Quebrada de Zonda Field Trip: The Cambrian carbonate sequence, litho and biostratigraphic features. Eastern Precordillera, San Juan, Argentina

SILVIO H. PERALTA

On the road to the Quebrada de Zonda, and before 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 are part of the north-south trending Villicum-Zonda-Pedernal structural arch (Baldis et al.,1982), also called "Zonda Swell" (Padula etal.,1967) or "Zonda Arch" (González Bonorino, 1976), which western boundary is marked by the Zonda regional fault. The mentioned structural arch form part of the Eastern Precordillera morph-structural setting (Ortiz and Zambrano,1981), which western boundary is marked by a regional thrust, the "Regional Zonda Fault", which-strik N-S dipping steeply , eastwards and the eastern boundary is marked by a modem faulting system, dipping to the east. In this scene, imbricate faults dipping the east displace oftenly, older to younger Cambrian rocks, however, Silurian, Carboniferous and Tertiary siliciclastic deposits on top of the thrust sheets are also involved. In the Quebrada de Zonda, on the whole, the Cambrian rocks form the base of the imbricates, and, toward the west, the dip o the imbricate thrust surface increases with the westermost fault planes standing almost vertical. In the Villicum-ZondaPedernal 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

Inside the gulch, a thick marine carbonate sequence are exposed (Fig. 1), which extent from Lower to Upper Cambrian, including several sandstone levels and interbedded black shales, related to shallow water environment. This Cambrian carbonate sequence totalizes a thickness of 2500 m which comprises, from the base upwards, La Laja Formation (Lower to Middle Cambrian), Zonda Formation (from the Middle/ upper Cambrian boundary up to the Lower part of the Franconian), La Flecha Formation (late? Franconian to at least late Trempeleauan, Saukia Zone), and La Silla Formation (Late Cambrian, uppermost Trempeleau to uppermost Tremadoc, deltifer Zone) (Keller et al.,1994). The limestones of the San Juan Formation, has not been recorded in the Quebrada de Zonda Section, but to the south, at the Quebrada de Las Lajas, on the eastern flank of the Chica de Zonda range, the Cambrian sequence is overlain in transitional mode by typical fossiliferous limestones of the San Juan Formation (uppermost Tremadoc to Arenig) yielding open sea marine faunas. The La Laja and Zonda Formations has been included in the Marquezado Group, since they both belong to a continuous Cambrian sedimentary cycle (Baldis and Bordonaro,1985).

La Laja Formation (Borrello, 1962):

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 and Leanza,1943). The Type Section is located in the Quebrada de Zonda, from the western flank of the Sierra Chica de Zonda to the Quebrada de Juan Pobre (Borrello, 1962). Here, this unit is 500 m of thickness, its Lower boundary is unknow, because at the base the La Laja Formation, is always cut by thrust. The upper boundary is drawn at the transition from the limestones to the dolomites of the Zonda Formation (Bordonaro, 1980). The best cross-section to look the sedimentary succession of the La Laja Formation, display on the south side of the Quebrada de Zonda, besides of the

National Road No 20, which runs from San Juan City to Calingasta Valley, through San Juan River valley.

Subtidal mudstones and wackestones indicating shallow marine platform, constitute the typical deposits of the La Laja Formation, including too oolite-barrier (packstones and grainstones) of near- shore paleoenvironment, which are related to sea level fluctuations. The sequence reveals six major shallowing upward cycles with basal marlstones-mud-wackestones, strongly bioturbated wacke-packstones and oolitic grainstone shaals (Bercowski *et al.,* 1990). In agree with Bordonaro (1980) three Members can be recongized in the La Laja Formation: the lowermost Marly Calcareous Member, the Black Limestones Member in the middle part of the succession, and the upper Dolomite Limestones Member. However, on the basis of the lithological features, the subdivision of the La Laja Formation varies according to different authors. For instante, Baldis and Bordonaro (1985) recognize five members, which were defined from the base to upwards, as follow:

1. De la Roza Member: 150 m minimum thickness, this unit is composed of black cherty limestones. The Lower boundary is unknow due to faulting, and no fossils have been found, for this reason a Lower Cambrian age is estimated.

2. El Estero Member: 300 m thickness, is formed by shales and quartzites, containing typical trilobite fauna of *Ollenellus* Zone which indicates Lower Cambrian.

3. Soldano Member: 400 m thickness, is composed of marls and mudstones, containing Antagmidae trilobites together with chitinous-phosphatic brachipods indicating the trilobite fauna a Lower Cambrian age.

4. Rivadavia Member: 175 m thickness, is integrated by homogeneous set of black limestones, containnig scarce trilobites and algal structures, indicating Lower Middle Cambrian age.

5. Juan Pobre Member: 280 m thickness, consist of oolitic limestones and black limestones to a lesser extent, bearing trilobites and brachipods in varied abundante, which extent through the whole Middle Cambrian.

Keller *et al.* (1998) suggest that an important uncoformiry 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 uncoformiry and above the sequence boundary, two trilobites zone seem to be absent, indicating an erosional event which could be correlative with that equivalent in timing to the Hawke Bay event described from the Appalachian margin of Laurentia (Palmer & James, 1980). The uncoformity separating both the El Estero and the Soldano Members, is correlative with the hardground and erosional unconformity described by Cañas (1988) to the late Upper Cambrian sequence at the Guandacol area, northernPrecordillera.

For the first time Borrello (1962,1963) detected Cambrian trilobite fauna at the Villicum range,northern of Zonda range, separating the fossiliferous Cambrian rocks from the Ordovician limestones, introducing the "Formation Caliza La Laja". Later, Bordonaro (1986, 1989) described

a detailed stratigraphy for the Lower and Middle Cambrian La Laja Formation. In this way, in agree with the later author, and Baldis and 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 - Onchocephalús Zone (topmost Lower Cambrian), Plagiura-Poliella Zone (base of the Middle Cambrian), Albertella Zone, *Glosspleura Zone and Bathyriscus-Elrathina* Zone (Middle Cambrian) , Bolaspidella Zone including trilobites of the uppermost Middle Cambrian (Fig. 2).

Zonda Formation (Bordonaro, 1980):

Its name is derived from the Sierra Chica de Zonda, where the formation is widely distributed, at the western part of the Zonda range, and where its type section is located, on the southein side of the Quebrada de Zonda (Bordonaro, 1980).The Zonda Formation, 300-350 m thickness, is composed of dolostones mostly of early diagenetic origin (dolomicrites). The seetions in the Sierra Chica de Zonda and Sierra de Villicum show an overwhelming majority of biolaminated deposits with only minor intercalations of dolomitized oolites, intraformational conglomerates and (dolo)mudstones with desiccation cracks or diagenetic evaporites. Stromatolites are rare and belong to the LLH-type (Logan et al., 1964). In the Zonda 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 (La Angostura section) (Keller et al.,1994).

The Zonda Formation is easily distinguished from the La Flecha Formation, in the Sierra Chica de Zonda. The distinction between both is made on lithology, colour 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 evidente 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 yBordonaro,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).

La Flecha Formation (Baldis *et al.*, 1981):

Is name is derived from the type locality in the Quebrada de La Flecha, at the southern part of the Sierra Chica de Zonda, where its Type Section is located (Baldis et al., 1981), with

400 m of thickness. 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 conspiuous lithostratigraphic sequence composed of two similar shallowing-upward sequences, but there is no well-defined boundary between them. In the lower cycle the abundante 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 subaerial erosion, coarse detrital quartz, abundant evaporites, or concentrations of calcrete horizons just beneath the main surface. For this raison, each of these sequence boundary has to be regarded as a type-1 sequence boundary (Keller, 1997; Keller et al, 1998). It is presumed that these sequence plus the La Flecha Formation sequence, were deposited during approximately 10 Ma, which qualifies them as third-order sequences (Keller, et al, 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 Formadon 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, Pletbopeltis cf. saratogensis, indicating a late Franconian age (Ludvigsen and 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 a1.,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 stripctus Rasetti indicates the Aphelaspis zone (Westrop, 1992).

La Silla Formation (Keller *et al., 1994):*

This formation constitutes a new litho-stratigraphic unit for the Villicum-Zonda-Pedernal structural arch. The La Silla Formation was defined at the Cerro La Silla section, 350 m 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 Formación 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 interynedius* Zone .In the upper part of the formation, conodont faunas belonging to Paltodus deltifer zone.

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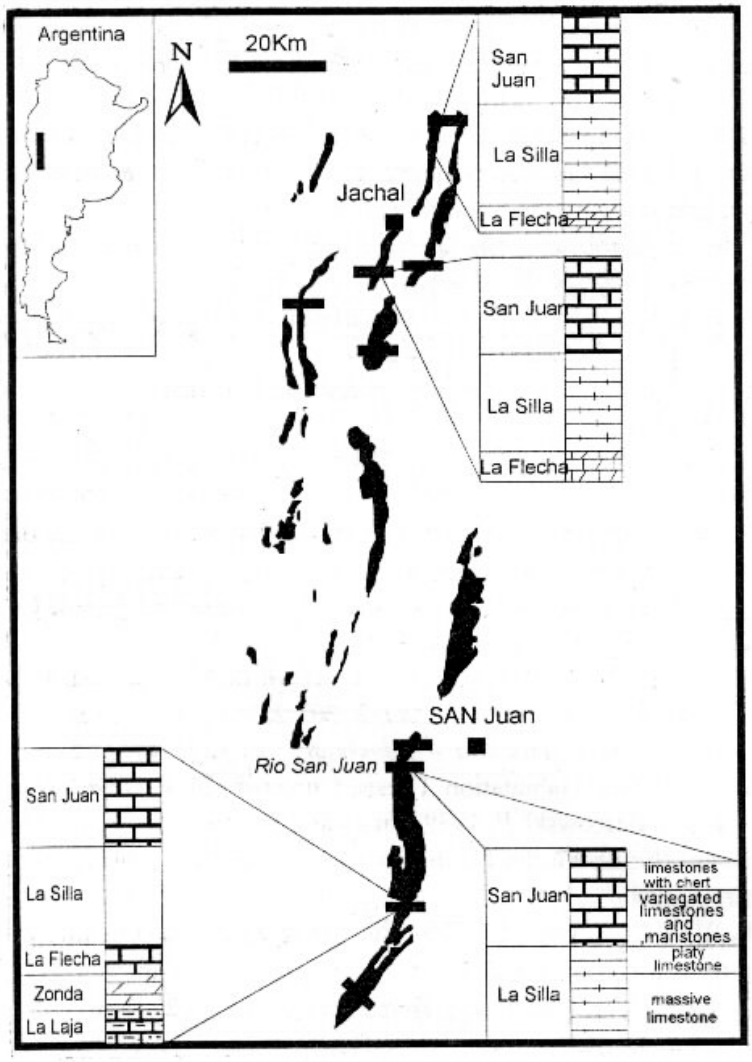

Fig 1. Distribution of the Cambrian deposits on the Precordillera, showing lithostratigraphic arrangement.(Modified from Keller *et al.*,1994)

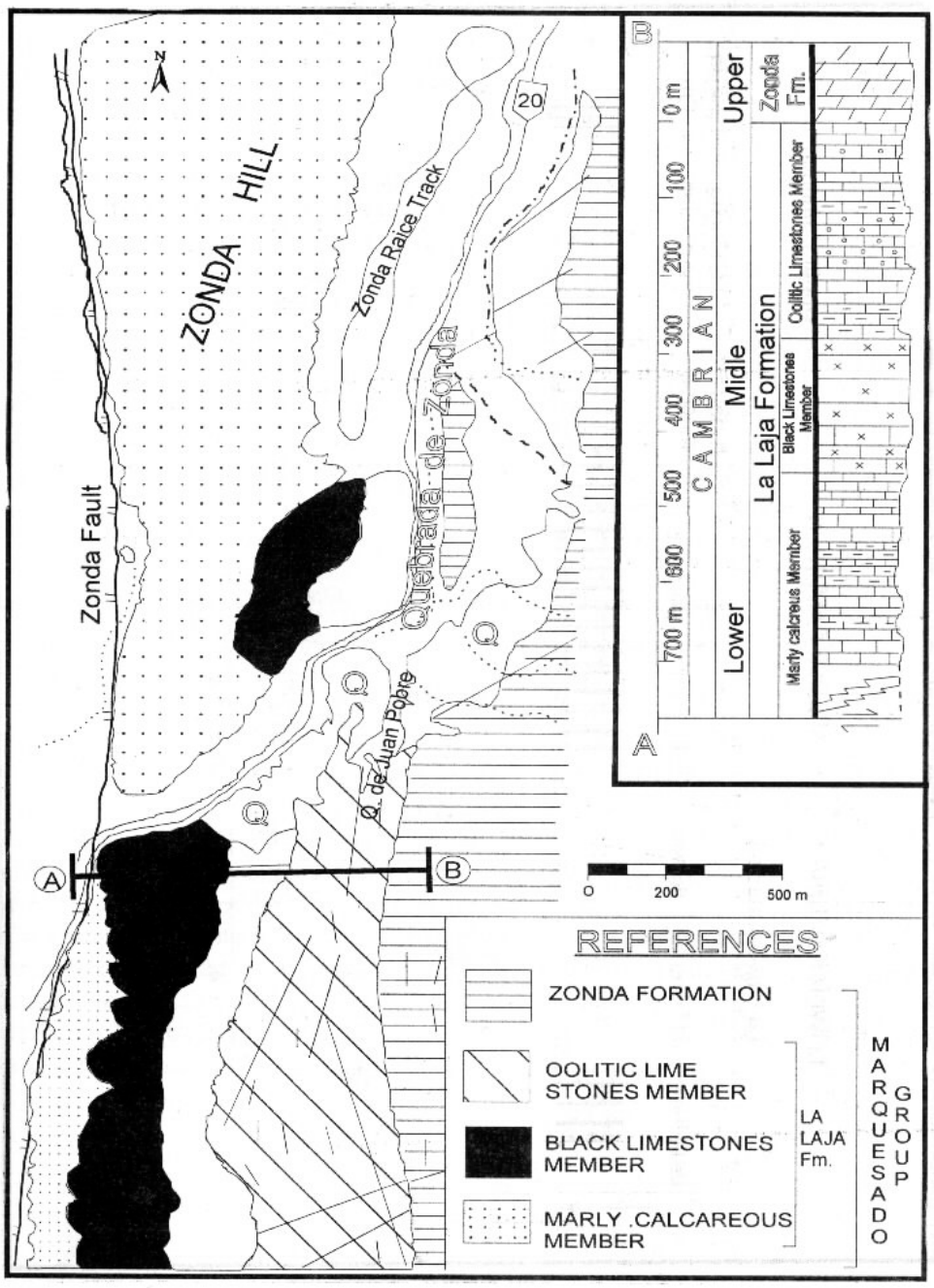

Fig 2. Cambrian of the Quebrada de Zonda (After Bordonaro, 1980).

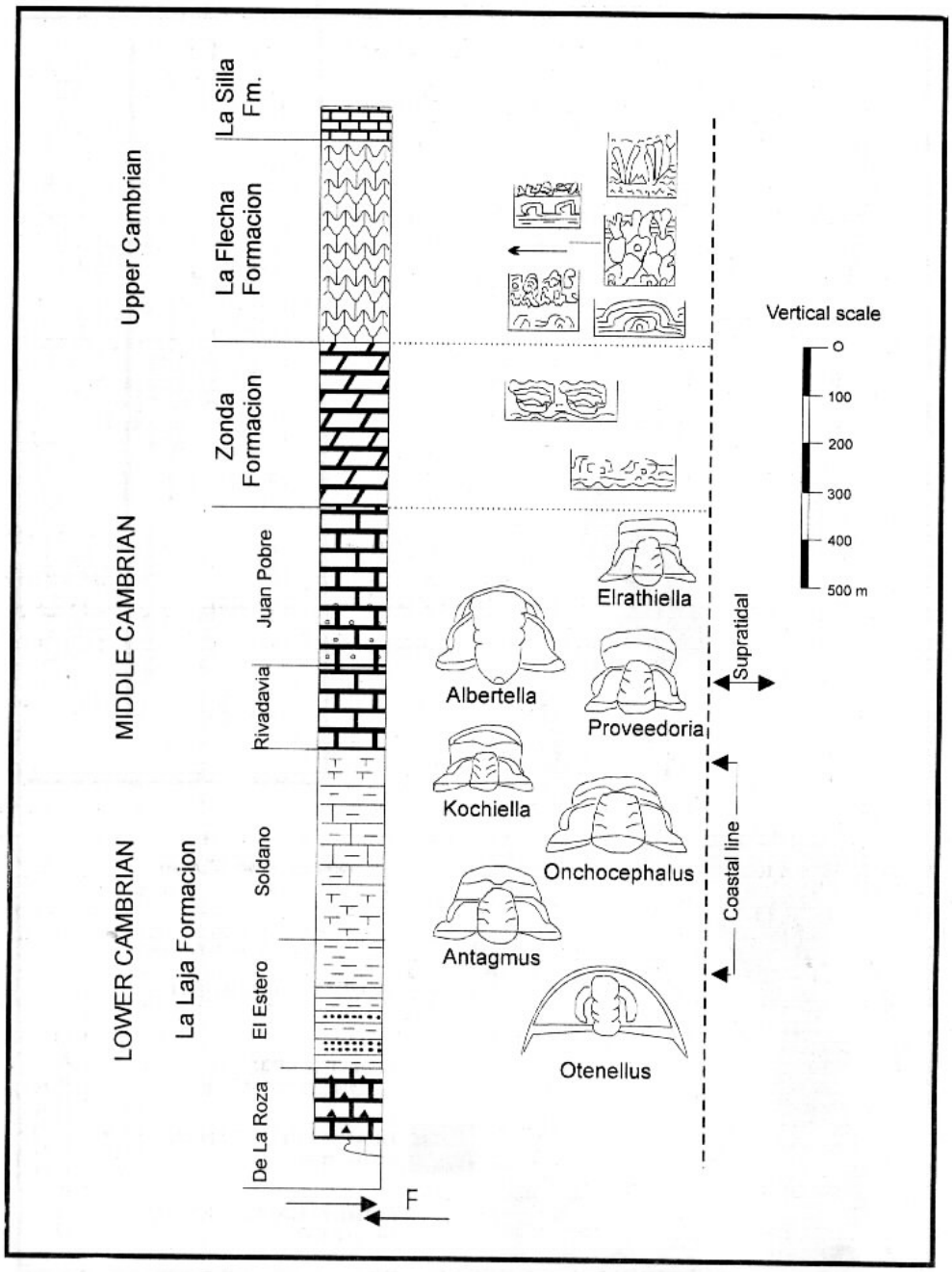

Fig 3. Stratigraphic column and environmental synthesis of the Cambrian sequence from the Precordillera of the province of San Juan, Argentina. Biostratigraphic data integrated from Quebrada de Zonda (La Laja and Zonda Formation) and Quebrada de La Flecha (Formation La Flecha) sections. Modified from Baldis and Bordonaro, 1985.