Zapla Range, Subandean Ranges, Jujuy Province

Gladys Ortega[1], M. Cristina Moya[2] and Guillermo L. Albanesi[1]

[1] CONICET. Museo de Paleontología, Universidad Nacional de Córdoba, C.C. 1598, 5000 Córdoba. E–mail: galbanesi@arnet.com.ar / gcortega@arnet.com.ar

[2] CONICET, CIUNSA. Universidad Nacional de Salta. Buenos Aires 177, 4400 Salta. e–mail:crismoya@unsa.edu.ar

Introduction

Stratigraphic framework

The Subandean Ranges (Sierras Subandinas) are placed between the Eastern Cordillera (Cordillera Oriental) to the west and Chaco–pampean Plain to the east, in northwestern Argentina. Stratigraphic and structural studies of this geological province were carried out by Bonarelli (1913, 1921), Baldis *et al.*(1975), Mingramm *et al.* (1979), and Ramos (1999), among others. Ancient deposits of the Subandean Ranges correspond to the Proterozoic and Ordovician System, which are restricted to the western part. Silurian–Devonian rocks of wider distribution integrate a thick marine–deltaic succession tapering to the east, which is linked to a foreland basin (Turner, 1967; Ramos, 1999).

The Ocloyic unconformity (Turner & Méndez, 1975; Ramos, 1986) separates Lower–Middle Ordovician rocks from Hirnantian and younger deposits (Moya, 1999).

The Lower Paleozoic succession is covered by thick marine and continental sequences of Neopaleozoic, Mesozoic and Cenozoic ages. An angular unconformity is present between ancient deposits and Miocene to Quaternary sediments.

The Subandean Ranges show wide east–vergence anticlines, limited by thrusts and overthrusts, whose detachment levels are Silurian–Devonian shales (Ramos, 1999). The structural style of this geological province allows for the identification of the Interandean System to the west, and the Subandean System *sensu stricto* to the east (Ramos, *op. cit.*). The Interandean System is separated from the Eastern Cordillera by a thrust (principal interandean thrust of Roeder, 1988), which rises Proterozoic and Eopaleozoic sequences over the Subandean System (Ramos, 1999).

The Labrado Hill, Zapla and Puesto Viejo ranges, located in the Interandean System, are brachianticlines with Paleozoic rock cores. The Ordovician (pre–Ocloyic) succession (Zanjón, Labrado, Capillas, and Centinela formations) consists of alternating sandstones and shales with calcareous subordinate levels (Harrington, 1957; Monaldi, 1986). The fossil record is usually scarce in these rocks. The Labrado and Capillas formations bear inarticulate brachiopods, conodonts, trilobites (*Thysanopyge argentina*), and trace fossils

(*Cruziana* and *Skolithos* ichnofacies), which indicate an Arenig age. The Capillas Formation includes a more diverse fauna (*"Brongniartella zaplensis", "Hoekaspis schlagintweiti", Ctenodonta* sp., *Lingula* sp., nautiloids, and ichnites) that is referred to the Llanvirn. The Centinela Formation yields inarticulate brachiopods, trilobites ("*Brongniartella zaplensis*"), and *skolithos* (Monaldi *et al.*, 1986).

Post–Ocloyica deposits commence in the upper Ashgill (Hirnantian) and evolve during the Silurian and Devonian. They are bounded by the Chánica unconformity (Late Devonian – Early Carboniferous). The Hirnantian Zapla Formation (Schlagintweit, 1943) is made of clastic heterogeneous deposits with subordinate sandstones and shales, and scarce fossils. The record of *Dalmanitina subandina* allowed to referring this unit to the Hirnantian (Monaldi & Boso, 1987). The glacial or glaci–marine origin attributed to this formation is linked to the presence of striate and facet clasts (cf., Turner, 1964; Boso, 1999). Silurian deposits of the Lipeón Formation overlie Hirnantian or younger units.

Stop 1. 9 de Octubre Mine.

The Lipeón Formation (Turner, 1960) is exposed in several areas of the Subandean Ranges. Outcrops in the Zapla range, located to the southeast of San Salvador de Jujuy City, Jujuy Province, are well–known because of the economically–important iron beds in the lower part of the Lipeón Formation (Angelelli, 1946; Cecioni, 1953) (Figure 1). In the Zapla range this unit conformably overlies the diamictites of the Zapla Formation and is transitional to the sandstones of the Arroyo Colorado Formation (early Devonian). In the Puesto Viejo range the Lipeón Formation is unconformably overlain by the Yacoraite Formation (Cretaceous–Paleocene) (Figure 2). The Lipeón Formation can be correlated with the Kirusillas Formation in Bolivia and with the Copo Formation of the Chaco–Paranense Basin (Vistalli, 1999).

The Lipeón Formation consists mainly of shales interbedded with fine micaceous sandstones. Red to grey haematitic beds characterize the basal part of the unit. In some exposures there are lenticular, sandy levels with cross bedding. Monteros *et al.* (1993) consider the beds in the Los Tomates stream, Zapla range as palaeochannel fillings which indicate a shallowing event. The irregular appearance of conglomerate lenses and dispersed quartz clasts in the lower levels suggested to some authors the presence of a local unconformity between the Lipeón Formation, and the underlying Zapla Formation (Oliver, *in:* Andreis *et al.,* 1982). On a regional scale there exists an apparent conformity between both units (e.g. Boso & Monaldi, 1990; Monteros *et al.,* 1993).

Cecioni (1949) and Baldis *et al.* (1976) recognised three members in the Lipeón Formation. The lower member ("areniscas amarillentas", ca. 220 m thick) consists of fine to medium micaceous wackes of yellow brown colour with iron staining. In the basal 17 m of this member there are two iron beds of haematitic wackes, the lowest one of economic value (Boso & Monaldi, 1990). The middle member ("areniscas y arcillas claras", ca. 300 m thick) is characterised by brown to grey siltstones and mudstones, including subordinate, dark wackes in the lower part. Near the top of the member, the sandy levels are more frequent, grading to the Arroyo Colorado Formation (early Devonian), which indicates the beginning of a regressive cycle.

The transitional levels constitute the upper member (ca. 100 m) of some authors (Cecioni, 1949) or the base of the Devonian Arroyo Colorado Formation (Andreis *et al.*, 1982). According to Donato *et al., in:* Vistalli (1999) the Zapla, Lipeón, Baritú and Porongal formations (late Ordovician–early Devonian) in the northern Subandean Ranges, encompass an upward grading granulometric cycle, the "Cinco Picachos" supersequence, which is developed between the Oclóyica and the Chánica unconformities.

The thickness of the Lipeón Formation is variable. Boso & Monaldi (1990) measured 680 m in the Los Tomates Stream (Zapla Range) and 480m in the Yuchán Ravine (Puesto Viejo Range). Graptolites are very rare in the Lipeón Formation and usually comprise monotypic and badly–preserved faunas.*Talacastograptus leanzai* Cuerda, Rickards and Cingolani and *Metaclimacograptus? robustus* (Cuerda *et al.*) are the dominant forms. *Normalograptus normalis* (Lapworth) and probable *N. rectangularis* (McCoy) specimens (Monteros *et al.*, 1993; Rickards *et al.*, 2002) are scarce (Figure 3). An internal zig–zag list structure, visible when the lateral peridermal wall is broken, was described for the first time for *Talacastograptus* by Rickards *et al.* (2002).

In the middle–upper portion of the lower member specimens of *Zoophycos* (ichnogenus) are abundant and graptolite remains scarce. Benthonic fossils are common in the middle–upper part of the Lipeón Formation ("light claystones and sandstones" member). The nautiloid, trilobite, brachiopod and pelecypod faunas were studied by many authors (e.g. Cecioni 1953; Baldis *et al.,* 1976; Malanca & Monaldi, 1987; Aceñolaza and Hünicken, 1989; Benedetto, 1991; Sánchez, l990, 1991; Waisfeld & Sánchez, 1993).

A trilobite assemblage with *Calymene ferrifera* Baldis & Blasco, *Diacalymene subandina* Baldis & Blasco, *Australoacaste palpalensis* Benedetto & Martel, *Trimerus* (*Trimerus*) *flexuosus* Benedetto & Martel, *T.* (*T.*) *grandis* Benedetto & Martel, *Jujuyops nonoctubrensis* Baldis & Blasco, *Zaplaops zaplensis* Baldis & Blasco and*Dalmanites sudamericanus* Benedetto & Martel was studied by Baldis *et al.* (1976), who referred the middle part of the Lipeón Formation to the Wenlock–Ludlow interval. The Silurian–Devonian boundary would be constrained to the upper member of the Lipeón Formation, which bears *Pericopyge transglabelaris* Benedetto & Martel and *Harringtonacaste harringtoni* Baldis & Blasco.

The graptolite localities are placed on the western flank of the Zapla range (9 de Octubre mine and Los Tomates stream) and in Puesto Viejo range (Yuchán ravine), Jujuy Province (Figure 1). They were found in the lower part (ca. 130 m) of the Lipeón Formation (Figure 2). The rock is a mica–rich, ferruginous sandstone, and a certain amount of soft sediment deformation is indicated by the twisting of the rhabdosomal fragments. Some of the ferruginous material infilling the graptolites is now limonite or goethite, with some haematite. The fauna is current sorted to a degree because a few proximal ends have been found in the collections.

T. leanzai and *M.? robustus* were originally recorded in the lower part of the La Chilca Formation, Precordillera of San Juan, associated with *Normalograptus angustus* (Perner), *N. normalis* (Lapworth), *N. rectangularis* (McCoy) and *Lagarograptus praeacinaces* Cuerda, Rickards & Cingolani (Cuerda *et al.*, 1988). The main difference between the two faunas is the absence in the Lipeón Formation of *Lagarograptus praeacinaces.* In the Argentine Precordillera only the highest recorded level with *T. leanzai* lacks *L. praeacinaces*, so the Lipeón Formation locality might perhaps equate with this horizon, namely uppermost *atavus*Biozone. Rickards *et* *al.* (2002) suggested that the Lipeón Formation is likely to be of *acuminatus* Zone near its base and probably *atavus* Zone (early Llandovery) near its middle portion.

Stop 2. Intermediate stops on Route 9, from San Salvador de Jujuy to Tilcara cities (Eastern Cordillera).

Punta Corral Creek (southern entrance to the Quebrada de Humahuaca) between Volcán and Tumbaya localities (Figure 5).

First view. The Punta Corral Creek runs along the homonymous fault trace. The fault separates the Alfarcito Ranges from the Tilcara Ranges (Figures 5 and 6). These ranges are mainly integrated by basement, Cambrian–Ordovician (MG and SVG), and Cretaceous–Tertiary (Salta Group) deposits.

Second view. When comparing quaternary terraces on both riverbanks, it is evident that the Río Grande Tectonic Front (Figure 6) causes a strong elevation of the western flank. Major tributary alluvial fans of the Grande River descend from this flank.

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