The Mojotoro Range, Eastern Cordillera, Salta Province

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Introduction

The Mojotoro Range (MR) is located at the SE end of the Argentine Eastern Cordillera, to the east of Salta City (Figure 7a,b). From a structural point of view, the MR is a complex anticlinorioum of N–S strike that closes to the north, at the latitude of San Antonio (Jujuy Province), and is cut to the south by the San Agustín fault (Salta Province) (Figure 7b).

The anticline core is a clastic basement (late Proterozoic–Early Cambrian) with low grade metamorphism. This basement unconformably underlies (Tilcara unconformity) deposits of the Mesón Group and the Santa Victoria Group. The Salta Group (Cretaceous–Eocene) crops out in the southern end of the Mojotoro Range and lies over different Ordovician units. Deposits of the Oran Group (Tertiary, Neogene) are distributed near the eastern flank of the MR, and the contact of those deposits with the basement or cover rocks is always tectonic (Figures 7b).

The Mojotoro Range is a typical structure of the Andean foreland, which is characterized by folding and overthrusts of eastern dip. The displacement took place by means of important reverse faults of N–S direction, affecting the basement and Palaeozoic cover on the eastern flank.

The main thrust is located in the middle part of the MR section, where the eastern flank is inverted. There only appear post–Tremadocian deposits because of the faulting that suppressed the Mesón Group and Tremadocian units of the Santa Victoria Group. However, these deposits are well–represented on the western flank of Mojotoro Range.

Another fault system of NO–SE direction transversally cuts the Mojotoro Range (Figure 7b), interrupting the lateral continuity of Palaeozoic rocks. They are left–handed faults, probably linked with the dynamics of El Toro Lineament. Two of these faults –Quebrada Honda and San Agustin (Figure 7b)– present evidences of pre–Cretaceous activity: a) It is supposed that the Quebrada Honda fault controlled the southern margin of the Cambrian basin, because deposits of the Mesón Group (only 17 m thick) lend out to the north of this fracture, and do not crop out to the south of it. b) It is verified that the San Agustín fault constitutes an erosive margin of the Ordovician basin (Moya, 1988a), which was worked previously to the deposits of Salta Group. Thick Ordovician deposits of the Mojotoro Range are abruptly interrupted against this fracture; toward the south, in the summits of Castillejo, the Salta Group covers the basement as well as few Ordovician tectonic sheets.

The San Bernardo Hill

The San Bernardo Hill is a historical, geographical and touristic landmark. It is the portal of Salta City, the geographical point of reference to locate the city in the physical context of northwestern Argentina. It is the presentation postcard of Salta and a forced walk for the tourist and the resident that want to enjoy the beauty of the Lerma Valley.

Within this framework, the Portezuelo de Salta is particularly significant in the history of the geological knowledge of the Ordovician System in Argentina. First Ordovician fossils described by Kayser (1876) and the first graptolite found in the country (Brackebusch, 1883; Kayser, 1897). A part of the graptolite collection described by Loss (1951) also come from the Portezuelo de Salta.

This author was the first one to point out an Arenig age for the deposits of the San Bernardo Hill and mentions, among others, *Clonograptus flexilis* (Hall), *Tetragraptus lavalensis* (Ruedemann), *T. sanbernardicus* Loss, *Didymograptus vacillans* Tullberg, *D. deflexus* Elles & Wood, *D. v–fractus* Salter and *D. nitidus*(Hall).

Later, Harrington (1957) defines the San Bernardo Formation to identify the deposits of the homonymous hill; this author describes an abundant trilobite fauna (the "*Thysanopyge*" Fauna) and a varied accompanying shelly fauna. Numerous subsequent studies enriched the knowledge of Ordovician deposits exposed in the San Bernardo hill (*e.g.,* Aceñolaza, 1973; Benedetto & Toro, 1975; Moya *et al.*, 1994; Moya, 1998; Gutiérrez–Marco & Aceñolaza, 1999; Monteros & Moya, 2002, 2003).

The San Bernardo Hill and the 20 de Febrero Hill were declared Natural Reservations. The extraction of rock and fossil samples from these natural heritages are not allowed (Decree Nº 1533/1997 of the Intendency of Salta City).

Stop 1. Portezuelo de Salta, San Bernardo Hill. Lower third of San Bernardo Formation (SBF) (Figures 5, 7, 8)

The SBF covers the Aspero Formation (Sandstone 3) and underlies the Mojotoro Formation (Sandstone 4). The SBF represents the transgressive event that succeeds to the NORE (*Notopeltis orthometopa Regresive Event*), which probably correlates with the *Ceratopyge Regressive Event* of Erdtmann (1986) (Moya*et al.,* 2003).

First view. The lower part of the SBF includes a thinning–finning upwards cycle that includes minor parasequences of similar arrangement. Deposits are represented by silty shales, siltstones and fine–grained olive–green wackes, interbedded with sandstones and conglomerate beds. These deposits would have accumulated on inner to outer shelf environments.

Sandy flows of high energy, rich in bioclasts, were frequently transported into the muddy marine platform. These flows would have been generated by storms surf (Moya, 1998) or for deltaic discharges (Barrientos, 2002).

Oldest deposits contain the last records of trilobites that characterize to the *Notopeltis orthometopa* Zone (Interval VI of Moya *et al.,* 2003).

Above these levels other deposits contain *Aorograptus victoriae* Hall, *Paradelograptus mosseboensis* Erdtmann, Maletz & Gutiérrez Marco, *P. onubensis* Maletz & Gutiérrez Marco, *Paradelograptus* sp., *Kiaerograptus* cf. *pritchardi* (Hall), *K. supremus* Lindholm, *Paratemnograptus isolatus* Williams & Stevens, *Clonograptus* sp.,*Adelograptus* sp. and *Bryograptus*? nov. sp. (Monteros & Moya, 2003) (Figure 11).

The last appearance of *A. victoriae* coincides with the first record of *Tetragraptus*? *bulmani* together with the first didymograptids that are being studied.

That graptolite association is accompanied by articulate and inarticulate brachiopods, bivalves, cephalopods, gasteropods, echinoderms and ostracods; microfossils are represented by conodonts, acritarcs, and chitinozoans.

Trilobites deserve a particular mention, since all recorded forms are typical representatives of the *Thysanopyge* Fauna. Reference species include *Thysanopyge argentina* Kayser, *Kayseraspis asaphelloides* Harrington, *K. brackebuschi* (Kayser), and *Sanbernardaspis pygacantha* Aceñolaza.

Monteros & Moya (2003) assign a Late Tremadocian age for the mentioned fossiliferous interval; that is, the time interval covered by the *Kiaerograptus* Zone and the lower part of the of *A. murrayi/pulchellus* Zone (*fide* Cooper, 1999).

Second view. Thick conglomerate packages and immature sandstones are interbedded in offshore shales. They are lenticular and channeled deposits, of erosive base, with furrows up to 0,60 m of depth, linked with quick discharges of grains and of detritus. A flow direction toward NW was established on the base of substratal structures (fluting, flow cast). Fossils of these deposits come from coquina clasts and blocks of conglomerates.

These deposits correlates with the detritus flows described by Moya (1997) in the Lesser Range. This author associates them with the tectonic during the tectonic event that caused the Tumbaya unconformity.

Stop 2. Summit of the San Bernardo Hill (Figures 5, 7). View of Salta City and of the main orographic and hidrographic features.

Recognition of deposits that constitute the middle–upper part of the SBF and the transition between this unit and the Mojotoro Formation (MF). Discussions regarding its features will be made by descending topographicaly and stratigraphicaly, so that the first observations will be referred to the mentioned transition, and will culminate in equivalent levels to the conglomerates and sandstones described in the *second view* of stop 1.

First view. Transition between the MF and the SBF. It consists on heterolithic successions (sandstones/mudstones) very bioturbated and separated by quartzites and quartz–calcareous sandtone packages of 1.5 m – 7 m in thickness. The latter contains *Araneograptus murrayi* and abundant didymograptids (study in progress).

Heterolithic successions are represented by facial associations of sandstone/mudstone or coquina/sandstone/mudstone that integrate fining upwards intervals. The coquinas consist of lingulid accumulations with diverse preservation degree.

Siltstones show a remarkable bioturbation. Mángano & Buatois (1999) mention vertical room traces (*Skolithos linearis*) and horizontal ones (*Palaeophycus tubularis*), shepherding hints *(Helminthoidichnites tenuis*), and feeding structures (*Chondrites* sp.). In general, they represent an example of the *Cruziana*ichnofacies within enviorenments that oscillate between a lower shoreface and upper offshore.

Second view. Middle–upper part of the SBF. Olive green silty and muddy shales, interbedding fine sandstone. In these deposits the fossil record is very scarce. This succession covers conglomerate and sandstone facies that constitute the lateral prolongation of flows observed in Stop 1.

Miraflores Area, San José Hill, Severino Creek, Gallinato Creek, Zapla Range

Stop 1. Miraflores Area, Floresta Formation (Figures 5, 7, 8).

Clayey and silty shales with a few intercalated beds of fine grain tempestites. Deposits were accumulated in a distal–outer shelf environment. Fossiliferous intervals are scarce; they are represented by well–preserved shelly organisms or even upholstered levels with monospecific graptolite faunas. Indicated levels contain abundant colonies of *Bryograptus* sp. aff. *B. kjerulfi*. Sampled strata correspond to the lower–intermediate tract of Floresta Formation.

Stop 2. Western flank of the San José Hill, upper part of the San José Formation (Figures 5, 7, 8).

Dark–gray fine wackes and clear–gray medium wackes finely laminated and banded, with rusty authigenic sulfurous. Green and clear–grey clayey and silty shales are intercalated. The deposits are linked with a distal and intermediate offshore environment and they bear an abundant benthonic fauna:*Jujuyaspis keideli* Kobayashi, *Parabolinella argentinensis* Kobayashi, *Apatokephalus exiguus* Harrington & Leanza, agnostids. Shales contain *Rhabdinopora flabelliformis* (Eichwald) remains.

Stop 3. Route 9, south of Severino Creek, middle part of the Floresta Formation (Figures 5, 7, 8).

First view. Thick beds of fine quartzose sandstones, generally amalgamated and separated by heterolithic intervals of shales and fine bioturbated wackes. Sandy beds frequently begin with trilobites and brachiopod coquinas. They are interpreted as tempestites deposited in a shoreface environment, where good time deposits would be represented by a bar–interbar complex, bearing anisograptid rhabdosomes (Monteros, in progress).

Fossil remains correspond to the *Kainella meridionalis* Zone, for example: *Asaphellus catamarcensis* Kobayashi, *Leptoplastides marianus* (Hoek), *Kainella meridionalis* Kobayashi, *Pseudokainella beats* (Kobayashi), *Pseudokainella sp.* cf. *P. conica* (Kobayashi), *Trilobagnostus hoeki* (Kobayashi), *P. argentinensis*, *Parabolinella coelatifrons* Harrington & Leanza, *Angelina kayseri* Harrington & Leanza, and numerous orthids and lingulids.

Second view. The Santa Rufina Fault (Figure 7). In the northern block the Campanario, Chalhualmayoc (Mesón Group, MG), Pedrera, and San José Formations crops out. The southern block corresponds to deposits of the Floresta Formation. The left slip of the fault and the uplift of the northern block can be verified because Cambrian (MG) and Tremadocian (Floresta Formation) deposits are confronted along the same line at equal topographic level.

Stops 4, 5, 6. Gallinato Creek, eastern flank of Mojotoro Range (Figures 5, 7, 9).

Stop 4. The Eastern Ocloyic Front faults (Figure 7).

This fault puts in contact basement rocks with post–Tremadocian deposits of the Santa Victoria Group (Mojotoro and Santa Gertrudis formations). These units are inverted, structural situation that will easily be proven looking at the position of sedimentary (tangential cross–bedding) and biogenic (*Cruziana*) structures.

Stop 5. Mojotoro Formation (MF) (Figures 7 and 9).

A succession of thick quarzites, heterolithic sandstone/mudstone intervals with strong bioturbation, phosphatics crusts, nodules, and eventual lingulid coquinas. The MF would have been deposited in a tide–dominated marine platform (subtidal–intertidals environments).

Mángano *et al. (*2001) identified the *Skolithos* and *Cruziana* ichnocoenosis. Dense pavements dominated by *Cruziana furcífera*, *C. rugosa*, *C. goldfussi*, *C. problematica*, *Monomorphichnus multilineatus*, and *Palaeophycus tubularis*, characterize the base quartzose sandstones layers.
The *Skolithos* ichnocoenosis is monospecific including *Skolithos linearis* endichnias structures crossing quartzite beds. This ichnocoenosis cuts the *Cruziana* ichnocoenosis giving place to a palimpsest factory that registers the activity of two successive communities.
The *Cruziana* ichnocoenosis give answers about the residing ichnofauna in sectors of moderate to low energy in subtidal to intertidal interbar areas, while the *Skolithos* ichnocoenosis registers opportunist colonization of the complex of subtidal waves, under high to moderate energy conditions (Mángano *et al.,* 1999).

Volkheimer *et al.* (1980) indentified two microfossils associations, and established a minimum Llanvirn age for the middle part of MF. Registered macrofossils of the MF correspond to lingulids. According to G.F. Aceñolaza (pers. comm.), they could trace a linkage between the MF and other deposits of the western border of Gondwana.

Stop 6. The Santa Gertrudis Formation (SGF) (Figures 7, 9, 12).

It consists of fine–medium slightly micaceous wackes and dark–greenish gray silts, with ripple cross–lamination and weak stratification. These deposits were assigned to a shallow platform influenced by waves, although not by streams, probably corresponding to the lower area of an inner platform. Thin beds of phosphatic limestones from the middle–upper portion of the SGF yielded an abundant conodont fauna dominated by hyaline forms of late Llanvirn – early Caradoc age (Albanesi and Rao, 1996; Albanesi in progress, see Figure 12). The conodont color alteration index indicates low overbunden paleotemperatures (60–140ºC) for the bearer strata. The abundant shelly fauna is integrated by *Hoekaspis* sp., *Neseuretus* (*Neseuretus*) sp., *Huemacaspis* sp. (trilobites), *Drabovinella mojotoroensis* Benedetto (brachiopod), *Cadomia typa* De Tromelin, Mallettidae indet., *Cyrtodontula* sp., *Cycloconcha* cf. *C. oblonga* Foerste and *Edmondiacea?* indet. (bivalve) (Waisfeld, 1996; Benedetto 1999; Sánchez, 1986).

References

Aceñolaza, F.G. 1973. *Sanbernardaspis pygacantha* nov. gen. *et* nov.sp. (Trilobita–Asaphidae) del cerro San Bernardo, Salta, República Argentina. *Ameghiniana*, 10: 132–138.

Albanesi, G.L. & Rao, R.I.. 1996. Conodont fauna from the Santa Gertrudis Formation (Middle–Later Ordovician), Eastern Cordillera, Northwestern Argentina. *Sixth International Conodont Symposium. Polish Academy of Sciences, Institute of Paleobiology. Warszawa, Poland*. Abstract: 3.

Barrientos Ginés, A. 2002. Análisis de facies en el tercio inferior de la Formación San Bernardo (Ordovícico), sierra de Mojotoro, Salta. *Actas 15º Congreso Geológico Argentino*, I: 734–737.

Benedetto, J.L. 1999. El género *Drabovinella* (Brachiopoda) en el Caradociano de la Sierra de Mojotoro, provincia de Salta, Argentina. *Ameghiniana* 36: 235–238.

Benedetto, J.L. y Toro, M. 1975. Desarrollo ontogenético de *Thysanopyge argentina* Kayser (Trilobita) y la validez de *Megalaspis saltaensis* (Kayser). *Actas 1º Congreso Argentino de Paleontología y Bioestratigrafía*, Tucumán, 1: 175–190.

Brackebusch, L. 1883. Estudio sobre la Formación Petrolífera de Jujuy. *Boletín Academia Nacional de Ciencias,* Córdoba, 5: 137–148.

Cooper, R.A. 1999. The Ordovician time scale–calibration of graptolite and conodont zones. *In*: P. Kraft & O. Fatka (eds.), *Quo vadis* Ordovician? Acta Universitatis Carolinae–Geologica*,* 43: 1–

Erdtmann, B–D. 1986. Early Ordovician eustatic cycles and their bearing on punctuations in early nematophorid (planktic) graptolite evolution. *In:* O. Walliser (ed.), *Global bio–events*, Lecture Notes in Earth Sciences, 8: 139–152.

Gutiérrez–Marco, J.C. y Aceñolaza, G.F. 1999. Hallazgo de *Lingulocystis* (Echinodermata, Eocrinoidea) en el Ordovícico del Cerro San Bernardo. *Actas 14º Congreso Geológico Argentino*, Salta, I: 350–354.

Harrington, H.J. 1957. Ordovician Formations of Argentina. *In*: H.J. Harrington & A.F. Leanza. Ordovician Trilobites of Argentina. *Department of Geology, University of Kansas*, Lawrence, Special Publication 1: 1–59.

Kayser, E. 1876. Über primordiale und untersilurische Fossilien aus der argentinischen Republik. *Palaeontographica, Berlin, suppl.* 3, Lief. 2.

Kayser, E., 1897. Beiträge zur Kenntnis einiger paläozoischer Faunen Südamerikas. *Zeitschr. deutsch. geol. Gesell.,* 49: 274–317.

Loss, R. 1951. Contribuciones al conocimiento de las faunas graptolíticas del norte argentino. 1. Graptolites del Cerro San Bernardo (Salta) y zona del Dique La Ciénaga (Jujuy). *Revista de la Asociación Geológica Argentina*, 6: 21–61.

Monteros, J.A. & Moya, M.C. 2002. La Zona de *Aorograptus victoriae* (Ordovícico Inferior) en la sierra de Mojotoro, Cordillera Oriental Argentina. *Actas 8º Congreso Argentino de Paleontología y Bioestratigrafía*, Corrientes: 88.

Monteros, J.A. & Moya, M.C. 2003. Late Tremadocian Graptolites from Mojotoro Range, Argentine Eastern Cordillera. *In:* G.L. Albanesi, M.S. Beresi & S.H. Peralta (eds.), *Ordovician from The Andes,* Proceedings of the 9th International Symposium on the Ordovician System and 7th International Graptolite Conference, Argentina.

Moya, M.C. 1988. Lower Ordovician in the Southern Part of the Argentine Eastern Cordillera. *In*: H. Bahlburg, Ch. Breitkreuz y P. Giese (Eds.). *The Southern Central Andes*, Lecture Notes in Earth Sciences, Springer–Verlag, Heidelberg, 17: 55–69.

Moya, M. C. 1997. La fase Tumbaya (Ordovícico Inferior) en Los Andes del norte argentino. *Actas 8º Congreso Geológico Chileno*, I: 185–189.

Moya, M.C. 1998. El Paleozoico inferior en la sierra de Mojotoro, Salta–Jujuy. *Revista de la Asociación Geológica Argentina*, 53:219–238.

Moya, M.C., Malanca, S. Monteros, J.A. y Cuerda, A., 1994. Bioestratigrafía del Ordovícico Inferior en la Cordillera Oriental argentina, basada en graptolitos. *Revista Española de Paleontología*, 9: 91–104.

Moya, M.C., Malanca, S. & Monteros, J.A. 2003a. The Cambrian–Tremadocian Units of the Santa Victoria Group (Northwestern Argentina). A New Correlation Scheme. *In:* G.L. Albanesi, M.S. Beresi & S.H. Peralta (eds.), *Ordovician from The Andes,* Proceedings of the 9th International Symposium on the Ordovician System and 7th International Graptolite Conference, Argentina.

Sánchez, T.M. 1986. Una fauna de bivalvos en la Formación Santa Gertrudis (Ordovícico) de la Provincia de Salta (Argentina). *Ameghiniana*, 23: 131–139.

Volkheimer, W., Melendi, D.L. y Aceñolaza, F.G. 1980. Una microflora ordovícica de la Formación Mojotoro, Provincia de Salta. *Revista de la Asociación Geológica Argentina*, 35: 401–416.