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Trace fossils from the Lower–Middle Jurassic Bardas Blancas Formation, Neuquén Basin, Mendoza Province, Argentina

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ABSTRACT:

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Trace fossil associations from the Lower–Middle Jurassic siliciclastic succession of the northern Neuquén Basin, Argentina are described and their palaeoenvironmental interpretation is discussed. The Bardas Blancas Formation displays facies of lower foreshore to offshore environments, such as massive and laminated mudstones, laminated siltstones, hummocky cross-stratified sandstones, massive and laminated sandstones, wave-rippled sandstones, as well as fine- to medium-grained bioclastic sandstones and massive conglomerates. They contain a trace fossil assemblage low in abundance but high in diversity. The assemblage, comprising eleven ichnogenera, is dominated by *Skolithos*, *Chondrites*, *Thalassinoides*, *Planolites*, *Palaeophycus*, *Taenidium*, *Gyrochorte* and *Arenicolites*. *Gordia*, ?*Diplocraterion* and *Lockeia* are less abundant. These trace fossils belong to the *Skolithos, Cruziana* and *Zoophycos* ichnofacies. Their distribution is controlled mainly by hydrodynamic energy, substrate consistency and oxygen levels. Storm beds exhibit two successive stages of colonization: (1) the pioneer stage, during which *Skolithos, Diplocraterion* and *Arenicolites* (elements of the *Skolithos* ichnofacies), were produced; and (2) the stable environment stage, represented by *Chondrites*, *Thalassinoides*, *Taenidium*, *Gyrochorte*, *Gordia*, *Lockeia*, *Palaeophycus* and *Planolites* (elements of the *Cruziana* ichnofacies). Deeper environments exhibit a low diversity association with *Chondrites* and *Thalassinoides*, characterizing the *Zoophycos* ichnofacies.

Key words: Trace fossils; Ichnotaxonomy; Ichnofacies; Neuquén Basin; Jurassic; Argentina.

INTRODUCTION

The Bardas Blancas Formation, northern Neuquén Basin, comprises a lower Toarcian–lower Bajocian marine siliciclastic platform, which is dominated by hummocky cross-stratified sandstones and shell beds produced by storm processes. Stratigraphic analysis of the Neuquén Basin has been undertaken by, among others, Gulisano (1981), Legarreta and Gulisano (1989), Legarreta *et al*. (1993) and Gulisano and Gutiérrez Pleimling (1994). Detailed sedimentological studies of the Bardas Blancas Formation (Junken 2002; Sanci 2005; Chacra 2007) refer only in passing to palaeontological aspects, albeit mention was made of the trace fossils *Skolithos*, *Chondrites*, *Thalassinoides*, *Planolites*, *Palaeophycus*, *Diplocraterion*, *Rhizocorallium* and *Arenicolites*. Additional data on the ichnology of this formation were provided in conference abstracts (Bressan and Palma 2007; Bressan and Palma 2008).

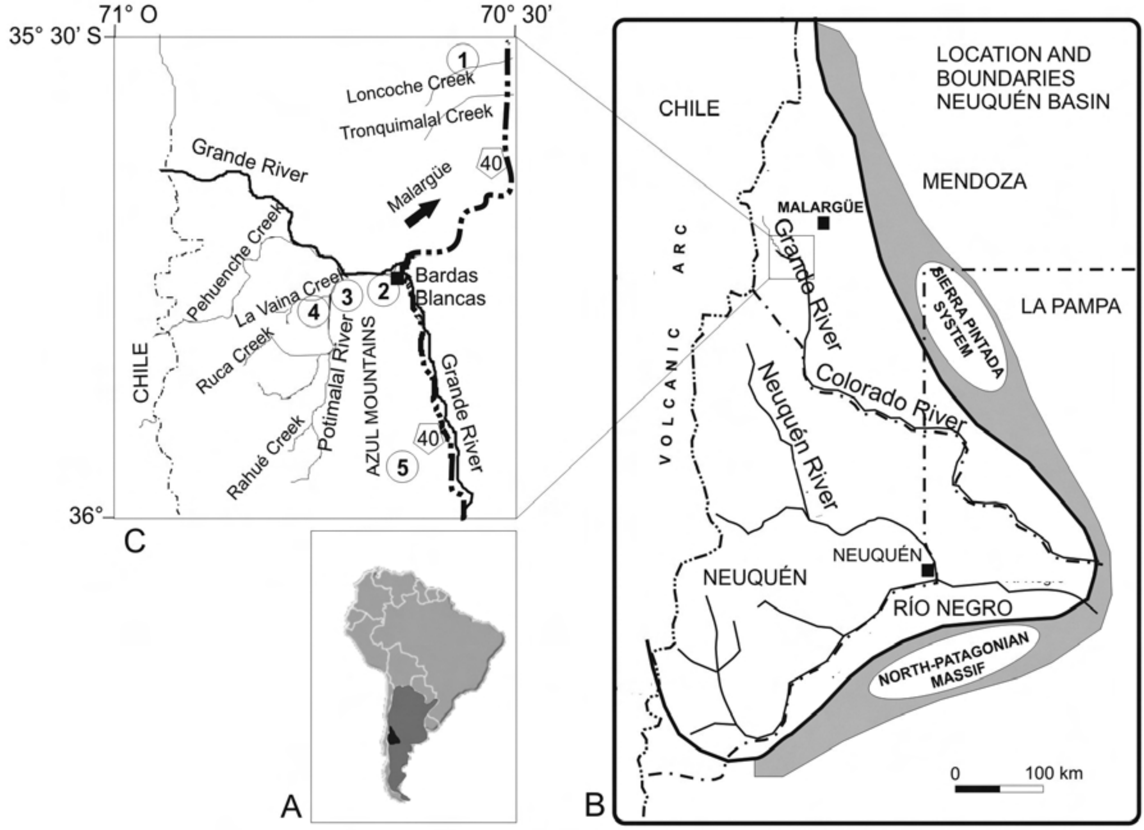
The aims of this paper are to document the trace fossils from the Lower–Middle Jurassic siliciclastic storm-dominated marine platform of the Neuquén Basin, which is exemplified by the Bardas Blancas Formation, and to interpret its depositional environment. An analysis of the distribution of the ichnotaxa in the different lithofacies and outcrops of this unit is provided.

GEOLOGICAL SETTING

The sedimentary infill of the Neuquén Basin can be subdivided into several mesosequences on the basis of regional stratigraphic discontinuities controlled by eustatic events (Legarreta *et al*. 1993). In Mendoza Province, the Cuyo Mesosequence (Hettangian-Callovian) is an equivalent of the Cuyo Cycle or “Cuyano” (Gulisano *et al*. 1984). This mesosequence is bounded by intra-Liassic (Gulisano *et al*. 1984) and intra-Callovian (Dellapé *et al*. 1979) regional discontinuities and includes alluvial-fan clastic deposits (El Freno Formation), marine inner shelf deposits (Puesto Araya Formation), and offshore shelf black mudstones (Tres Esquinas Formation). These deposits are overlain by fluvial-marine siliciclastic (Lajas Formation) and carbonate-dominated deposits (Calabozo Formation). The stratigraphic succession ends with the evaporites of the Tábanos Formation, which developed mainly in the centre of the basin and records a strong restriction of the Neuquén Basin coeval with a global sea-level fall (Riccardi *et al*. 2000). The Cuyo Cycle records the first marine transgression in the Neuquén Basin.

The Bardas Blancas Formation is the middle unit in the Cuyo Mesosequence (Gulisano 1981; Gulisano *et al*. 1984). This unit overlies the Remoredo Formation (Upper Triassic–Hettangian) and is covered by the Auquilco Formation (Oxfordian), Tres Esquinas Formation (Bajocian) or the La Manga Formation (Oxfordian).

The localities studied are situated in the northern portion of the Neuquén Basin, in the Malargüe area, in Mendoza Province. Five outcrops (Text-fig. 1) were studied, from north to south: Loncoche creek (157 m thick), Bardas Blancas (92 m), Potimalal river (68 m), La Vaina creek (67 m), Coihueco creek (55 m).



Text-fig. 1. A – Map of South America showing the location of Neuquén Basin. 1.B – General aspect of Neuquén Basin. 1.C – Map showing the geographic location of the outcrops. 1 – Loncoche Creek; 2 – Bardas Blancas; 3 – Potimalal River; 4 – La Vaina Creek; 5 – Coihueco Creek

METHODS

For a better interpretation of the ichnotaxa, the lithofacies bearing them are briefly characterized

Trace fossils were described in the field. Selected specimens are housed in the University of Buenos Aires paleontology collection under the registration numbers FCEN Nº20255–20263. The ichnogenera and ichnospecies are listed alphabetically.

Modifying the terminology used by Moghadam and Paul (2000), the occurrence of trace fossils in a bed was recorded as abundant (examples visible in all or in a majority of square metres of bedding surface), frequent (visible in a minority of square metres of bedding surface) and isolated (seen only locally throughout a 50 m section). To describe the distribution through the section we used the terms low (occurring only occasionally), medium (occurring in a few beds) and high (occurring in most beds).

The bioturbation index for *Skolithos* and *Thalassinoides* was recorded. It is based on the degree of disruption of primary lamination, and ranges from 1 (virtually undisturbed lamination) to 6 (complete bioturbation) (Droser and Bottjer 1986).

LITHOFACIES DESCRIPTION

The Bardas Blancas Formation is essentially a succession of interbedded storm deposits and fair-weather deposits. Massive and laminated mudstones, laminated siltstones, hummocky-cross stratified, massive and laminated sandstones, fine- to medium-grained bioclastic sandstones, and massive conglomerates (see Table 1) are the most abundant lithofacies.

Massive and laminated mudstones (lithofacies A)

Description: The textural composition of the massive and laminated mudstones ranges from silt to clay. The beds are mostly tabular, 2–90 cm thick. Some of them change their thickness laterally or pinch out completely. The tabular beds have gradational lower contacts, usually with sandstones (lithofacies C, D and E) and fine-

Lithofacies	Description	Interpretation	Trace fossil content
A	Massive and laminated mudstones	Fair-weather deposits in an offshore-transition to offshore zone	Only occasional *Chondrites*
B	Laminated siltstones	Fair-weather deposits in an offshore-transition zone	*Thalassinoides* and *Chondrites*
C	Hummocky cross-stratified sandstones; sometimes amalgamated, with wave-ripples and dewatering structures	Storm deposits in the middle-lower shoreface (amalgamated) and lower shoreface-upper offshore-transition zone	*Arenicolites*, *Chondrites*, ?*Diplocraterion*, *Gordia*, *Gyrochorte*, *Lockeia*, *Palaeophycus*, *Skolithos*, *Taenidium* and *Thalassinoides*
D	Massive; sometimes with interbedded shell beds and massive/laminated mudstones	Storm deposits between the lower shoreface and the offshore-transition zone	*Planolites, Palaeophycus, Taenidium, Chondrites* and *Skolithos*
E	Laminated sandstones, sometimes with lenticular shell beds	Slow currents deposits between the lower shoreface and the offshore-transition zone	*Chondrites, Thalassinoides* and *Skolithos*
F	Wave-rippled sandstones	Deposits produced under oscillatory flows above fair-weather wave base	*Chondrites* and *Skolithos*
G	Tabular shell beds	Storm deposits originated between the shoreface and beach zone and deposited in the upper and middle shoreface	Without bioturbation evidences
H	Massive conglomerates	Storm beds in the lower shoreface	Without bioturbation evidences

Table 1. Lithofacies of the Bardas Blancas Formation

to medium-grained bioclastic sandstones (lithofacies G) and less frequently with conglomerates (lithofacies H). The contact with the overlying lithofacies (C, D and E) is sharp.

These mudstones generally lack autochthonous fossils; they rarely yield fragments of *Trigonia* (*Trigonia*) sp. exhibiting evidence of transport. Trace fossils are represented by local *Chondrites* occurrences

Interpretation: These mudstones are interpreted as deposits accumulating during fair-weather periods (Spalletti and Del Valle 1990), below fair-weather wave base, in an offshore-transition to an offshore zone (Reading and Collinson 1996).

Fragments of *Trigonia* (*Trigonia*) sp. were redeposited from shallower zones by currents.

The absence of autochthonous fauna and the rare presence of the trace fossils *Chondrites* and *Thalassinoides* (both burrow systems communicating with water-sediment interface), suggest restricted oxygenation (Rhoads and Morse 1971; Ekdale and Mason 1988; Savrda *et al*. 1991). The complete absence of trace fossils throughout much of this lithofacies suggests anoxic conditions

Laminated siltstones (lithofacies B)

Description: This lithofacies is characterized by laminated siltstones in tabular beds 1–140 cm thick. Contacts to overlying sandstone lithofacies C, D and E, and underlying lithofacies C, D, E and G are sharp.

Locally the siltstones are intercalated with lenticular massive sandstone bodies, which have sharp basal contacts and planar or undulatory upper surfaces.

The laminated siltstones rarely contain ammonites ?*Phylloceras* cf. *trifoliatum* Neumayr, *Westermanniceras groeberi* (Westermann and Riccardi), and bivalves, some of them in situ, such as *Pholadomya laevigata* Hupé and *Pholadomya* sp., and others redeposited, including *Grammatodon* sp., *Trigonia* (*Trigonia*) sp., ?*Gryphaea* sp. and *Camptonectes* (C.) sp. Trace fossils include isolated *Thalassinoides* and *Chondrites*.

Interpretation: These siltstones are interpreted as fallout of suspended fine material or storm-emplaced sediments. The lenticular sandstones reflect the waning flow deposits of storm-generated currents (Brenchley *et al*. 1993; Cantalamessa and Di Celma 2004). These deposits characterize an environment below fair-weather wave base, in an offshore-transition zone (Reading and Collinson 1996).

The presence of sparse bivalve shells, including in situ material, suggests bottom sediments that were at least partially oxygenated. Where autochthonous bivalves are absent and only *Thalassinoides* and *Chondrites* are present, the bottom waters could have been permanently poorly oxygenated (Rhoads and Morse 1971; Ekdale and Mason 1988; Savrda *et al*. 1991).

Hummocky cross-stratified sandstones (lithofacies C)

Description: Fine- medium-grained sandstones with hummocky cross-stratification. Beds are tabular, with erosive basal contacts overlying fine-grained lithofacies (lithofacies A and B), sandstone lithofacies (lithofacies C and D) and conglomeratic lithofacies (lithofacies H). The upper contacts are sharp or gradational into overlying sandstones (lithofacies D and E) or fine-grained lithofacies (lithofacies A and B).

This lithofacies includes two different forms of hummocky cross-stratified sandstones, the scour and drape form (Cheel and Leckie 1993), and the migrating form (Brenchley 1989; Cheel and Leckie 1993), defined originally as “low-angle trough cross-stratification” by Arnott and Southard (1990).

First order truncations with shell lags and sandy and muddy rip-up clasts, define hummocky beds that can reach thicknesses over 1.5 m. The shell lags are characterized by disarticulated bivalve shells, usually highly fragmented, showing evidence of transport.

Second order truncations with plant and shell detritus separate laminae sets 20 cm thick. Third order truncations, also with plant and shell detritus, separate laminae less than 1 cm thick.

Amalgamation in these sandstones is frequent. The amalgamated packages are up to 16 m thick.

The top of these beds can have wave-ripples with wavelengths between 7–8 cm and 0.5 cm high, and climbing ripples. Dewatering structures are common.

These sandstones contain redeposited bivalves belonging to the genera *Pleuromya, Modiolus*, *Lucina* and *Trigonia*. Gastropods and cephalopods are present but less common. The latter are represented by belemnites and by ammonites such as *Phylloceras* cf. *trifoliatum* Neumayr, *Tmetoceras* cf. *flexicostatum* Westermann and *Phylloceras* cf. *trifoliatum* Neumayr.

These sandstones are usually extensively bioturbated. Trace fossils including *Taenidium*, *Palaeophycus*, *Planolites*, *Thalassinoides, Gyrochorte* and *Chondrites* are found usually at the top of these beds. *Chondrites* is also very frequent along laminae, and less frequent *Thalassinoides* occurs at the base of these beds. *Skolithos* crosses the beds and is seen in lateral view.

Interpretation: Hummocky cross-stratified sandstones are interpreted as storm deposits (Dott and Bourgeois

1982). Amalgamated sandstones are deposited above fair-weather wave base, in the middle–lower shoreface. Non-amalgamated sandstones are distributed between the lower shoreface and the upper offshore-transition zone, above the storm-wave base (Reading and Collinson 1996). Thinner beds suggest deeper waters (Cheel and Leckie 1993).

Wave-ripples at the top of these sandstones record oscillatory flow during the waning stage of the storm or subsequent fair-weather period (Kerr and Eyles 1991). Shell lags are composed of mechanically reworked material deposited during the peak of the storm (Kreisa 1981). Isolated bivalve and gastropod shells were probably reworked during a waning storm phase.

The abundant trace fossils indicate aerobic conditions at the sea floor after the storm, when the tracemakers colonized the newly deposited sediments (Rhoads and Morse 1971; Ekdale and Mason 1988; Savrda *et al*. 1991).

Massive sandstones (lithofacies D)

Description: Fine- medium-grained massive sandstones with tabular beds, which are 2–204 cm thick and display a sharp or erosive base and a sharp top, both in contact with lithofacies B, C, D, G and H. Intercalations of shell concentrations or layers of massive/laminated mudstones occur locally. Some beds exhibit dewatering structures. Exceptionally, these sandstones contain pebbly lenticular bodies with erosional basal surfaces which are composed of well-rounded to sub-rounded pebbles and sandstone matrix.

The upper parts of the beds are bioturbated. *Planolites*, *Palaeophycus*, *Taenidium* and *Chondrites* are seen on their tops. Vertical *Skolithos* is present at the top of the beds and decreases in abundance downward. Redeposited bivalves and belemnites are present.

Interpretation: Massive sandstones suggest episodic rapid deposition (Collinson and Thompson 1989). This interpretation is supported by the presence of dewatering structures. These sandstones are interpreted as storm-generated sediments, deposited between the lower shoreface and the offshore-transition zone (Reading and Collinson 1996).

Shell concentrations are interpreted as basal deposits transported when the flow was initially presumably stronger prior to the deposition of massive sandstones. Successive shell layers intercalated with massive sandstones suggest amalgamation of beds. Massive or laminated mudstones indicate decantation deposits during fair-weather periods, below fair-weather wave base (Reading and Collinson 1996). When these mudstones are present, massive sandstones are restricted to an offshore-transition zone.

Lenticular pebbly bodies are interpreted as rip current deposits (Hart and Plint 1995), originated in the upper shoreface and deposited in lower shoreface to open shelf environments (Reading and Collinson 1996).

Laminated sandstones (lithofacies E)

Description: This lithofacies consist of fine- to very fine-grained sandstones, in tabular, laterally extensive sets with horizontal-planar or undulatory lamination; sets of laminae may thicken and thin slightly. Basal contacts are sharp, mostly over hummocky cross-stratified sandstones (lithofacies C) and less frequently over lithofacies A, D, E, G and H. Upper contacts are sharp with sandstone lithofacies (usually lithofacies C, and less frequently D, E, G and H) and gradational into overlying siltstones (lithofacies B). Lenticular shell concentrations and concretions are common.

Fossils include rare specimens of the ammonite *Westermanniceras groeberi* (Westermann and Riccardi). The tops of beds are extensively bioturbated with *Chondrites* and *Thalassinoides*. Frequent *Skolithos* is seen in vertical cross sections.

Interpretation: Laminated sandstones are produced by slow currents (Guy *et al*. 1966) between the lower shoreface and the offshore-transition zone (Reading and Collinson 1996). Irregularities in the lamination (undulatory surface) are attributed to wave action (De Raaf *et al*. 1977).

Lenticular shell beds are interpreted as high-energy storm deposits. The presence of these lenses interstratified with laminated sandstones suggests the alternation of low-energy processes, when laminated sandstones were deposited, and high-energy events, characterized by lenticular shell beds.

Wave-rippled sandstones (lithofacies F)

Description: Tabular fine-grained sandstones, which are 5–43 cm thick. Basal contact sharp (over lithofacies F) or transitional (over lithofacies C and G). Upper contact irregular (below lithofacies C, D and F) with straight-crested symmetrical ripples, which range from 2–5 cm in wavelength and 0.3–0.4 cm in high. These beds are highly bioturbated with *Chondrites*, and less frequently with *Skolithos.*

Interpretation: Straight-crested symmetrical ripples are interpreted as wave ripples, produced under oscillatory flows over non-cohesive surfaces (Reineck and Singh

1975), conditions prevailing above fair-weather wave base.

Fine-medium grained bioclastic sandstones (lithofacies G)

Description: Tabular, laterally continuous shelly sandstone beds which are 5–80 cm thick. Basal contacts are usually erosive or, more rarely, sharp (over lithofacies B, D, E and F) and upper contacts are horizontal or undulatory (below lithofacies A, D and E).

These concentrations are dominated by bivalve shells, almost invariably disarticulated, with different degrees of fragmentation. Less common are other molluscs belemnites, ammonites and brachiopods. Bioclasts are usually matrix-supported, rarely bioclastic-supported, with a fine- to medium-grained sandstone matrix. Most of the bioclasts are concordant with the stratification. No bioturbation structures have been recognized in this lithofacies.

Interpretation: The high degree of disarticulation and fragmentation indicates prolonged exposure on the seafloor and/or repeated exhumation/burial cycles (Jennette and Pryor 1993). These shell beds are interpreted as storm deposits originated in shoreface and beach zones, where transported and mixed assemblages are common (Kreisa 1981). Deposits over 10 cm thick correspond to amalgamated event beds. These sandstones indicate environments between the upper and middle shoreface.

Massive conglomerates (lithofacies H)

Description: Tabular fine to coarse conglomerate beds, which are 35–115 cm thick. Basal contact is erosive (over lithofacies D, E and H) and upper contact is horizontal (under lithofacies C and D). Matrix-supported conglomerate with a fine- medium-grained or even coarse-grained sandstone matrix. The grain size ranges from sabulitic sands to pebbles (0.4–14 cm), which are prolate to equidimensional, well rounded to subrounded, rhyolitic and basaltic in composition. Selection is poor, with occasional clasts reaching 30 cm. Fractured clasts are usual.

Interpretation: The massive conglomerate lithofacies can be interpreted as storm beds in the lower shoreface (Cantalamessa and Di Celma 2004), where the tabular geometry would be a result of uniform reworking by waves, while the matrix-supported fabric suggests proximity to fluvial distributary mouths (Hart and Plint 1995). The lack of fossils is a common feature in high-energy marine conglomerates (Hart and Plint 1995).

SYSTEMATIC ICHNOLOGY

Ichnogenus *Arenicolites* Salter, 1857

DIAGNOSIS: Vertical U-tubes without spreite (Fürsich 1974a).

INTERPRETATION: *Arenicolites* is a dwelling trace (domichnion) attributed to shrimps (Bromley 1996) or detritus-feeding lugworms (Swinbanks 1981).

Arenicolites isp.
(Text-fig. 2A)

MATERIAL: Field observations.

DESCRIPTION: *Arenicolites* appear on bedding surfaces as paired circular marks, which are terminations of the limbs of an endichnial U-shaped, thinly-lined tubular burrow. Burrow diameter varies between 2 and 5 mm, and the limbs are 3–15 mm apart.

Ichnogenus *Chondrites* Sternberg, 1833

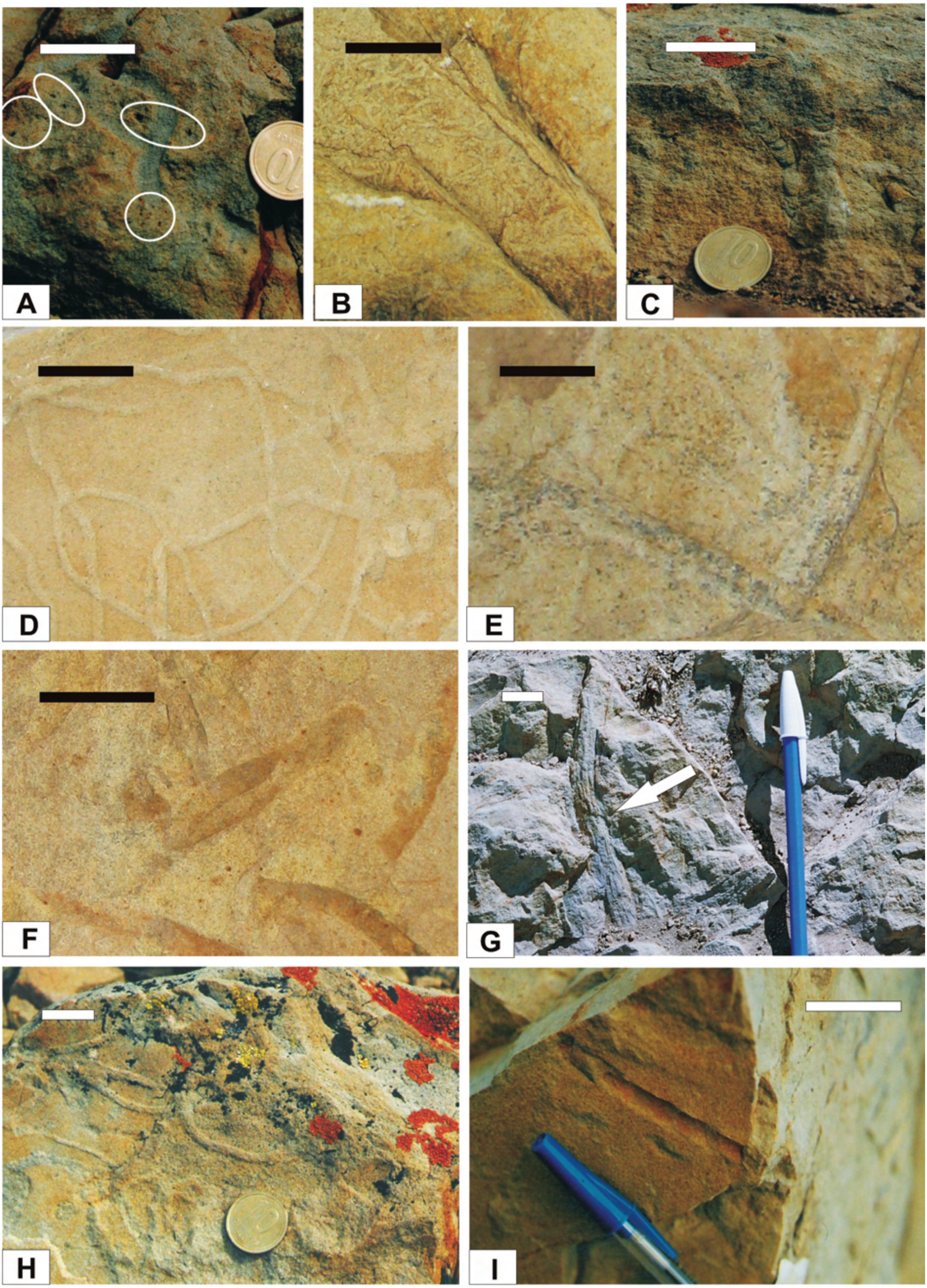
DIAGNOSIS: Regularly branching tunnel systems consisting of a small number of master shafts open to the surface, which ramify at depth to form a dendritic network (Uchman 1999).

INTERPRETATION: *Chondrites* is a feeding structure (fodinichnion) produced by deposit feeders such as annelids or sipunculoid worms (Richter 1927; Osgood 1970).

Chondrites intricatus Sternberg 1833
(Text-fig. 2B)

DIAGNOSIS: Small *Chondrites* composed of numerous downward-radiating, mostly straight branches. The an-

Text-fig. 2. Trace fossils of the Bardas Blancas Formation: A – *Arenicolites* isp.; B – *Chondrites intricatus*; C – ?*Diplocraterion* isp.; D – *Gordia* isp.; E – *Gyrochorte* isp.; F – *Lockeia* isp.; G – *Palaeophycus striatus*; H – *Palaeophycus tubularis*; I – *Palaeophycus* isp.; J – *Planolites beverleyensis*; K – *Skolithos verticalis*; L – *Taenidium serpentinum*; M – *Taenidium* isp.; N – *Thalassinoides* isp. type A; O – *Thalassinoides* isp. type B; P – horizontal trace fossils; Q – horizontal trace fossil with *Chondrites intricatus* in its filling. Scale (bar): 2 cm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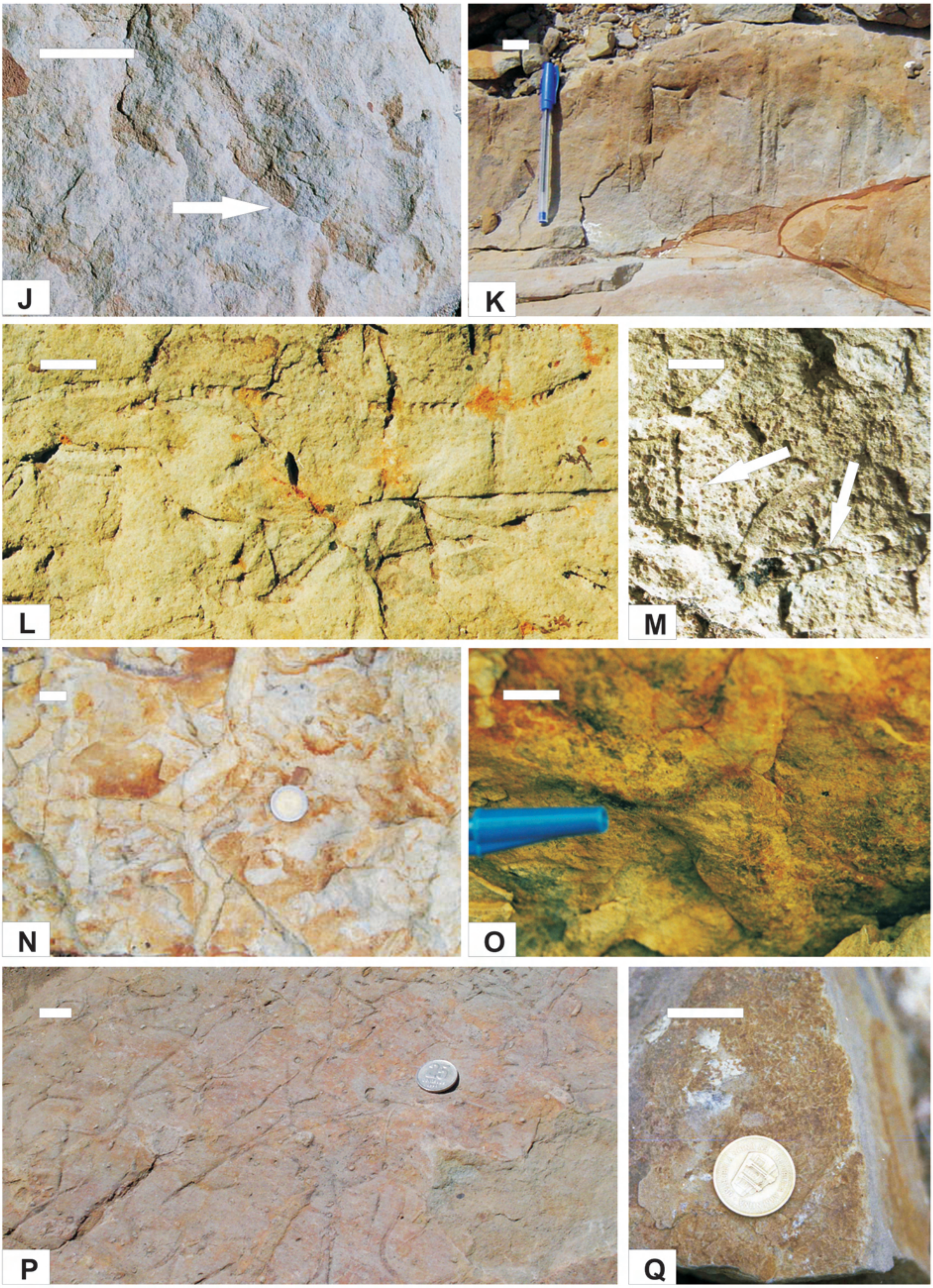


[Text-fig. 2]

gle of branching is usually less than 45º. The branches are less than 1.0 mm (mostly about 0.5 mm) wide. The burrow system is more than 20 mm wide (Uchman 1999).

MATERIAL: Field observations, sample FCEN 20256 (lithofacies D, Coihueco section), sample FCEN 20263 (lithofacies C, La Vaina section).

DESCRIPTION: Small, branching burrow systems which spread out in horizontal or gently inclined endichnial or rarely epichnial tunnels. Burrow diameters remain more or less constant, and range from 0.5 to 0.8 mm. Smooth margins. Burrows are usually infilled by sediments from the overlying bed. Branches, usually bifurcating, a few millimetres apart.

REMARKS: *Chondrites* commonly penetrates in the infill of *Thalassinoides* and horizontal trace fossils, possibly assigned to *Palaeophycus* or *Planolites*. The reworking in the infill and margins does not enable a reliable ichnogenus determination.

Ichnogenus *Diplocraterion* Torell 1870

DIAGNOSIS: Vertical U-shaped spreiten-bearing burrows (Fürsich 1974b).

INTERPRETATION: Dwelling burrow of suspension-feeding animal (Fürsich 1974b) or benthic predators (Bromley 1996).

?*Diplocraterion* isp.
(Text-fig. 2C)

MATERIAL: Field observations

DESCRIPTION: Vertical U-shaped endichnial burrows with parallel limbs and unidirectional spreiten, retrusive, continuous and regular. Tube diameter is 4–5 mm thick and separation of vertical burrows is 1.5 cm. There is lateral displacement of the U-tube, an unusual feature in this ichnogenus.

Ichnogenus *Gordia* Emmons, 1844

DIAGNOSIS: Horizontal, thin, unbranched, simple smooth worm-like trails of uniform thickness throughout; mostly bent but not meandering, characterized by self-overcrossing (Häntzschel 1962; Fillion and Pickerill 1990; MacNaughton and Pickerill 1995).

INTERPRETATION: *Gordia* is interpreted as a grazing trail (fodinichnia).

Gordia isp.
(Text-fig. 2D)

MATERIAL: Field observations and sample FCEN 20262 from lithofacies C at Bardas Blancas section.

DESCRIPTION: Smooth worm-like, epichnial horizontal structure, with uniform thickness, 2–3 mm. Segments gently bent each 5–10 cm, crossovers are numerous.

Ichnogenus *Gyrochorte* Heer, 1865

DIAGNOSIS: Wall-like burrow with a top part (positive epirelief) consisting of two convex lobes with a median furrow and a bottom part (negative hyporelief) consisting of two grooves and a median ridge. The lobes on the top, and more rarely the grooves at the base, commonly exhibit transverse meniscus-like discontinuities and often obliquely aligned plaits. The burrow exhibits an irregular meandering or arcuate course, but more rarely it can be straight or gently curved (emended diagnosis, Gibert and Benner 2002).

INTERPRETATION: Burrow produced in the active search for food of a deposit feeder, probably an opportunistic animal colonizing sandy bottoms after high-energy event deposition (Gibert and Benner 2002).

Gyrochorte isp.
(Text-fig. 2E)

MATERIAL: Field observations and sample FCEN 20257 from lithofacies D at the Coihueco section.

DESCRIPTION: Straight to gently curved bilobate epireliefs up to 4 mm wide. The lobes exhibit slight transverse ribs, perpendicular to the long axis of burrow, with a distance between ribs that varies between 0.5 and 1 mm.

REMARKS: Even in the absence of the associated concave hyporeliefs, it is possible to distinguished this *Gyrochorte* from *Aulichnites* because the former has transverse ribs, which are absent in *Aulichnites* (Gibert and Benner 2002).

Ichnogenus *Lockeia* James, 1879

DIAGNOSIS: Small, almond-shaped, oblong bodies preserved in convex hyporelief; tapering to sharp and obtuse points at both ends. Surface commonly smooth. Mostly symmetrical. Usually with a mid-ridge. Sometimes with vertical spreiten (Schlirf *et al*. 2001).

INTERPRETATION: This structure is a resting trace (cubichnion) of small burrowing bivalves (Osgood 1970).

Lockeia isp.
(Text-fig. 2F)

DESCRIPTION: Small concave epireliefs with pointed terminations and a narrow keel along the main axis. They are 30–40 mm long and 3–5 mm wide.

Ichnogenus *Palaeophycus* Hall, 1847

DIAGNOSIS: Branched or unbranched, smooth or ornamented, lined, essentially cylindrical, predominantly horizontal burrows of variable diameter; infilling typically structureless, of same lithology as host rock (Pemberton and Frey 1982).

INTERPRETATION: Interpreted as a dwelling burrow (domichnion) probably produced by polychaetes (Häntzschel 1975; Pemberton and Frey 1982; Uchman 1995).

REMARKS: To distinguish *Palaeophycus* from *Planolites* we followed the criteria of Pemberton and Frey (1982), which involves examination of the burrow margins and internal fill of the burrows.

Palaeophycus striatus Hall, 1852
(Text-fig. 2G)

DIAGNOSIS: Thinly lined burrows sculpted by fine, continuous, parallel, longitudinal striae (Pemberton and Frey 1982).

MATERIAL: Field observations.

DESCRIPTION: Branched, winding, cylindrical, epichnial burrow, with longitudinal parallel-striated infilling. Burrow diameter uniform, reaches 1.5 cm.

Palaeophycus tubularis Hall, 1847
(Text-fig. 2H)

DIAGNOSIS: Smooth, unornamented burrows of variable diameter, thinly but distinctly lined (Pemberton and Frey 1982).

MATERIAL: Field observations and sample FCEN 20261 from lithofacies C at the Coihueco section.

DESCRIPTION: Unbranched, smooth, thinly-lined, straight and curved, cylindrical, horizontal to subhorizontal epichnial burrows. Their diameter ranges between 0.3 and 2 cm and it is uniform in the same specimen. The burrow fills are similar to the surrounding sediment.

Palaeophycus isp.
(Text-fig. 2I)

MATERIAL: Field observations

DESCRIPTION: Branched or unbranched, cylindrical to subcylindrical epichnial burrows, with distinctly lined walls. Oriented horizontal to slightly inclined, straight to curved. Burrow diameters generally constant between 0.2 and 1 cm; in some specimens the diameter varies in an irregular way. Infilling structureless, with the same lithology as the host rock.

Ichnogenus *Planolites* Nicholson, 1873

DIAGNOSIS: Unlined, rarely branched, straight to tortuous, smooth to irregularly walled or annulated burrows, circular to elliptical in cross-section, with variable dimensions and configurations; infillings essentially structureless, differing in lithology from host rock (Pemberton and Frey 1982).

INTERPRETATION: *Planolites* is a feeding burrow (pascichnion) produced by the activity of vagile endobenthic deposit feeders (Alpert 1975, Pemberton and Frey 1982).

Planolites beverleyensis (Billings, 1862)
(Text-fig. 2J)

DIAGNOSIS: Relatively large, smooth, straight to gently curved or undulose cylindrical burrows (Pemberton and Frey 1982).

DESCRIPTION: Horizontal to inclined, cylindrical to sub-cylindrical in cross-section, smooth-walled, unbranched, straight to slightly curved epichnial burrows of uniform width, about 10 mm in diameter. Infilling structureless, differing in lithology from host rock.

Ichnogenus *Skolithos* Haldeman, 1840

DIAGNOSIS: Single, vertical, unbranched burrows, cylindrical or subcylindrical, lined or unlined. Burrows perfectly straight to curved, and may be inclined from the vertical. Diameter 1 to 15 mm, length from a few centimetres up to a metre; diameter may vary slightly along length of burrow. Burrow wall distinct or indistinct, smooth to rough, may be annulated. Prominent funnel-shaped aperture absent. The sediment that infills the burrow is generally structureless; it may exhibit a passive, meniscus fill (Alpert 1974).

INTERPRETATION: *Skolithos* is interpreted as the dwelling burrow (domichnion) of annelids or phoronids (Alpert 1974).

Skolithos verticalis (Hall, 1843)

(Text-fig. 2K)

DIAGNOSIS: Burrows cylindrical to prismatic (where in contact), straight to curved, vertical to inclined. Diameter 1 to 4 mm, length 2 to 15 cm. Burrow wall smooth, rarely corrugated (Alpert 1974).

MATERIAL: Field observations.

DESCRIPTION: Burrows cylindrical, straight, vertical to slightly inclined. Diameter 1–3 mm, the same for each specimen, length 1 to 15.5 cm. Burrow wall smooth. The infilling sediment tends to weather out and leaving the burrows as holes in the rock.

REMARKS: In storm deposits of the Bardas Blancas Formation erosion events were important and some of these burrows interpreted as *Skolithos* could be *Monocraterion*, which differs from *Skolithos* in having a prominent funnel-shaped aperture at the top of the burrow. Individual circular marks on bedding surface has also been interpreted as *Skolithos*, with burrow diameter 1–2 mm.

Ichnogenus *Taenidium* Heer, 1877

DIAGNOSIS: Unlined or very thinly lined, unbranched, straight or sinuous cylindrical burrows containing a segmented fill articulated by meniscus-shaped partings (D´Alessandro and Bromley 1987).

INTERPRETATION: *Taenidium* is thought to have been a feeding burrow (pascichnion) produced by the activity of a worm-like deposit feeder (D´Alessandro and Bromley 1987)

Taenidium serpentinum Heer, 1877

(Text-fig. 2L)

DIAGNOSIS: Serpentiform *Taenidium* having well-spaced, arcuate menisci; distance between menisci about equal to or a little less than burrow width. Secondary subsequent branching and intersections occur. Boundary sharp, lining lacking or insignificant (D´Alessandro and Bromley 1987).

MATERIAL: Field observations

DESCRIPTION: Sinuous unbranched epichnial burrows with back-fill of alternating meniscus-shaped packets, which display crossovers. Burrow diameters vary between 0.5 and 1 cm, and are constant for each specimen.

Taenidium isp.

(Text-fig. 2M)

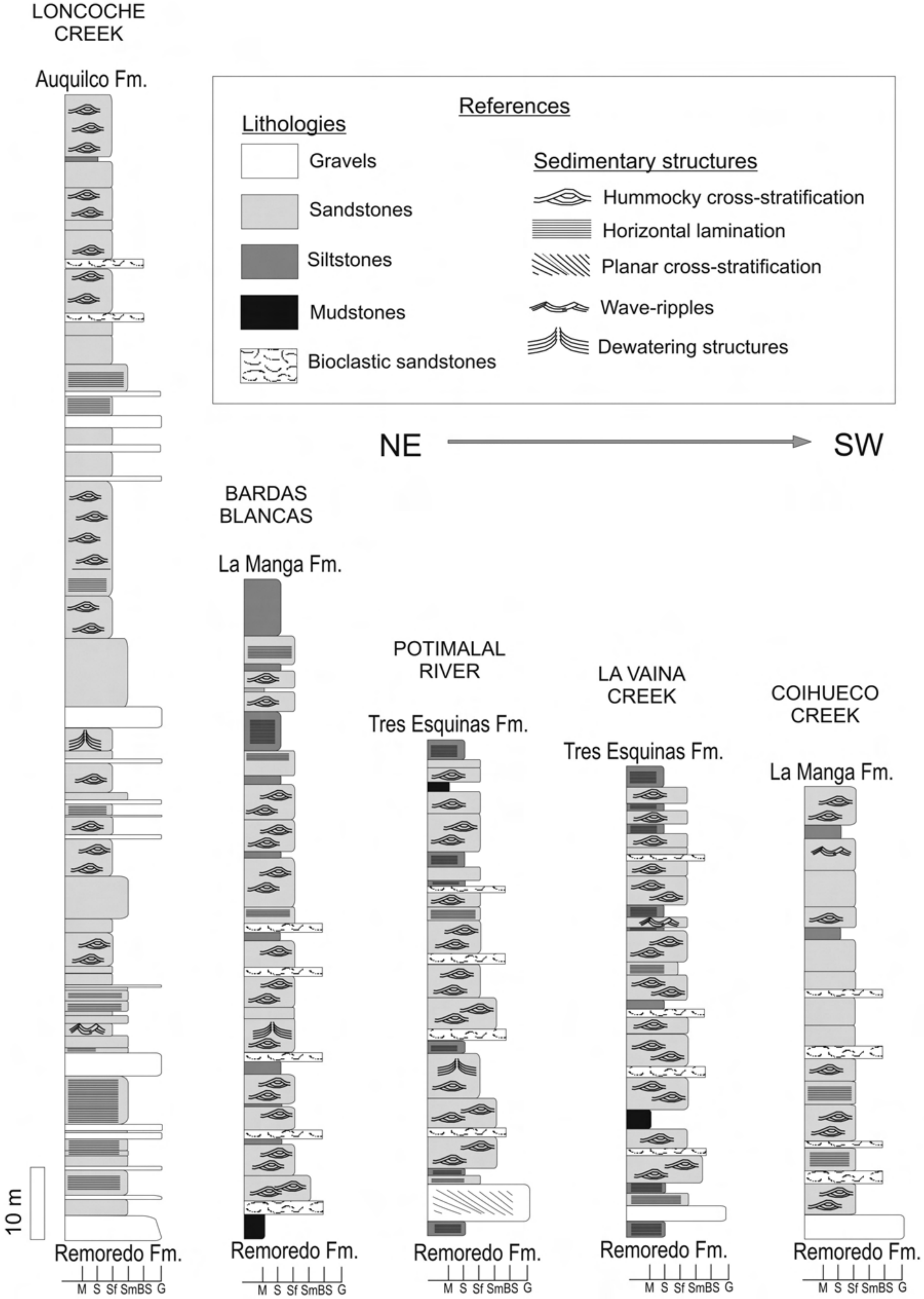
MATERIAL: Field observations

DESCRIPTION: Straight, curved or sinuous epichnial *Taenidium*, 6–8 mm wide, at least 50 mm long, having badly preserved, irregular (deformed) menisci, variably oriented in relation to stratification plane.

Ichnogenus *Thalassinoides* Ehrenberg, 1944

DIAGNOSIS: Three-dimensional burrow systems consisting predominantly of smooth-walled, essentially cylindrical components of variable diameter; branches Y- to T-shaped, enlarged at points of bifurcation (Howard and Frey 1984).

INTERPRETATION: This structure is considered to be the dwelling structure (domichnion) of decapod crustaceans, particularly certain members of the Superfamily Thalassinidea (Swinbanks and Luternauer 1987).



Text-fig. 3. Distribution of lithofacies in the Bardas Blancas Formation

Thalassinoides isp. type A
(Text-fig. 2N)

MATERIAL: Field observations

DESCRIPTION: Predominantly horizontal to subhorizontal, straight to slightly curved, epichnial or hypichnial burrows. Branches are Y-shaped, with a wide angle between the arms, thus almost T-shaped . The burrows are cylindrical to sub-cylindrical, commonly from 1 to 3.5 cm, constant for every specimen. Internal surfaces are smooth. Vertical connections were not observed. The field situation does not allow determination of the depth of penetration of these galleries into the substrate.

Thalassinoides isp. type B
(Text-fig. 2O)

MATERIAL: Field observations

DESCRIPTION: Straight, horizontal , hypichnial or epichnial burrows with Y-shaped branches. In some specimens a slight meniscate structure is visible. Burrows width is 4 cm and side branches are 2 cm, with swellings at junctions.

Horizontal trace-fossils (Text-fig. 2P, Q)

DESCRIPTION: Straight to sinuous, horizontal cylindrical epichnial trace fossils. Burrow diameter 0.5–2 cm. The quality of the exposures does not allow recognition of possible branching or meniscate backfills but locally it is possible to recognize that the sediment infilling the burrows is coarser than the matrix of the host rock. Individual specimens can appear crossing over other ichnotaxa (e.g. horizontal trace fossils overcrossing *Thalassinoides*). The infilling can be penetrated by *Chondrites*.

INTERPRETATION: The sinuosity of some of the trace fossils and the texture of the infilling suggest the activity of deposit-feeders (fodinichnion), while straight burrows where is not possible to recognize the infilling are interpreted as dwelling burrow (domichnion).

REMARKS: The poor preservation does not allow closer determination.

DISTRIBUTION OF LITHOFACIES

Facies change from north to south (Text-fig. 3). The northernmost locality (Loncoche section) contains about 25% of gravel lithofacies, while mudstones and siltstones are almost completely absent. Most of the beds are hummocky cross-stratified sandstones (lithofacies C). This lithofacies succession has been interpreted as the shallower deposits of this unit, characterizing environments from the lower foreshore to the upper offshore-transition zone.

The southernmost locality (Coihueco section) is composed mostly of hummocky cross-stratified sandstones (lithofacies C) and massive sandstones (facies D), with a basal conglomerate (lithofacies H) and scarce siltstones (lithofacies B) in the last metres. These deposits are interpreted as representing an environment between the upper shoreface to the upper offshore-transition zone.

Between these two localities, the Bardas Blancas section is dominated by hummocky cross-stratified sandstones (lithofacies C) and siltstones (lithofacies B). A similar trend is found in the Potimalal and La Vaina sections, which are characterized by a succession of hummocky cross-stratified sandstones (lithofacies C) but with a higher proportion of fine-grained beds (lithofacies A and B), with basal conglomeratic deposits. In these three sections, shell beds (lithofacies G) are abundant and are intercalated with hummocky cross-stratified sandstones. These deposits correspond to an environment between the shoreface to the lower offshore-transition zone.

DISTRIBUTION OF TRACE FOSSILS

The distribution of trace fossils in the sections studied with estimation of their frequency is shown in table 2.

Eleven ichnogenera has been recognized. *Chondrites* is the most abundant ichnogenus, which appears in all the outcrops studied and in the greatest number of lithofacies types (lithofacies A to F). Most of the structures are dwelling traces (*Arenicolites*, *Thalassinoides*, *Skolithos*, and *Palaeophycus*) and deposit feeder structures (*Chondrites*, *Gyrochorte*, *Planolites* and *Taenidium*), which are closely related with the substrate, particularly the second group since the availability of food is related to substrate type (Fürsich and Hurst 1974).

The diversity of trace fossils is similar but not the same in different outcrops of the Bardas Blancas Formation. The ichnogenera *Chondrites*, *Palaeophycus*, *Skolithos* and *Thalassinoides* have been noted in all the sections studied, and *Arenicolites*, *Gyrochorte* and *Planolites* have been observed in four of the five sections. *Gordia*, *Lockeia*, *Taenidium* and ?*Diplocraterion*

Ichnotaxa	Loncoche section	Bardas Blancas section	Potimalal section	La Vaina section	Coihueco section
Arenicolites isp.		Frequent in lit. C (low)	Frequent in lit. C (low)	Frequent in lit. C (low)	Frequent in lit. C (low)
Chondrites intricatus	Abundant in lit. C (medium) Frequent in lit. D (high)	Abundant in lit. C (medium)	Abundant in lit. C (medium) Frequent in lit. D (high) Frequent in lit. A and B (medium)	Abundant in lit. C (medium) Frequent in lit. D and E (high) Frequent in lit. A and B (medium)	Abundant in lit. C (medium) Frequent in lit. D (high) Frequent in lit. F (high)
Diplocraterion isp.			Isolated in lit. C (low)		Isolated in lit. C (low)
Gordia isp.		Isolated in lit. C (low)			
Gyrochorte isp.		Isolated in lit. C (low)	Isolated in lit. C (low)		Isolated in lit. D (low)
Lockeia isp.					Isolated in lit. C (low)
Palaeophycus tubularis					Isolated in lit. C (low)
Palaeophycus striatus					Isolated in lit. D (low)
Palaeophycus isp.	Frequent in lit. C (medium) Isolated in lit. E (low)	Frequent in lit. C (medium)	Frequent in lit. C (medium)	Frequent in lit. C (medium)	Frequent in lit. C (medium) Isolated in lit. D, F and G (low)
Planolites beverleyensis	Isolated in lit. D (medium) Isolated in lit. E (low)	Isolated in lit. C (medium)	Isolated in lit. C (medium)		Isolated in lit. D (medium)
Skolithos verticalis	Frequent in lit. C (medium)	Frequent in lit. C (medium) Frequent to isolated in lit. D and E (low)	Frequent in lit. C (medium)	Frequent in lit. C (medium) Frequent to isolated in lit. E (low)	Isolated in lit. F (low)
Taenidium serpentinum	Frequent in lit. C (low) and isolated in lit. D (low)				
Taenidium isp.			Isolated in lit. C (low)		Isolated in lit. D (low)
Thalassinoides isp. type A	Frequent in lit. C (medium)	Frequent in lit. C (medium)	Frequent in lit. C (medium) Isolated in lit. B (low)	Frequent in lit. C (medium) Isolated in lit. D (low)	Frequent in lit. C (medium)
Thalassinoides isp. type B	Isolated in lit. D (low) and abundant in lit. C (low)				
Horizontal trace fossils	Isolated to frequent in lit. C and E (low-medium)	Isolated to frequent in lit. C and E (low-medium)	Isolated to frequent in lit. C and E (low-medium)	Isolated to frequent in lit. C and E (low-medium)	Isolated to frequent in lit. C and E (low-medium)

occur only rarely in one or two of the sections studied (except for *Taenidium serpentinum*, which is frequent in a single bed in the Loncoche section). The most diverse trace fossil assemblages occur in the Coihueco section, which displays a higher proportion of sandstone lithofacies.

The abundance of bioturbation varies throughout the different lithofacies. All the trace fossils mentioned are present in sandstone lithofacies. *Arenicolites*, *Gordia*, *Lockeia*, and ?*Diplocraterion* are restricted to hummocky cross stratified sandstones (lithofacies C), which displays the higher diversity. When these sandstones are amalgamated, trace fossils are absent, except for occasional *Skolithos*. It is not excluded that trace fossils were eroded at the top of the beds prior to the amalgamation. Of the sandstone beds, the laminated sandstones (lithofacies E) and wave-rippled sandstones (lithofacies F) display the lowest trace fossil diversity.

In the siltstone beds (lithofacies B) *Chondrites* and *Thalassinoides* are present, while in the shale beds (lithofacies A) only *Chondrites* occurs.

Although post-storm deposits were bioturbated, the fine- to medium-grained bioclastic sandstones (lithofacies G) and massive gravels (lithofacies H) appear to be devoid of trace fossils, presumably due to the large size of the shells (Kidwell 1991) and the coarse grains respectively.

ICHNOFACIES

The Bardas Blancas Formation contains elements of the *Cruziana*, *Skolithos* and possibly the *Zoophycos* ichnofacies.

Storm sandstones contain trace fossils indicative of the *Skolithos* ichnofacies, such as *Skolithos*, *Arenicolites* and ?*Diplocraterion*. This ichnofacies suggests the colonization of storm sands by a community of opportunistic organisms in a post-event, high-stress, physically-controlled environment (Pemberton *et al.* 1992). In these conditions, diversity is low and the abundance of individual ichnogenera is usually high (Pemberton *et al.* 1992). However, the Skolithos ichnofacies elements in this unit are less abundant than expected. The Ichnofabric index measured for *Skolithos* ranges from 1 (no bioturbation recorded) to 2 (discrete, isolated trace fossils).

The sandstone beds (lithofacies C, D, E and F) exhibit a trace fossil assemblage indicative of the proximal expression of the *Cruziana* ichnofacies (MacEachern *et al*. 2008), with *Chondrites*, *Gordia*, *Gyrochorte*, *Lockeia*, *Palaeophycus*, *Planolites*, *Taenidium* and *Thalassinoides*. This association characterizes low-energy environments (storm sands once the environment stabilizes or fair-weather deposits), colonized by deposit feeders and also by mobile carnivores, omnivores and suspension feeders (Pemberton *et al*. 1992; MacEachern *et al*. 2008). As is typical in this ichnofacies, the diversity is high and individual densities of most ichnogenera are low (Pemberton *et al*. 1992).

Siltstones (lithofacies B) with *Thalassinoides* type A and *Chondrites*, and mudstones (lithofacies A) with isolated *Chondrites*, could represent the distal expression of the *Cruziana* ichnofacies or the *Zoophycos* ichnofacies (MacEachern *et al*. 2008), characterizing low-energy environments (lower offshore-transition zone to offshore zone, Reading and Collinson 1996). The low diversity suggests that these *Thalassinoides* and *Chondrites* are elements of the *Zoophycos* ichnofacies, which commonly develops during dysaerobic to anoxic conditions (MacEachern *et al*. 2008).

PRESERVATION AND UNDERESTIMATION OF TRACE FOSSILS

Syn-depositional and post-depositional processes affected the preservation of trace fossils in the Bardas Blancas Formation. High-energy processes related to storm deposits erased traces on the tops of the beds, while the stacking of sandstone beds in amalgamated intervals hides superficial trace fossils on the top and in the base of the beds. Where the nature of the outcrop allowed the tops of these amalgamated sandstones to be seen, horizontal trace fossils were found to be present, and hence the abundance and diversity of trace fossils in this lithofacies is probably higher than actually observed.

Moreover, trace fossils in the sandstone lithofacies have been affected by weathering and by the activity of other organisms. Composite forms (sensu Pickerill and Narbonne 1995) and overcrossing between burrows are common in sandstone beds in this unit. The producers

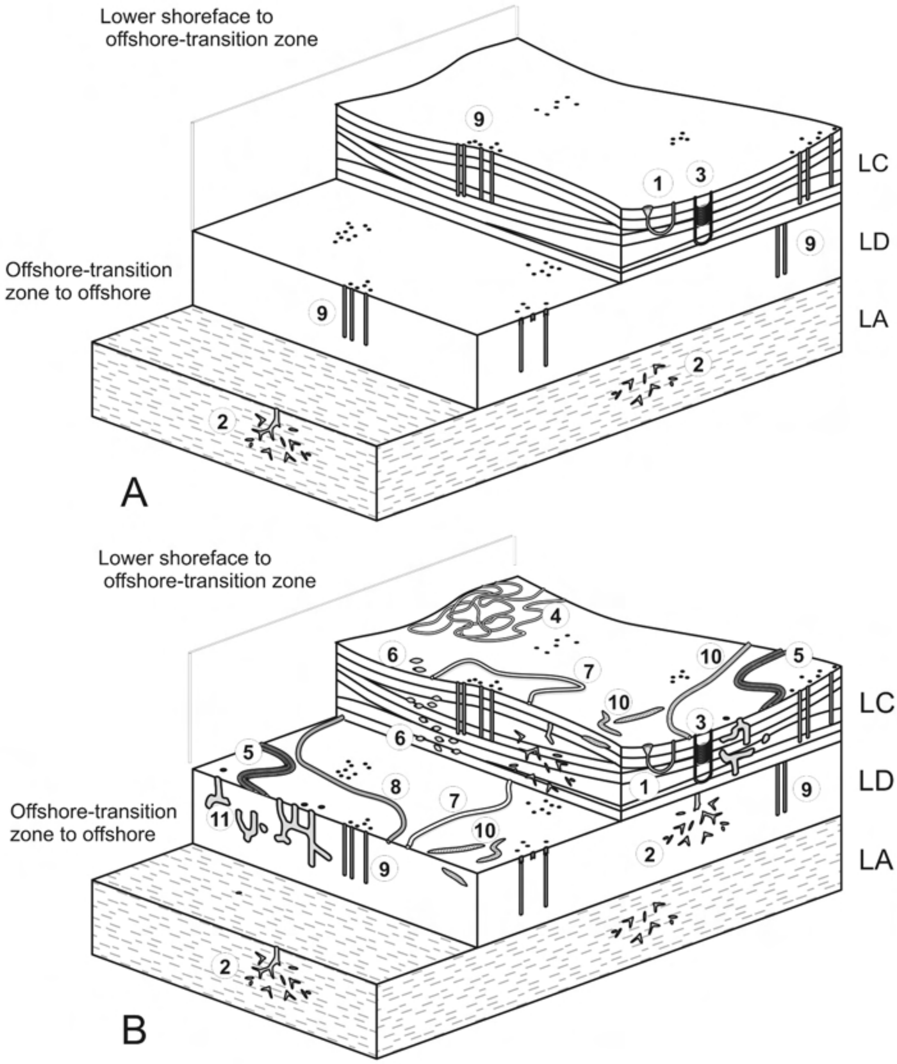
Table 2. Trace fossils occurrence in Bardas Blancas Formation. Lithofacies (lit.): A – massive and laminated mudstones; B – laminated siltstones; C – hummocky cross-stratified sandstones; D – massive sandstones; E – laminated sandstones; F – wave-rippled sandstones; G – fine-medium grained bioclastic sandstones; H, massive gravels. Occurrence of trace fossils in any bed was recorded as abundant (examples visible in all or in a majority of square meter of bedding surface), frequent (examples visible in a minority of square meters of bedding surface) and isolated (seen only one time throughout a 50 m section). To describe the distribution through the section the terms used are: low (occurring only occasionally), medium (occurring in a minority of beds) and high (occurring in the majority of beds)

of *Chondrites* modified the infilling of trace fossils making it impossible to differentiate between some taxa, notably *Planolites* and *Palaeophycus*.

Trace fossils in the fine-grained beds are scarce and it is difficult to compare the variation in preservation between these beds and the sandstones beds; however, *Chondrites* found in the shale beds (lithofacies A) and siltstone beds (lithofacies B) appear to be better preserved than those present in other facies.

Diagenesis enhanced the lining of *Arenicolites*, which appear as double circular marks, with a darker circle around each opening.

Even when there are reasons to believe that horizontal trace fossils are underestimated, the low abundance in vertical trace fossils (elements from *Skolithos* ichnofacies) cannot be explain by considering only the preservation potential. Vertical burrows (preserved as endichnia) are present at the tops of the beds, decreasing in abundance downward; erosion could have erased the uppermost centimetres of the beds where the density



Text-fig. 4. Schematic diagram showing the distribution of trace fossils in Bardas Blancas Formation. Trace fossils in the diagram A illustrates the opportunistic community which colonizes the massive sandstone beds (lithofacies D) and hummocky cross-stratified sandstone beds (lithofacies C), which are elements from *Skolithos* ichnofacies. The diagram B illustrates the climax community in the same beds, once the environmental energy decreases, interpreted as elements from *Cruziana* ichnofacies. In both diagrams, the *Zoophycos* ichnofacies is illustrated in LA. Representative forms include: 1 – *Arenicolites*; 2 – *Chondrites*; 3 – *Diplocraterion*; 4 – *Gordia*; 5 – *Gyrochorte*; 6 – *Lockeia*; 7 – *Palaeophycus*; 8 – *Planolites*; 9 – *Skolithos*; 10 – *Taenidium*; 11 – *Thalassinoides*. LC – lithofacies C (hummocky cross-stratified sandstones); LD – lithofacies D (massive sandstones); LA – lithofacies A (massive and laminated mudstones) of burrows would be expected to be higher. It does not explain why isolated *Skolithos* reaching 15 cm occur in sandstone beds. According to Droser and Bottjer (1989), physical processes (including rate of sedimentation, rate and nature of episodic sedimentation and rate and nature of erosion) and biological controls (life habits and behaviour of the infauna, sizes of organisms, rates at which organisms colonize substrates) are determining factors in the development of the ichnofabric. In the Bardas Blancas Formation the answer to the low diversity probably lies in biological factors such as the nature of the burrowing organisms.

INTERPRETATION OF THE DEPOSITIONAL SETTING

The sediments of the Bardas Blancas Formation were deposited on a marine platform, including foreshore to offshore zone environments. Body fossils (which include marine cephalopods such as ammonites and belemnites) confirm this interpretation. The ichnogenera content is typical of storm deposits (Pemberton *et al*. 1992).

Differences in the distribution of trace fossils in the outcrops considered are related to facies changes. The sections with a higher proportion of sandstone beds exhibit a higher diversity in trace fossils.

The high diversity noted in hummocky cross-stratified sandstones (lithofacies C) can be attributed to the presence of ichnogenera from two ichnofacies (*Skolithos* and *Cruziana*), in two successive stages of colonization. The distribution of trace fossils in these sandstones suggests early colonization by pioneers (elements of the *Skolithos* ichnofacies), followed by the activity of a community exploiting a low-energy environment (elements of the *Cruziana* ichnofacies) (Text-fig. 4).

Trace fossil diversity is determined by physical parameters. As seen, different colonization phases were controlled by high-energy and low-energy processes. The ethological categories registered in the Bardas Blancas Formation (Domichnia and Fodinichnia) suggest that the distribution of the producers was controlled in some degree by the substrate (Pickerill *et al*. 1984). Oxygen levels were also a controlling factor.

The low diversity in fine-grained lithofacies (lithofacies A and B) would be related to low oxygen levels. The complete absence of epifaunal and infaunal body fossils and trace fossils in some levels suggests anoxic bottom waters, while other levels with some isolated body fossils and/or trace fossils (*Chondrites* or *Thalassinoides*) suggest low oxygen levels (dysaerobic bottom waters and anaerobic interstitial waters) (Ekdale and Mason 1988).

CONCLUSIONS

The Bardas Blancas Formation was deposited on a marine platform, dominated by high-energy processes (storms). The body fossils and associated trace fossils confirm this interpretation.

Trace fossils in the sandstone beds are interpreted as elements of the *Skolithos* and *Cruziana* ichnofacies. Their distribution suggests an environment between the shoreface and the offshore-transition zone. Isolated *Chondrites* in the mudstone beds, and *Chondrites* and *Thalassinoides* type A in the siltstone beds, are interpreted as elements of the *Zoophycos* ichnofacies, indicating environments between the lower offshore-transition zone and the offshore zone.

Depositional processes exerted a strong effect on the emplacement and preservation of the trace fossils. Erosion and amalgamation of sandstone beds were the principal factors that led to the underestimation of horizontal trace fossils in the sandstone lithofacies. In these beds, vertical trace fossils would be affected by erosion and biological parameters.

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REFERENCES

Alpert, S.P. 1974. Systematic review of the genus Skolithos. *Journal of Paleontology*, **48**, 661–669

Alpert, S.P. 1975. Planolites and Skolithos from the upper Precambrian-Lower Cambrian. White-Inyo Mountains, California. *Journal of Paleontology*, **49**, 509–521.

Arnott, R.W.C. and Southard, J.B. 1990. Exploratory flow-duct experiments on combined-flow bed configurations, and some implications for interpreting storm-event stratification. *Journal of Sedimentary Petrology*, **60**, 211–219.

Brenchley, P.J. 1989. Storm sedimentation. *Geology Today*, **5**, 133–137

Brenchley, P.J., Pickerill, P.K. and Stromberg, S.G. 1993. The role of wave reworking on the architecture of storm sandstone facies, Bell Island Group (Lower Ordovician), eastern Newfoundland. *Sedimentology*, **40**, 359–382.

Bressan, G.S. and Palma, R.M. 2007. Las trazas fósiles en las areniscas con estratificación cruzada tipo hummocky de la Formación Bardas Blancas, Cuenca Neuquina. In: III Simposio Argentino Jurásico, pp. 31. Mendoza.

Bressan, G.S. and Palma, R.M. 2008. Trace fossil assemblages from lower Toarcian-lower Bajocian siliciclastic marine platform-Neuquén Basin, Argentina. In: 5th International Symposium of IGCP 506, pp. 55–56. Hammamet.

Bromley, R.G. 1996. Trace fossils. Biology, taphonomy and applications, pp. 1–361. Chapman and Hall; London.

Cantalamessa, G. and Di Celma, C. 2004. Sequence response to syndepositional regional uplift: insights from high-resolution sequence stratigraphy of late Early Pleistocene strata, Periadriatic Basin, central Italy. *Sedimentary Geology*, **164**, 283–309.

Chacra, J. 2007. Evolución paleoambiental, ciclicidad y estratigrafía secuencial en los depósitos de la Fm. Bardas Blancas (Mesosecuencia Cuyo), Cuenca Neuquina-Mendoza. Unpublished Tesis de Licenciatura, Universidad de Buenos Aires, 125 pp., Buenos Aires.

Cheel, R.J. and Leckie, D.A. 1993. Hummocky cross-stratification. In: V. P. Wright (Ed.), Sedimentology Review 1, Blackwell Scientific Publications, 103–122.

Collinson, J.D. and Thompson, D.B. 1989. Sedimentary structures, pp. 1–207. Unwin-Hyman, London.

D´Alessandro, A. and Bromley, R.G. 1987. Meniscate trace fossils and the Muensteria-Taenidium problem. *Palaeontology*, **30**, 743–763.

Dellapé, D.A., Mombrú, C., Pando, G., Riccardi, A.G., Uliana, M.A. and Westermann, G.E.G. 1979. Edad y correlación de la Formación Tábanos en Chacay Melehue y otras localidades de Neuquén y Mendoza. Con consideraciones sobre la distribución y significado de las sedimentitas del Lotenian. In: Obra Centenario Museo La Plata, 5, 81–105.

De Raaf, J.F.M., Boersma, J.R. and Van Gelder, A. 1977. Wave-generated structures and sequences from a shallow marine succession, Lower Carboniferous, County Cork, Ireland. *Sedimentology*, **24**, 451–483.

Dott Jr., R.H. and Bourgeois, J. 1982. Hummocky stratification: significance of its variable bedding sequences. *Geological Society of America Bulletin*, **93**, 663–680.

Droser, m.l. and Bottjer, d.j. 1986. A semiquantitative classification of ichnofabric. *Journal of Sedimentary Petrology*, **56**, 558–569.

Droser, M.L. and Bottjer, D.J. 1989. Ichnofabric of sandstones deposited in high-energy nearshore environments: measurement and utilization. *Palaios*, **4**, 598–604.

Ekdale, A.A. and Mason, T.R. 1988. Characteristic trace-fossils associations in oxygen-poor sedimentary environments. *Geology*, **16**, 720–723.

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

Fürsich, F.T. 1974a. Corallian (Upper Jurassic) trace fossil from England and Normandy. *Stuttgarter Beträge zur Naturkunde, Serie B* **13**, 1–51.

Fürsich, F.T. 1974b. On Diplocraterion Torell 1870 and the significance of morphological features in vertical, spreitenbearing, U-shaped trace fossils. *Journal of Paleontology*, **48**, 952–962.

Fürsich, F.T. and Hurst, J.M. 1974. Environmental factors determining the distribution of brachiopods. *Palaeontology*, **17**, 879–900.

Gibert J.M. de and Benner J.S. 2002. The trace fossil Gyrochorte: ethology and paleoecology. *Revista Española de Paleontología*, **17**, 1–12

Gulisano, C.A. 1981. Ciclo Cuyano en el norte de Neuquén y Sur de Mendoza. In: VIII Congreso Geológico Argentino, pp. 579–592. San Luis.

Gulisano, C.A. and Gutiérrez Pleimling, A.R. 1994. Field Trips Guidebook B, Neuquen Basin, Mendoza Province. In: 4th International Congress on Jurassic Stratigraphy and Geology, pp. 1–113. Mendoza.

Gulisano, C.A. 1984. Esquema estratigráfico de la secuencia jurásica del oeste de la provincial del Neuquén. In: IX Congreso Geológico Argentino, pp. 236–259. San Carlos de Bariloche

Gulisano, C.A., Gutiérrez Pleimling, A. and Digregorio, R.E. 1984. Esquema estratigráfico de la secuencia jurásica del oeste de la provincia de Neuquén. In: IX Congreso Geológico Argentino, pp. 236–259. Buenos Aires.

Guy, H.P., Simons, D.B. and Richardson, E.V. 1966. Summary of alluvial channel data from flume experiments, 1956–61. *U.S. Geological Survey Professional Paper* **462–I**, pp. 1–66. Washington D.C.

Häntzschel, W. 1962. Trace fossils and problematic. In: R.C. Moore (Ed.), Treatise on invertebrate paleontology, Part W, Miscellanea. Geological Society of America and University of Kansas Press, 177–245.

Häntzschel, W. 1975. Trace fossil and problematica. In: C. Teichert (Ed.), Treatise on Invertebrate Paleontology. Part W, Misellanea, Supplement 1. Geological Society of America and University of Kansas Press, 1–269.

Hart, B.S. y Plint, A.G. 1995. Gravelly shoreface and beachface deposits. Special Publication of the International Association of Sedimentologists, 22, 75–99.

Howard, J.D., and Frey, R.W. 1984. Characteristic trace fossils in nearshore to offshore sequences, Upper Cretaceous of East-Central Utah. *Canadian Journal of Earth Sciences*, **21**, 200–219.

Jennette, D.C. and Pryor, W.A. 1993. Cyclic alternation of proximal and distal storm facies: Kope and Fairview Formations (Upper Ordovician), Ohio and Kentuchy. *Journal of Sedimentary Petrology*, **63**, 183–203.

Junken, E.A., 2002. Sedimentación dominada por tormentas en el Bajociano (Jurásico medio): Formación Bardas Blancas, Cuenca Neuquina, Mendoza. Unpublished Tesis de Licenciatura, Universidad de Buenos Aires, 92 pp., Buenos Aires.

Kerr, M. and Eyles, N. 1991. Storm deposited sandstones (tempestites) and related ichnofossils of the Late Ordovician Georgian Bay Formation, Southern Ontario, Canada. *Canadian Journal of Earth Sciences*, **28**, 266–282.

Kreisa, R.D. 1981. Storm-generated sedimentary structures in subtidal marine facies with examples from the Middle and Upper Ordovician of Southwestern Virginia. *Journal of Sedimentary Petrology*, **51**, 823–848.

Kidwell, S.M. 1991. The stratigraphy of shell concentrations. In: P.A. Allison and D.E.G. Briggs (Eds), Taphonomy: releasing the data locked in the fossil record, Plenum Press, 211–290.

Legarreta, L. and Gulisano, C.A. 1989. Análisis estratigráfico secuencial de la Cuenca Neuquina (Triásico Superior-Terciario Inferior). In: G. Chebli and L. Spalleti (Eds), Cuencas Sedimentarias Argentinas, pp. 221–243. S.M. de Tucumán.

Legarreta, L., Gulisano, C.A. and Uliana, M. 1993. Las secuencias sedimentarias jurásico-cretácicas. In: XII Congreso Geológico Argentino y II Congreso de Hidrocarburos, pp. 87–114. Mendoza.

MacEachern, J.A., Kerrie, L.B., Pemberton, S.G. and Gingras, M.K. 2008. The ichnofacies paradigm: high-resolution paleoenvironmental interpretation of the rock record. In: J.A. MAcEachern, K.L. Bann, M.K. Gingras, and S. G. Pemberton (Eds), Applied ichnology. SEPM Short Course notes, 27–64.

MacNaughton, R.B. and Pickerill, R.K. 1995. Invertebrate ichnology of the nonmarine Lepreau Formation (Triassic), southern New Brunswick, eastern Canada. *Journal of Paleontology*, **69**, 160–171.

Moghadam, H.V. and Paul, C.R.C. 2000. Trace Fossils of the Jurassic, Blue Lias, Lyme Regis, Southern England. *Ichnos*, **7**, 283–306.

Osgood, R.G., Jr. 1970. Trace fossils of the Cincinnati area. *Palaeontographica Americana*, **6**, 281–444.

Pemberton, S.G. and Frey, R.W. 1982. Trace fossil nomenclature and the Planolites-Palaeophycus dilemma. *Journal of Paleontology*, **56**, 843–881.

Pemberton, S.G., MacEachern, J.A. and Ranger, M.J. 1992. Ichnology and event stratigraphy: the use of trace fossils in recognizing tempestites. In: S.G. Pemberton (Ed.), Applications of ichnology to petroleum exploration-A core workshop. Society of Economic Paleontologists and Mineralogists, Core Workshop 17: 15–118.

Pickerill, R.K. and Narbonne, G.M. 1995. Composite and compound ichnotaxa: a case example from the Ordovician of Québec, eastern Canada. *Ichnos*, **4**, 53–69.

Pickerill, R.K., Fillion, D. and Harland, T.L. 1984. Middle Ordovician trace fossils in carbonates of the Trenton Group between Montreal and Quebec City, St. Lawrence Lowland, Eastern Canada. *Journal of Paleontology*, **58**, 416–439.

Reading, H.G. and Collinson, J.D. 1996. Clastic coasts. In: H.G. Reading (Ed.), Sedimentary environments: processes, facies and stratigraphy. Blackwell Science, 154–231.

Reineck, H.E. and Singh, I.B. 1975. Depositional sedimentary environments, pp.1–439. Springer; Berlin-Heidelberg-New York

Rhoads, D.C. and Morse J.W. 1971. Evolutionary and ecologic significance of oxygen-deficient basins. *Lethaia*, **4**, 413–428.

Riccardi, A.C., Leanza, H.A., Damborenea, S.E., Manceñido, M.O., Ballent, S.C. and Zeiss, A. 2000. Marine biostratigraphy of the Neuquén Basin. In : H. Miller and F. Hervé (Coordinators), Geoscientific Cooperation with Latin America. 31st International Geological Congress, Zeitschrift für Angewandte Geologie. Sonderheft SH1, pp. 103–108. Río de Janeiro.

Richter, R. 1927. Die fossilen Fährten und Bauten der Würmer, ein Uberblick über ihre biologischen Grundform und deren geologische Bedeutung. *Paläontologische Zeitschrift*, **9**, 193–240.

Sanci, R. 2005. Evolución ambiental y bioestratigrafía de las Formaciones Bardas Blancas y Tres Esquinas (Grupo Cuyo), Cuenca Neuquina. Unpublished Tesis de Licenciatura, Universidad de Buenos Aires, 115 pp., Buenos Aires.

Savrda, C.E., Bottjer, D.J. and Seilacher, A. 1991. Redox-related benthic events. In: G. Einsele, W. Ricken and A. Seilacher (Eds), Cycles and Events in Stratigraphy. Springer; Berlin, 524–541.

Schlirf, M., Uchman, A. and Kümmel, M. 2001. Upper Triassic (Keuper) non-marine trace fossils from the Haßberge area (Franconia, south-eastern Germany). *Paläontologische Zeitschrift*, **75**, 71–96.

Spalletti, L.A. and Del Valle, A. 1990. Plataformas silicoclásticas. In: G.E. Bossi (Ed.), 10º Congreso Geológico Argentino- 1º Simposio de ambientes marinos y modelos sedimentarios. Boletín Sedimentológico, **4**, 161–187. San Juan.

Swinbanks, D.D. 1981. Sediment reworking and the biogenic formation of clay laminae by Abarenicolapadifica. *Journal of Sedimentary Petrology*, **51**, 1137–1145.

Swinbanks, D.D. and Luternauer, J.L. 1987. Burrow distribution of thalassinidean shrimp on a Fraser Delta tidal flat, British Colombia. *Journal of Paleontology*, **61**, 315–332.

Uchman, A. 1995. Taxonomy and palaeoecology of flysch trace fossils: The Mamoso-arenacea Formation and associated facies (Miocene, Northern Apennines, Italy). *Beringeria*, **15**, 3–115.

Uchman, A. 1999. Ichnology of the Rhenodanubian Flysch (Lower Cretaceous-Eocene) in Austria and Germany. *Beringeria*, **25**, 67–173.

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