Cretaceous Ray Traces?: An Alternative Interpretation for the Alleged Dinosaur Tracks of La Posa, Isona, NE Spain

JORDI MARTINELL, JORDI M. DE GIBERT, ROSA DOMÈNECH
Departament d'Estratigrafia i Paleontologia, Universitat de Barcelona, Martí Franquès s/n, 08071 Barcelona, Spain

A. A. EKDALE, PETER P. STEEN
Department of Geology and Geophysics, University of Utah, 135 South 1460 East, Salt Lake City, Utah 84112-0111

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At the locality of La Posa, Isona, Spain, an extensive Upper Cretaceous bedding plane is exposed and exhibits thousands of ovate prints that had been interpreted as dinosaur tracks. Detailed study of these trace fossils allows the proposal of an alternative hypothesis that they were produced by the feeding activity of rays or other fish with similar behavior. Comparison with modern stingray pits from a tidal flat in Puerto Peñasco, Sonora, Mexico, reveals a great deal of similarity with the Cretaceous trace fossils in their distribution, morphology, environmental setting, and associated invertebrate bioturbation. Moreover, ray body fossils are known from neighboring contemporaneous deposits. The trace fossils here are attributed to the ichnogenus Piscichnnus.

INTRODUCTION

The Upper Cretaceous (Maastrichtian) locality of El Barranc de la Posa at Isona, Spain, exposes a large sandstone bedding plane with abundant ovate depressions that have been interpreted as dinosaur tracks (Santafé et al., 1997). The locality is visited frequently by both scientists and tourists as it is located in an area of great geological interest well known because of its richness in Upper Cretaceous dinosaur fossils (bones, eggs, and footprints). Several routes have been established to guide visitors to the geologically interesting localities. A sign at the site explains to visitors that the depressions are "fossilized dinosaur footprints," but no detailed paleoichnologic study of the locality has been conducted.

During several visits to the site by some of the authors, suspicions were raised regarding the dinosaur origin of the traces based on their morphology and spatial distribution. Observations on recent tidal flats near Puerto Peñasco, Sonora, western Mexico, have resulted in the recognition of striking similarities between the Spanish trace fossils and modern stingray traces. This paper offers an alternative hypothesis that the dinosaur footprints may be trace fossils produced by rays (elasmobranch fish) instead.

LOCATION AND GEOLOGICAL SETTING

The trace fossil locality studied is located about 4 km northeast of Isona, Catalonia, Spain (Fig. 1). The area is part of the Tremp-Graus Basin, a foreland piggy-back basin that overlies the Montsec thrust, one of several thrust units constituting the southern part of the Pyrenean Range (Puigdefabregas et al., 1986). The coastal and continental deposits of the Cretaceous-Tertiary transition reach nearly 1000 m in thickness and consist of two stratigraphic units: the Arén Formation and the Tremp Group (also known as Tremp Formation or "Garumnian"; Cuevas, 1992). The Arén Formation and the lower part of the Tremp Group are Maastrichtian in age, while the remainder of the Tremp Group is Early Tertiary.

The strata exposed at the locality of La Posa belong to the lower part of the Tremp Group, known as the La Posa Formation (Cuevas, 1992). The La Posa Formation is composed of grey clays, lignites, and sandstones containing a brackish-water invertebrate fauna (Liebau, 1973). Some sandstone tongues belonging to the Arén Formation are interbedded with the finer-grained and more carbonaceous sediments of the La Posa Formation. The La Posa and Arén Formations are interpreted as deposits of a barrier island-lagoon system (Nagtegaal et al., 1983; Díaz-Molina, 1987; Cuevas, 1992).

The trace fossils described in this paper are situated on top of a sandstone bed, probably corresponding to a tongue of the Arén Formation. Similar traces have been found in at least another locality of the Arén Formation near the locality of Arén, west of Isona. A detailed study of this second locality has not been carried out to date.

DESCRIPTION OF LA POSA SITE

The trace fossils occur on a medium-grained sandstone bed, about 8 meters thick, that exhibits high scale cross bedding in its lower part and rectilinear current ripples locally on its top. The bed is overlain by grey marls with root bioturbation, brackish-water mollusk coquines, and lignites.

The top of the sandstone bed is covered by thousands of ovate pits (Figs. 2, 3). To study these traces, several areas were mapped (Fig. 4), and about three hundred pits were measured. The pits range from 9–53 cm wide (average 34 cm wide, $\sigma = 9.25$) and from 32–70 cm long (average 43 cm long, $\sigma = 11.5$). Width and length exhibit a high correlation, $r^2 = 0.72$ (Fig. 5A). The size distribution of the traces is close to normal (Fig. 5B). The traces show an asymmetrical U profile in longitudinal section, with one side steeper than the other (Fig. 6). The density of traces is close to one pit per square meter. The trace fossil densities for the three mapped areas are 0.78, 0.9, and 1.7. Overlapping of individual pits is extremely unusual.

Other trace fossils occur in association with the large pits. Branching burrow systems (Fig. 7), corresponding to the ichnospecies *Ophiomorpha nodosa* and *Thalassinoides suevicus,* both attributable to crustacean burrows, are common. There also are abundant vertical burrows that occur with a density between 250 and 400 burrows per square meter. It is quite possible that these may be unpelleted vertical shafts that extend down in the sediment into branched *O. nodosa* and/or *T. suevicus* burrow systems. It appears that some of the vertical shafts might be arranged in pairs, which means they could be U-burrows belonging to the ichnogenus *Arenicolites,* but a U-shaped geometry could not be documented.

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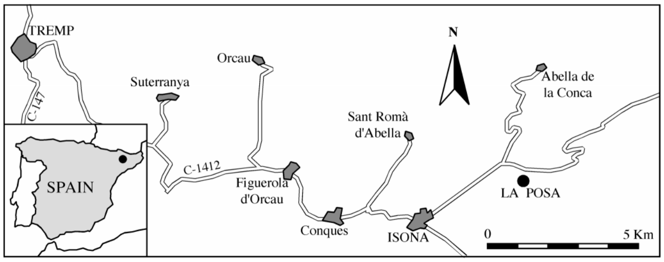

FIGURE 1—Location of the studied locality of La Posa.

Trace fossils, sedimentary structures, and associated facies are consistent with a shallow water, coastal environment of deposition for the sandstone bed.

DINOSAUR TRACK INTERPRETATION

The Upper Cretaceous part of the Tremp Group is well known for the abundant dinosaurs remains. It includes dinosaur eggs (Lapparent, 1958; Sanz et al., 1995; Ardévol et al., 1996; Santafé et al., 1997; Vianey and López-Martínez, 1997; López-Martínez et al., 2000), tracks (Llompart et al., 1984; Ardévol et al., 1996; Santafé et al., 1997), and bones (Lapparent and Aguirre, 1956; Brinkmann, 1985; Casanovas et al., 1985, 1988, 1993, 1995; Ardévol et al., 1996; Santafé et al., 1997). The dinosaur body fossil record of the Tremp Basin consists mostly of sauropods and ornithopods, but ankylosaurs and theropods are also present.

Considering the important dinosaur fossil record of the basin, the dinosaur hypothesis for the origin of the Isona trace fossils seemed to be a straightforward interpretation. However, detailed observation of the trace fossils at this locality raises some questions regarding this interpretation, mostly coming from the morphology of the traces and their distribution.

Morphology and Relation with the Sediment

None of the thousands of traces appears to show typical morphologic features of a footprint such as the imprint of digits. Instead, all of them have a consistent ovate outline (Fig. 3C,D). Moreover, their vertical profile does not show a flat base, as would be expected of a footprint, but rather a curved concave morphology.

This absence of footprint features and a flat floor could be attributed to deterioration by weathering or to undertrack preservation, but this interpretation is believed to be unlikely. Weathering can be ruled out because of the discovery of traces in the locality of Arén, that are casts filled by the overlying sediment and exhibit the same morphology (Fig. 8). On the other hand, undertracks should show soft sediment deformation. No such evidence has been observed, although this may be due to the absence of clear internal lamination of the hosting sandstone.

Distribution

Two aspects of the distribution of the traces are not consistent with a dinosaur interpretation: (1) absence of clear trackways indicating directed locomotion, and (2) absence of overlapping pits. Only in a few cases do some traces seem to be arranged in a straight row, but these apparent arrangements could be fortuitous owing to the abundance of pits on the bedding plane. On the other hand, one might argue that it is difficult to recognize clear trackway patterns because of the abundance of tracks and the superposition of several trackways. To solve this possible problem, three areas were mapped and the dimensions of the traces measured. Considering that tracks belonging to the same trackway should have the same size, at least for symmetrical limbs, the traces were separated in distinct groups of sizes (lengths) in order to reveal hidden trackways if they were present (Fig. 4). The procedure was repeated twice using different size intervals (21–30 cm, 31–40, 41–50, etc. and 16–25 cm, 26–35, 36–45, etc.) to avoid possible mistakes derived from minor size differences among tracks belonging to a same trackway. This procedure did not reveal any arrangement comparable to a trackway pattern. On the other hand, considering their abundance, if these traces were dinosaur tracks, some overlapping between them most likely would have taken place, as one might expect if multiple dinosaurs walked all over the same place.

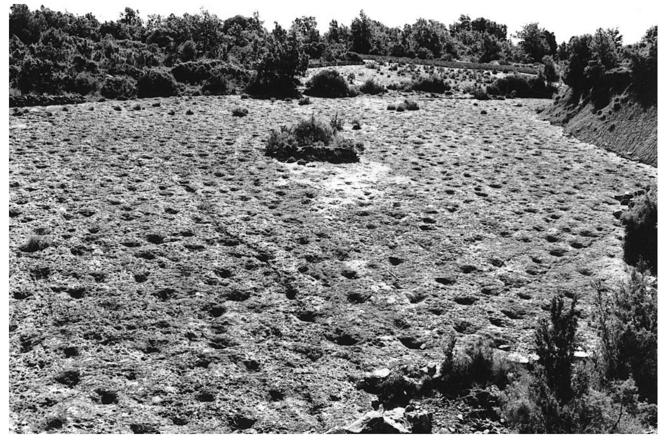

FIGURE 2—General view of the locality of La Posa showing the abundant pits that are the object of this paper and also the numerous vertical burrows (smaller holes).

RAY TRACE INTERPRETATION

The alternative interpretation proposed, namely that these trace fossils are pits produced by rays (elasmobranch fish), was inspired by ichnologic observations on the modern tidal flat of Estero Morua near Puerto Peñasco, Sonora, western Mexico, at the northern end of the Gulf of California (Fig. 9). Estero Morua is a coastal embayment that experiences mixed semidiurnal tides (Flessa and Ekdale, 1987). The tide range translates an appreciable distance over the flat embayment giving rise to a tidal flat with a remarkable zonation of biologically and ichnologically distinctive subenvironments (Steen, 1999). The sediment composition in Estero Morua ranges from clean, well-sorted medium-grained sand in the lower intertidal zone to firm, uncemented mud in the upper intertidal salt marsh (Flessa and Ekdale, 1987).

Bioturbation is very abundant in the tidal flats at Estero Morua, and stingray traces are very common in the lower and middle intertidal zones (Fig. 10). The interpreta-

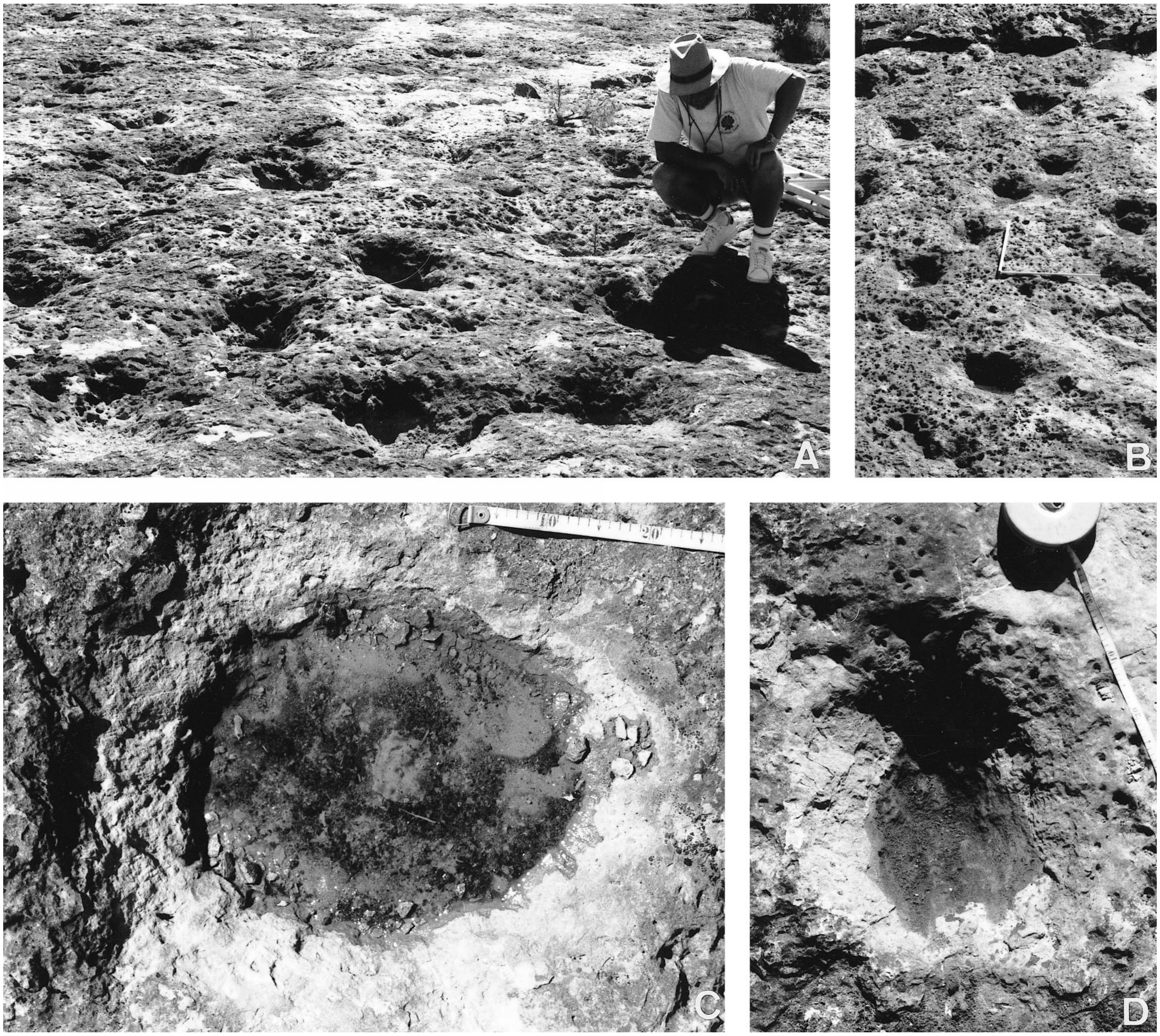

FIGURE 3—Upper Cretaceous pits of La Posa. (A) Several specimens. (B) Six apparently aligned pits. Observe the abundant vertical burrows (smaller holes). Scale = 1mx1m. (C) Detail of one of the pits. (D) Detail of one of the pits.

tion of the Cretaceous trace fossils of La Posa as produced by rays is supported by their morphologic and distributional similarities to recent stingray depressions, by the ichnologic and environmental similarities between the Cretaceous and the modern locality, and by the recent discovery of ray teeth in the lower part of the Tremp Group.

Morphology and Relation with the Sediment

Stingray traces in Estero Morua are circular to ovate depressions (Fig. 10), commonly between 10 and 30 cm in diameter, which typically have a gently sloped concave bottom 2 to 10 cm deep. These biogenic structures are produced by wing-flapping during the feeding process, most commonly by the ray *Urolophus halleri* (Fam. Dasyatididae). The excavated sediment accumulates near the posterior end of the stingray (Fig. 10 C, D), giving rise to a certain asymmetry with a steeper slope at one end of the depression. Less commonly, larger traces (up to 1 m diameter) with similar morphologic features have been recognized, and they probably are produced by the much larger ray *Dasyatis brevis* (Fam. Dasyatididae). The fossil traces from La Posa are morphologically similar to those modern ones of Estero Morua in both horizontal outline and vertical profile.

Other burrowing mechanisms have been described for recent rays. Gregory et al. (1979) found that the New Zealand eagle ray, *Myliobatis tenuicudatus* (Fam. Myliobatidae), produces deep, vertical-sided excavations by means of jetting water out their mouths. This process has not been clearly documented for stingrays in Estero Morua, and it results in deep, steep-walled pits unlike those at La Posa.

The excavation of sediment by stingrays does not produce plastic deformation features in the substrate, as would be expected by dinosaur footprints in a saturated medium. The boundary of a stingray trace should cut the internal structure of the substrate. To date, recognition of

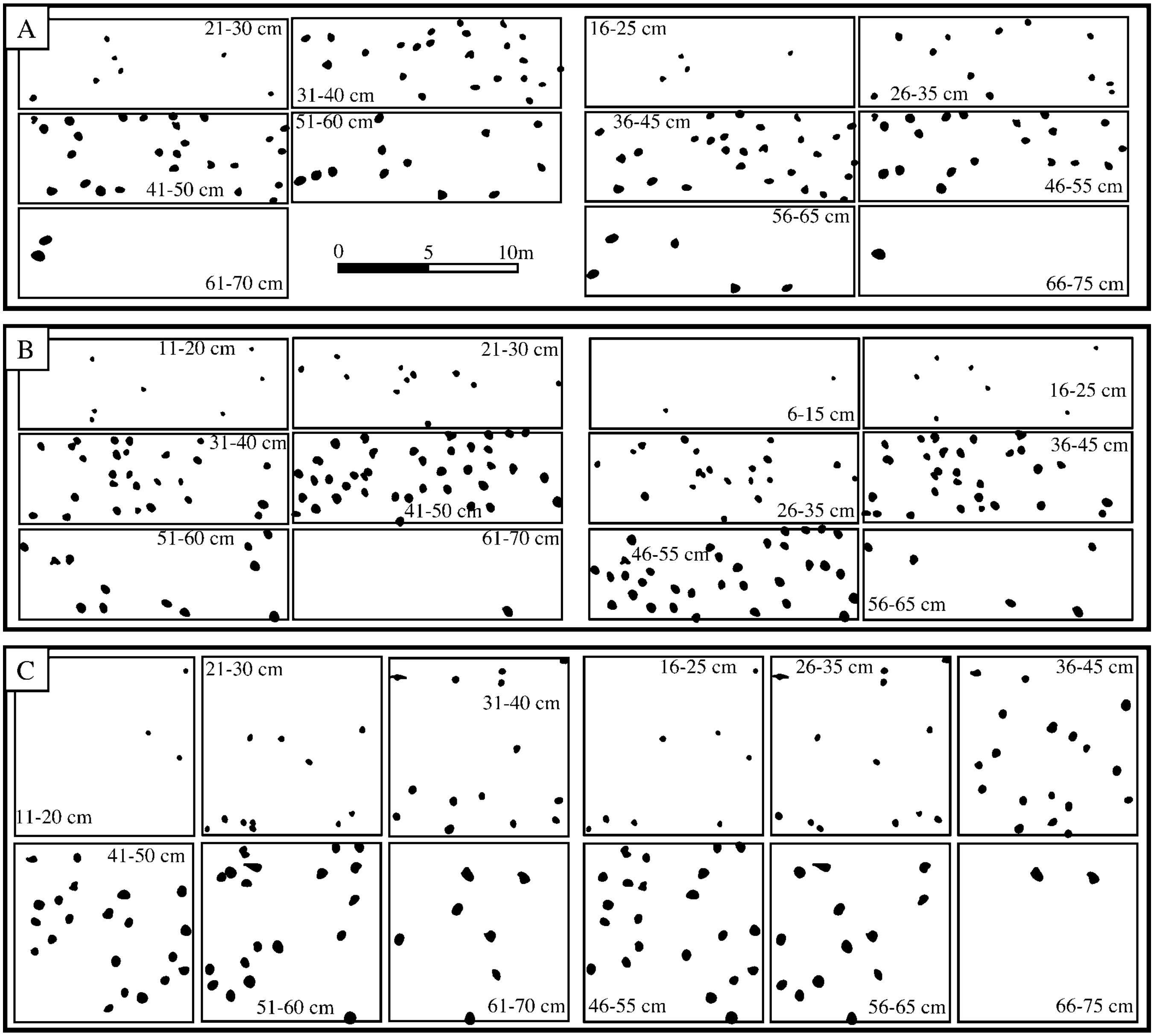

FIGURE 4—Diagrams showing the distribution of the traces in the three mapped areas (A, B, and C) by groups of size (length). Two different sets of size intervals have been established for each area: 11–20 cm, 21–30, 31–40, etc. (left) and 6–15 cm, 16–25, 26–30, etc. (right). See explanation in the text.

this kind of relation in the La Posa traces has not been possible due to the absence of lamination in the hosting sandstone. However, the associated vertical burrows do not exhibit any deformation.

Distribution

Density of stingray traces is very variable in the tidal flat of Estero Morua, reaching up to 2 to 3 traces per square meter locally. Higher densities are found where food resources are more abundant. Despite their abundance, ray pits rarely have been found to overlap. Stingrays burrow to feed upon shallow infaunal animals buried in the sand. This feeding behavior is the reason for the absence of overlapping traces as the animals try to avoid searching for food more than once in the very same place. The absence of trace overlapping in La Posa is difficult to explain by the dinosaur track interpretation but is consistent with a ray pit origin. Modern stingray pits typically are found in groups of similar size (Fig. 10B), sometimes aligned in a single row, likely resulting from a single ray foraging for food within a small area. This same kind of distribution pattern has been observed in La Posa (Fig. 3B).

Environment

Stingray traces in Estero Morua are distributed widely throughout the middle and lower intertidal zones. The structures are produced during high tides when the sting-

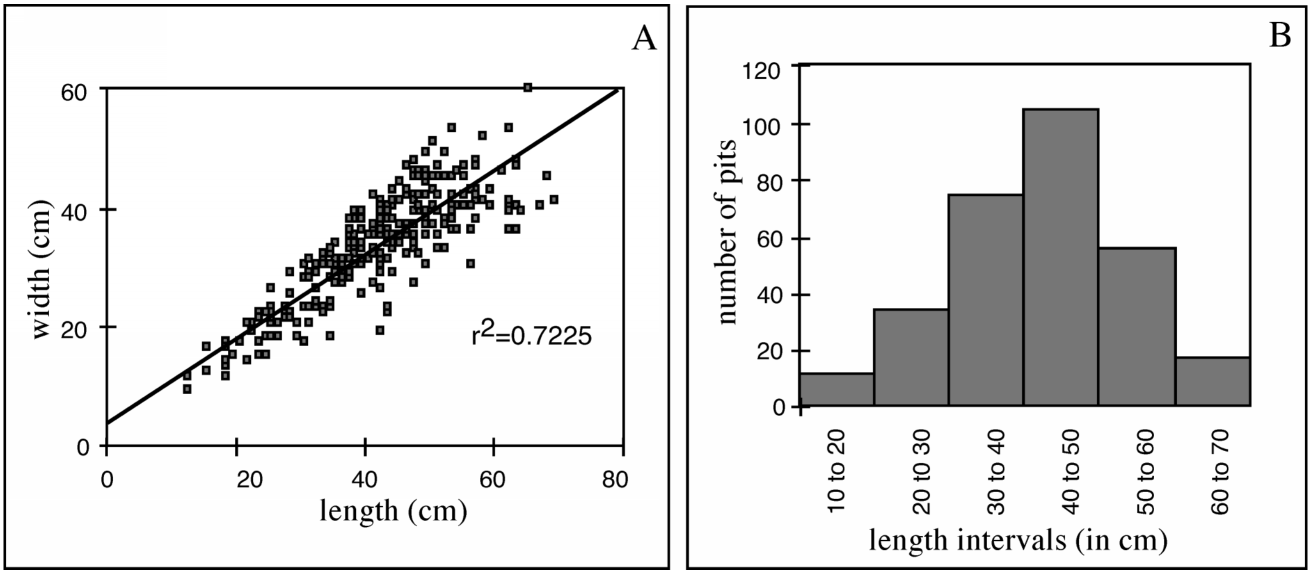

FIGURE 5—Morphology and size distribution of the La Posa pits. (A) Diagram showing the relation between width and length. (B) Histogram showing the distribution of size (length).

rays swim into the estuary. The paleoenvironments interpreted for the lower part of the Tremp Group likewise are coastal environments with tidal influence (Cuevas, 1992). It is possible, of course, that Cretaceous dinosaurs may have walked on the tidal flat, but it is even more likely that rays also inhabited the peritidal realm at this time.

Associated Ichnological Evidence

The lower and middle intertidal areas in modern Estero Morua commonly are bioturbated very heavily. Some of the more prominent burrows are those produced by callianassids (e.g., *Upogebia* and *Callianassa*) and annelid worms (e.g., *Chaetopterus, Arenicola,* and *Diopatra*). Infaunal bivalves also are common (e.g., *Glycymeris, Tagelus,* and *Chione*) and epifaunal gastropods (e.g., *Olivella, Natica,* and *Cerithium*) are locally abundant. All these animals provide a rich diet for the stingrays.

The trace fossil assemblage present in the Upper Cretaceous locality in Spain is quite comparable to that of Estero Morua. The branching burrow systems, *Ophiomorpha* and *Thalassinoides,* commonly are attributed to crustaceans and are close in morphology to modern callianassid burrows in Estero Morua. If it can be shown that the very abundant vertical burrows at La Posa are not connected to *Ophiomorpha* and/or *Thalassinoides* burrow systems and, in fact, are *Skolithos* and/or *Arenicolites* instead, then they would be comparable to modern annelid burrows present in Estero Morua. Hence, the Maastrichtian trace fossil assemblage in Spain suggests that a rich food source, remarkably similar to that available for modern stingrays in the Gulf of California, was present at the time of production of the presumed fossil ray traces in the Late Cretaceous.

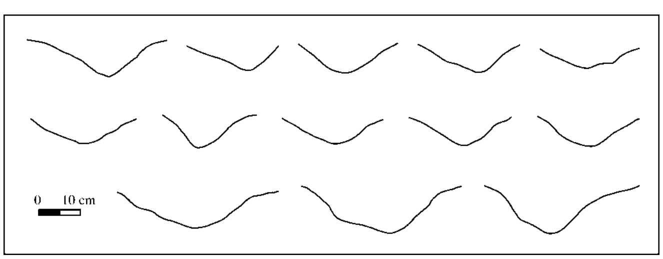

FIGURE 6—Several examples of profiles of the La Posa pits.

Presence of Ray Body Fossils in the Tremp Group

Soler-Gijón and López-Martínez (1997) recovered abundant fossil ray teeth in samples from the lower part of the Tremp Group in the Tremp Basin. They recognized three fossil ray species: *Rhinobatos* sp., *Igdabatis indicus,* and *Rhombodus* sp. One of the genera, *Rhinobatos* (Fam. Rhinobatidae), is still living today in shallow-water environments, and it is known to be a benthic feeder (Du Preez et al., 1990). The genus *Igdabatis* is known only from Upper Cretaceous strata (Soler-Gijón and López-Martínez, 1997), but representatives of its family, Myliobatidae, are common in modern seas. The feeding and burrowing behavior of two modern species belonging to this family, *Myliobatis californica* and *Myliobatis tenuicaudatus,* have been described by several authors (MacGinitie, 1935; Gregory et al., 1979; Gray et al., 1997; Hines et al., 1997). Both species excavate depressions comparable to those seen in Estero Morua and La Posa to feed on infaunal bivalves, worms, and shrimp. The third ray taxon found in the Cretaceous of Spain, *Rhombodus* sp., belongs to the extinct Cretaceous family Rhombodontidae, whose closest living relatives are the Myliobatidae (Soler-Gijón and López-Martínez, 1997).

FOSSIL RECORD OF RAY TRACES

Ray traces are not recognized commonly in the fossil record, but they are known from the Upper Cretaceous of Utah (Howard et al., 1977) and Antarctica (Scasso et al., 1991), the Miocene of New Zealand (Gregory, 1991), and

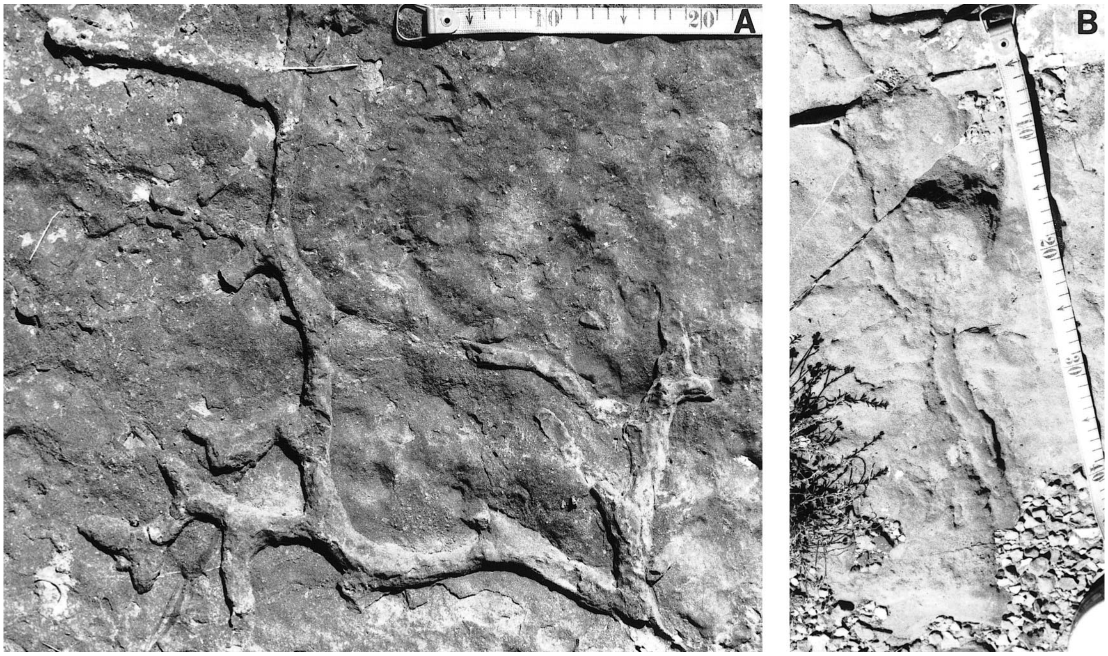

FIGURE 7—Invertebrate trace fossils from La Posa. (A) *Thalassinoides suevicus.* (B) *Ophiomorpha nodosa.*

the Pleistocene of Florida, Georgia, and North Carolina (Howard et al., 1977). Fossil ray traces may be assigned to the ichnogenus *Piscichnus,* which was described by Fiebel (1987) from the lacustrine Plio-Pleistocene of Kenya. However, the particular ichnotaxon *P. brownii* was interpreted by Fiebel (1987) as a nesting trace produced by bony fishes of the families Cichlidae or Salmonidae, rather than as a ray feeding trace. Other modern fishes, such as flatfish (Cook, 1973), are known to produce shallow depressions that would be assigned to *Piscichnus* if they were preserved as trace fossils. The Cretaceous traces at La Posa are comparable to modern stingray traces, but they also could have been produced but other fish with similar behavior. The La Posa traces have to be attributed to the ichnogenus *Piscichnus* and they constitute the most extensive occurrence of this ichnotaxon known until now.

CONCLUSIONS

The interpretation of the Upper Cretaceous traces at La Posa as dinosaur tracks poses several problems, particularly when considering their morphology and distribution. Comparison of the traces with modern stingray traces of Estero Morúa, Mexico, reveals remarkable similarities that allow the proposal of an alternative interpretation for the alleged dinosaur tracks. The morphological features, distribution, and paleonvironmental setting of the traces is consistent with their interpretation as feeding depressions produced by rays (or by other fish with similar behavior). Additionally, it is known from the body-fossil record that rays lived in the Tremp-Graus basin during the Late Cretaceous. Hence, the La Posa trace fossils are proposed here to be a new occurrence of the rare ichnogenus *Piscichnus.*

FIGURE 8—Vertical section of a fossil pit from the locality of Arén. Scale = 15 cm.

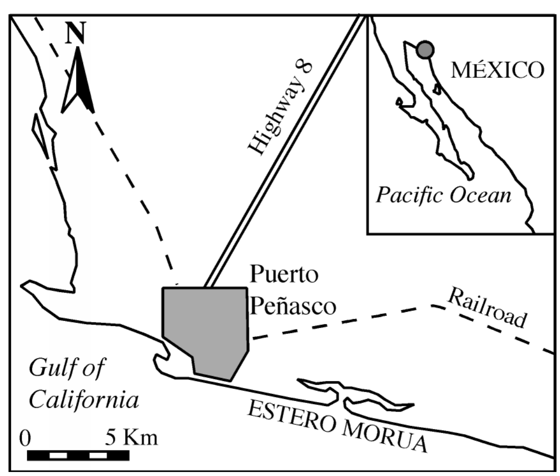

FIGURE 9—Location of Estero Morua.

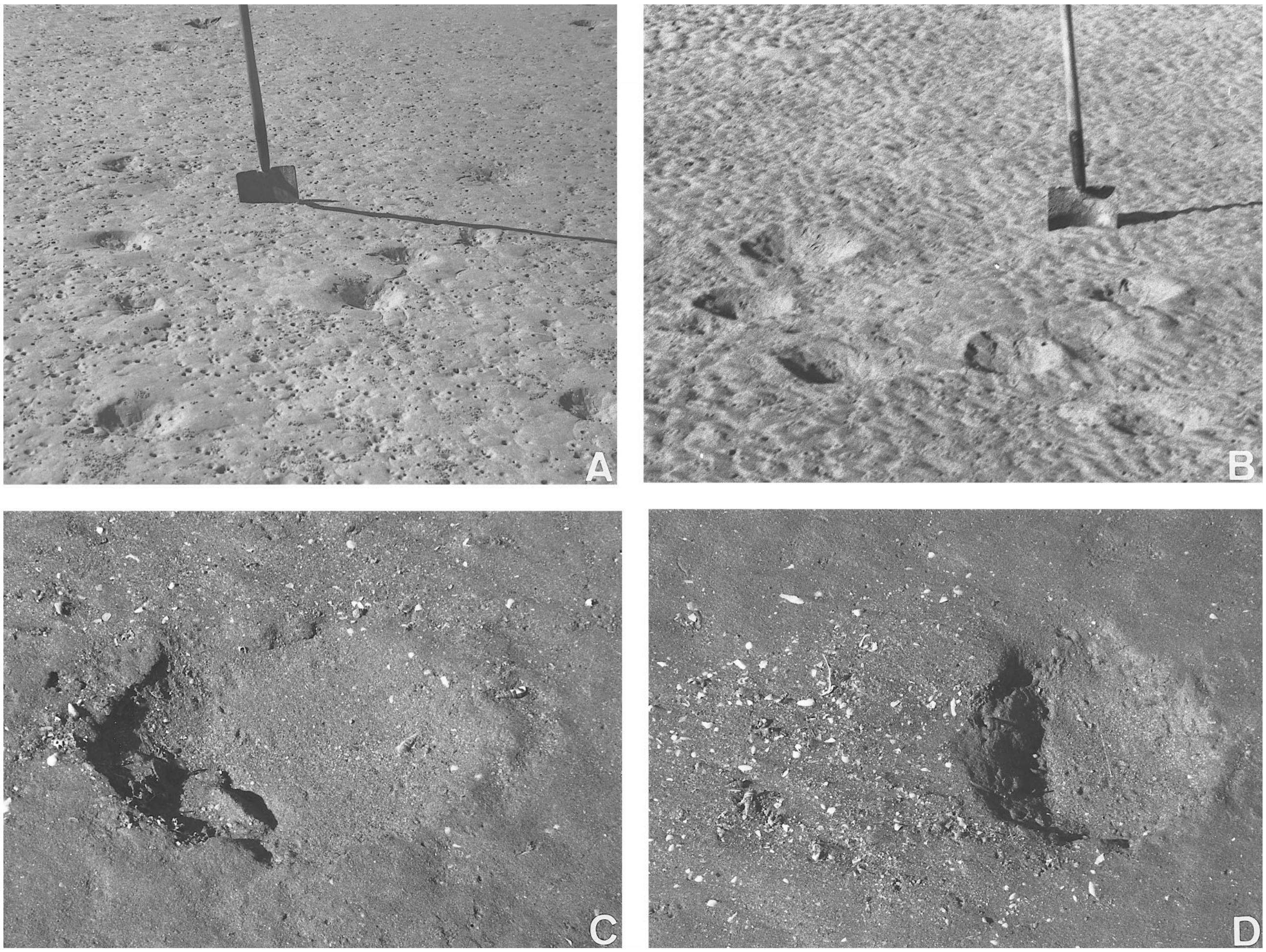

FIGURE 10—Modern stingray pits from Estero Morua. (A) Several stingray pits. Observe the vertical burrows (smaller holes). (B) Several stingray pits. (C) Detail of one of the stingray pits (ϕ = 35cm). (D) Detail of one of the stingray pits (ϕ = 30cm).

The assessment of the La Posa traces as ray feeding pits not only has paleobiological implications but also sedimentological and biostratigraphical implications. Dinosaur tracks might indicate terrestrial or very shallow water conditions, while ray traces, although present in higher densities in intertidal areas, also can be found at greater depths. On the other hand, the finding of this kind of traces in the basin would not be of any biostratigraphic value if they were interpreted as fish traces.

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