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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 (Ježek 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 worldwide. *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 elsewhere 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 convoluted 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 yielded 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 *Leiostrigium 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) Mesón 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-

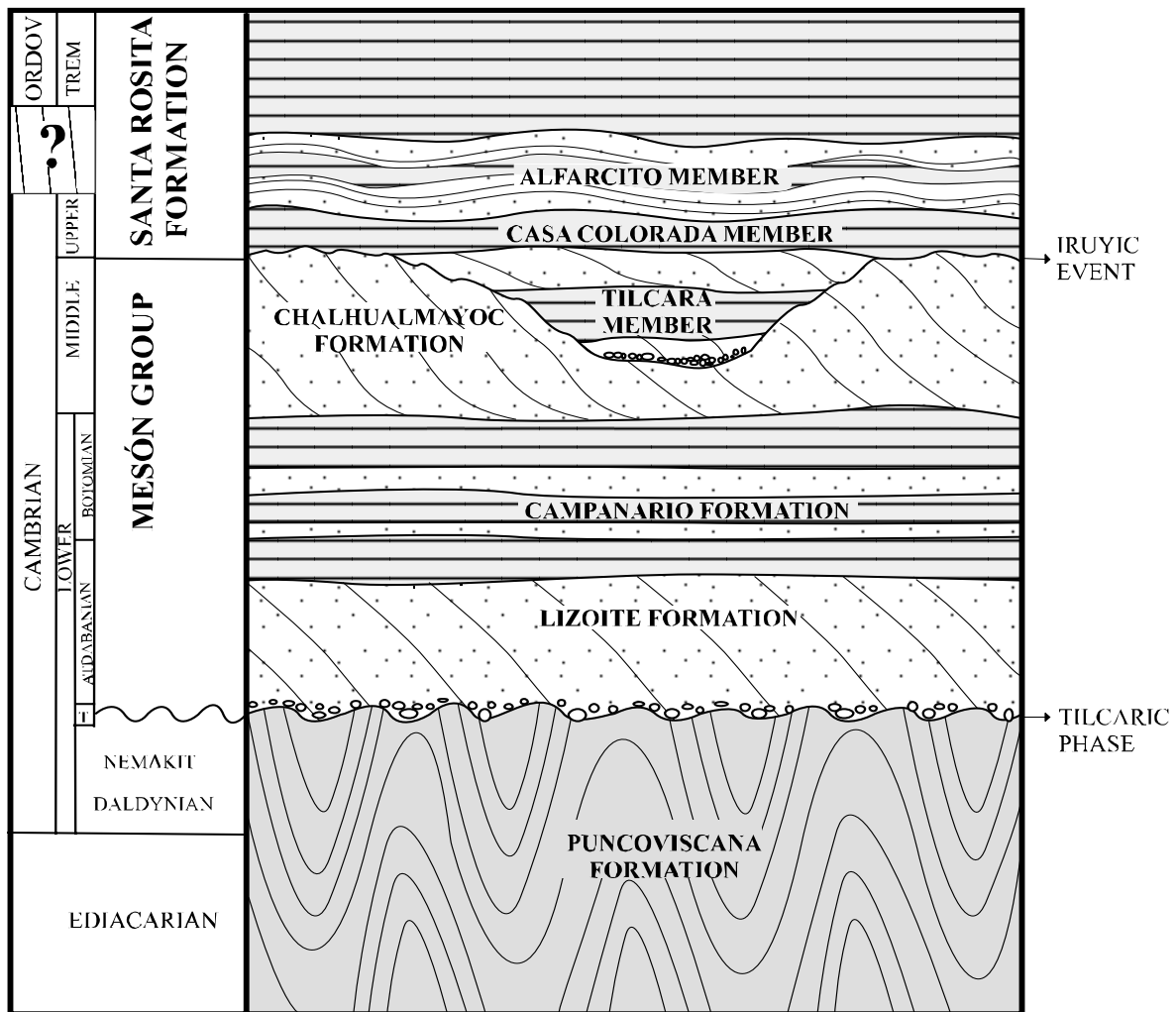


FIGURE 1 | Stratigraphic chart of Cambrian units in northwest Argentina (after Mángano and Buatois, 2004a). Only the lower members of the Santa Rosita Formation are included.

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 unconformity 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 unconformity 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 overlapped the interfluvies 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 precedence 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 *Helminthorhaphé* isp. Because *Helminthoida* is a junior synonym of *Nereites*, regular meandering trace fossils preserved as positive hyporeliefs should be included in *Helminthorhaphé*. 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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