BURROWERS DIG THE MIOCENE: TRACE FOSSILS, PHYSICAL SEDIMENTARY STRUCTURES, AND PALEOENVIRONMENTS OF TWO AREAS IN SOUTHEASTERN SPAIN

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INTRODUCTION

This study focuses on the ichnology and physical sedimentary structures of two areas of sedimentary rock exposure of Miocene age in southeastern Spain. The El Arcodebanea Ridge (El Arco), Tortonian in age, formed in a restricted basin under normal marine conditions (Mankiewicz, 1986). The rocks of the Nijar Ridge formed in a progressively restricted basin under hypersaline conditions during Messinian time (Mankiewicz, 1986). In the El Arco area, measured stratigraphic sections and detailed descriptions of the lithologic units and trace fossil assemblages were made. On the Nijar Ridge, three of Mankiewicz's (1986) stratigraphic sections (1, 5, 11) were further examined in terms of the vertical distribution of the trace fossils and physical sedimentary structures. The goals of this study are to describe and interpret the sedimentological and paleontological findings in terms of the paleodepositional environments of these two areas.

GEOLOGIC SETTING

El Arco, in the Fortuna Basin, is a long, N-S trending, arcuate ridge of well cemented quartz sandstone situated between the towns of Abanilla and Fortuna. The stratigraphic sequence from the base upwards is as follows: Unit 1-- a homogeneous marl containing benthic foraminifera; Unit 2-- a coarse layer composed of terrigenous siliciclastic and lithic fragments and occasional shell fragments. This layer is variable in its position (either immediately above the marl interface or a few centimeters above it), thickness (approx. 2.5 cm. to 17.5 cm.), and grain-size (coarse to very coarse sand to small pebbles); Unit 3-- a massively bedded quartz sandstone that contains abundant trace fossils, convoluted laminations, and exhibits hummocky cross-stratification; Unit 4-- return to homogeneous marl. The marl/sandstone interface exhibits burrow fills and well developed loading structures. The El Arco stratigraphic section is shown in Figure 1, and the trace fossils, their occurrence, and abundance are shown in Table 1.

The Nijar Ridge is located 1.5 km southwest of the town of Nijar. The facies, after Mankiewicz (1986) and in ascending order, are as follows: Facies 1-- yellow wackestone; Facies 2-- yellow packstone; Facies 3-- gray grainstone to packstone; Facies 4--white, fine-grained packstone; Facies 5-- fossiliferous packstone; and Facies 6-- *Porites* framestone. Facies 5 consists of packages of coarse reefal material that fine upward. All units, except the reef complex, are bioturbated. *Ophiomorpha* and *Thalassinoides* are the dominant trace fossils present. Furthermore, vertical transitions from beds dominated by *Thalassinoides* to beds dominated by *Ophiomorpha* are abrupt, and there seem to be some lateral transitions as well, particularly between sections 5 and 11.

INTERPRETATION OF PALEOENVIRONMENTS

El Arco

The rock units at this site were formed below normal wave base and above storm wave base. Initially, calcareous silt and clay were deposited from the water column and mixed with benthic foraminifera, forming the marl unit. Probably a lowering of sea level caused the sea floor to become more susceptible to wave action. Consequently, the marl style of deposition was interrupted when, during a storm event(s), the massive sandstone was deposited. The hummocky cross stratrified surface(s) exhibited in the massive sandstone is a primary indicator of a storm dominated sequence (Bourgeois and Dott, 1982). Secondary sedimentary features such as: well formed loading structures at the marl/sandstone interface,

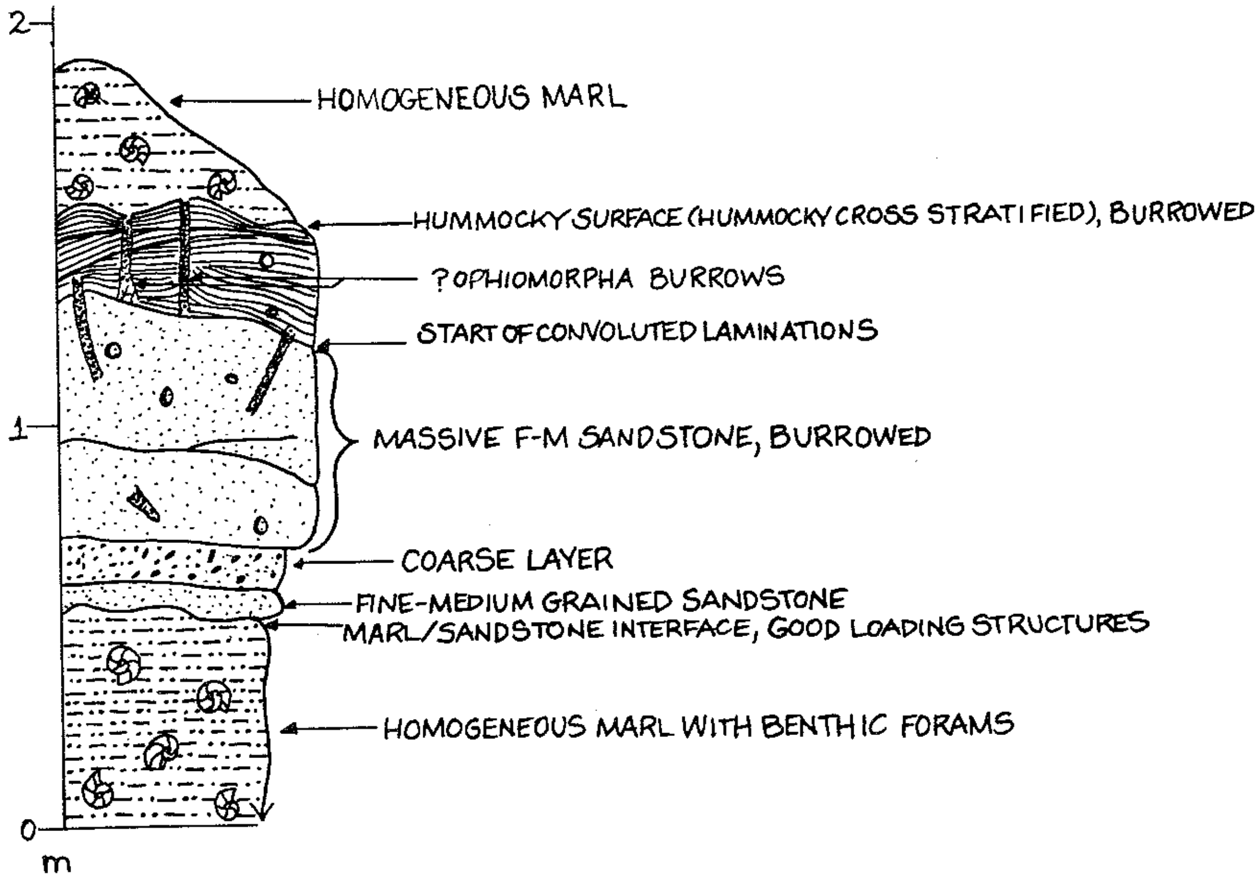

Figure 1. The generalized stratigraphic sequence at El Arco.

fining upwards from the coarse layer, and convoluted laminations in the finer sands also are indicative of this type of storm deposition (Bourgeois and Dott, 1982). There are three hummocky layers in the El Arco sandstone unit, which can be interpreted as either three separate storm events or as three major surges in one large storm event. With a subsequent rise in sea level, the marl deposition resumed.

Two ichnofacies can be recognized at El Arco, the *Cruziana* Ichnofacies, dominated by the trace fossil *Thalassinoides*, with *Planolites* also present, and the *Skolithos* Ichnofacies, represented by ? *Ophiomorpha* burrows. Generally, these ichnofacies are depth related. The burrowers of the *Cruziana* Ichnofacies are highly diverse and prefer a low-energy, offshore, below fair weather wave base environment. The burrowers of the *Skolithos* Ichnofacies prefer a nearshore, above normal wave base, higher-energy environment, and the *Skolithos* Ichnofacies typically grades seaward (in beach- to-offshore sequences) into the *Cruziana* Ichnofacies (Ekdale et al., 1984). At El Arco, the *Cruziana* burrowers are present only at the marl/sandstone interfaces at the top and bottom of the sequence. The *? Ophiomorpha*burrows are present in the massive sandstone unit. This sucession of ichnofacies suggests a fall in sea level after the initial deposition of the marl. It appears as though the marl was inhabited by the *Cruziana* Ichnofacies burrowers until sea level fell, thus making the area more susceptible to wave dominance. When, during a storm, the massive sandstone bed was deposited, the *Cruziana* burrowers were wiped out. Favoring the energized environment, the *? Ophiomorpha* burrower invaded the fresh sediment and began to destroy the storm layers. During a second storm surge or event, the sandstone sediment was resuspended and quickly redeposited, creating fresh storm layers which were bioturbated by the *? Ophiomorpha* burrower. After a third similar event, it appears that sea level rose again, the storm dominance was removed, and thus this sequence was terminated and the low-energy environment re-established. As the marl style of deposition resumed, the burrows of the *Skolithos* Ichnofacies were selectively excluded, and the *Cruziana* Ichnofacies burrowers returned.

TABLE 1. SYSTEMATIC ICHNOLOGY OF TRACE FOSSILS FROM EL ARCO

ICHNOGENUS	DESCRIPTION	RELATIVE ABUNDANCE
Furculosus	Meandering U-shaped burrow, diameter 0.2-0.3 cm; length approx. 5.2 cm; unlined, burrow fill in half relief, convex down from bedding plane; could be a small form of *Planolities.*	rare
? Ophiomorpha	Vertical, lined, annulated to pelleted burrow walls; outside diameter 0.8 - 2.6 cm; length up to 34 cm; burrow fills well lithified and standing in positive relief or in shallow negative relief; possibly U-shaped; rare apparent lateral branching.	abundant
Planolites	Unlined horizontally meandering burrows; diameter 0.8 - 2.0 cm; length up to 12 cm; burrow fill in half relief, convex down from bedding plane.	rare
Thalassinoides	Sinuous unlined burrow tunnels with Y-shaped junctures; regular branching; diameter of tunnels 1.1 - 2.3 cm; length up to 26 cm; burrow fills in half relief, convex down from bedding surface.	common

Nijar

The paleodepositional interpretations of these units, after Mankiewicz, 1986, are as follows: Units 1 and 2 appear to have been deposited in an increasingly shallowing, low-energy environment. Unit 3 is composed of fining- and thinning-upward packages that indicate pulses in sea-level fall during a relative (episodic) rise in sea-level. Unit 4 is a deeper marine deposit. Unit 5 is comprised of 8 or 9 wedge-shaped packages. Each overlying wedge represents a shallower water or more proximal reef environment, yet in individual beds, there are small scale fining-upward events. Mankiewicz concluded that this reefal sequence was deposited during a net relative fall of sea level, punctuated by episodic rises and falls.

The *Cruziana* and *Skolithos* Ichnofacies are present in the Nijar Ridge sequence. The three main types of burrows are *Thalassinoides, Ophiomorpha,* and a delicate branching burrow. The *Ophiomorpha* burrows (*Skolithos* Ichnofacies), which usually indicate a higher energy environment, are found in all the facies except the white, fine-grained packstone (Facies 4). On the other hand, the *Thalassinoides* burrows (*Cruziana* Ichnofacies), indicative of a lower energy environment, are found only in the white, fine-grained packstone. The delicate branching burrow is found in all facies and is associated with the larger

CONCLUSIONS

At El Arco, the position of the massive sandstone unit, bioturbated by the *Skolithos* Ichnofacies, between two marl units containing the *Cruziana* Ichnofacies, indicates that there was a fall of sea level after the initial deposition of the marl. The marl represents a lower-energy, deeper environment, and the sandstone indicates a higher-energy, shallower, storm dominated environment. In addition, the appearance of three hummocky cross stratified surfaces in the El Arco sandstone indicates either three separate storm events or three surges in one storm event. In either case an interpretation analagous to the LAMSCAM (laminated and scrambled, as in Ekdale et al., 1984) sequence for the massive sandstone unit is indicated. According to this scenario, the massive sandstone unit was deposited during a storm event(s) on the marl, thus killing the *Cruziana* burrowers. The newly deposited sandstone bed allowed colonization by the *Skolithos* Ichnofacies burrowers. The *? Ophiomorpha* burrower bioturbated the newly deposited sediment, partially destroying the primary sedimentary structures (hummocky cross stratification). In a second surge or event, the sediment was resuspended and quickly deposited as the storm subsided. This sediment again was bioturbated until a third event occurred. This sequence was terminated by a deepening event and consequent resumption of the marl style of deposition, and return of the *Cruziana* Ichnofacies burrowers.

At the Nijar Ridge site during deposition of the sediments, there appears to have been an overall shallowing punctuated by episodic rises and falls of sea level. The trace fossil assemblages seem to reflect these punctuations in sea level. The coarser sediment contains abundant *Ophiomorpha* burrows, and the finer beds are dominated by *Thalassinoides* burrows. Moreover, there are abrupt vertical transitions from one burrow type and its associated bed to another, seen best in Section 11. There also seems to be some lateral transitions from *Ophiomorpha* dominated beds to beds dominated by *Thalassiniodes*, particularly between sections 5 and 11. The trace fossils are useful in that *Thalassinoides* appears to mark deeper water sedimentation events, whereas *Ophiomorpha* signals shallower water sedimentation.

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