The Cambrian sequence on the type section of the Quebrada de La Flecha (Southern extreme of the Argentine Eastern Precordillera)

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According to structural stratigraphic and morphological features, the geological province of the Argentine Precordillera has been divided into three subprovinces (Western, Central and Eastern Precordillera).

Eastern Precordillera

The Eastern Precordillera is integrated by Villicum to the north, Sierra Chica de Zonda (to central part), Pedernal and Loma de los Pozos ranges (to the south), and few other smaller hills and ranges. They are developed on some 200 km, with a general N-S alignement. The central sector is topographically the higher.

This mountain system is located 10 km west of San Juan city and separates the valleys of Zonda to the west and Tulum to the east. Good roads let us arrive to the north of the Sierra Chica de Zonda (Ullúm dump) while others do cut across of the central sector of the range through the Quebrada de Zonda. Towards the north it is possible to reach the sourthern sector of the Villicum range by the National Road N° 40. Going to the south two localities can be visited: Pedernal Range (Road N° 34),10 km to the south of Los Berros Locality, and a second: Quebrada de la La Flecha, located 8 km to the north of the Los Cerros (mining road) (Fig 1).

The Eastern Precordillera has been for a long time known by the excellent limestones Lower Paleozoic outcrops, and they were known as "San Juan Limestones". Harrington y Leanza, (1943), had demostrated at first time the partial corresponding of the limestones to the Cambrian. Borrello (1962); Baldis (1981 a, b); Baldis et al. (1982); Baldis y Bordonaro (1981,1984,1985); Beresi (1986) and Bordonaro (1980), carried out investigations on the stratigraphic record of Precordilleran limestones.

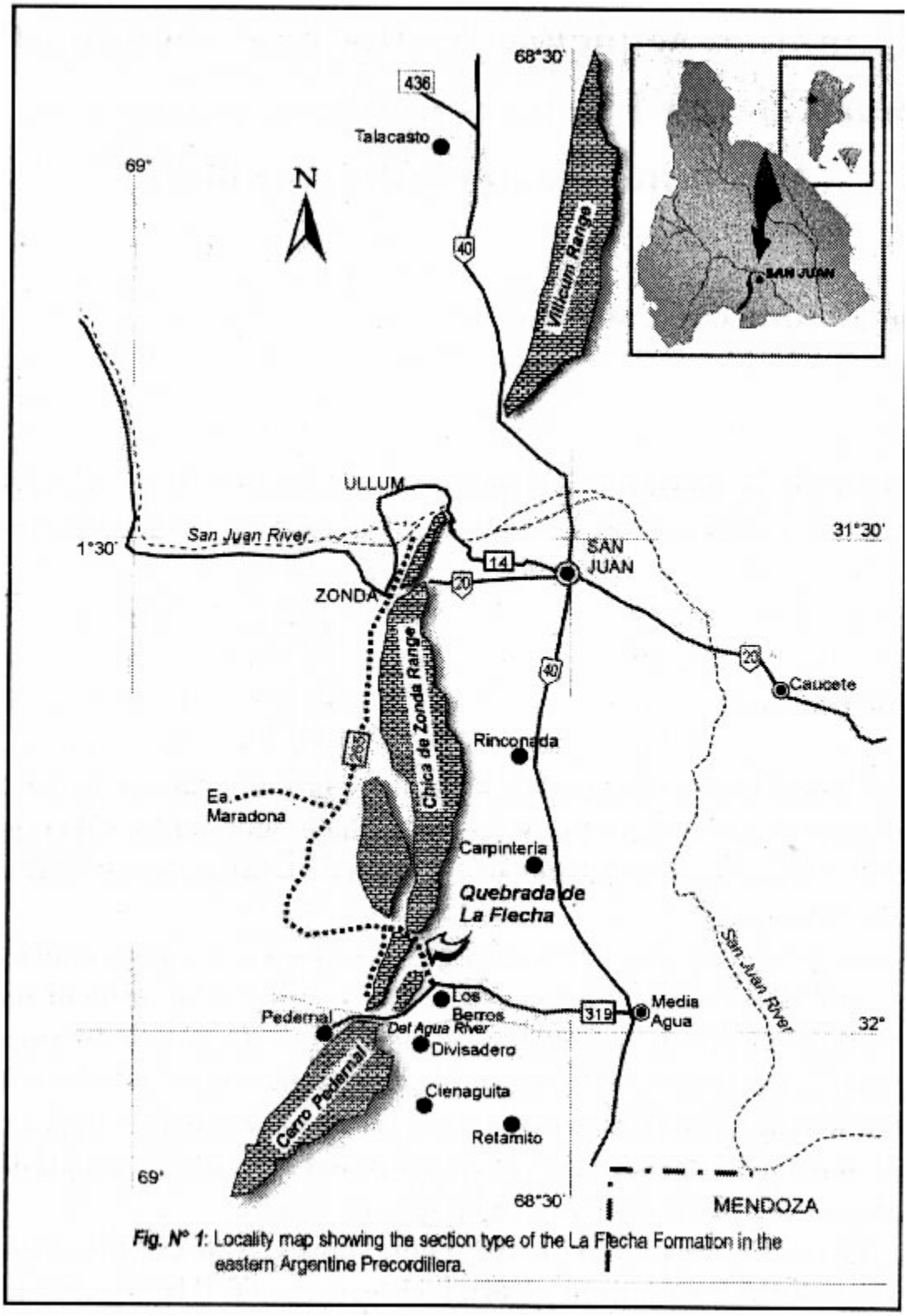


Fig. N° 1: Locality map showing the section type of the La Flecha Formation in the eastern Argentine Precordillera.

Historical background on the Cambrian and Ordovician of Eastern Precordillera

The limestones of the Precordillera are known from Kayser (1867); Stelzner (1873), but it was included in the Ordovician by Kobayashi (1937); whorhas so-called "San Juan Limestones". Harrington and Leanza (1943), based on trilobites asigned a Cambrian age to part of the sequence. Harrington and Leanza (1957), continued using the name "San Juan Limestones" for all of the carbonatic secuence.

Borrello (1962), identified fosiliferous rocks of Cambrian age and he separated them from the Ordovician limestones, naming them as "La Laja Limestones Formation".

Bordonaro (1980,1986), carried out a detailed stratigraphic study in Lower and Middle Cambrian rocks of La Laja Formation, calling as "Zonda Formation" the non fosiliferous dolomites which separated the La Laja Formation and San Juan Formation.

Later, Baldis et al. (1981b), subdivided the Zonda Formation, and recognized an interval with stromatolites, calling it as "La Flecha Formation" for the southern Precordillera outcrops, while in the northern area, nearly identical sediments were called "San Roque Formation". An Upper Cambrian to lowermost Ordovician (Tremadoc) age was inferred for the deposits of La Flecha Formation (Baldis *et al.* 1981a).

Keller *et al.* (1994), identified a new stratigraphyc unit in the lowermost part of San Juan Formation, calling it as "La Silla Formarion", whose age comprises Late Cambrian (upper Trempealeau) to uppermost Tremadoc *(deltifer* zone). (Fig. 2)

Thus the discovering of new fossils of Lower and Middle Cambrian age and the stratigraphical criteria applied to the Upper Cambrian - Lower Ordovician, the latter replaces the original name of "San Juan Limestones".

Eastern Precordillera: Tectonic Framework

The Geological Province of Eastern Precordillera (Harrington and Leanza,1957), includes the following ranges: Huaco, Las Salinas, Niquivil, Tucunuco; Mógna, Víllicum, Loma de las Tapias, Chica de Zonda, Pedernal and Acequión.

They are presented like assymetrical anticlines with axes of N-S strike -associated to western, vertical and reversed limbs -. The vergency of the main structures is west, while an increasing degree of stress can be seen towards the southern areas. These thrusts are represented by the presence of many inverse faults plain plunging to the east, while towards south of La Flecha gulch are more frequent, resulting in the imbrication and recurrente of the Paleozoic sequences, (Baldis *et al.* 1990). (Fig. 4-5)

Regional Geology

The Eastern Precordillera is a high-level thrust-and-fold with a thick Lower Palaeozoic sedimentary succesion that includes many and different depositional environments. Cambrian to Devonian sediments show a marine depositional environment, whereas the rest of the Neopalaeozoic succesion is particulary influenced by sedimentation in a continental environment. Red sediments of continental environment (Paleogene-Neogene), completes the stratigraphycal scheme associated to modern sedimentary infilling. (Fig. 5)

Carbonatic rocks of the Eastern Precordillera are exclusively Cambrian and Ordovician, reaching up to 2500 m in thickness, (Baldis and Bordonaro, 1981). This secuence is represented by limestones and dolomites of a shallow wide platform comprising the east and central part of the Precordillera. (Fig. 2)

Until 1979, only La Laja and Villicum Formation were recognized as Cambrian in age, while San Juan Formation was interpreted as Ordovician. Bordonaro (1980), proposed the name of Zonda Formation for the dolomites of Chica de Zonda and Villicum ranges (assigned to the Upper Cambrian only by stratigraphic criteria). The same author grouped all those materials in the Marquesado Group: (Fig. 2)

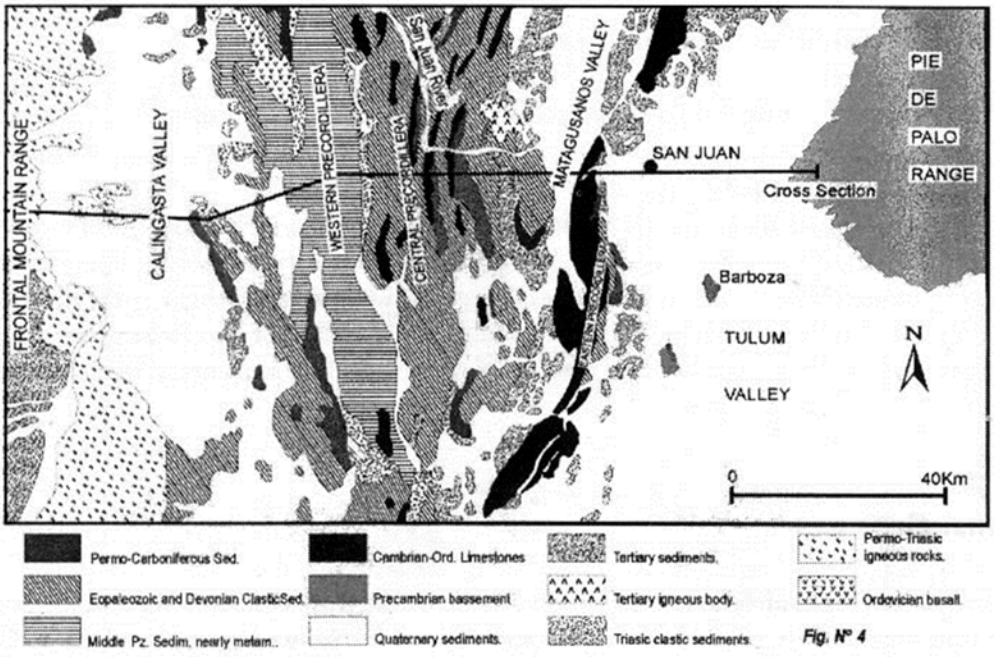
Marquesado Zonda Fm.

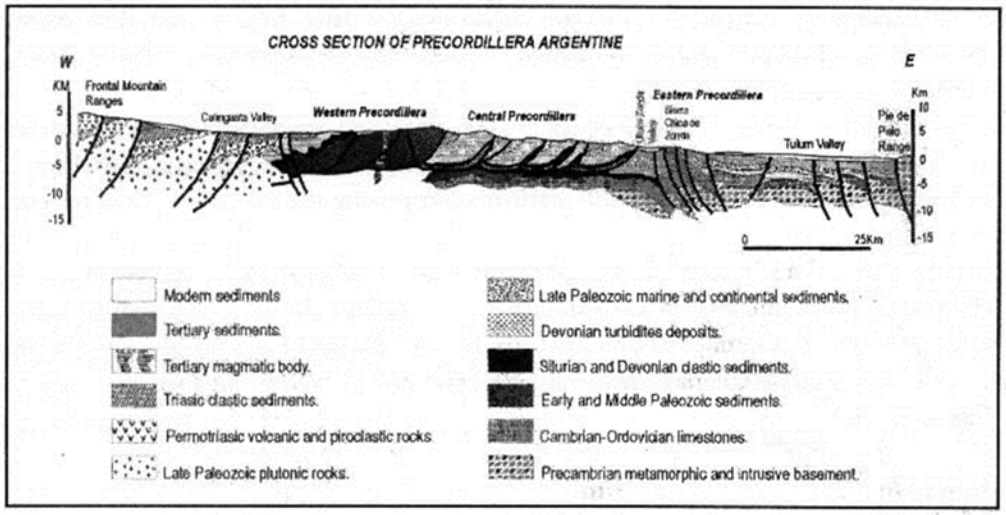
Group (Boxdonaro,1980)

(Bordonaro,1980) La Laja Fm. / / / Villicum Fm.

(Borrello,1962) (Borrello,1969)

The recognition of the lower boundary of San Juan Formation was always doubtful due to the type of sedimentary transition. Baldis et al. (1981) carried out detailed studies in the type locality and recognized two new equivalent formational units that draw the transition between the Cambrian and Ordovician limestones, including them in the Matagusanos Group. (Fig. N°2)





Cross section of Argentine Precordillera next to the 31° 31'south latitude, interpreted by Zambrani (1985). The Cambro-Ordimentary sequence by the main strenght in a tropical thin-skinned tectonic.

La Flecha Section

The Quebrada of La Flecha cuts transversally the Eastern Precordillera from East to West, fact that helps on a good observation of the excellent Section with nearly vertical plunged beds. The Cambro-Ordovician transition will be observed as we detail below:

Base: *La Laja Formation:* (Fig. 2)

Its name comes from the Quebrada de La Laja (Borrello,1962), locality where the first Cambrian faunas were described for the wholePrecordillera (Harrington and Leanza,1943). This rocks crop out on the western flank of the Sierra Chica de Zonda and Villicum.

The lower boundary is unknown due to tecnonic disturbance. The upper boundary is drawn at the transition from limestones to the dolomites of the Zonda Formation (Bordonaro, 1980).

The age comprises Lower to Middle Cambrian (Bordonaro 1980, 1986).

Zonda Formation: (Fig. 2)

Bordonaro (1980) named these rocks, stablishing the southern flank of the Quebrada de Zonda as the type section. Zonda Formation is lithollogically represented by dolomicrites, biolaminated deposits, intraformational conglomerates and mudstones with mud cracks. The stromatolites are scarce and belong to the LLH-type (Logan *et al.* 1964). Small silicified mud mounds also occur.

The lower boundary is given by the transition from limestones of the La Laja Formation to the dolomites of the Zonda Formation.The upper boundary was established by the sudden occurrence of abundant stromatolites at the base of La Flecha Formation.

The age of this formation is assignated by stratigraphical criterion, since in the top of La Laja Formation in the Sierra Chica de Zonda were found fossils indicating an uppermost Middle Cambrian age (Bordonaro,1980, 1986). Trilobites of the lowermost part of La Flecha Formation indicates an Franconian age; therefore the age of the Zonda Formation would be comprised between the Middle/upper Cambrian boundary and the lower part of the Franconian.

The thickness of the Zonda Formation varies between 300 and 400 m both in the Sierra Chica de Zonda and Villicum range.

La Flecha Formation: (Fig. 2)

No formal boudaries have been established in the base of section since it is cutted by a thrust, (Baldis, *et al.* 1981 a,b).). Keller *et al.* (1994) proposed the lower boundary where the first beds with abundant stromatolites or thrombolites occur (LLH- and SH-types of Logan *et al.* 1964). In some sections the boundary can be drawn by the change of white to brown dolomites.

The upper boundary was established in the interval where the contents of stromatolites rapidly decreases and the limestones start to predominate over the dolomitic rocks.

The age of the La Flecha Formation was stablished with trilobites from the base of the formation in the type locality in the Quebrada de La Flecha: *Plethopeltis cf. Saratogen*sis and according to Ludvigsen y Westrop (1983) y Ludvigsen *et al.* (1989), P. *Saratogen*sis indicates a late Franconian age. In the middle of the section was found *Stenopilus convergens* (Raymond), which is characteristic of the *Saukia* zone of the late Trempealeau (Longagre 1970, Ludvingsen *et al.* 1989).

The thickness of La Flecha Formation in the type section is about 400 m . In Guandacol area 600 m were reported at the Cerro La Silla 730 m were measured which is the maximun thickness recorded for this Fomation.

La Flecha Formation is composed of small-scale shallowing-upward cycles (1m - 5m), which exhibit a great variety of stromatolites, thrombolites and associated structures (Baldis *et al.* 1981a, Armella 1989a,b; Cañas 1990), together with subtidal to supratidal lithologies, characteristic of arid tidal flats (Keller *et al.* 1989). Early diagenetic dolomites are most abundant and it is frecuent the replacement of biogenetic structures as well as entire oolite beds by chert and chalcedony. Limestones or clacareous dolomites are scarce.

La Flecha Formation was eary defined as a succession of limestones and dolomites with abundant stromatolites, thrombolites and cryptalgal laminites ("Stratifera" de Baldis *et al.* 1981 a). The relative abundance of these biogenic structures was used to subdivide this formation into three members: (Los Berros, Arrecifal and Cañada Honda). Keller *et al.* (1994), proposed the elimination of the names "San Roque Formation" and "Los Sapitos formation" and they recommended the use of the name "La Flecha Formation" (in the sense of Baldis *et al.* 1981b) throughout the Precordillera.

Top: La Silla Formation. (Fig. 2)

Keller *et al,* (1994),

Age: Upper Cambrian (uppermost Trempealeau) to Upper Tremadoc *(deltifer* zone).

Algal biocycles associated to La Flecha Formation (Upper Cambrian)

The stromatolitic sequence of La Flecha was first described by Baldis (1981 a). He pointed out a cyclothematic arrangement and the continuous association of stromatolites and thrombolites, indicating changes in the biogenetical conditions.

Baldis *et al.* (1981b), carried out a study on the sector of dispersion of the stromatolites and presented the analysis of the cyclothemes. He defined La Flecha Formation and characterized the depositional environment as hipersaline in a high stability condition. The process was iniciated previously in Zonda Formation, whose sedimenta indicate a period of regression changing to a bottom stability period.

Baldis *et a!.* (1985), stablished the secuenciality an idealized algal biocycle with a basal hemicycle associated to chemical sedimentation. Also to the top a hemicycle characterized by biological sedimentation-characterized by limestones-planar stromatolites-domal stromatolites and thrombolites.

Baldis *et al.* (1985), concluded that the algal biocycles of Precordillera were a result of the fluctuation on the water depth changing from shallow conditions in the basal section to deeper conditions in the upper section of biocycle.

Armella (1989a), also stablished the trhombolitical microfacies of an ideal biocycle for the La Flecha Formation, identifying eigth microfacies:

MF-1: Steril micritic mud.

MF-2: Planar and domal stromatolites of slow relief, with *Stratifera, Irregularia, Collenia, Paniscollenia* and *Weedia.*

MF-3: Domal and composed stromatolites: with *Collenia* and *Criptozoon.*

MF-4: Mantle trombolites.

MF-5: Spheric trombolites.

MF-6: High relief trombolites.

MF-7: Microfacies of interthrombolitic channel.

MF-8: Microfacies ofinfill interthrombolitic no channalized.

The same author concluded that the combination of the eight microfacies indicates a ciclycal subsident feature for the Cambro-Ordovician basin. This showed biocycles that generated slightly transgresive episodes, where the rate of subsidence was equal or bigger than the biosedimentation, characterized by an sharp regression on top of each cycle.

According to Keller *et al.* (1989), The Upper Cambrian sedirrients of La Flecha Formation, consist mainly of peritidal cyclic carbonates. The depositional environment extended from the shallow subtidal to the supratidal, sometimes even calcretes were formed. Typical subtidal units show thrombolites, oolites and lithoclastic limestones. The intertidal shows a great variety of stromatolitic associations, among which for the first time mudmounds and fenestral mudmounds of a peritidal origin. Supratidal sediments, mostly mudstones, ehibit mudcracks, tepee-structures and some diagenetic evaporites. The sediments and their arrangement in shallowing-upward cycles represent an acient sabkha system

developed on a stable shelf, probably the western passive continental margin of Gondwana.

The shallowing-upward cycles (according to Keller *et al.* 1989)

The carbonates of the La Flecha Formation shows well developed cyclicity, which was descibed by Baldis *et al.* (1981 a,1984). Keller *et al.* 1989, also considered the accopmanying sediments, where the cyclicity becomes more pronounced.

The cycles normally start with a transgression over a pre-existing, lithified topography with only a smooth relief. The basal oolites and lithoclastic graintones are the remnants of the transgression and are either preserved as laterally persistent sheets or in erosional and dessication structures such as scours, mudcracks and tepees. Laterally, these high energy deposits interfinger with thrombolites, which grew under subtidal conditions. The lower intertidal unit comprises most of the LLH-type stromatolites. Wave and water activity determine, whether the accompanying sediment is of low (mud) or high energy origin (oolites, lithoclasts). They grade upward into more stratified, laminated deposits (microbial laminites, mudstones) of the upper intertidal zone. Here we find many sedimentary structures higly indicative of a tidal flat environment: mudcracks, tepees and fenestral fabrics. Upwards, storm-deposited mud on supratidal flats is rapidly lithified and often fractured into poligons by desiccation or growth of evaporite minerals. This is the zone, where flat pebble breccias form and the majority of the evaporites is precipitated within the sediment column. Finally, longterm exposure leads to the formation calcretes, which arrange only rocks formed in a terrestrial environment. (Fig 6)

In the La Flecha Formation more than 100 superimposed cycles were found. An autocyclic model was proposed for the origin of the shallowing-upward cycles: Subtidal and intertidal sedimentation exceeded the subsidence (or sea level rise) of the eastern Precordillera resulting in a regression. This led to a supratidal or even terrestrial environment with a low sedimentation rate or even nondeposition. Continuous subsidence resulted in a relative fast transgression which was balanced by sedimentation as soon as subtidal to intertidal organisms (e.g. thrombolites and stromatolites) resettled the subtidal to intertidal environment.

In the Precordillera, the Grand Cycles comprise the lower and middle Cambrian strata (Baldis and Bordonaro 1982), and each of them shows a shallowing-upward (regressive) tendency. Thus, the La Flecha Formation was interpreted as the culmination of an overall regressive sequence from the Lower to the Upper Cambrian, followed by a renewed transgression during the Lower Ordovician (see Baldis and Bordonaro,1981).

FACIES OF UPPER CAMBRIAN SHALLOWING-UPWARD CYCLES

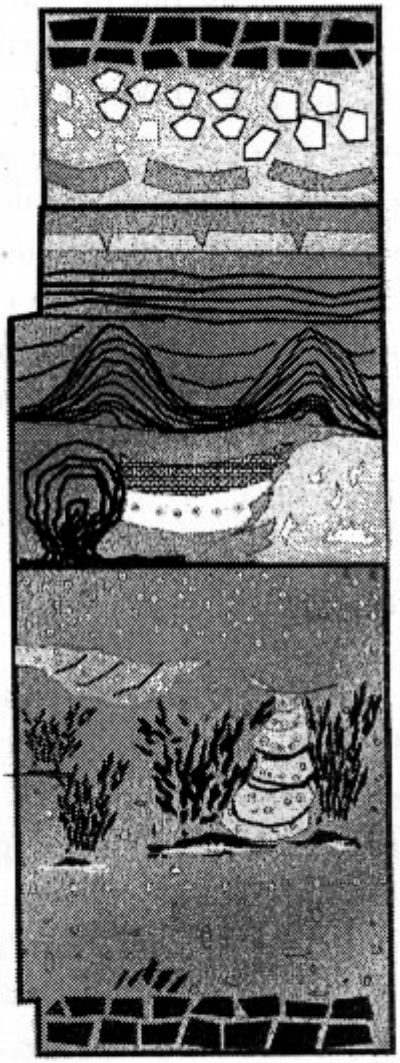


Fig. N° 6: Ideal shallowing-upward cycle of the La Flecha Formation. Thickness of one cycle in the range of 1 - 10 m. Keller et al. (1989).

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