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Discussion and reply: The Cambrian System in Northwestern Argentina: stratigraphical and palaeontological framework Discussion

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INTRODUCTION

As part of the Special Issue on "Advances in the knowledge of the Cambrian System" edited by himself, Aceñolaza (2003) attempted to summarize present knowledge on the Cambrian of northwest Argentina. Although he is congratulated for tackling such a complex topic, we would like to take advantage of Geologica Acta as a forum for discussion to address some issues that remain unclear and to advance alternative ideas, providing pertinent additional literature. We will discuss these aspects by referring to the three most important stratigraphic units that include Cambrian rocks in northwest Argentina, the Puncoviscana Formation, the Mesón Group and the Santa Rosita Formation. Aspects addressed are tectonic setting, stratigraphic relations, age and depositional environment. Trace fossil data included in the appendix are briefly reviewed.

PUNCOVISCANA FORMATION

Tectonic setting

While discussing the tectonic setting of the Puncoviscana basin, Aceñolaza (2003) only mentioned the hypothesis by Aceñolaza and Durand (1986) of a "triple junction point placed in the centre of Bolivia. The southern branch of this rift corresponds to the early above-mentioned Puncoviscana basin". This gives the wrong impression that there is some sort of consensus on this topic, which is incorrect. Interestingly enough, this southern rift branch is perpendicular to the Gondwana Pacific trench (see his figure 3), an active subduction margin. Further explanation or geologic evidence supporting this model is not presented. The tectonic setting of the Puncoviscana basin is still highly controversial, with alternative interpretations including a foreland basin (Kraemer et al., 1995; Keppie and Bahlburg, 1999), a rift basin (Omarini et al., 1999) and a passive margin basin (Jeˇzek et al., 1985), among other tectonic settings. In a book on the regional geology of Argentina, Ramos (1999, Fig. 7) illustrated the different tectonic frameworks that have been proposed for this unit. Undoubtedly, the absence of measured representative stratigraphic sections of the Puncoviscana Formation precludes an accurate understanding of the timing of the various events that affected deposition and militates against robust tectonic models. Further efforts to integrate structural, geochemical, ichnologic and sedimentologic data within a stratigraphic framework are essential to advance on this topic.

Age

Aceñolaza (2003, fig. 2) provided a stratigraphic scheme for the Precambrian to Middle Palaeozoic units of

Argentina. In that figure, the Puncoviscana Formation ranges from the Sturtian to the Manykian (= Nemakit-Daldynian in this scheme). However, in the most specific stratigraphic column depicted in his figure 4, the lowermost Cambrian is gone and the Tommotian is placed right above the Vendian, with the Puncoviscana Formation ranging from the Vendian to the Tommotian. In contrast, in his figure 5, the Puncoviscana Formation is entirely included within the Upper Proterozoic.

While addressing these points, he claimed that "among the recognizable Vendian traces are: *Nereites saltensis* ACEÑOLAZA AND DURAND, *Tasmanadia* and probably *Sekwia*". This is certainly unsupported by ichnologic studies worlwide. *Tasmanadia* is an arthropod trackway and this group of trace fossils is unknown from the Vendian. Relatively robust, meandering trace fossils, such as those traditionally assigned to *Nereites saltensis* in the Puncoviscana Formation, are not present in the Vendian either. Smaller, supposedly meandering trails recorded elsewere in Vendian strata are not longer considered trace fossils (Jensen, 1996, 2003; Gehling et al., 2000; Haines, 2000; Seilacher et al., 2003). Finally, *Sekwia*, whose presence in the Puncoviscana Formation is highly controversial, is a body fossil, not a trace fossil (Narbonne and Aitken, 1990); in fact it is listed as part of the "soft body faunas" in figure 4. Also, we note that the position of the *Nereites* association as older than the *Oldhamia* association and coincident with the Precambrian-Cambrian transition contradicts previous views expressed by Aceñolaza and Aceñolaza (2001) and is in need of clarification. The biostratigraphic implications of the Puncoviscana ichnofauna have been recently addressed by Buatois and Mángano (2003a, b). Integration of ichnologic, stratigraphic and geochronologic data suggest that the Puncoviscana Formation probably ranges from the Vendian to the Nemakit Daldynian, with the trace fossil-bearing beds representing the earliest Cambrian (Mángano and Buatois, 2004a).

Depositional Environment

Following the traditional interpretation by Ježek et al. (1985) and Ježek (1990), Aceñolaza (2003) regarded the Puncoviscana Formation as having been accumulated in a "deep slope depositional setting, associated to large coalescent submarine fans". Although this has been the standard interpretation for a long time, it has been recently suggested that this unit also includes shallow-marine deposits (Mángano et al., 2000; Buatois et al., 2000a; Buatois and Mángano, 2003a, 2004). It is interesting to note that views on this topic are changing at a very fast pace, resulting in a rather convolute story with interpretations frequently going back and forth. For example, only one year after the original suggestion of shallow-marine facies, Aceñolaza and Aceñolaza (2001) regarded the Puncoviscana depositional setting as "a same relatively shallow sea, within the western margin of Gondwana" (sic), implicitly adopting that idea. However, two years later Aceñolaza and Tortello (2003, p. 100), while referring to the suggestion by Buatois et al. (2000a) of the presence of shallow-marine deposits in the Puncoviscana Formation, stated that "we consider this hypothesis as possible, mentioning that much additional sedimentological work must be done in order to improve the knowledge on the environments represented in the unit". Our studies indicate that the Puncoviscana is made up not only of deep-marine turbidites, but also of wave-influenced, shallow-water deposits (Buatois and Mángano, 2003a, 2004). Recent field work allows identification of a number of structures indicative of deposition above storm wave base, including hummocky stratification and combined-flow ripples. This suggests that the standard view of the Puncoviscana Formation as consisting *entirely* of deep-marine deposits should be abandoned.

MESÓN GROUP

Age

The Mesón Group overlies metasedimentary rocks of the Puncoviscana Formation and underlies Upper Cambrian to Tremadocian strata of the Santa Rosita Formation. The Mesón Group has historically been considered as Middle to Late Cambrian owing to three different lines of evidence: stratigraphic relations, body fossils, and trace fossils (Aceñolaza et al., 1982; Aceñolaza and Aceñolaza, 2000). However, this view has been questioned a long time ago by Alonso and Marquillas (1981), who suggested an Early Cambrian age based on ichnologic data. More recently, Mángano and Buatois (2000) raised the possibility that the Mesón Group ranges into the Lower Cambrian, a view that seems to be now adopted by Aceñolaza (2003, p. 28), although in his figure 2 the traditional view (Middle to Upper Cambrian age for the Mesón Group) is maintained. A critical reassessment of the available evidence is essential to accurately review the problem.

Aceñolaza (2003, p. 28) stated "The age of the Mesón Group has been established on the basis of scarce fossils yelded by the Chalhualmayoc Fm.". However, in his figure 5 body fossils are located in the Lizoite and Campanario formations and the Chalhualmayoc Formation is depicted as lacking body fossils. The body fossil content of the Mesón Group is meager, consisting mostly of the inarticulate brachiopod *Lingulepis* sp. (Sánchez and Herrera, 1994). Aceñolaza (2003) reiterated the presence of the trilobite *Asaphiscus* as biostratigraphic evidence. This trilobite was recorded in supposed strata of the Lizoite Formation in Puna, suggesting a late Middle Cambrian age (Aceñolaza, 1973; Aceñolaza and Bordonaro, 1990).

However, recent field work indicates that a lateral equivalent of the Santa Rosita Formation, rather than the Mesón Group, is represented in that area (Buatois and Mángano, 2003c). Additionally, the trilobite specimen has been recently reassigned to *Leiostegium douglasi*, a Tremadocian taxon (Vaccari and Waisfeld, 2000). Aceñolaza (2003) referred to the presence of the trilobite *Parabolina* (*N.*) *frequens argentina* in outcrops of the Mesón Group at Azul Pampa as a reliable biostratigraphic index. The source is not mentioned, but recent field work in the Azul Pampa area indicates that part of what has been originally regarded as the Chalhualmayoc Formation in previous studies (Fernández et al., 1982; Fernández, 1983) actually corresponds to the Santa Rosita Formation (Such and Mángano, 2003). In fact, *Parabolina* (*N.*) *frequens argentina* is a very common trilobite in Late Cambrian-Early Tremadocian strata of the overlying Santa Rosita Formation. In short, no trilobites have been found in the Mesón Group so far.

The supposed presence of *Cruziana semiplicata* in an outcrop of the Mesón Group also has been taken as evidence of Late Cambrian age. However, the finding is controversial. Originally, Manca (1981) mentioned *C. semiplicata* as float from the Angosto de Perchel section. Study of this specimen (PIL 13261) fails to reveal any of the diagnostic characteristics of *Cruziana semiplicata*. In a subsequent paper on the Campanario ichnofauna, Manca (1986) did not mention this specimen, but described and illustrated another one as coming from a different outcrop, Huacalera. Re-examination of the specimen (12477) confirms the taxonomic assignment, but raises serious doubts regarding its stratigraphic provenance. In fact, the specimen may come from the overlying strata of the Santa Rosita Formation, where this ichnotaxon is widespread. Mángano and Buatois (2001a, 2003a) recently documented the presence of *Rusophycus leifeirikssoni* in the Campanario Formation. This ichnospecies is known from Upper Cambrian-Tremadocian strata in Newfoundland (Bergström, 1976; Fillion and Pickerill, 1990). However, the Campanario Formation specimens may belong to a different ichnosubspecies and, therefore, their biostratigraphic meaning is unclear. Alonso and Marquillas (1981) recorded the ichnogenus *Syringomorpha* in the Campanario Formation, noting that this ichnotaxon occurs in Lower Cambrian rocks. This identification was questioned by Manca (1989) who collected additional specimens and reassigned this material to *Daedalus*. Re-examination of the specimens and additional collections by Mángano and Buatois (2000, 2001b) support inclusion in *Syringomorpha*, a view adopted by Aceñolaza (2003, p. 28). *Syringomorpha* is known only from the Lower Cambrian (Mángano and Buatois 2001b, 2004a).

In short, there seems to be no definitive indicator of a Late Cambrian age in the Mesón Group. The standard notion of regarding the Mesón Group as ranging into the Late Cambrian probably stems from the previous idea of considering the Santa Rosita Formation as entirely Tremadocian (e.g., Harrington and Leanza, 1957; Turner, 1960; López and Nullo, 1969; Fernández et al., 1982; Aceñolaza and Manca, 1982). Subsequent studies, however, demonstrated that the lower part of the Santa Rosita Formation ranges into the Upper Cambrian (Benedetto, 1977; Moya et al., 1994; Rao et al., 1994; Rao and Hünicken, 1995; Tortello et al., 1999; Moya and Albanesi, 2000; Zeballo et al., 2003; Rubinstein et al., 2003). In fact, integration of biostratigraphic and sedimentologic data within a sequence stratigraphic framework suggests that a significant part of the Santa Rosita Formation (including two or three depositional sequences) is Upper Cambrian (Buatois et al., 2003; Mángano and Buatois, 2004a). To summarize, integration of available evidence suggests that the Mesón Group may range from the upper Lower to the Middle Cambrian (Mángano and Buatois, 2004a).

Depositional Environment

Aceñolaza (2003) stated that "the deposition of the Mesón Group and of the lower part of the Santa Victoria Group took place mostly on shore lines, strongly influenced by the eustatic variations that characterized the Cambro-Ordovician transition". In fact, only a relatively small part of these units can be regarded as representing deposition on shorelines. As noted by Aceñolaza (2003) while referring (p. 28) to work on the Mesón Group by Moya (1998), Sánchez (1999) and Sánchez and Salfity (1999), the Lizoite and Chalhualmayoc formations record deposition in subtidal settings, in particular subtidal sandbar complexes (see also Buatois and Mángano, 2001 and Mángano and Buatois, 2004b). Only the dominantly intertidal Campanario Formation can be properly regarded as a shoreline setting. The recurrent statement on the eustatic variations during the Cambrian-Ordovician transition is becoming a sort of mantra. Obviously, sea level changes that took place at the Cambrian-Ordovician transition could not have affected deposition of the (older) Meson Group.

SANTA ROSITA FORMATION

Stratigraphic relations

Aceñolaza (2003, p. 29) mistakenly referred to the unconformity between the Mesón Group and the Santa Rosita Formation as the "Tilcaric" unconformity. The Tilcaric unconformity actually separates the Puncoviscana Formation and the Mesón Group (see his own fig. 2 and our fig. 1) and is a remar-

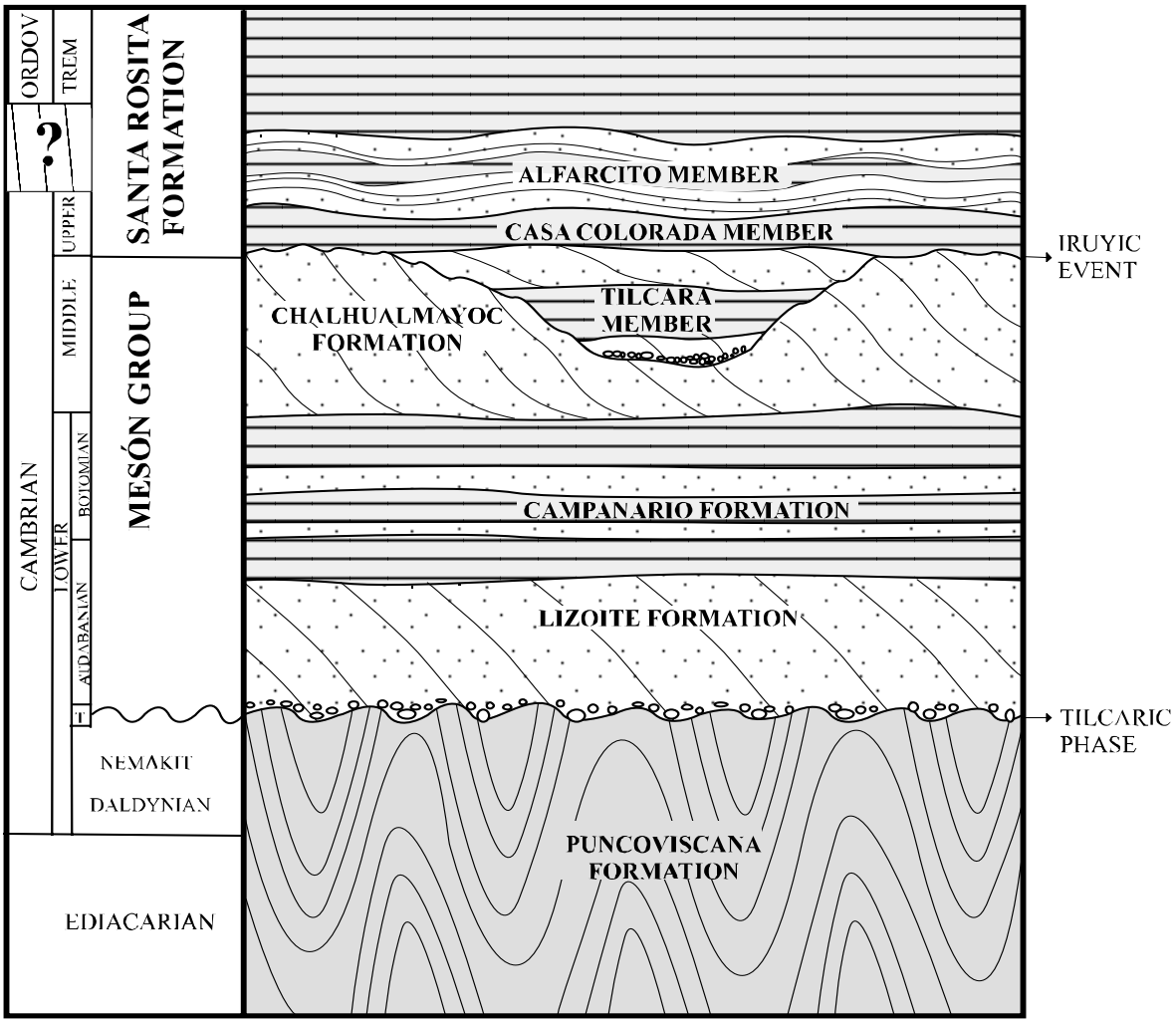

FIGURE 1 | **Stratigraphic chart of Cambrian units in northwest Argentina (after Mángano and Buatois, 2004a). Only the lower members of the Santa Rosita Formation are included.**

kable angular unconformity of tectonic origin (Turner, 1979). The unconformity between the Mesón Group and the Santa Rosita Formation is known as "Iruyic" (Fig. 1). We agree with Aceñolaza (2003) that the nature of this contact is a matter of discussion and we would like to explore the topic in a more systematic way.

Three different interpretations have been proposed: (1) an angular unconformity resulting from tectonic movements of the Iruyic Orogeny (e.g. Turner, 1960; Turner and Méndez, 1975; Moya, 1988), (2) an erosional uncomformity resulting from a relative fall in sea level (Moya, 1998; Buatois et al., 2000b; Buatois and Mángano, 2003c), and (3) a conformable depositional transition between the two units (Ruiz Huidobro, 1975; Fernandez et al., 1982; Tortello and Aceñolaza, 1999; Aceñolaza and Aceñolaza, 2000). Aceñolaza (2003) mentioned "conglomerate beds in the *transitional* levels between both units" (our italics) favouring interpretation 3. He then noted that "the lithology mostly does not change below and above the conglomerates and quartzites and sandstones are dominant" as evidence to place the unconformity within the Chalhualmayoc Formation. Finally, he stated that "these conglomerate layers have been interpreted as a channel fill within the platform, being related to the several eustatic episodes that characterised the Cambro-Ordovician transition (Aceñolaza and Aceñolaza, 1992; Aceñolaza, 1996)", although it is relevant to note here that we are dealing with strata that are older than that transition. The rationale behind placing this uncomformity within the Chalhualmayoc Formation instead of the boundary between the two units is left unstated. Conglomerate beds do occur within the Chalhualmayoc Formation, but mostly represent transgressive deposition during ravinement (Buatois and Mángano, 2001).

As noted by Mángano and Buatois (2004a), these conflicting interpretations result from pervasive confusion in the recognition of some stratigraphic units. Although the bulk of the Santa Rosita Formation records deposition in open-marine, wave-dominated environments, its lowermost unit, the Tilcara Member, represents sedimentation within a tide-dominated fluvio-estuarine valley incised into the underlying Mesón Group (Moya, 1998; Buatois et al., 2000b; Mángano and Buatois, 2002; Buatois and Mángano, 2003c). Buatois and Mángano (2003c) noted that tectonism may have played a role in the origin of the incision observed at the base of the Santa Rosita Formation; long-distance elongate valleys such as the Tilcara valley are common in tectonically-active basins. Because the Tilcara Member contains tide-dominated facies, these may have been confused with similar deposits in the older Mesón Group. Detailed facies descriptions and interpretations have been recently presented by Buatois and Mángano (2003c). A relative sea-level fall was responsible for valley incision, producing an erosional contact between the Mesón Group and the Santa Rosita Formation, which represents a sequence boundary (Moya, 1998; Buatois and Mángano, 2003c). Along the valley axis, a significant thickness of the Chalhualmayoc Formation was removed. Basal, fluvial deposits of the Tilcara Member are restricted to the valley axis. While older tidal deposits in the basin recorded by the Mesón Group are regionally extensive, probably reflecting deposition on a gently dipping shallow-marine ramp, tidal facies of the Tilcara Member are geomorphically constrained to an incised valley. During the subsequent transgression, tidal deposits of the Tilcara Member accumulated along the valley axis, but also onlapped the interfluves where they mantled a co-planar surface of lowstand and transgressive erosion. Towards the valley margins, tidal deposits of the Tilcara Member occur directly above tidal deposits of the Mesón Group, making distinction between the two units very difficult if no detailed sedimentologic and sequence stratigraphic studies are performed.

Depositional Environments

As noted earlier, Aceñolaza (2003) considered the lower part of the Santa Victoria Group as shoreline deposits. The Cambrian strata of the Santa Rosita Formation (Santa Victoria Group) comprise the Tilcara, Casa Colorada Member and, at least in part, the Alfarcito Member. Sedimentary facies and depositional environments of these units have been discussed by Mángano and Buatois (2002) and Buatois and Mángano (2003c). While the Tilcara Member records deposition in fluvial to tide-dominated estuarine settings, the overlying units represent deposition in open-marine wave-dominated environments. The latter may range from shoreface to lower offshore environments, and therefore include deposits that accumulated at a considerable distance from the shoreline.

TRACE FOSSIL DATA

An appendix entitled "Biostratigraphic record of the Cambrian in NW Argentina" is presented by Aceñolaza (2003) to summarize palaeontologic data. Evaluation of the body fossil information is beyond the scope of this discussion and, in fact, beyond our field of expertise. However, we briefly comment here on the trace fossil list provided by this author. It is clear that the list is a compilation of the ichnotaxa documented or mentioned by different authors. Our main concern is that no attempt has been made to address the problem of synonymies, even in the case where forms were explicitly introduced by subsequent authors to replace previous ichnotaxa. This undoubtedly led to an overestimation of diversity. No data are provided on stratigraphic procedence of each ichnotaxon, but presumably the three units addressed in this discussion (Puncoviscana Formation, Mesón Group and Santa Rosita Formation) are mixed in a single list. Unfortunately, this procedure results in a considerable loss of biostratigraphic and evolutionary information. Additionally, it is unclear what is the meaning of the statement "Asterisk indicates the first Ordovician taxa" in this context. For example, an asterisk denotes *Phycodes pedum* (more correctly, *Treptichnus pedum*) which marks the base of the Cambrian.

The absence of more specific information regarding stratigraphic provenance and bibliographic source for *each* ichnotaxon precludes a comprehensive analysis, so only the most obvious synonymies will be discussed here based on our recent reviews of Lower Palaeozoic trace fossils of northwest Argentina (see Mángano and Buatois, 2003a, b, and Buatois and Mángano, 2003a for further details). *Aulichnites* is a junior synonym of *Psammichnites*. Specimens included in *Glockerichnus* lack the diagnostic branching of this ichnotaxon and should be relocated in another radial ichnogenus. Specimens referred to as *Gordia* isp. have been relocated in *Helminthopsis tenuis* and *Helminthoidichnites tenuis*. *Helminthoida* cf. *H. miocenica* is listed together with *Helminthorhaphe* isp. Because *Helminthoida* is a junior synonym of *Nereites*, regular meandering trace fossils preserved as positive hyporeliefs should be included in *Helminthorhaphe*. Accordingly, *Helminthoida* should be removed from updated ichnotaxonomic lists. The structure from the Puncoviscana Formation assigned to *Multipodichnus holmi* lacks any relevant morphologic feature and has been regarded as a pseudofossil. Some of the specimens that were referred to *Oldhamia antiqua* are now regarded as *Oldhamia curvata*. Specimens from northwest Argentina compared with the graphoglyptid ichnotaxon *Protopaleodictyon* are not trace fossils, but structures formed by microbial activity, such as elephant skin and wrinkle marks. The ichnospecies *Phycodes pedum* was documented based on a single specimen in the Puncoviscana Forma-

tion. However, re-examination of the specimen does not reveal the classic branching pattern of this ichnospecies; the structure more likely records false branching resulting from overlap of two *Palaeophycus*-like trace fossils. The specimen assigned to the arthropod trackway *Protichnites* isp. is in all probability an inorganic tool mark. Specimens included in *Rusophycus jenningsi* have been relocated in *R. leifeirikssoni*. The name *Scolicia* have been recurrently used for very simple trails present in the Palaeozoic of Argentina. However, *Scolicia* is a complex endichnial structure, produced by spatangoid echinoids, and characterized by a meniscate backfill, a double ventral cord or drain, and mucus-lined vertical shafts. *Scolicia* occurs in Mesozoic and Cenozoic strata and Palaeozoic recordings should be transferred to other ichnogenera. The specimens included in *Torrowangea* isp. lack the diagnostic transverse constrictions of *Torrowangea* and should be removed from this ichnotaxon.

FINAL COMMENTS

The Cambrian of northwest Argentina is becoming a topic of lively discussions. In this brief note we have tried to reflect how the integration of sedimentologic, biostratigraphic, ichnologic and sequence stratigraphic data performed by different working groups has revitalized this field and is providing new insights on the topic. To advance in our understanding of these Cambrian rocks, updated conceptual frameworks, appropriate methodologies, consistent and precise terminology and adequate explanatory schemes must be employed. Undoubtedly, this will shed light and provide new ideas on old problems.

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REFERENCES

Aceñolaza, F.G., 1973. Sobre la presencia de trilobites en las cuarcitas del Grupo Mesón en Potrerillos, provincia de Salta. Revista de la Asociación Geológica Argentina, 28, 309-311.

Aceñolaza, F.G., Aceñolaza, G.F., 1992. The genus *Jujuyaspis* as a world reference fossil for the Cambrian-Ordovician boundary. In: Webby, B., Laurie, J.R. (eds.). Global Perspectives on Ordovician Geology. Rotterdam, Balkema, 115-120.

Aceñolaza, F.G., Bordonaro, O., 1990. Presencia de *Asaphiscus* (Asaphiscidae–Trilobita) en la Formación Lizoite, Potrerillos, Salta y su significado geológico. Serie Correlación Geológica, 5, 21-28.

Aceñolaza, F.G., Durand, F.R., 1973. Trazas fósiles del basamento cristalino del noroeste argentino. Boletín de la Asociación Geológica de Córdoba, 2, 45-55.

Aceñolaza, F.G., Durand, F.R., 1986. Uper Precambrian-Lower Cambrian biota from the northwest of Argentina. Geological Magazine, 123, 367-375.

Aceñolaza, F.G., Manca, N. del V., 1982. *Bifungites* sp. (traza fósil) en capas del Ordovícico inferior de la región de Perchel, Quebrada de Humahuaca, Provincia de Jujuy. Ameghiniana, 19, 157-164.

Aceñolaza, F.G., Fernández, R.I., Manca, N. del V., 1982. Caracteres bioestratigráficos y paleoambientales del Grupo Mesón (Cámbrico Medio-Superior), centro-oeste de América del Sur. Estudios Geológicos, 38, 385-392.

Aceñolaza, G. F., 1996. Bioestratigrafía del límite Cámbrico-Ordovícico y Ordovícico basal en la Quebrada de Humahuaca, Provincia de Jujuy, República Argentina. Doctoral thesis. Universidad Nacional de Tucumán. (Unpublished).

Aceñolaza, G.F., 2003. The Cambrian System in Northwestern Argentina: stratigraphical and palaeontological framework. Geologica Acta, 1, 23-39.

Aceñolaza, G.F., Aceñolaza, F.G., 2000. The Cambrian System in Northwest Argentina. In: Aceñolaza, G.F., Peralta, S. (eds.). Cambrian from the southern edge, Instituto Superior de Correlación Geológica, Miscelánea, 6, 46-50.

Aceñolaza, G.F., Aceñolaza, F.G., 2001. Ichnofossils and microbial activity in the Precambrian/Cambrian transition of northwestern Argentina. Palaeoworld, 13, 241-244.

Aceñolaza, G.F., Tortello, M.F., 2003. El Alisal: a new locality with trace fossils of the Puncoviscana Formation (late Precambrian-early Cambrian) in Salta Province, Argentina. Geologica Acta, 1, 95–102.

Alonso, R.N., Marquillas, R.A., 1981. Trazas fósiles de la Formación Campanario (Grupo Mesón, Cámbrico) en el norte argentino. Consideraciones ambientales y geocronológicas. Revista del Instituto de Geología y Minería, 4, 95-110.

Benedetto, J.L., 1977. Algunas consideraciones acerca de la posición del límite Cambro-Ordovícico en Sudamérica. Geos, 23, 3-11.

Bergström, J., 1976. Lower Palaeozoic trace fossils from eastern Newfoundland. Canadian Journal of Earth Sciences, 13, 1613-1633.

Buatois, L.A., Mángano, M.G., 2001. Ichnology, sedimentology and sequence stratigraphy of the Cambrian Mesón Group in northwest Argentina. In: Buatois, L.A., Mángano, M.G. (eds.). Ichnology, Sedimentology and Sequence Stratigraphy of Selected Lower Paleozoic, Mesozoic and Cenozoic Units of Northwest Argentina. Fourth Argentinian Ichnologic Meeting and Second Ichnologic Meeting of Mercosur, San Miguel de Tucumán, Field Guide, 8–16.

Buatois, L.A., Mángano, M.G., 2003a. La icnofauna de la Formación Puncoviscana en el noroeste argentino: Implicancias

en la colonización de fondos oceánicos y reconstrucción de paleoambientes y paleoecosistemas de la transición precámbrica-cámbrica. Ameghiniana, 40, 103-117.

Buatois, L.A., Mángano, M.G., 2003b. Early colonization of the deep sea: Ichnologic evidence of deep-marine benthic ecology from the Early Cambrian of northwest Argentina. Palaios, 18, 572-581.

Buatois, L.A., Mángano, M.G., 2003c. Sedimentary facies and depositional evolution of the Upper Cambrian to Lower Ordovician Santa Rosita Formation in northwest Argentina. Journal of South American Earth Sciences, 16, 343-363.

Buatois, L.A., Mángano, M.G., 2004. Terminal Proterozoic–Early Cambrian ecosystems: Ichnology of te Puncoviscana Formation, Northwest Argentina. In: Webby, B.D., Mángano, M.G, Buatois, L.A. (eds.). Trace Fossils in evolutionary palaeoecology. Fossils and Strata, 51, 1-16.

Buatois, L.A., Mángano, M.G., Aceñolaza, F.G., Esteban, S.B., 2000a. The Puncoviscana ichnofauna of northwest Argentina: A glimpse into the ecology of the Precambrian-Cambrian transition. In: Aceñolaza, G.F., Peralta, S. (eds.). Cambrian from the southern edge, Instituto Superior de Correlación Geológica, Tucumán, Miscelánea, 6, 82-84.

Buatois, L.A., Mángano, M.G., Moya, M.C., 2000b. Incisión de valles estuarinos en el Cámbrico Tardío del noroeste argentino y la problemática del límite entre los grupos Mesón y Santa Victoria. Resúmenes, Segundo Congreso Latinoamericano de Sedimentología, Mar del Plata, 55.

Buatois, L.A., Moya, M.C., Mángano, M.G., Malanca, S., 2003. Paleoenvironmental and sequence stratigraphic framework of the Cambrian-Ordovician transition in the Angosto del Moreno area, northwest Argentina. International Symposium on the Ordovician System, San Juan, Proceedings 9th, 397-401.

Fernández, R., 1983. Contribución al conocimiento geológico de la región de Iturbe (Departamento de Humahuaca), Provincia de Jujuy. Facultad de Ciencias Naturales e Instituto Miguel Lillo, Universidad Nacional de Tucumán. (Unpublished).

Fernández, R., Guerrero, C., Manca, N., 1982. El límite Cámbro-Ordovícico en el tramo medio y superior de la quebrada de Humahuaca, Provincia de Jujuy, Argentina, Congreso 5º Latinoamericano de Geología, Buenos Aires, Actas, 1, 3-22.

Fillion, D., Pickerill, R.K., 1990. Ichnology of the Lower Ordovician Bell Island and Wabana Groups of eastern Newfoundland. Palaeontographica Canadiana, 7, 1-119.

Gehling, J.G., Narbonne, G.M, Anderson, M., 2000. The first named Ediacaran body fossil, *Aspidella terranovica*. Palaeontology, 43, 427-456.

Haines, P.W., 2000. Problematic fossils in the late Neoproterozoic Wonoka Formation, South Australia. Precambrian Research, 100, 97-108.

Harrington, H.J., Leanza, A.F., 1957. Ordovician Trilobites of Argentina. Department of Geology, University of Kansas, Special Publication, 1, 1-276.

Jensen, S., 1996. Palaeobiology and stratigraphy of Vendian trace fossils. In: Meidla, T. et al. (eds.). The Third Baltic Stratigraphical Conference, Abstracts and field guide, 29-30.

Jensen, S., 2003. The Proterozoic and Earliest Cambrian Trace Fossil Record: Patterns, Problems and Perspectives. Integrative and Comparative Biology, 43, 219-228.

Ježek, P., 1990. Analisis sedimentologico de la Formación Puncoviscana entre Tucumán y Salta. In: Aceñolaza, F.G., Miller, H., Toselli, A.J. (eds.). El Ciclo Pampeano en el Noreste Argentino. Argentina, Serie Correlación Geológica, 4, 9-36.

Ježek, P., Willner, A.P., Aceñolaza, F.G., Miller, H., 1985. The Puncoviscana trough – a large basin of Late Precambrian to Early Cambrian age on the Pacific edge of the Brazilian shield. Geologische Rundschau, 74, 573-584.

Keppie, J.D., Bahlburg, H., 1999. Puncoviscana Formation of northwestern and central Argentina: Passive margin or foreland basin deposit? In: Ramos, V., Keppie, J.D. (eds.). Laurentia-Gondwana connections before Pangea. Geological Society of America, Special Paper, 336, 139-143.

Kraemer, P.E., Escayola, M.P., Martino, R.D., 1995. Hipótesis sobre la evolución tectónica neoproterozoica de las Sierras Pampeanas de Córdoba (30° 40'-32° 40'), Argentina. Revista de la Asociación Geológica Argentina, 50, 47-59.

López, C.R., Nullo, F.E., 1969. Geología de la margen izquierda de la Quebrada de Humahuaca, de Huacalera a Maimara. Dpto. Tilcara- Provincia de Jujuy, República Argentina. Revista de la Asociación Geológica Argentina, 24, 173-182.

Manca, N., 1981. Contribución al conocimiento geológico de la zona Angosto de Perchel. Trabajo de Seminario Facultad de Ciencias Naturales e Instituto Miguel Lillo, Universidad Nacional de Tucumán, 98 pp. (Unpublished).

Manca, N., 1986. Caracteres icnológicos de la Formación Campanario (Cámbrico superior) en Salta y Jujuy. Ameghiniana, 23, 75-87.

Manca, N., 1989. La presencia de *Daedalus labechei* (traza fósil) en la Formación Campanario (Cámbrico Superior) de la provincia de Jujuy. IV Congreso Argentino de Paleontología y Bioestratigrafía, Mendoza, Actas, 4, 131-138.

Mángano, M.G., Buatois, L.A., 2000. Ichnology, sedimentary dynamics, and sequence stratigraphy of the Mesón Group: A Cambrian macrotidal shallow-marine depositional system in northwest Argentina. In: Aceñolaza, G.F., Peralta, S. (eds.). Cambrian from the southern edge, Instituto Superior de Correlación Geológica, Miscelánea, 6, 109-110.

Mángano, M.G., Buatois, L.A., 2001a. *Rusophycus leiferikssoni* en la Formación Campanario: Implicancias paleobiológicas, paleoecológicas y paleoambientales. Cuarta Reunión Argentina de Icnología y Segunda Reunión de Icnología del Mercosur, San Miguel de Tucumán, Resúmenes, 54.

Mángano, M.G., Buatois, L.A., 2001b. The *Syringomorpha* ichnofabric: Pervasive bioturbation and the Cambrian explosion. 6th International Ichnofabric Workshop, Porlamar, Puerto La Cruz. Abstracts, unpaginated.

Mángano, M.G., Buatois, L.A., 2002. Evolución depositacional de la Formacion Santa Rosita (Cambrico Superior-Tremadoc) en el noroeste argentino. XV Congreso Geológico Argentino, El Calafate, Actas, 1, 812-813.

Mángano, M.G., Buatois, L.A., 2003a. *Rusophycus leiferikssoni* en la Formación Campanario: Implicancias paleobiológicas, paleoecológicas y paleoambientales. In: Buatois, L.A., Mángano, M.G. (eds.). Icnología: Hacia una convergencia entre geología y biología. Publicación Especial de la Asociación Paleontológica Argentina, 9, 65–84.

Mángano, M.G., Buatois, L.A. 2003b. Trace Fossils. In: Benedetto, J.L. (ed.). Ordovician Fossils of Argentina. Universidad Nacional de Córdoba, Secretaría de Ciencia y Tecnología, 507-553.

Mángano, M.G., Buatois, L.A., 2004a. Integración de estratigrafía secuencial, sedimentología e icnología para un análisis cronoestratigráfico del Paleozoico inferior del noroeste argentino. Revista de la Asociación Geológica Argentina, 59, 273-280.

Mángano M.G., Buatois, L.A., 2004b. Reconstructing early Phanerozoic intertidal ecosystems: Ichnology of the Cambrian Campanario Formation in northwest Argentina. Fossils and Strata, 51, 17-38.

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

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., Albanesi, G.L., 2000. New stratigraphic section to define the Cambrian-Ordovician boundary in Eastern Cordillera, northwest Argentina. In: Aceñolaza, G.F., Peralta, S. (eds.). Cambrian from the southern edge, Instituto Superior de Correlación Geológica, Tucumán, Miscelánea, 6, 114-116.

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

Narbonne, G.M., Aitken, J.D., 1990. Ediacaran fossils from the Sekwi Brook area, Mackenzie mountains, northwestern Canada. Palaeontology, 33, 945-980.

Omarini, R.H., Sureda, R.J., Götze, H.-J., Seilacher, A., Pflüger, F., 1999. Puncoviscana folded belt in northwestern Argentina: testimony of Late Proterozoic Rodinia fragmentation and pre-Gondwana collisional episodes. International Journal of Earth Sciences, 88, 76-97.

Ramos, V.A., 1999. Evolución tectónica de la Argentina. In: Caminos, R. (ed.). GeologíaArgentina, Instituto de Geología y Recursos Minerales, Anales, 29, 715-784.

Rao, R.I., Hünicken, M.A., 1995. Conodont biostratigraphy of the Cambrian-Ordovician boundary in northwestern Argentina. Ordovician Odyssey. 7th International Symposium on the Ordovician System, Las Vegas, Short Papers, 125-128.

Rao, R.I., Ortega, G., Hünicken, M.A., 1994. Cambrian-Ordovician boundary in the Sierra de Cajas, Cordillera Oriental, Jujuy, Argentina. In: Baldis, B., Aceñolaza, F.G. (eds.). Early Paleozoic Evolution in NW Gondwana. Argentina, Serie Correlación Geológica, 12, 298-299.

Rubinstein, C., Mángano, M.G., Buatois, L.A., 2003. Late Cambrian acritarchs from the Santa Rosita Formation: Implications for the recognition of the Cambrian-Ordovician boundary in the Eastern Cordillera of northwest Argentina. Revista Brasileira de Paleontologia, 4, 43-48.

Ruiz Huidobro, O.J., 1975. El Paleozoico Inferior del centro y sur de Salta y su correlación con el Grupo Mesón. 1er Congreso Argentino de Paleontología y Bioestratigrafía, San Miguel de Tucumán, Actas, 1, 91-107.

Sánchez, M.C., Herrera, Z., 1994. Braquiópodos inarticulados cámbricos en la Formación Campanario (Grupo Mesón), Río Reyes, Provincia de Jujuy. VI Congreso Argentino de Paleontología y Bioestratigrafía, Trelew, Resúmenes, 69.

Sánchez, M.C., 1999. Sedimentología y paleogeografía del Grupo Mesón (Cámbrico). In: Gonzalez Bonorino, G., Omarini, R., Viramonte, J. (eds.). Geología del Noroeste Argentino. Relatorio del XIV Congreso Geológico Argentino, 126-133.

Sánchez, M.C., Salfity, J.A., 1999. La cuenca cámbrica del Grupo Mesón en el Noroeste Argentino: desarrollo estratigráfico y paleogeográfico. Acta Geologica Hispanica, 34, 123–139.

Seilacher, A., Grazhdankin, D., Legouta, A., 2003. Ediacaran biota: The dawn of animal life in the shadow of giant protists. Paleontological Research, 7, 43-54.

Such, P., Mángano, M.G., 2003. Estratigrafía y análisis paleoambiental del Paleozoico Inferior en la región de Azul Pampa, Provincia de Jujuy. V Jornadas de Comunicaciones, Facultad de Ciencias Naturales, Universidad Nacional de Tucumán, 95 pp.

Tortello, M.F., Aceñolaza, G.F., 1999. Trilobites agnóstidos del Ordovícico basal en la localidad de Purmamarca, Provincia de Jujuy, Argentina. Temas Geológico-Mineros Instituto Tecnológico Geominero de España, 26, 585-588.

Tortello, M.F., Rábano, I., Rao, R.I., Aceñolaza, F.G., 1999. Los trilobites de la transición cámbrico-ordovícico en la Quebrada Amarilla (Sierra de Cajas, Jujuy, Argentina). Boletín Geológico y Minero, 110, 555-572.

Turner, J.C.M., 1960. Estratigrafía de la Sierra de Santa Victoria y adyacencias. Boletín de la Academia Nacional de Ciencias de Córdoba, 41, 163-196.

Turner, J.C., 1979. Paleozoico Inferior de América del Sur. Anales de la Academia de Ciencias Exactas, Físicas y Naturales, 31, 25-71.

Turner, J.C.M., Mendez, V., 1975. Geología del sector oriental de los Departamentos de Santa Victoria e Iruya, Provincia de Salta, República Argentina. Boletín de la Academia Nacional de Ciencias de Córdoba, 51, 11-24.

Vaccari, N.E., Waisfeld, B.G., 2000. Trilobites tremadocianos de la Formación Las Vicuñas, Puna Occidental, provincia de Salta, Argentina. XIV Congreso Geológico Boliviano, en CD-rom, La Paz.

Zeballo, F.J., Albanesi, G.L., Ortega, G., Tortello, F., 2003. Biostratigraphy of Ordovician sequences from Alfarcito area, Tilcara, Eastern Cordillera of Jujuy, Argentina. 9th International Symposium of the Ordovician System, San Juan, Proceedings, 167-171.

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