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THE MIDDLE-UPPER CAMBRIAN TRANSITION IN THE IBERIAN CHAINS, NE SPAIN. AN INTEGRATED APPROACH

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Riassunto. La deposizione dei sedimenti prevalentemente silicoclastici al passaggio Cambriano Medio-Cambriano Superiore nelle catene Iberiche (NE della Spagna) è avvenuta secondo 4 processi principali. 1) azione delle tempeste in condizioni di mare aperto; 2) azione delle onde e delle correnti nei complessi di barra; 3) deposizione ad opera delle normali correnti di marea nelle aree confinate dalle barre; 4) influenza della tettonica sinsedimentaria. Le parasequenze di 4° ordine con tendenza regressiva sembrano rappresentare episodi di progradazione di barre costiere emerse o di delta, concluse alla sommità da depositi di marea. Su questi si sovraimpongono eventi tettonici sinsedimentari di più breve durata, che provocano frane alla scala locale.

Le associazioni di tracce fossili sono largamente correlative con litofacies e sequenze deposizionali, consentendo di ottenere importanti informazioni sulle comunità bentoniche a corpo molle. Esse mostrano una distribuzione stratigrafica complessa confrontabile con la gerarchia delle sequenze.

Abstract. Dominantly siliciclastic, shallow-marine sediments of the Middle-Upper Cambrian transition in the Iberian Chains (NE Spain) accumulated through four main processes: the storm effects in open-sea conditions, the action of waves and currents in shoal complexes, the deposition from normal tidal currents in back-shoal areas, and the influence of synsedimentary tectonic processes. Fourth-order shallowing-upward parasequences seem to represent episodes of prograding barrier island or delta trends, covered at the top by tidal-induced deposits. Superimposed shorter duration synsedimentary tectonic events took place, developing gravity-induced processes across local slopes within the basin.

Trace fossil assemblages are broadly correlative with lithofacies and depositional sequences, which permit to reflect valuable informations about benthic soft-bodied communities. They show a composite stratigraphic distribution, similar to the hierarchical scheme of sequences.

Introduction.

This paper shows an integrated approach to reconstruct benthic conditions in a siliciclastic platform, controlling the occurrence, distribution and preservation of body and trace fossils. Terrigenous sediments of the Middle-Upper Cambrian transition in the Iberian Chains (NE Spain) provide a good opportunity to evaluate the paleoecological effects on a poorly fossiliferous seafloor of some significant geological markers: transgressive-regressive depositional trends and their sequence framework. Commonly, a pure lithofacial approach does not permit a complete interpretation of depositional environments in stratigraphic successions. In this case, contribution of trace fossils is double: (1) many of the traces are facies-restricted serving as reliable indicators of different sedimentary processes within a broad depositional setting, and (2) yielding important environmental information in sediments characterized by scarcity of body fossils and physical sedimentary structures. Furthermore, isolated bioclastic concentrations will reflect valuable information about episodes of faunistic development and sedimentary dynamics of the seafloor.

The best approach in reconstructing the sedimentary and benthic paleoecological conditions in a poorly fossiliferous siliciclastic seafloor is a complete facies and sequential analysis, incorporating evidence from body fossils and their taphonomic features, trace fossils and inorganic sedimentary structures.

Geological setting and stratigraphy.

The uppermost Middle Cambrian to Arenig deposits of the Iberian Chains (Fig. 1) are characterized by a thick (2500-3500 m) and conformable succession of terrigenous sediments. Shales, sandstones and conglomerates, between the Mesones Group (which comprises the Lower-Middle Cambrian transition; Liñán et al., 1992) and the Armorican Quartzite (Arenig in times; Wolf, 1980), show rapid lateral thickness and facies changes. This complex lithologic framework led to the recognition of several informal units (Lotze, 1929, 1958, 1961; Scheuplein, 1967; Schmitz, 1971; Josopait, 1971, 1972). These units have been revised by Wolf (1980) and Álvaro (1995) as a result of detailed mapping and facial di-

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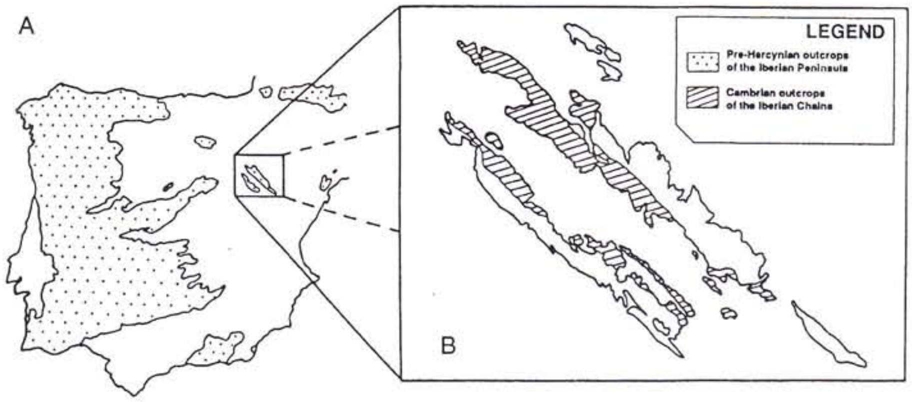


Fig. 1 - (A) Geological sketch showing pre-Hercynian outcrops in the Iberian Peninsula, and (B) the Cambrian outcrops in the Iberian Chains.

stinction (Fig. 2); their lithostratigraphic units are based on the predominance of coarse and fine terrigenous sediment associations. The Middle-Upper Cambrian transition lies within the upper part of the Acón Group, which is composed, from bottom to top, of the Borobia, Valdeorea, Torcas, Encomienda and Valtorres Formations (Álvaro, 1995). This study is focused on the Encomienda and Valtorres Formations, where the Middle-Upper Cambrian transition has been situated (Shergold & Sdzuy, 1991).

The Encomienda Formation comprises 150 to 200 m of sandstones and shales, whilst the Valtorres Formation is mainly represented by more than 300 m of shales with isolated sandstone intercalations.

According to biostratigraphical data, based on the study of trilobites, brachiopods, acritarchs and trace fossils (Schmitz, 1971; Josopait, 1971, 1972; Havlíček & Josopait, 1972; Shergold & Sdzuy, 1991; and Álvaro, 1995), the latest Middle Cambrian trilobite debris (represented by *Solenopleura* s.l.), is situated at the lower part of the Encomienda Formation. This taxon is associated with some pelmatozoan debris, the hyolith *Ortotheca*, and the inarticulate brachiopods *Lingulella* sp., *Obolus* sp., Obolidae spp., *Schuchertina* cf. *cambrica*, *Westonia* aff. *iphis* and *Westonia* sp. The upper part of the Encomienda Formation has yielded no age diagnostic fauna, composed of the inarticulate brachiopods *Obolus* sp. and *Westonia* cf. *iphis*. Trilobites reappear in the upper part of the Valtorres Formation, and in the lower part of the overlying Valconchán Formation (Wolf, 1980). This Late Cambrian faunal assemblage includes the trilobites agnostid gen. et sp. indet., aphelaspidinae gen. indet. aff. "*Olenus*" *rarus*, *Elegantaspis* sp. cf. *E. beta*, *Parachangshania*? sp. indet., *Pseudoagnostus (Pseudoagnostus)* sp. ind., *Punctuaspis*? *schmitzi*, Solenopleuroidean gen. et sp. ind., *Valtorresia volkeri*, and the brachiopods *Billingsella jalonensis*, *B.* cf. *jalonensis* and *B. perarea*. According to Shergold & Sdzuy (1991), this last fauna can be considered as probably early Franconian (on the North American biochronological chart), and approximately *Parabolina spinulosa* Zone in northern Europe (Late Cambrian).

Facies analysis and sedimentary environments.

Based on distinctive associations of rock types and primary sedimentary structures, the Encomienda and Valtorres Formations are subdivided into six facies (Fig. 3).

Facies A.

Two subfacies can be distinguished. Subfacies A1 consists of alternating laminae of mudstone, siltstone and subordinate very fine-grained sandstones, with laminae thickness varying from less than 1 mm to 5 cm. The laminae are generally nearly horizontal, never inclined at angles exceeding 15°, and truncated in places by low-angle erosion surfaces. Minor sedimentary structures, forming units of 5 to 40 cm thick, are interbedded. They include flaser and lenticular siltstone bedding (Pl. 1, fig. 2), convoluted laminae, ripple cross-lamination and wave ripples.

In addition, subfacies A2 consists of trough cross-bedded siltstone- and fine-grained sandstone beds, 5-20 cm deep and 0.5-1.8 m wide, which exhibit erosional bases. This subfacies occurs eroding the previous laminated subfacies.

Interpretation. The episodic preservation of alternating laminae in subfacies A1 is interpreted to be a product of mixed deposition from suspension and traction transport of fine-grained sandstones. This suggestion is supported by the presence of minor flaser-to-lenticular structures (Reineck & Wunderlich, 1968), small wave ripples and ripples cross-lamination (Weimer et al., 1982; Galloway & Hobday, 1983). In spite of the absence of herringbone structures, the thin intercalations of mudstone/siltstone may represent tidal-induced processes in either back-shoal or inter-shoal areas (shoals are described in facies B).

Subfacies A2 represents scarce small channels, filled predominantly with very fine-grained sandstones and trough cross-bedding structures, which are inferred to represent tidal channels which drained the tidal-induced accumulations.

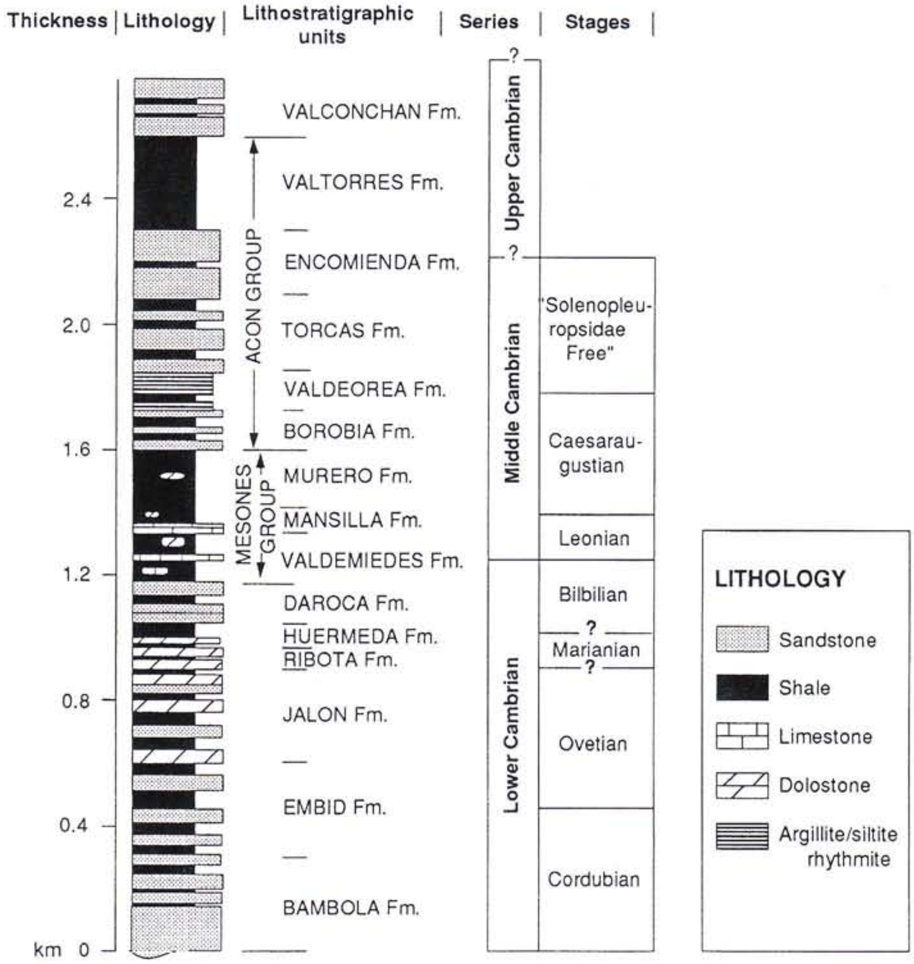


Fig. 2 - Litho- and chronostratigraphic units of the Cambrian sediments in the Iberian Chains.

Facies B.

Two subfacies are recognized. Subfacies B1 mainly consists of very-fine to medium-grained sandstone beds, 10 to 70 cm thick, and very well-sorted. Trough cross-bedding display sharp bases that may be flat, gently undulating, or broadly scoured; the depth of scour at the base of some beds may be as much as 60 cm (Pl. 1, fig. 1). Cross-stratification sets persist laterally for a few decimetres to several metres. Reactivation surfaces are present within some of the sets. Clay laminae, less than 4 cm thick, commonly separate cross-stratification sets. In addition, paleocurrent data (derived primarily from cross-lamination sets; Fig. 4B) suggest that structures are southwest-directed.

On the other hand, subfacies B2 consists of lenticular units, less than 20 or 40 cm deep, which occur at the top of some amalgamated sets, exhibiting a calcareous sandy conglomerate composition and erosional bases. Sandstone clasts, which are the main component of the lag deposits, are intraformational in origin, because of their close petrographic similarities to in situ sandstone beds.

Body fossils are locally abundant, consisting mainly of inarticulate brachiopods. The shells are commonly randomly oriented, dispersed on the sandstone beds and disarticulated, but neither fragmented nor abraded. In addition, the larger number of abraded valves are concentrated and densely packed in coquinas in erosional troughs and channeling lenses.

Interpretation. The ubiquity of amalgamated trough lensoid cross-bedding sandstones indicates that sandstones of subfacies B1 were originally deposited as large migrating bed forms. The predominance of trough shapes further shows that the bed forms were short-crested megaripples. Sandstone sets indicate a depositional regime in which migrating sand waves attained heights of at least 0.8 m. The common occurrence of thin clay laminae bounding sandstone sets and reactivation surfaces point to episodic fluctuations in flow regime (Soegaard & Eriksson, 1985; Hamberg, 1991). These evidences permit to represent the episodic development of some type of shoals or bars.

The presence of lagged erosional surfaces overlain by sandstones (subfacies B2), some of which show fining-upward trends, is consistent with deposition in channels. Therefore, barrier shoals recorded minor storm washover sands at their top. Long-distance transport of their coarser clasts as traction bedload is highly unlikely.

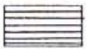
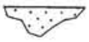
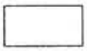
FACIES		SYMBOL	DESCRIPTION	INTERPRETATION
A	A1		Thin-bedded laminae of mudstone and siltstone, with flaser and lenticular siltstones and wave ripples. Rich intervals of bioturbation.	Tidal-influenced back-shoals dissected by channels
	A2		Very fine-to fine-grained sandstones, dominated by trough cross-bedding, reactivation and erosional surfaces. Non-identified bioturbation.	
B	B1		Thick-bedded, fine-grained sandstones, with medium-scale trough cross-bedding and wave ripple laminations. Scarce bioturbation.	Shoal complexes in a shoreface environment dominated by onshore and longshore currents, recording minor storm washover sands.
	B2		Lagged erosional channels, composed of intraclastic conglomerates and abraded brachiopods. Non-identified bioturbation.	
C			Massive mudstones, poor in benthic fauna, with cm-thick graded layers and scarce ripple laminations. Wide diversity of bioturbation density.	Suspension sedimentation on a well-oxygenated outer shelf close to the storm-wave base.
D			Fine-grained sandstone beds exhibiting scoured bases, hummocky structures and laminated graded units. Scarce bioturbation.	Storm-dominated shelf.
E			Intraclast blocks and swarms of pillows, composed of cemented sandstones and laminated siltstones.	Gravity- and liquefaction-induced processes across talus

Fig. 3 - Summary of lithofacies of the Encomienda and Valtorres Formations, and their environmental interpretations.

In addition, taphonomic features indicate somewhat varied environmental processes. Brachiopods that are disarticulated but unabraded suggest long-term accumulation in a low-energy environment (Brett & Baird, 1986). Areas of essentially random brachiopod orientations indicate intervals of very quiet conditions. The predominance concave-down orientations indicate some current and/or wave activity. Finally, broken and abraded brachiopods debris, associated to conglomerate lag deposits of channels, probably represent a mechanism related to storm-generated flows.

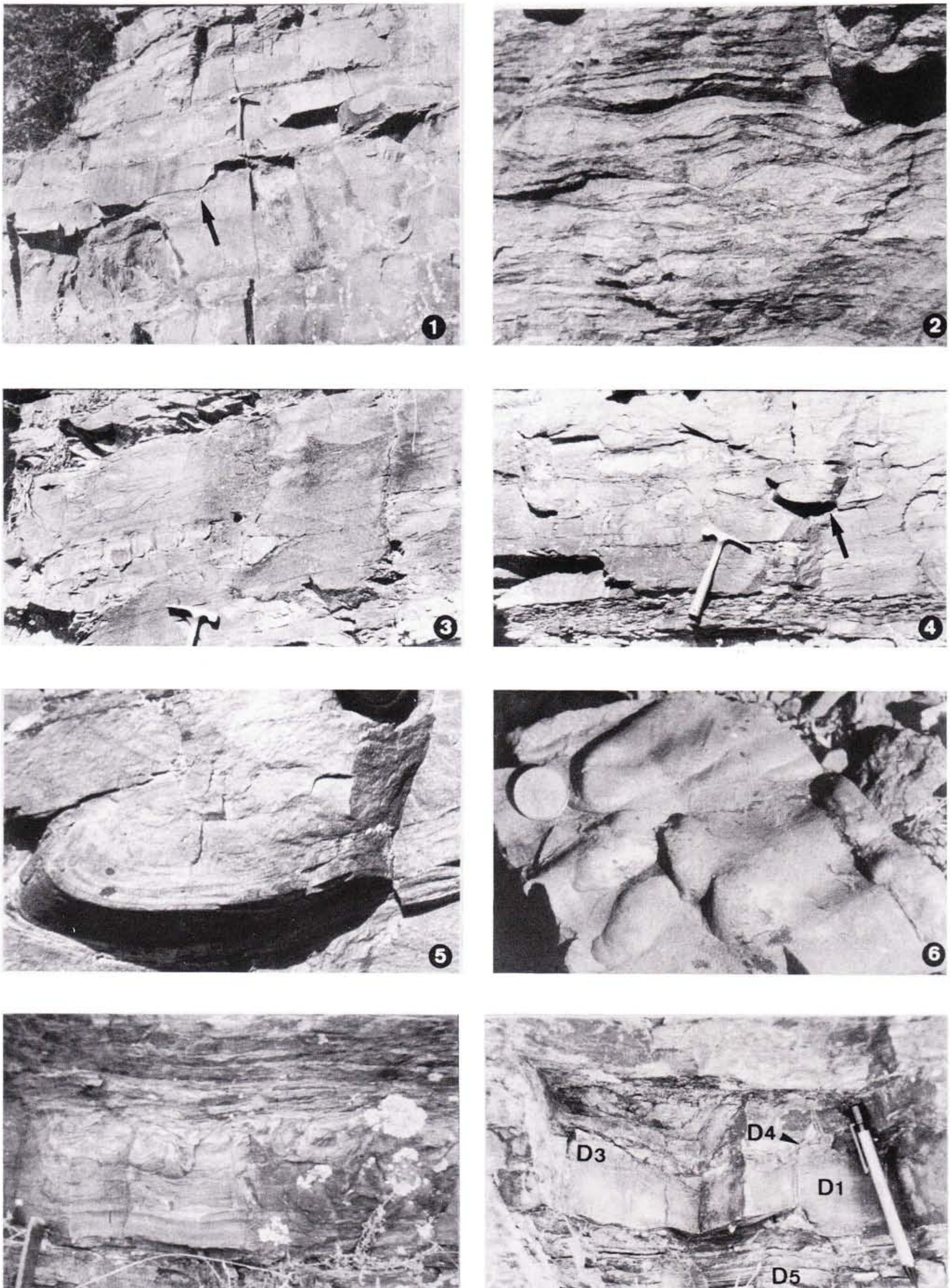
Facies C.

Green mudstones with few sedimentary structures are typical of this facies. It is mainly composed of muddy siltstones with abundant mica, which often emphasizes the bedding parallel shaly lamination. Delicate silty laminae may show small-scale wave-ripple lamination and subordinate graded siltstone beds, 1-3 cm thick (silt layers; Aigner & Reineck, 1982; Pedersen, 1985).

Shelly fossils are uncommon except in calcareous layers and nodules, where they contain relatively well preserved trilobites. Hyoliths, pelmatozoan debris, and

PLATE 1

Fig. 1 - Sandstone sets of facies B exhibiting a broadly scoured base (arrow). Encomienda Formation, At 22/27.
Fig. 2 - Flaser structures of facies A showing cross-laminae and symmetric ripples. Encomienda Formation, At 22/29.
Fig. 3 - Penecontemporaneous deformations associated with fluidized sediment flow preserved as a swarm of pillows, which are composed of laminated sandstones and siltstones (facies E), up to 40 cm in size, within shale beds. Encomienda Formation, At 22/18.
Fig. 4 - Swarms of pillows composed of sandstones and siltstones (facies E), included within shales. Encomienda Formation, At 22 /18.
Fig. 5 - Detail of a pillow represented in the last figure by an arrow.
Fig. 6 - Flute-marks of facies D. Valtorres Formation, At 27/2.
Fig. 7 - Alternating of siltstone and shale beds (cm-scale) showing liquefaction features (facies D). Valtorres Formation, At 27/2.
Fig. 8 - A complete small-scale sequence of facies D (see sketch in Fig. 4F). Valtorres Formation, At 27/1.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D5
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inarticulate and articulate brachiopods are generally sparse, usually occurring as scattered and isolated specimens.

Interpretation. The dominant lithology and scarce sedimentary structures indicate predominantly low-energy suspension sedimentation on a shelf, which was generally below storm-wave base.

Facies D.

This facies consists of sandstone beds intercalated with silty to sandy shales. Sandstones are either structureless or display hummocky cross-stratification (HCS), parallel lamination, ripple cross-lamination, ripple marks and shale intercalations. The typical small-scale sequence (Pl. 1, fig. 8; Pl. 2, fig. 1), 15 to 30 cm thick, starts with a sharp and erosive based sandstone (D1); tool marks are common on the bottom of these scoured beds. Overlying this sandstone bed is a planar-laminated bed (D2), which is commonly eroded by HCS beds (D3). The last beds grade upward into symmetric ripple marks (D4), which finally pass upward into an irregular laminated bed (D5). D5 is composed of alternating shales and coarse-to-fine silt-sized graded units (1 to 5 cm thick), exhibiting erosive bases.

Scarce liquefaction structures, and common flute-marks (Pl. 1, fig. 6), groove marks, impact marks (produced by objects striking the sediment surface) occur bounding previously described small-scale sequences.

Interpretation. Similar small-scale sequences have been described in storm-dominated shelf or lower shoreface environments (Dott & Bourgeois, 1982; Walker, 1984). Therefore, the sedimentary setting was likely between fairweather and storm wave-base. Small depth changes may be responsible for the thickening and thinning of the D1, D3 and D5 units.

On the other hand, liquefaction structures (Pl. 1, fig. 7) and sole-marks may indicate episodes of rapid sedimentation, related to quick and unstable pulses. These processes could attest either the intense scouring of storm-induced currents, or the turbidity-influenced currents related to slight slopes.

Facies E.

Facies E consists of unsorted and ungraded blocks, and pillows (*sensu* Allen, 1982), of sizes up to a few decimetres, 'floating' in a shaly matrix (Pl. 1, fig. 3, 4, 5). Beds range from 0.8 to 2 m in thickness and do not maintain uniform thickness laterally. Bases are planar or gently undulating and scoured. Paleocurrent data show dominant south-western directions.

Blocks are composed of cemented sandstones, whilst swarms of pillows consists of laminated siltstones and sandstones, which are related to the underlying lithologies.

Interpretation. Olistolithic intraclast blocks represent gravity-induced processes, which seem to be related to local tectonic slopes within the basin. Furthermore, the basal portions of some beds contain penecontemporaneous deformation structures preserved as swarms of pillows; the laminae of pillows are complexly folded and contorted. This deformation is probably related to liquefaction and fluidized sediment flow processes, which seem to be induced by tectonic movements.

Sequence framework.

Using the interpretations presented above, the depositional model for the Middle-Upper Cambrian transition spans a spectrum of processes and environments. The Encomienda and Valtorres Formations are inferred to represent a siliciclastic shelf deposit, which accumulated through four main processes: the storm effects in open-sea conditions, the action of waves and currents in shoal complexes, the deposition from normal tidal currents in back-shoal areas, and the influence of synsedimentary tectonic processes.

The Encomienda and Valtorres Formations of the Iberian Chains display three superimposed orders of sequence stratigraphy: (1) high-frequency depositional cycles (15-30 cm in thickness; fifth-order), (2) low-frequency depositional sequences (15-40 m thick; fourth-order), and (3) third-order depositional sequences (150-200 m thick) defined by the vertical stacking patterns of the fourth-order sequences.

(1) High-frequency fifth-order depositional cycles.

At the At 27 section, more than 20 storm-induced cycles are recognized within the Valtorres Formation. They average 20 cm in thickness, ranging from 15 to 30 cm. These units represent vertical facies successions of marine siliciclastic sediments (facies D), which are bounded by erosional surfaces. Sediments show a widespread development of hummocky facies, flute-marks, slumped beds and tool marks, suggesting deposition of siltstone and sandstone beds in a storm-dominated open-shelf.

Lithofacies of these cycles are commonly arranged in asymmetric cycles made up of repeated lithofacies such as patterns of D1-D2-D3-D4-D5. In addition, incomplete cycles are characterized by top-truncated caps (e.g., D1-D3-D5 lithofacies).

Other outcrops of the Valtorres Formation (At 22 section, located 15 km at the SE of the At 25 section; Fig. 4D) lack recognizable small decimetre-scale cycles. In this area, sediments (facies C) were deposited in a low energy outer-shelf environment, with only fine-grained terrigenous input and low to moderate sedimentation rates.

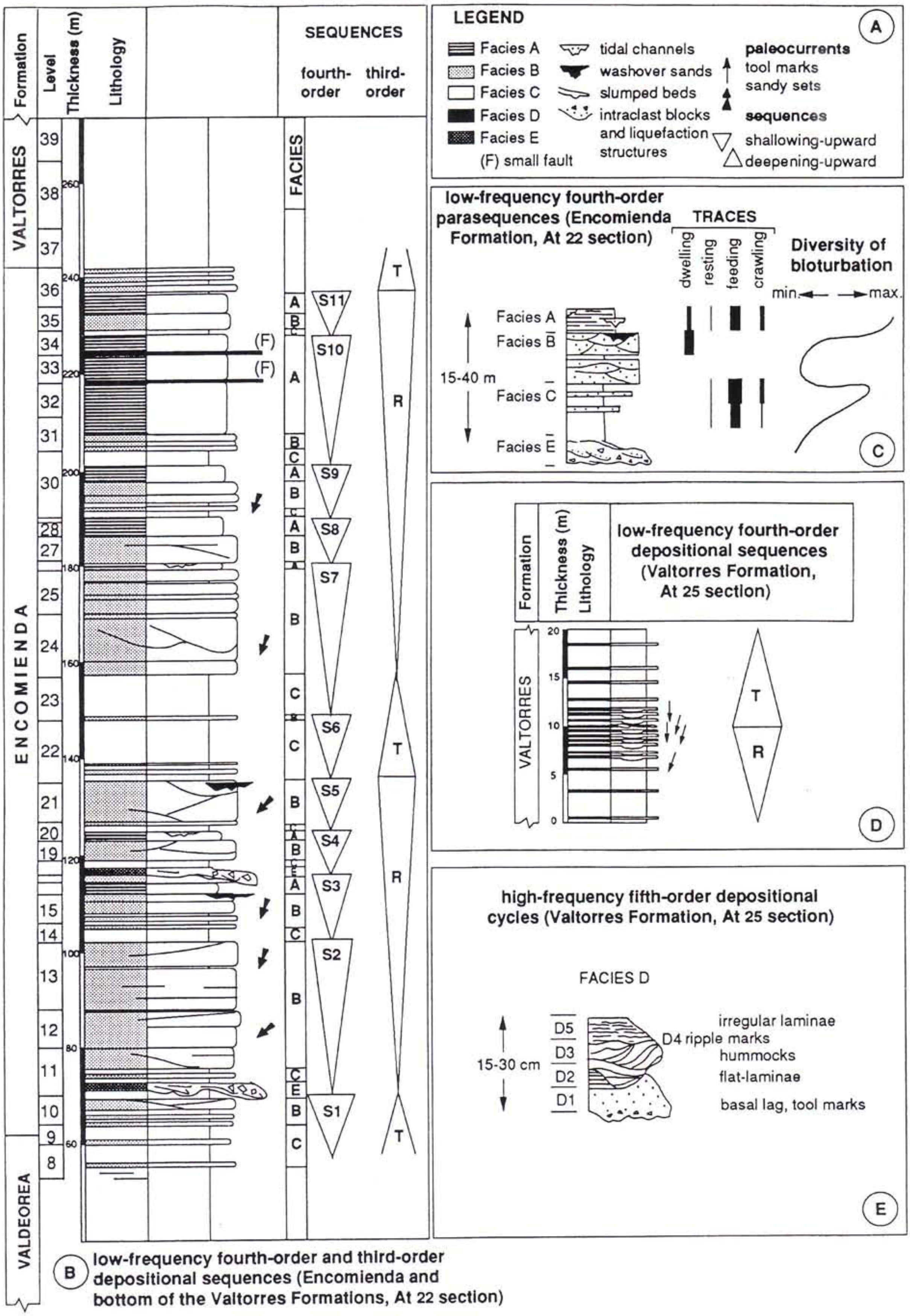

Fig. 4 - (A) Legend. (B) Type-section of the Middle-Upper Cambrian transition in the Iberian Chains (At 22). (C) A complete fourth-order shallowing-upward parasequence of the Encomienda Formation in the At 22 section. (D) At 27 section of the Valtorres Formation. (E) A complete small-scale storm-induced fifth-order cycle of the Valtorres Formation in the At 27 section.

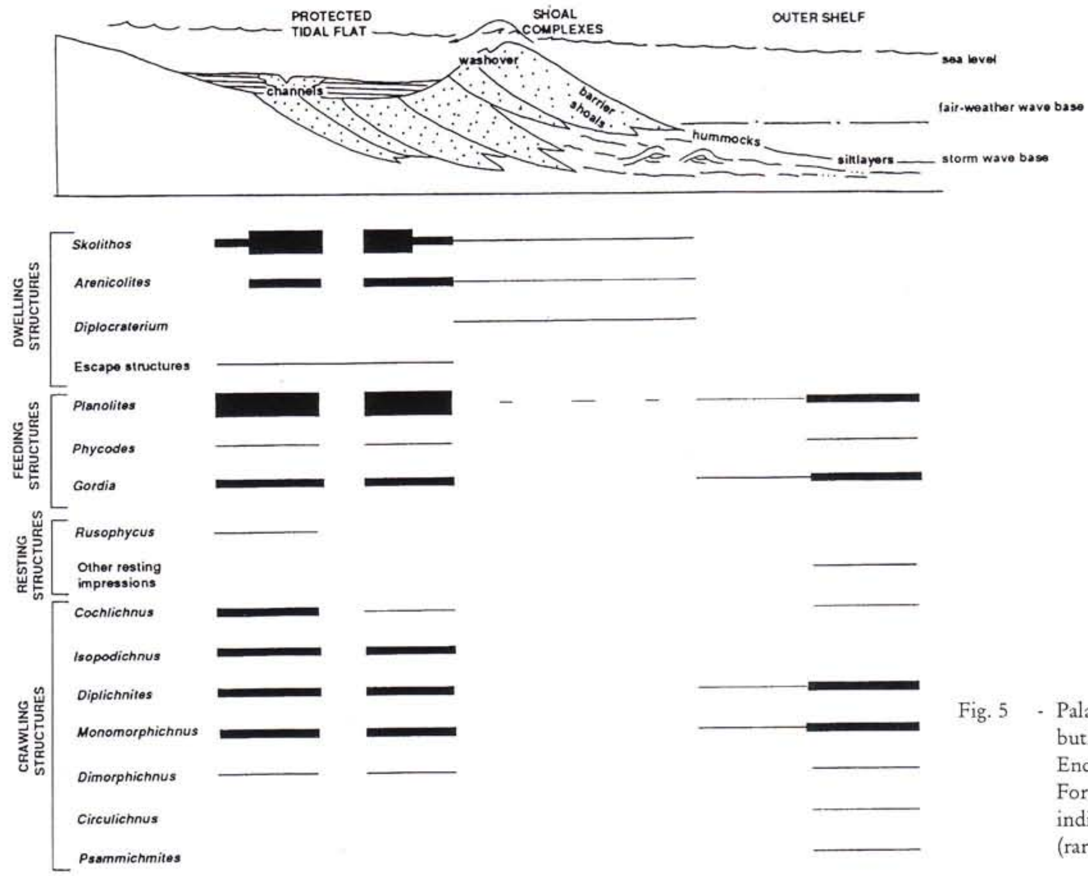

Fig. 5 - Palaeoenvironmental distribution of trace fossils in the Encomienda and Valtorres Formations. Width of lines indicates relative abundance (rare/common/abundant).

(2) Low-frequency fourth-order depositional sequences.

About 75% of the aggregate thickness of the Encomienda Formation stratotype (At 22 section), is incorporated into 11 fourth-order shallowing-upward sequences (S1 to S11 in Fig. 4B), which average 5-25 m in thickness. From bottom to top, almost all of the sequences display a systematic succession from facies C to B to A (Fig. 4D). The relative thickness proportions of these three facies vary considerably. The upward transition from facies C to B is completely gradational (in which sandstone beds increase upwards in thickness and abundance, and become dominant), whilst facies A rest sharply overlying previous sediments. At the bottom of two fourth-order sequences (S2 and S4 in Fig. 4C), erosional surfaces occur truncating facies A. These surfaces are overlain by intraclast blocks and liquefaction tectonic-induced structures (facies E). Therefore, within the Encomienda Formation, facies are grouped into shallowing- and coarsening-upward sequences, in which the finer-grained outer-shelf deposits are overlain gradationally by coarser shoal complexes, and covered at the top by tidal-induced deposits.

The mechanism proposed for the creation of the coarsening-upward sequences is somewhat analogous to that of prograding barrier island and delta depositional trends (Winker & Edwards, 1983). Shoal complexes grow and migrate seawards during times of rapid sediment influx giving rise to coarsening-upward sequences. Tidal currents would be more likely to rework sediments on the back-barrier parts of the shelf.

In summary, the stratotype of the Encomienda Formation reflects the stepwise progradation of wave- and current-dominated shoal complexes, and their protected inner shelf tidal-induced deposits, onto a muddy outer shelf. The facies framework of these sequences can

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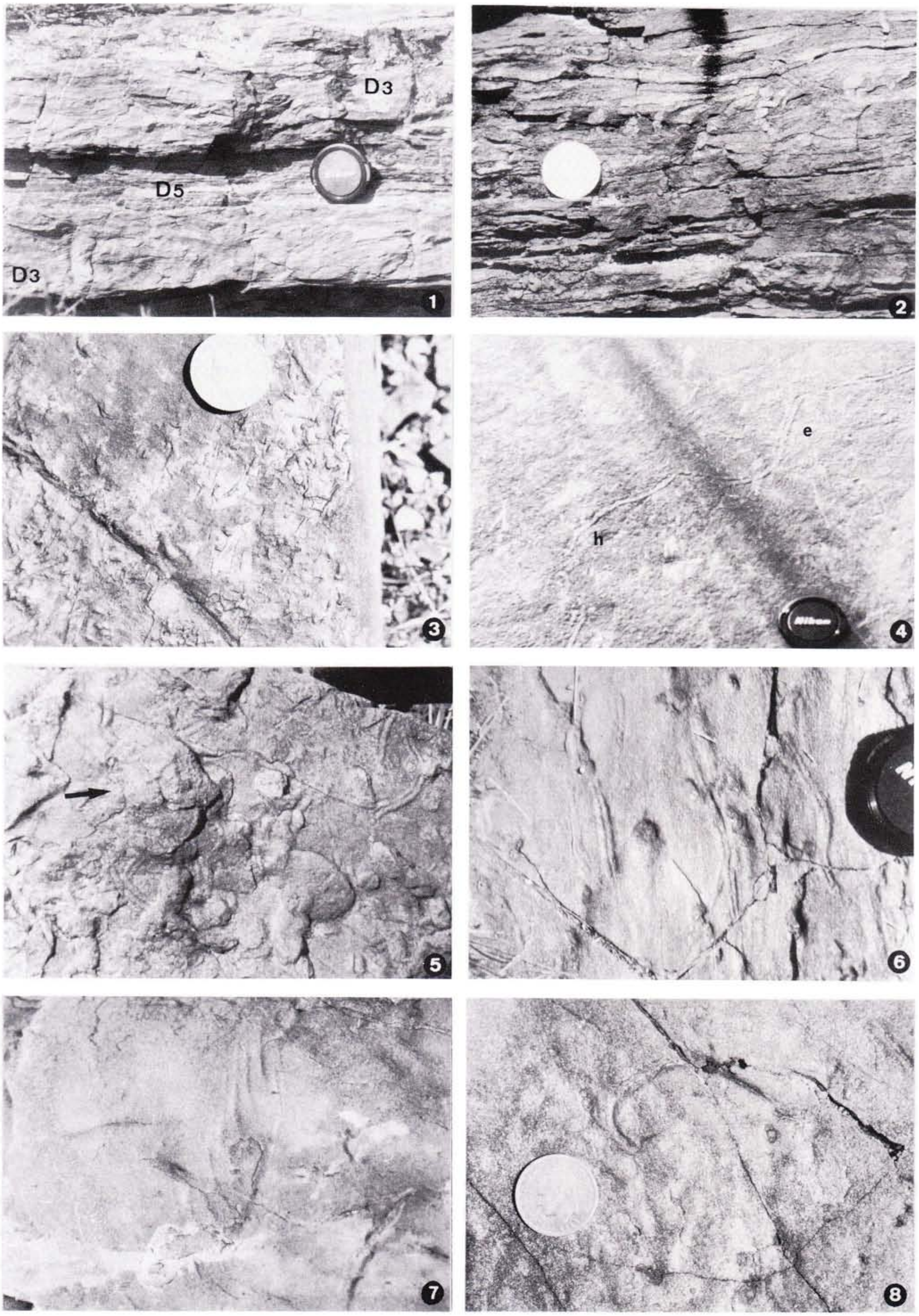
PLATE 2

Fig. 1 - Incomplete small-scale sequence of facies D. Valtorres Formation, At 27/2.
Fig. 2 - Non-identified vertical simple burrows filled with silstone. Facies A, Encomienda Formation, At 22/16.
Fig. 3 - Branching burrows of several *Phycodes* traces. Facies C, bottom of the Encomienda Formation, At 22/8.
Fig. 4 - Eroded *Psammichmites* exhibiting its epirelief (e) and hyporelief (h). Facies C, Valtorres Formation, At 27/2.
Fig. 5 - *Rusophycus* (arrowed) and *Isopodichnus* traces. Facies A, Encomienda Formation, At 22/26.
Fig. 6 - *Isopodichnus* and vertical traces. Facies A, Encomienda Formation, At 22/20.
Fig. 7 - *Monomorphichnus* traces. Facies C, Valtorres Formation, At 27/1.
Fig. 8 - Bilobated trace of uncertain affinity. Facies A, Encomienda Formation, At 22/16.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be considered as partial shelf progradational units, beginning with the deeper outer shelf facies (facies C), shallowing-upward to nearshore facies (facies B), and ending in one protected tidal-influenced environment (facies A). The characteristics of these sequences fit the description of the high sediment supply parasequences of Mitchum & Van Wagoner (1991), Swift et al. (1991) and Einsele (1993), which have been documented widely in siliciclastic platforms. Such sequences repeated episodes of rapid deepening followed by slow progradation of facies under static or slowly falling relative sea-level. Mechanism proposed for these sequences would include either repeated episodes of rapid tectonic-induced subsidence followed by progradation, or high-frequency oscillations of eustatic sea-level.

Available evidence along the northern section of the Western Iberian Chain suggests that fourth-order parasequences and most individual facies intervals persist laterally for kilometres, but the lack of recognized outcrops recording the Middle-Upper Cambrian transition in other areas of the Iberian Chains, do not allow us to propose further correlations.

On the other hand, in the Valtorres Formation, fourth-order sequences are constructed of component fifth-order cycles described above. At the At 25 section (Fig. 4D), one fourth-order sequence is recognized.

(3) Third-order depositional sequences.

In addition to the fifth-order and fourth-order cyclicity, two long-term lower-frequency trends are observed at the At 22 section (Fig. 4B). These third-order sequences are delineated by the vertical stacking patterns of the fourth-order parasequences, and are probably related to third-order accomodation trends.

Occurrence and distribution of biogenic structures

This preliminary study covers trace fossil assemblages in a range of environments from protected tidal-flats to outer shelf settings. Recurrent trace fossil assemblages occur in close proximity at the same lithologies, bedding features and physical sedimentary structures. Thus, trace assemblages are broadly correlative with lithofacies (Fig. 5), indicating that trace producers were sensitive to changes in the physical environmental regimes.

Four broad trace assemblages are recognizable in the Encomienda and Valtorres Formations: (1) the *Skolithos* assemblage, (2) the *Skolithos-Planolites* assemblage, (3) the *Isopodichnus* assemblage, and (4) the *Planolites*-dominant assemblage.

(1) The *Skolithos* assemblage consists of vertical and inclined *Skolithos*, *Arenicolites* and *Diplocraterion* traces. It is restricted to the upper few centimetres of trough cross-bedding sandstones of facies B, which has been interpreted as shoal barrier deposits. Very few traces occur and the assemblage is not very diverse, probably due to the higher energy conditions of the environment. No trace fossils have been identified in coarse-grained channel deposits.

(2) The *Skolithos-Planolites* assemblage consists of a mixed association of vertical, inclined and horizontal traces. It is mainly composed of vertical and inclined *Skolithos*, *Planolites* and other horizontal traces. It occurs frequently at the clay laminae bounding cross-stratification sandstone beds of the shoal complexes (Facies B). These horizons contain vertically- and horizontally-oriented burrows, representing periods in which the bedform ceased to migrate and was colonised by suspension- and detritus-feeding infauna and epifauna. This colonization phase was followed by scour and renewed bedform migrations, disappearing horizontal traces. Therefore, decreased energy episodes in migrating sandy shoals (Facies B) can be recognized by the presence of the *Skolithos-Planolites* assemblage, bounding the more common *Skolithos* assemblage.

(3) The *Isopodichnus* assemblage (Pl. 2, fig. 2, 5, 6, 8) is composed of vertical and horizontal burrows, as well as traces constructed by mobile organisms. It is characterized by a high diversity and abundance of traces, which include *Diplichnites*, *Monomorphichnus*, *Dimorphichnus*, *Rusophycus*, *Planolites*, *Circulichnus*, *Cochlichnus*, meandering bilobate traces of uncertain affinity, inclined *Skolithos*, *Arenicolites*, non-identified escape structures (subvertical burrows with downward oriented deflections of adjacent laminations, not assigned to a formal ichnotaxon), and other traces. This assemblage appears in facies A, which has been interpreted above as deposited in a protected back-shoal setting. Furthermore, trace fossils permit to characterize two distinct subfacies. A high-energy coarse-grained subfacies contain burrowed surfaces dominated by vertical traces, which presumably was deposited in meandering intertidal channels. A lower-energy, fine-grained thin-bedded sandstone and shale subfacies, containing abundant horizontal and crawling traces, was probably deposited on low tidal flats drained by the intertidal channels.

(4) The *Planolites*-dominant assemblage (Pl. 2, fig. 3, 4, 7) characterizes the Facies C. It is constitued of *Phycodes*, *Gordia*, and scarce *Monomorphichnus*, *Diplichnites* and *Psammichmites* traces. Its burrowing density is very variable; the local intense bioturbation indicates a reduced sedimentation rate, representing quiet normal conditions on a substrate free of the influence of storm currents.

Some significant patterns of trace fossil distribution can be related to depositional environments and fourth-order parasequences described above. In the lower part of the described parasequences (Facies C), representing shaly outer shelf sediments, feeding structures prevail, although in the gradual transition between facies C and B, crawling and resting traces become more abundant and feeding structures decreased in density. In the coarser-grained parts of facies B, the number of trace fossils rapidly decreases, mainly represented by dwelling structures at the top of trough cross-bedding sets. Apparently, these higher energy depositional environments were not favorable for the formation and preservation of trace fossils; this sandy substrate would be constantly reworked, with only sporadic preservation of structures formed by suspension-feeding fauna. Clay laminae bounding sandstone sets contain dwelling and feeding structures, representing colonization of the top of bedforms during quite periods and clay falling out suspension. Channels representing washover deposits do not present trace fossils, while brachiopod coquinas are relatively abundant. The fine-grained laminae of facies A (at the top of sequences) are frequently burrowed by dwelling, feeding, resting and crawling traces, exhibiting the higher diversity and density of traces.

Discussion and conclusions.

The Middle-Upper Cambrian transition occurs within a dominantly terrigenous succession in the Iberian Chains (NE Spain), across the Encomienda-Valtorres Formations transition. The distinctive suites of physical and biogenic sedimentary structures and their vertical arrangement within both formations suggest deposition in a spectrum of adjacent environmental settings, from protected back-shoals, to barrier complexes and storm-dominated open-sea environments.

The repetitive nature of cyclicity and stacking patterns of lithofacies and trace fossil assemblages across this transition indicate that a multifold framework of processes operated to influence sedimentary patterns and stratigraphy. The studied stratigraphic sections are an excellent example of composite stratigraphic cyclicity composed of fifth-order cycles grouped into fourth-order sequences, which in turn stack vertically to define third-order depositional sequences. At the core of this hierarchical scheme are the trace fossil assemblages, which show a similar composite stratigraphic distribution.

Parasequences are best developed in middle- to outer-platform beds. However, the abundance of fifth-order cycles in the open-sea offshore environments (represented in the Valtorres Formation) may be related to higher net subsidence rates, which affects generation of accomodation space.

Finally, in spite of the scarcity of body fossils, trace fossils permit to recognize the endobenthic and epibenthic behavioral patterns produced by soft vermiform organisms and arthropods. Depositional environments and fourth-order parasequences contain similar trace fossil assemblage successions, permitting a partial reconstruction of the benthic soft-bodied communities that colonized the Iberian seafloor across the Middle-Upper Cambrian transition.

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