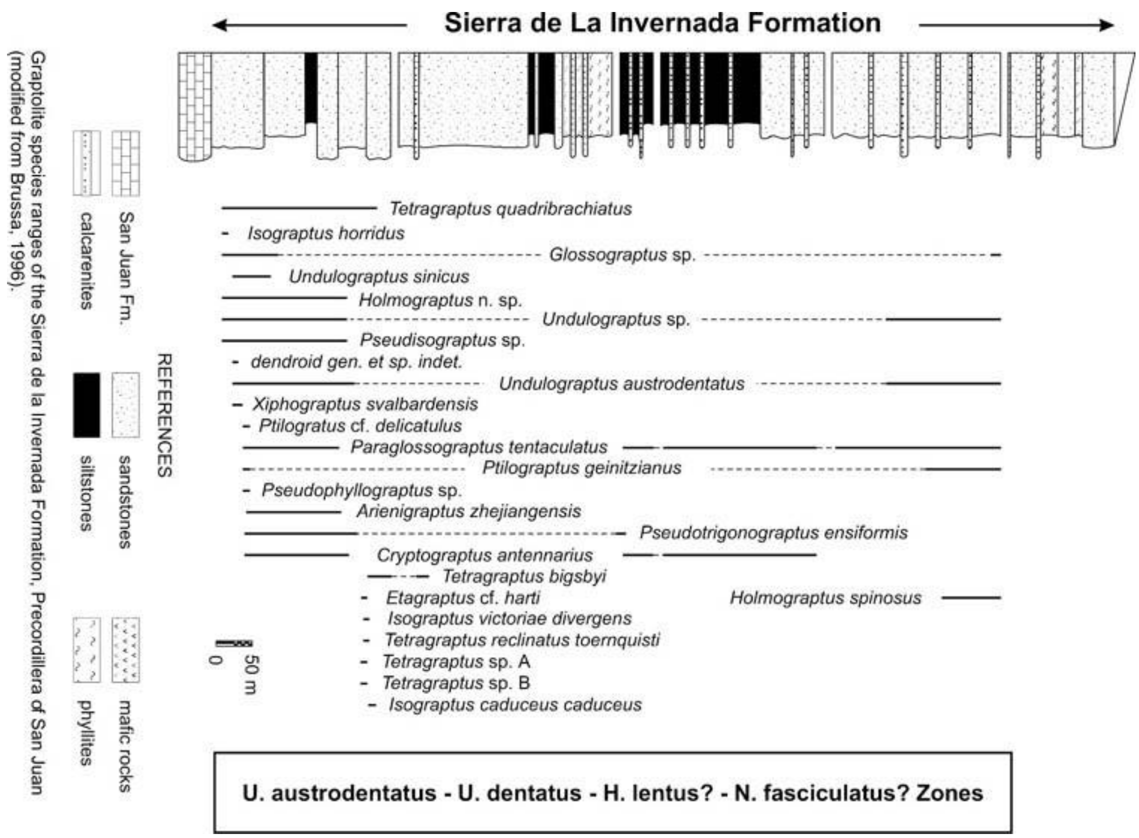
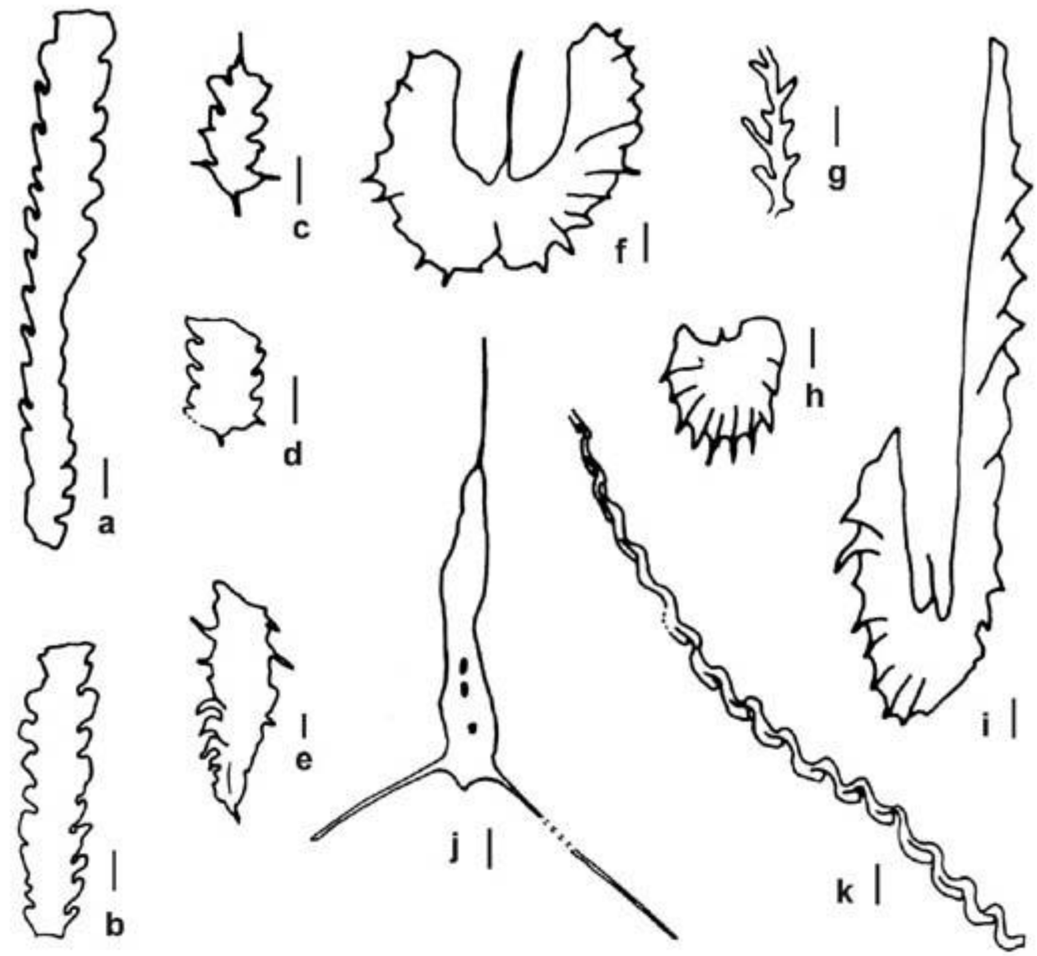


Figure 15. Stratigraphic column and graptolite species ranges of the Sierra de La Invernada Formation (Modified from Brussa, 1996).



References

Darriwilian graptolite assemblage *(Undulograptus austrodentatus - U. dentatus* Zone*)* from the Yerba Loca Formation at Ancaucha creek and El Divisadero locality. **a, b**, *Undulograptus* sp. cf. *U. dentatus* (Brongniart), a, CEGH-UNC 1537; **c**, *Undulograptus* sp. cf. *U. sinicus* (Mu & Lee), CEGH-UNC 1537; **d**, *Undulograptus* sp., CEGH-UNC 1537; **e**, *Glossograptus* sp., CEGH-UNC 1537; **f**, *Tetragraptus* sp. cf. *T. bigsbyi* (Hall), CEGH-UNC 1537; **g**, *Ptilograptus* sp., CEGH-UNC 1819; **h, i**, *Isograptus caduceus caduceus* (Salter), h, CEGH-UNC 1763, I, CEGH-UNC 1763; **j**, *Cryptograptus antennarius* (Hall), CEGH-UNC 1768; **k**, *Holmograptus serpens* Brussa, CEGH-UNC 1768. Scale bar: 1 mm.
Modified from Ortega, Brussa & Astini (1991).

Fig. 16