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Aspects of the Ordovician System in Argentina.

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Ordovician Trace Fossils of Argentina

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Abstract: *Ordovician trace fossils of Argentina.* Trace fossils are recurrent elements in the Ordovician strata of Argentina. Biogenic structures commonly occur in siliciclastic and limestone sequences (with or without volcanigenic participation), characterizing different aspects related to the behaviour of the producer organism under a spectrum of different paleoenvironmental conditions. Shelf, talus, estuarine and deltaic facies with particular conditions were colonized during the Ordovician, being reflected by the record of the ichnological forms within sequences. The scarcity of typical deep water traces support the existence of relatively large shallow platforms over much of Argentina during the period, with the exception of the western Puna deeper facies. The Ordovician biodiversification is recorded by the increasing ichnodiversity within the strata that includes the Cambro-Ordovician transition. Tremadocian strata display mid to high diversity ichnoassemblages, while Arenig sandstones in NW Argentina outstands by low to mid diversity impressive ichnofossiliferous pavements. Younger sediments display a general deepenning of facies with an increasing ichnodiversity. A tight relation between ichnological associations and paleoenvironmental conditions is highligted by means of sedimentological characters and environmental interpretation of sequences.

Resumen: *Trazas fósiles del Ordovícico de Argentina.* Las trazas fósiles son un elemento frecuente en los estratos ordovícicos de Argentina. Estructuras biogénicas aparecen en secuencias siliciclásticas (con y sin participación volcanigénica) y carbonáticas, caracterizando diferentes aspectos del comportamiento de los organismos productores bajo variadas condiciones paleoambientales. Facies de plataforma, talud, deltaicas y estuarinas con distintos grados de restricciones ambientales fueron colonizadas durante el Ordovícico, situación que se ve reflejada en el abundante registro icnológico de las secuencias. Las asociaciones de trazas denotan la escaséz de facies típicamente de llanura abisal o zonas profundas, situación que pone de manifiesto la existencia de amplias plataformas relativamente someras durante el Ordovícico en gran parte del territorio

argentino. Asimismo, se registra la biodiversificación Ordovícica por medio del aumento de la icnodiversidad en los estratos que incluyen la transición Cambro-Ordovícica. Los estratos Tremadocianos presentan asociaciones icnológicas con una diversidad moderada a alta, mientras que el Arenigiano se caracteriza por una diversidad algo menor y sus facies arenosas, donde son destacables los pavimentos icnofosilíferos. Los niveles más modernos dentro del Ordovícico se caracterizan por una profundización general de facies, junto a un aumento en la diversidad relativa de formas. Por último se destaca la cercana relación entre las asociaciones icnológicas y las condiciones paleoambientales, situación que es consecuente con la caracterización sedimentológica y ambiental de las secuencias.

Key words: Trace fossils. Ichnodiversity. Palaeoenvironments. Ordovician. Argentina.

Palabras clave: Trazas fósiles. Icnodiversidad. Paleoambientes. Ordovícico. Argentina.

Introduction

The first mention of trace fossils in Ordovician strata for South America belongs to the French naturalist Alcide D'Orbigny (1842), who named the ichnogenus *Cruziana* as an homage to the Mariscal Santa Cruz, president of Bolivia at that time. He identified the trace as remains of "bivalved organisms". Posteriorly furher studies on similar material from the Armorican region of France introduced the known assignation of "fucoides". D'Orbigny ´s finds were done in the Cordillera Oriental of Bolivia, a geological unit dominated by the extensively developed siliciclastic sequences of Lower Paleozoic age, that continues southwards into the argentine Cordillera Oriental.

No further mention of ichnofossils occur until the last decades of the 19th century, a time when trace fossils start to be frequently mentioned within publications dealing with Ordovician rocks in Argentina.

The systematic research of Ordovician sequences along the country were initiated by German geologists from the Academia Nacional de Ciencias at Córdoba, La Plata Museum and the Dirección de Minas, Geología e Hidrogeología at Buenos Aires. Research carried out by these scientists in Argentina were highly influenced by the renowned paleontologist Karl Zittel and by the field work done by Steinmann's disciples in Bolivia.

The potential importance of trace fossils to solve some stratigraphic problems within the Cambro-Ordovician strata of Argentina and Bolivia was already mentioned in these early studies. *Cruziana* and *Skolithos* were already used in field work as index fossils to identify Ordovician strata. In addition, well preserved ichnofossils were also described from the southern Buenos Aires systems of Tandilia and Ventania, revealing a basinal connection with those sequences of the Andean margin and South Africa. These regions are today interpreted to be earlier united in the western margin of Gondwana.

Bioturbation in the Ordovician sequences of Precordillera have been mentioned long ago, but studies focusing this matter started much later, in the late 70 's.

Taking in account that modern ichnological studies in Latin America started, and were strongly developed in Argentina during the 60 's and early 70 's, this contribution pretends to give an up-to date summary on the knowledge of the Ordovician trace fossils of Argentina.

An increasing ichnodiversity within the strata that includes the Cambro-Ordovician transition reveals the Ordovician biodiversification in these high to mid latitude marginal seas, highlighting a tight relation between ichnological associations and paleoenvironmental conditions.

A general panorama on the ichnodiversity of different Ordovician sequences is given, considering the acceptable amount of bibliography on the matter. The taxonomic status of some early described material was also analysed and few re-assignations are here presented. We have decided to leave some controvertial ichnogenus as originally mentioned in early papers (eg. *Allocotichnus, Asaphoidichnus*, *Petalichnus*, *Tomaculum*, *Alcyonidiopsis*) until further studies are carried out on them. Lastly, the stratigraphic distribution of the known taxa is presented, mentioning some important papers that will help on a better sight of argentine Ordovician trace fossils.

Stratigraphic framework and distribution of trace fossils

Ordovician siliciclastic sequences with trace fossils display an extensive distribution in the Puna, Cordillera Oriental and Sierras Subandinas of northwestern Argentina (Salta and Jujuy provinces). Remarkable outcrops bearing ichnofossils have been described in the particular volcano-sedimentary strata of the Famatina System (Catamarca and La Rioja provinces) and in the carbonates and siliciclastics of the Precordillera (San Juan and Mendoza provinces). Eastwards, in the Atlantic margin of Buenos Aires Province, the Tandilia and Ventania systems have provided as well, nicely preserved ichnoassociations (Figure 1).

Puna, Cordillera Oriental and Sierras Subandinas

Tremadocian: There is an accepted consensus that the lower boundary of the Ordovician System

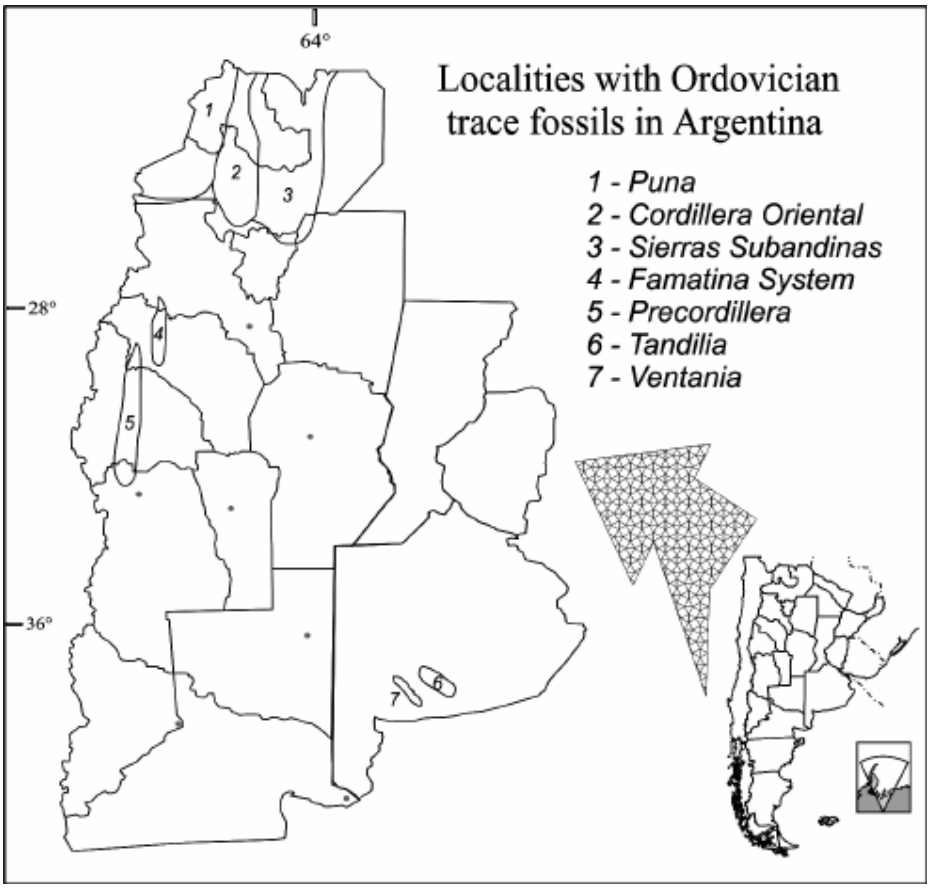

Figure 1. Location of Ordovician outcrops in Argentina and geological provinces mentioned in the text.

is placed within the sandstones of the lower part of the Cardonal Formation (= lower part of the Santa Rosita Formation), Santa Victoria Group. *Iapetognathus-Cordylodus* (Conodonta), *Rhabdinopora* (Graptolithina) and *Jujuyaspis* (Trilobita) are mentioned among the index fossils for the early referred boundary in the area. Siliciclastic sequences with abundant trace fossils are frequently found with a submeridional alignment over the Cordillera Oriental and margins of the latter. The reason for this distribution is interpreted as related to the paleogeography of the region, where part of the Cordillera Oriental was a structural high producing shallow environments in the region ("Cratógeno Central Argentino" *sensu* Bracaccini, 1960). Outstanding Ordovician ichnofossiliferous outcrops are found in several localities as Cajas and Zenta ranges, Quebrada de Humahuaca (Jujuy province), Santa Victoria range and Quebrada Del Toro (Salta province).

Nicely preserved mid to high diversity traces have been described from different marine siliciclastic sequences and marginal on shore paleoenvironmental conditions (Fig. 2, 3).

Arenicolites isp., *Asaphoidichnus* isp., *Bergaueria* isp., *Protovirgularia* isp., *Arthraria antiquata*., *Chondrites* isp., *Conostichus* isp., *Cruziana* isp., *Diplocraterion* isp., *Lockeia* isp., *Monocraterion* isp., *Monomorphichnus* isp., *Palaeophycus tubularis*, *Planolites* isp., *Skolithos linearis* and*Skolithos magnus* were mentioned in shallow tide dominated sequences (Aceñolaza, 1978; Aceñolaza and Fernández, 1984; Mshallow tide dominated sequences (Aceñolaza, 1978; Aceñolaza and Fernández, 1984; Mángano *et.al., 1996b). Highly bioturbated Skolithos beds are frequent in sandstones and quatrzites, reaching* ichnofabric indices up to four and five in some pipe rocks at Zenta and Santa Victoria ranges (Salta province).

Faecal material represented by *Alcyonidiopsis pharmaceus* and *Tomaculum problematicum* are found in black and green shales interbeded to quartzites at Coraya , Azul Pampa, Huichaira and Alfarcito localities (Jujuy province) (Aceñolaza, 1996; Aceñolaza and Gutiérrez Marco, 1998).

Other levels
with *Cruziana* isp., *Conostichus* isp., *Didymaulichnus* isp., *Dimorphichnus* isp., *Diplichnites* isp., *Helminthopsis abeli*, *Isop odichnus* isp., *Lockeia* isp., *Megagrapton* isp., *Monocraterion* isp., *Monomorphichnus bilinearis, Monomorphichnus multilineatus, Monomorphichnus*isp., *Palaeophycus tubularis*, *Palaeophycus* isp., *Petalichnus* isp., *Planolites montanus*, *Planolites* isp., *Phycodes* isp., *Sublorenzinia* isp., *Teichichnus rectus* and *Trichophycus* isp. were found within intertidal sandstones and shales of the Quebrada de Humahuaca, Zenta, Coraya ranges (Jujuy province) and Lampazar / Parcha area (Salta Province).

Tremadocian and Arenig intertidal, estuarine and other marginal environments are characterized by elements of the "*Cruziana*" ichnocoenosis, particularly well preserved in the base of sandstones and quartzites up to 40 cm in thickness. *Cruziana* (*C. semiplicata*, *C. furcifera*, *C. cajasi*, *C. omanica*, *C.* cf. *tortworthi*, *Cruziana* isp. A, *Cruziana* isp.), associated to «resting» traces of *Rusophycus (R. carbonarius*, *R. latus*, *R. polonicus*, *Rusophycus* isp. A, *Rusophycus* isp. B., *Rusophycus* isp.) (Fig. 3, 4).

Other sectors in NW Argentina as Escaya-Cochinoca, Santa Catalina and Calalaste ranges in Jujuy province are characterized by ritmcally interbedded heterolithic facies with notorious hypichnial traces as *Helminthopsis abeli*, *Megagrapton* isp., *Paleophycus* isp., *Planolites*isp. and *Protopaleodyction* isp. These traces are interpreted to be developed in the western deeper facies of the Ordovician basin in NW Argentina. Promising studies are being carried out by the authors in these facies, from a number of different localities of the northern provinces of Jujuy and Salta.

Trace fossils have been described from well distributed strata in NW Argentina, reflecting a varied behavioural patterns in different environmental conditions (Aceñolaza, 1978; Aceñolaza 2001a; Aceñolaza 2001b; Aceñolaza and Durand, 1978; Aceñolaza and Fernandez, 1978a,b; Aceñolaza and Manca, 1982; Aceñolaza and Poiré, 1999; Aceñolaza *et al*., 2001; Benedetto *et al*., 2002; Mángano and Buatois, 2001; Mángano *et al*., 1996b).

Arenig-Llanvirn: Arenig sandstone levels are regarded as the strata with the most impressive and well preserved trace fossils in the region. Mid to low diversity ichnoassociations characterize these Series.
The *Cruziana* ichnoassociation is nicely developed, specially those materials bearing the "*rugosa*" group. A classic section is placed at the Sierra de Mojotoro, in the Quebrada del Gallinato, near

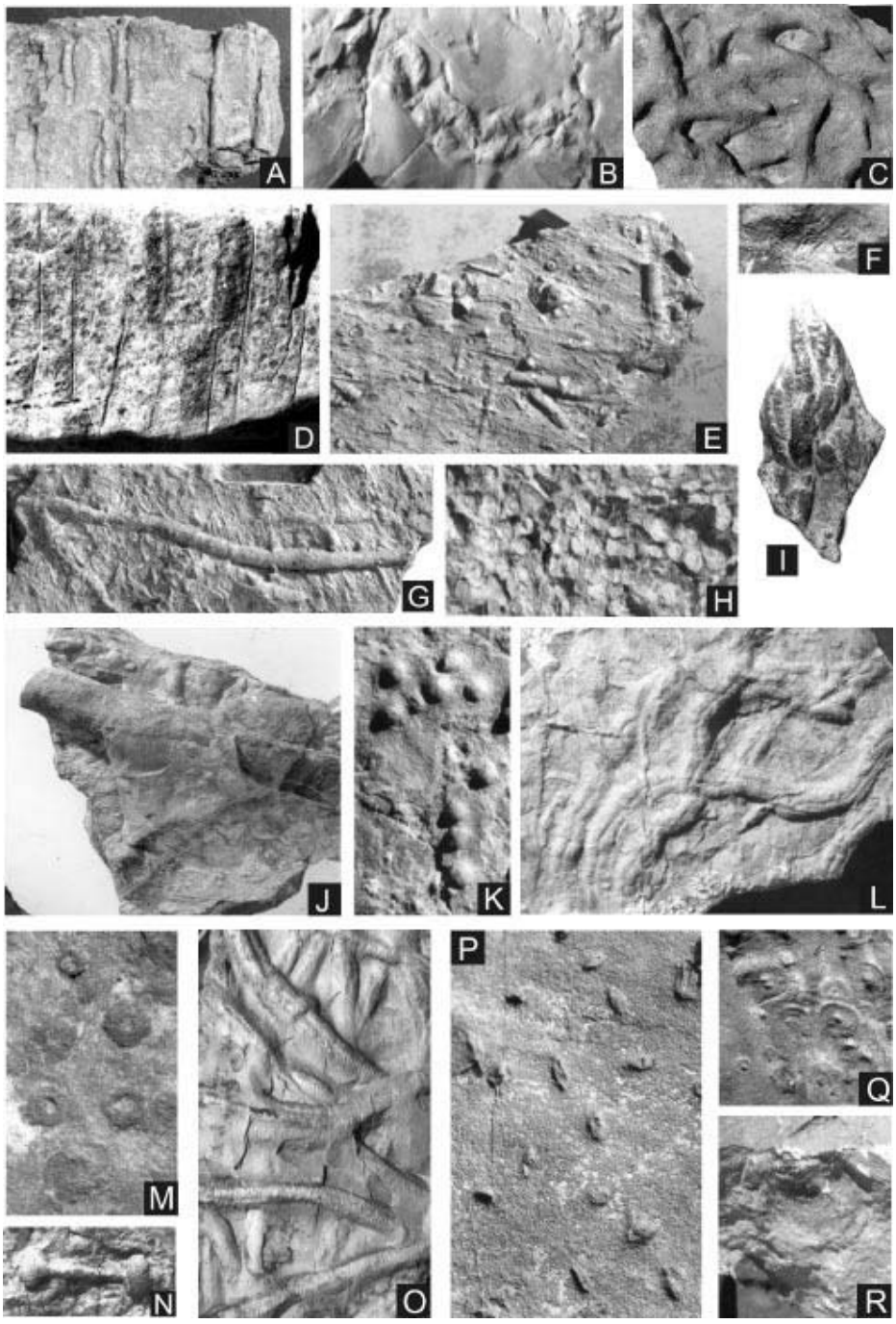

Figure 2. Cambro-Ordovician trace fossils from the Puna, Cordillera Oriental and Sierras Subandinas of NW Argentina. **A.** *Skolithos magnus* from Lampazar Formation at Salta province (x 0,4). **B.** *Bolonia* isp. from Tremadoc shales of Zenta Range (Salta-Jujuy) (x 0,2). **C.** *Thalassinoides* isp. from Cambro-Ordovician strata at Azul Pampa range (x 0,2). **D.** Sandstone pakage with *Skolithos linearis* from the lower part of santa Victoria Group at Jujuy province (x 0,2). **E.** Sandstone sole with *Palaeophycus tubularis* and *Skolithos* isp. from Chucalezna, Jujuy province (x 0,2). **F.** Small *Tomaculum problematicum* from Alfarcito locality, Jujuy province (x 0,7). **G.** *Palaeophycus* isp. from Chucalezna, Jujuy province (x 0,5). **H.** *Skolithos magnus* pipe rock from Zenta Range, Salta province (x 0,4). **I.** *Phycodes*isp. from the Cambro-Ordovician beds of Jujuy province (x 0,8). **J.** Basal view of *Trichophycus* isp. from Upper Tremadocian beds outcropping at Chucalezna, Jujuy (x 0,4). **K.** Small *Bergaueria* isp. from the lower levels of Santa Victoria Group in Salta province (x 0,5). **L.** ?*Scolicia* isp. (x 0,3). **M.** Upper surface of sandstone pakage with *Monocraterion* isp., Mojotoro Range,

Salta province (x 0,9). **N.** *Arthraria antiquata* from Perchel locality, Jujuy province (x 1,1). **O.** Upper Tremadocian *Arthrophycus* cf. *alleganensis* form Jujuy province (x 1). **P.** Sandstone sole with few orientated *Lockeia* isp. from Jujuy Province (x 0,4). **Q.** Different diameter *Laevicyclus* isp. from the Eastern Cordillera of Jujuy (x 0,9). **R.** lateral and upper view of *Diplocraterion* isp. showing distinctive spreiten, Tremadocian beds of Jujuy province (x 0,7).

Salta city. Other promising less know sections are found in Santa Victoria, Santa Barbara and Zenta ranges (Jujuy and Salta provinces). Strata are dominated by sandstones and quartzites with highly bioturbated low to mid diversity heterolithic facies (Fig. 4).

Well preserved ichnofossils associated to low diversity trilobite assemblages have been mentioned and described from the Acoite and Sepulturas Formation in the western flank of the Cordillera Oriental. These units have been interpreted as storm dominated deltaic system and estuarine environments (Astini and Waisfeld, 1993; Astini, 1994). Among known ichnotaxa in these levels are: *Arenicolites* isp., *Arenicolites*?, *Bergaueria* isp., *Cruziana furcifera*, *Cruziana rugosa*, *Cruziana goldfussi*, *Dimorphichnus obliquus, Dimorphichnus*isp., *Diplichnites* isp., *Laevicyclus* isp., *Lockeia* isp., *Monomorphichnus multilineatus, Monomorphichnus* isp.*, Palaeophycus tubularis, Palaeophycus* isp., *Rusophycus* isp., *Skolithos linearis*, *Skolithos magnus*, *Skolithos* isp. and *Thalassinoides* isp. (Borrello, 1966a; Aceñolaza, 1978; Volkheimer *et al*., 1980; Mángano *et al*., 2001; Astini, 2001, 2002; Aceñolaza and Aceñolaza, 2002).

Caradoc : The record of ichnofossils is restricted to the Capillas and Santa Gertrudis formations of the Cordillera Oriental and Sierras Subandinas. *Cruziana* isp., *Monomorphichnus* isp., *Palaeophycus* isp. and *Skolithos linearis* have been recorded in sandstone soles of the upper part of the sequences. Albanesi and Rao (1996) give an early Caradoc age for the last unit, while bivalves and trilobites support a partial correlation of both formations (Waisfeld, 1996; Sánchez, this volume).

Ashgill: The upper boundary of the Ordovician System is placed within a sandstone package related to the diamictites of Zapla Formation (Aceñolaza, 1992; Benedetto *et al*., 1992; Aceñolaza *et al*., 1996; 1999). Abundant *Chondrites* isp. and *Didymaulichnus* isp. are recorded within the reddish-grayish sandstones in outcrops of Puesto Viejo Range, in Jujuy province.

Famatina System

Tremadocian: The Cambrian – Ordovician boundary is recognized in the Volcancito Formation, within the upper part of the 170 m thick Lower Member. *Iapetognathus* (Conodonta), *Rhabdinopora* (Graptolithina) and *Jujuyaspis* (Trilobita) have been found in the type section at Volcancito River (Harrington, 1938; Harrington and Leanza, 1957; Turner, 1959; Toselli, 1977; Aceñolaza and Durand, 1984; Esteban and Gutiérrez-Marco, 1997; Tortello and Esteban, 1997, 1999; Albanesi *et al*., 1999). Bioturbation occurs restricted to certain levels within the Volcancito Formation, situation that has been interpreted as restricted environmental conditions with low oxygen content of water. *Gyrophyllites*, *Trichichnus* and *Tomaculum* have been recently mentioned in the unit (Esteban, 1993; 2001) (Fig. 6).

Arenig-Llanvirn: The Suri Formation is a particular volcanosedimentary sequence that crops out in the northern sector of the Famatina System. Aceñolaza and Mángano (1990) describe *Cruziana furcifera* for the unit cropping out at the locality of Chaschuil, while in the same section Mángano and Buatois (1994) reported *Cruziana furcifera, Phycodes* isp., *Palaeophycus tubularis* and *Planolites montanus* from the lower and middle part of the unit. Additional information was given by Mángano *et al.* (1996a), who focused a paper on the ichnology of the sequence at the same locality, describing two ichnoassemblages: a *Planolites* assemblage with *Planolites montanus, Palaeophycus tubularis* and *Helminthopsis abeli*, and a *Cruziana* assemblage represented by *Cruziana furcifera*, *Palaeophycus tubularis*,*Phycodes* isp., *Planolites beverleyensis* and *Helminthopsis* isp. Recently, Aceñolaza *et al.* (*in press*) describes and figures *Arachnostega gastrochaenae* associated to fossiliferous moulds within the mid-upper part of the Suri Formation, highlighting the biological implications of this particular trace (Fig. 6).

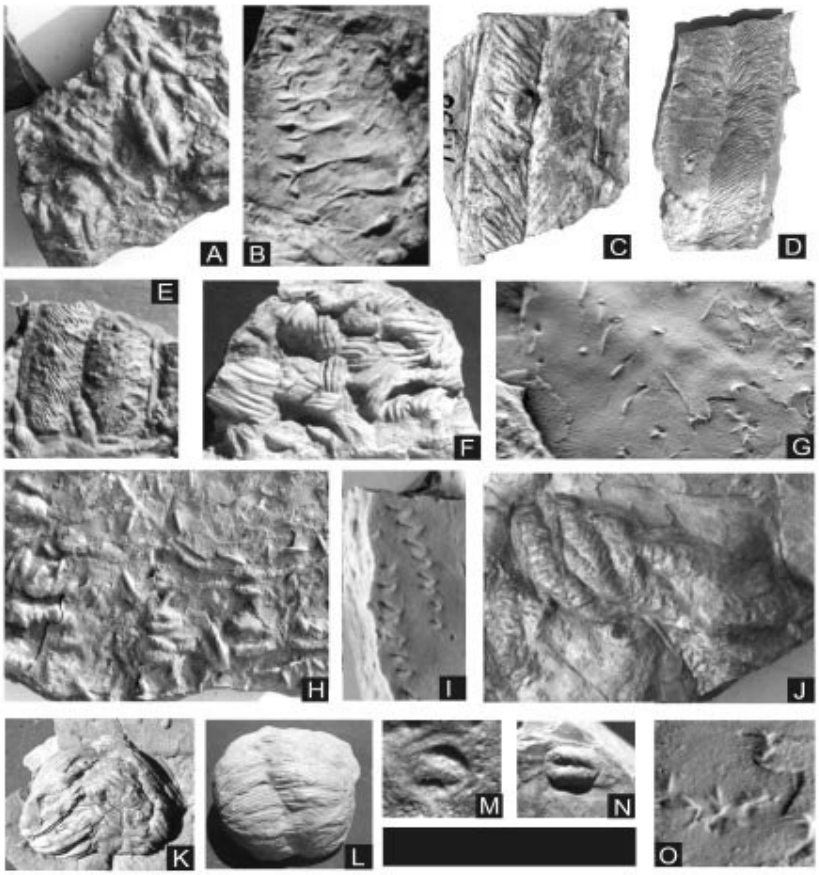

Figure 3. Trace fossils of the Cambro-Ordovician transition from the Cordillera Oriental, Puna and Sierras Subandinas of NW Argentina.. **A**. multiple association of *Rusophycus* isp. from the lower levels of Santa Victoria Group cropping out at the Quebrada of Humahuaca, Jujuy province (x 0,8) **B**. *Asaphoidichnus* isp. from the Tremadocian beds of Santa Victoria Group (x 0,6). **C**. *Cruziana semiplicata* with disctinctive exopodal markings from the early mentioned unit at Chucalezna, Jujuy province (x 0,8). **D**. Upper Tremadocian *Cruziana furcifera* from Jujuy province (x 0,8). **E**. Upper Tremadocian *Cruziana furcifera* from Chucalezna, Quebrada de Humahuaca, Jujuy province (x 0,8). **F**. Overimposed *Monomorphichnus multilineatus* «digging marks» from the Tremadocian beds of Cajas Range (Jujuy province) (x 0,5). **G**. *Asaphoidichnus* isp. and *Allocotichnus* isp., walking traks of trilobites from the Cambro-Ordovician beds of Iruya, Salta province (x 1). **H**. *Rusophycus* isp. and *Palaeophycus* isp. on a sandstone sole of the Lower part of Santa Victoria Group at Quebrada de Moya, Jujuy Province (x 0,3). **I**. *Diplichnites* isp. from Iruya locality, Salta province (x 0,7). **J**. Aligned *Rusophycus* isp. A. with distinctive subparalell scratching of lobes from the Tremadocian beds of Jujuy province (x 0,8). **K**. *Rusophycus*isp. B with high relief scratch marks from Jujuy province (x 0,5). **L**. Large *Rusophycus* cf. *latus* from Cambro-Ordovician Santa Victoria Group (x 0,4). **M**. Small and shallow form of *Rusophycus* isp (x 1). **N**. *Rusophycus carbonarius* with supparalell smooth lobes from Purmamarca, Jujuy province (x 0,9). **O**. *Allocotichnus* isp. from Cambro-Ordovician beds at Iruya, Salta province (x 1,1).

Precordillera

Tremadocian: The Cambro-Ordovician boundary has been placed within the lower sector of La Silla Formation (Keller *et al*., 1994, Peralta, 2000, with references). Conodonts, trilobites, molluscs, algal- stromatolites and micritic carbonates characterize the sequence. Bordonaro (1999, with references) summarizes the biostratigraphic framework of the unit. Highly bioturbated levels with *Thalassinoides* isp. have been described in the "burrowed peloidal-intraclastic grain to-packstone facies" from the mid-upper part of the section (Cañas, 1995). *Thalassinoides* is a common element in the mid-upper part of the section, with a massive and boxwork preservation, clearly differentiated by a ferrigenous silica filling (Fig. 6).

Arenig: San Juan Formation limestones with abundant *Thalassinoides* isp and *Planolites* isp. crop out at La Silla Range. They are lithologically represented by grey limestones associated to algal mounts with an important sandy participation. In Mendoza province, a sequence of greyish sandstones and shales assigned to the Cortaderas Formation display an nicely preserved ichnoassociation of a probable early Ordovician age with *Didymaulichnus* isp. A and B, cf. *Helminthopsis* isp*., Planolites* isp. and *Tomaculum problematicum*(Durand *et al*., 1997).

Caradoc: *Trypanites* isp. was recently mentioned over the briozoan *Solenopora* sp. in the limestones of La Pola Formation at Villicum Range (San Juan Province). This strata is lithologically characterized by several levels with briozoan-red algae (Astini, 2001).

Ashgill: No ichnological studies have been done on the highly bioturbated upper member of Don Braulio Formation (Astini and Buggisch, 1993). Peralta and León (1993) describe elements of the deeper *Zoophycos* ichnofacies (*Phycosyphon* and *Chondrites*) within the green shales of the lower member of Tambolar Formation cropping out at Pachaco (San Juan Province). The section is regarded as of an Upper Ashgill age by the last mentioned authors. Finally, Keller (1999) mentions the presence of abundant bioturbation within the sandstone facies of the Don Polo Formation.

Tandilia System

Undifferentiated Cambro-Ordovician strata: A 100 m thick quartzite sequence crops out in the southern part of Buenos Aires Province, named as Balcarce Formation. The unit is composed of white sheet-like quartz sandstones and granule sandstones with subordinated mudstones and quartz conglomerates deposited in a nearshore and inner shelf environment of a tide dominated and storm influenced platform (Poiré et al., 2000). These siliciclastic strata is interpreted to be connected to the Central Andean Ordovician basin by a narrow passage placed towards the north-northwestern sector of the basin. Recent disscussions are being carried out on a probable Silurian age for these sequences, but no detailed integrated analysis has been done on the matter yet. In this opportunity we follow the interpretation on basis of the available data.

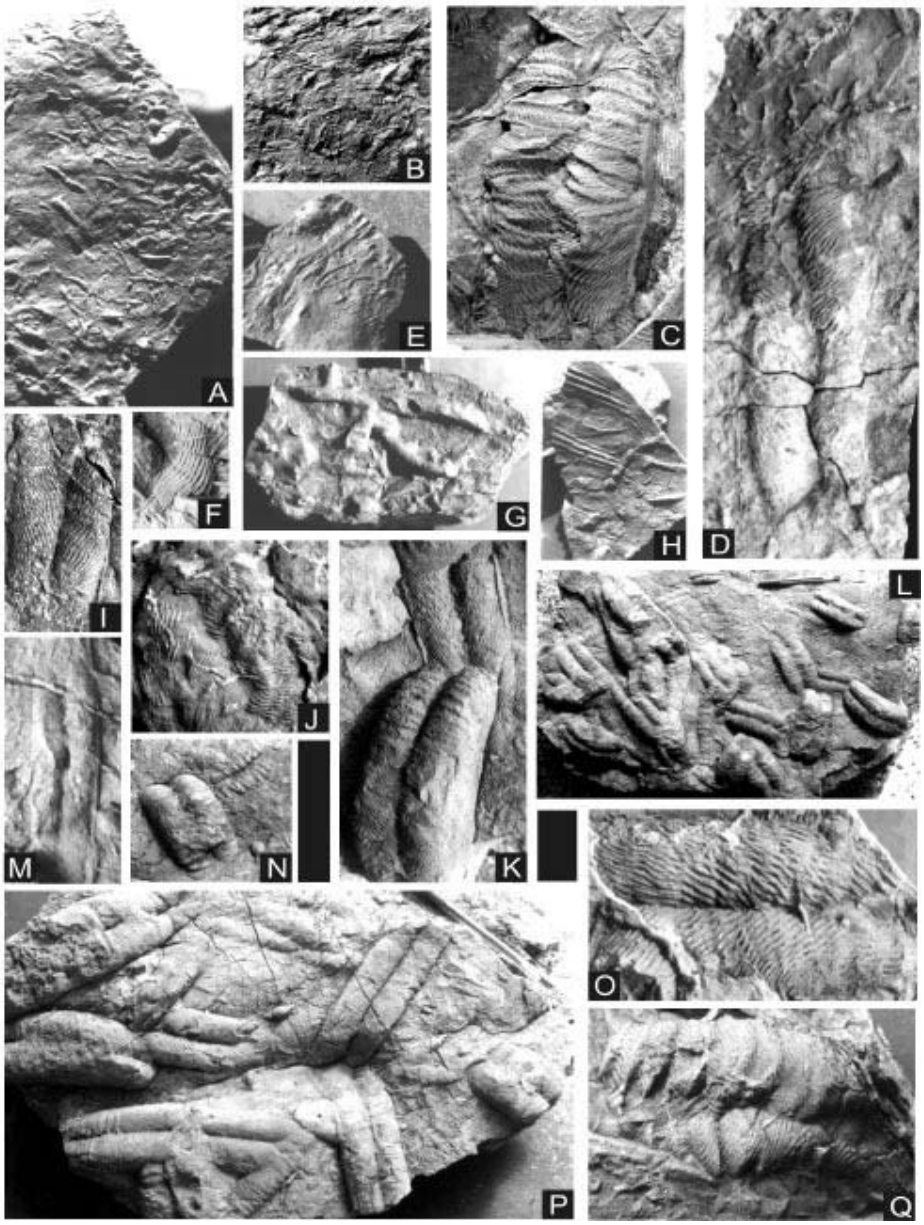

Figure 4. Arenig trace fossils from the eastern Cordillera of NW Argentina. A. *Dimorphichnus* isp. from the Arenig strata outcropping at Espinazo del Diablo, Jujuy province (x 0,6). B. Large subparalell grooves assigned to *Monomorphichnus* isp. from Zenta Range, Salta Province (x 0,25). C. High relief *Cruziana rugosa* from Zenta Range (Jujuy-Salta) (x 0,4). D. *Cruziana furcifera* with deepening variation along the trace, Zenta Range (x 0,3). E. *Dimorphichnus obliquus* fom Jujuy (x 0,3). F. *Monomorphichnus* isp. from the last referred locality (x 0,15). G. *Thalassinoides* isp. from Espinazo del Diablo locality, Jujuy province (x 0,2). H. *Monomorphichnus multilineatus* from Zenta Range (Jujuy- Salta) (x 0,6). I. *Cruziana furcifera* showing distinctive morphology, same locality than last (x 0,3). J. Sandstone level with *Monomorphichnus multilineatus* from same locality (x 0,3). K. Sandstone sole with sample of high relief *Cruziana rugosa* associated to a low relief *Cruziana furcifera* from Zenta Range (x 0,3). L. Large quartzite bed with few *Cruziana* of the "*rugosa*" group. Zenta Range (lenght of slab is 0,70 m). M. *Cruziana goldfussi* from last locality (x 0,65). N. Shallow and deep furrow of *Cruziana rugosa* from same locality (x 0,2). O. Sandstone sole with several *Cruziana* of "*rugosa*" group, Zenta Range (length of slab is 0,50 m). P. *C. rugosa* and *C. furcifera* from same locality than last (x 0,4). Q. Shallow sample of *Cruziana rugosa*, Zenta Range (x 0,4).

Among the different authors that mentioned and described trace fossils in this sequence are Hauthal (1896), Nágera (1919,1926), Borrello (1966b) and Aceñolaza (1978). Later records were done by Alfaro (1981),

Regalía and Herrera (1981), Zalba et al. (1982), Cingolani et al. (1985), Del Valle (1987a,b), Poiré and Del Valle (1994; 1996), Poiré (1998) and Poiré et al. (2000). Among the different trace fossils described in the Balcarce Formation are: *Ancorichnus ancorichnus, Arthrophycus alleghanensis, Arthrophycus* isp.*, Bergaueria*isp.*, Cochlichnus* isp.*, Conostichus* isp.*, Cruziana furcifera, Cruziana* isp.*, Daedalus labeckei, Didymaulichnus lyelli, Didymaulichnus* isp.*, Diplichnites* isp.*, Diplocraterion* isp.*, Herradurichnus scagliai, ?Monocraterion* isp.*, Monomorphichnus* isp.*, Palaeophycus alternatus, Palaeophycus tubularis, Palaeophycus* isp.*, Phycodes aff. pedum, Phycodes* isp.*, Plagiogmus* isp.*, Planolites* isp.*, Rusophycus* isp.*, Scolicia* isp. *and Teichichnus* isp. (Poiré et al., 2000, with references) (Fig. 5).

Ventania System

Sandstone levels of the Napostá Formation were included within the Ordovician System by Andreis et al. (1989). Dimieri and Japas (1986) identified in these strata few tectonically deformed trace fossils as *Skolithos* isp.*, Daedalus* isp.*, Corophiodes* isp. *and Diplocraterion*isp. Shallow tide dominated sequences characterize these high energy sequences as supported by the ichnofossiliferous association (Fig. 5).

Paleoenvironment and distribution of ichnoassociations

Different areas of distinct paleobathimetric positions are recognized in the Ordovician strata of Argentina. The record of trace fossils is better known within the shallower littoral and marginal marine sequences of the Cambro-Ordovician transition, displaying a better diversified ichnological record. A restricted knowledge on younger levels and deeper environments is caused by a lack of extensive typical deep water Ordovician strata.

The more attractive trace fossils are frequently recorded within shallow environments, resulting that most ichnological studies have been focused on these strata. This panorama will shortly change indeed, with few projects carried out by the authors that are focused on the little known deep sea ichnoassociations of western Argentina.

Subtidal, tidal and supratidal paleoenvironments characterize the record of ichnoassociations in the Puna, Cordillera Oriental, Sierras Subandinas, Famatina System, Precordillera and Tandilia/Ventania systems. The Cambro-Ordovician transition is regarded as a time characterized by sea level fluctuation. These, strongly influenced environmental types, today reflected by the sedimentological patterns and trace fossils associations.

A subtidal - tidal influenced and wave dominated open marine paleoenvironment has been interpreted for the Cambro-Ordovician Santa Rosita Formation (Moya, 1998; Aceñolaza and Poiré, 1999; Mángano and Buatois, 2002), reaching up to storm dominated deltaic systems and estuaries for the Arenig Acoite and Sepulturas formations (Astini and Waisfeld, 1993, Astini, 1994). In addition a tide dominated and shallow marine setting has also been recorded long ago in the Mojotoro Formation cropping out in diverse areas of the homonymous range by Volkheimer *et al.* (1980) and later with a modern perspective by Moya (1998) and Mángano *et al.* (2001).

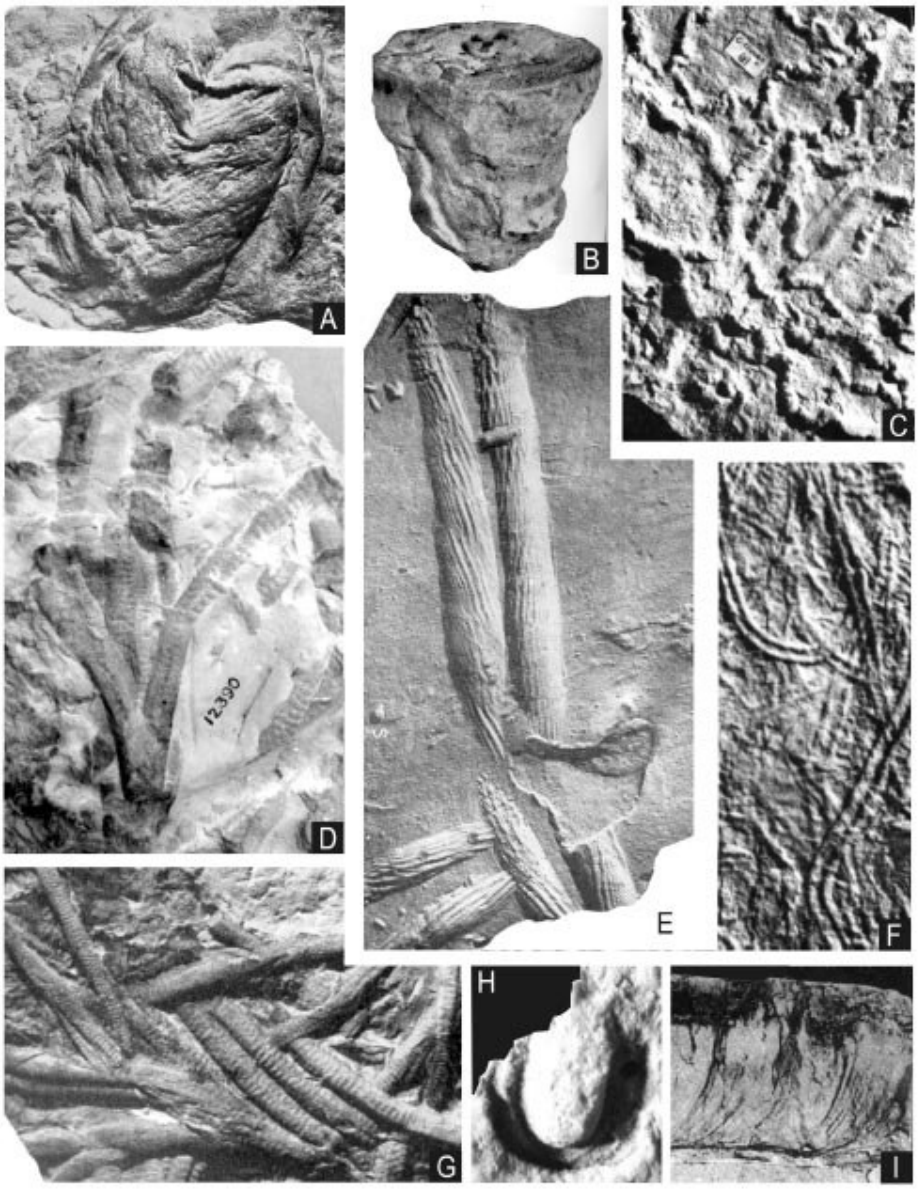

Figure 5. Trace fossils from the Tandilia and Ventania systems in southern Buenos Aires province. A. *Rusophycus bonariensis* (Borrello) (x 0,4) from La Tinta Formation. B. *Conostichus* isp. (x 2). C. *Palaeophycus tubularis* from Cerro Corral, Buenos Aires. D.*Arthrophycus* isp. from the Balcarce Formation cropping out at Los Padres Range (x 0,4). E. *Cruziana furcifera* from Tandilia (x 0,5) . F. *Didymaulichnus lyelli* from Cerro Corral, Buenos Aires Province (x 0,3). G. *Arthrophycus* isp. from Tandilia (x 0,5). H.*Herradurichnus scagliai* (Borrello), from Balcarce Formation at Cabo Corrientes (x 1). I. *Daedalus labeckei* Rouault from Balcarce Formation at Cabo Corrientes (x 0,6).

The different paleoenvironments represented in the Ordovician strata of NW Argentina records a variety of ichnofossils related mainly to living habits of the different groups that conformed the biota of the Cambro-Ordovician Central Andean Basin (Volkheimer,*et al.* 1980; Mángano *et al.*, 2001; Aceñolaza and Aceñolaza, *in press*).

The paleogeography of NW Argentina during most of the Lower Paleozoic was ruled by the high "Cratógeno Central Argentino" (Bracaccini, 1960). In the Cordillera Oriental and the Sierras Subandinas, the strata refers to a shallow shelf basin developed eastwards and a deeper western facies, associated to a regional volcanism (Famatina System and Puna). Obviously, the abundance of ichnofossils is strongly related to the great biodiversity of the Ordovician seas in the western margin of Gondwana, and the palaeogeographic elements

involved in the morphological construction of basins. The early referred structure was probably aerial exposed in certain areas, with the consequent development of fluvial and stuarine environments that highly influenced Upper Cambrian-Lower Ordovician sequences (Astini and Waisfeld, 1993; Astini, 1994; Aceñolaza and Aceñolaza, 2002). Bordering this structure, large tidal surfaces were developed, characterized by the relative abundance of typical tidal washed mature quartzites (including sand bars and subtidal sandstones) with high energy ichoassociations ("*Skolithos* ichnofacies" *s.l.*).

Eastwards, subtidal sand bars have been described from Tandilia and Ventania systems, interpreted to be connected to the early mentioned shallow seas of the Central Andean Basin (Poiré and Del Valle, 1996 with references). The southern Buenos Aires basin has been related to those Cambro-Ordovician units cropping out in Uruguay (El Cordobés Formation), Brasil (Furnas Formation) and South Africa (Kuibis Formation), many of them bearing similar ichnoassociations (Aceñolaza and Ciguel, 1987).

Finally, the Precordillera had a different geological history with development of shallow carbonate platforms eastwards with siliciclastic and deeper facies westwards. This story is related to a para-autochthonous (Aceñolaza and Toselli, 1999; Aceñolaza, Miller and Toselli, 2002; Finney *et al.*, 2003) or allochthonous genesis (Astini *et al.*, 1996 with references).

Diversity and concluding remarks

Highly bioturbated Ordovician strata are recorded in different sectors of Argentina. Tremadocian and Arenig successions of the Cordillera Oriental have been proportionally more studied, so their ichnological record is better understood that others of the Ordovician Series.

A preliminary number of about forty six ichnogenera and over sixty ichnospecies are known so far from the Ordovician beds of Argentina.

The Cambro-Ordovican sequences outcropping in Tandilia and Ventania, as well as the Arenig strata of the NW region of Argentina display the most impressive pavements with trace fossils, represented by a variety of arthropod activities (mostly "*Cruziana*ichnofacies").

Diversity is higher in the coarser facies and most of all, in the heterolithic part of sequences. Sandstone soles within heterolithic facies of the Uppermost Cambrian – Tremadocian and the Arenig represent the best preservational facies for ichnological means. This type of succession frequently display high ichnofabric indices, where reworking of sediment destroy discrete traces and homogenize strata. There is a virtually lack of complex horizontal traces in most of the Ordovician sequences of Argentina (typical "*Nereites*association" in a classic concept).

Exclusively well sorted mature sandstones and quartzites show a great decline in trace fossils diversity, restricting them to the classical high energy ichnoassociations represented by such forms as *Skolithos*, *Monocraterion*, *Diplocraterion* and *Arenicolites*.

The early Ordovician biodiversification is also recognized in the stratigraphy by means of ichnofossils, and may have started a short time before the flooding of shelves during the late Cambrian/early Tremadocian. Their record in the finer sediments (shales and sandstones) of the lower part of the Cambro-Ordovician Santa Victoria Group is related to the known increasing biota diversification of most of typical Early Paleozoic groups (Aceñolaza *et al.*, 1996; Gutiérrez-Marco and Aceñolaza, 1996; Waisfeld *et al.*, 1999).

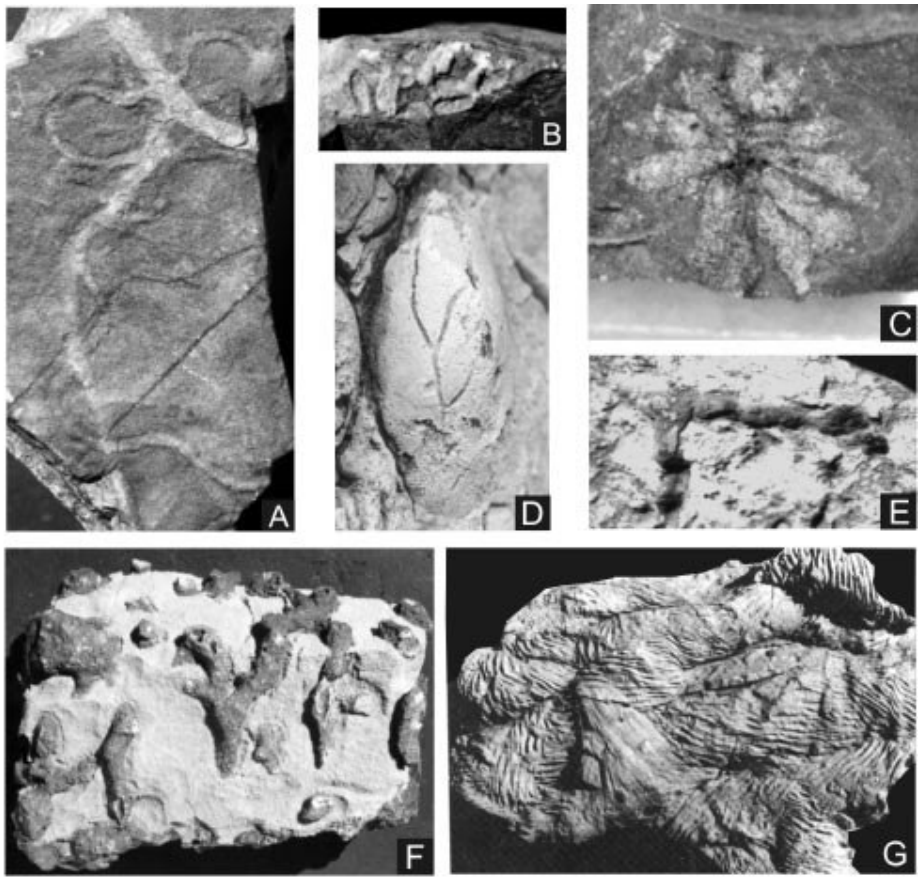

Figure 6. Trace fossils from the Famatina System and Precordillera. A. *Helminthopsis abeli* from Suri Formation at Chaschuil, Famatina System, Catamarca province (x 1,1). B. *Tomaculum problematicum* from the black shales of Volcancito Formation in the Famatina System, La Rioja province (x 1,2). C. *Gyrophyllites* isp. from the Volcancito Formation, Famatina System, La Rioja province (x 1). D. *Arachnostega gastrochaenae* in fossil moulds from the upper part of the Suri Formation, Sierra de Narváez, Famatina System, Catamarca province (x 1). E. *Thalassinoides* isp. from limestones of La Silla Formation cropping out at Cerro La Silla, Precordillera of San Juan (x 0,9). F. *Thalassinoides* isp. from La Silla limestones of Precordillera at San Juan province (x 0,7). G. *Cruziana furcifera*D'Orbigny with overimposed *Phycodes* isp. from the upper part of Suri Formation at Chaschuil locality, Famatina System (x 0,7).

The number of taxa represented in the underlying strata (Puncoviscana Formation and Mesón Group of a Precambrian/Cambrian age) is smaller compared to the ones of the transitional levels to the Ordovician. Trace fossils are the most important biostratigraphical elements within the older units, while more diversified ichnoforms appear associated to a varied spectrum of taxa represented in the overlaying Cambro-Ordovician strata of the Santa Victoria Group.

Trace fossil assemblages tends to confirm the earlier described paleoenvironmental interpretations of sequences supported by sedimentology and fossil associations (Bracaccini, 1960; Volkheimer *et al.*, 1980; Aceñolaza and Baldis, 1984; Aceñolaza and Toselli, 1986; Moya, 1988, 1998; Astini and Waisfeld, 1993; Astini, 1994; Mángano and Buatois, 1994; Mángano *et al.*, 1996a,b; Waisfeld *et al.*, 1999; Aceñolaza *et al.*, 1999; Mángano *et al.,* 2001; Aceñolaza and Aceñolaza, 2002; Aceñolaza *et al.*, *in press*).

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