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DEPOSITIONAL ENVIRONMENTS AND TRACE FOSSILS OF THE TRINIDAD SANDSTONE, SOUTHERN RATON BASIN, NEW MEXICO

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INTRODUCTION

The Upper Cretaceous Trinidad Sandstone (Hills, 1899), the most widely exposed formation in the Raton Basin, records the final regression of the epeiric Western Interior Cretaceous seaway from northern New Mexico and southern Colorado. The shift from marine to continental conditions is reflected in the sequence of lithofacies and trace fossils in the Trinidad Sandstone. The Trinidad, which underlies Cretaceous and Tertiary coal-bearing rocks (Fig. 1), is a target in the search for oil, gas and the ground water that is vital to further coal development in the area.

AGE AND DESCRIPTION

Correlative to the Cretaceous Fox Hills Sandstone of the Rocky Mountains and to the Pictured Cliffs Sandstone of the San Juan Basin, the Trinidad Sandstone conformably overlies the Pierre Shale. The Trinidad is, in turn, overlain by the Upper Cretaceous coal-bearing Vermejo Formation and by the Upper Cretaceous and Paleocene Raton Formation.

The Trinidad ranges from a featheredge to 44 m in thickness in the New Mexico part of the Raton Basin and forms a high cliff along the east margin of the basin. It consists of clayey to clean, very fine-grained to medium-grained, very thin-bedded to thick-bedded, calcareous, feldspathic sandstone. It is light gray to light medium gray, and weathers light gray to yellowish-gray with stains of grayish-orange and brown. Oblate, brown, calcareous concretions as large as 1.2 m in diameter locally characterize the unit. Transgressive tongues of the Trinidad extend into the Vermejo along the southern margins of the basin between Dawson and Cimarron, New Mexico (Lee, 1917; Wanek, 1963). The contact between the Trinidad and the overlying Vermejo Formation, usually placed at the base of the lowest carbonaceous zone, is generally sharp and well defined (Fig. 2). The basal contact with the Pierre Shale,

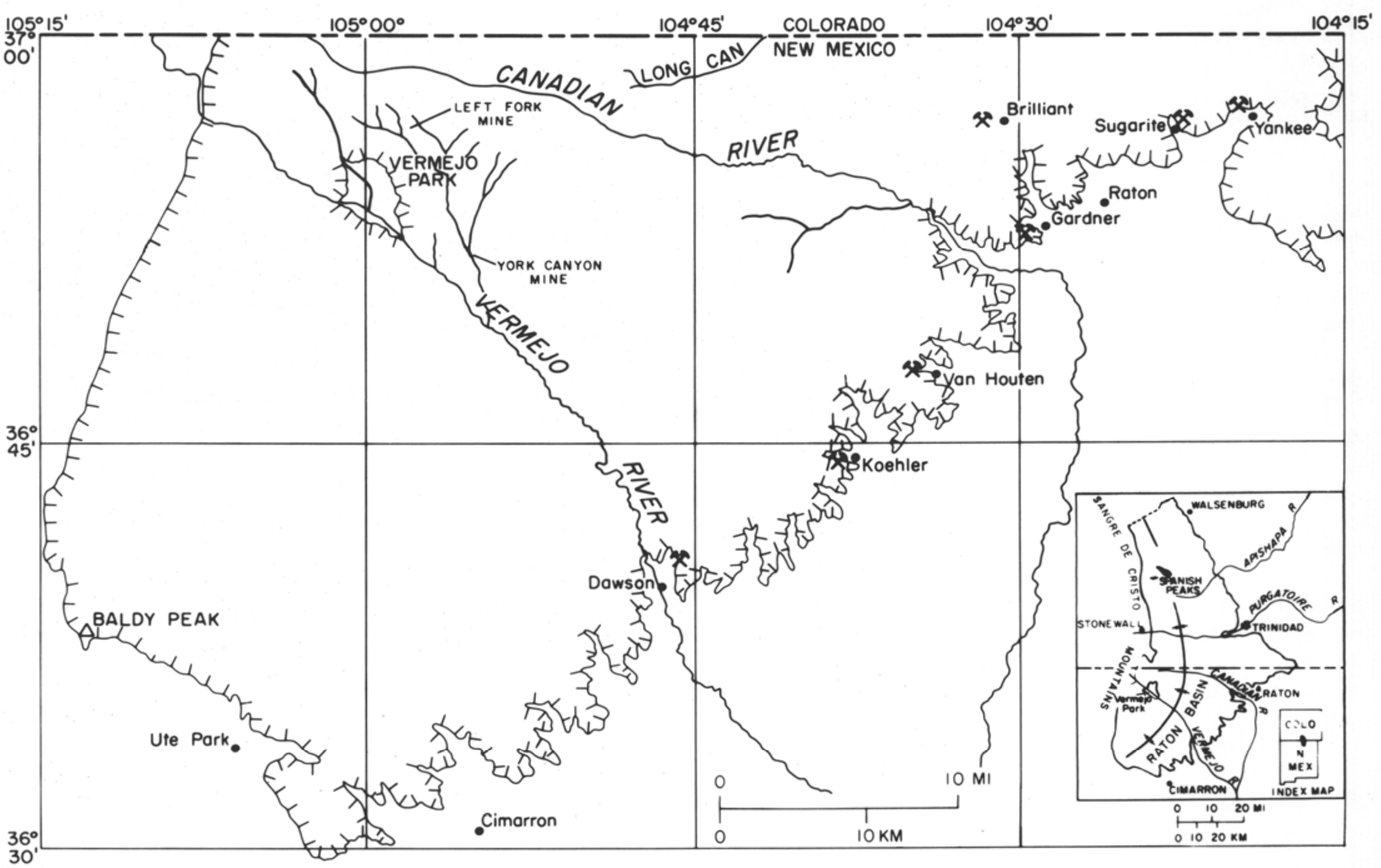

Figure 1. Map showing Raton coal field, New Mexico (hachured line), almost completely underlain by Trinidad Sandstone. Abandoned coal mines are shown by crossed picks. Inset map (modified from Johnson and Wood, 1956) outlines distribution of Upper Cretaceous and Tertiary rocks of the Raton Basin, New Mexico and Colorado.

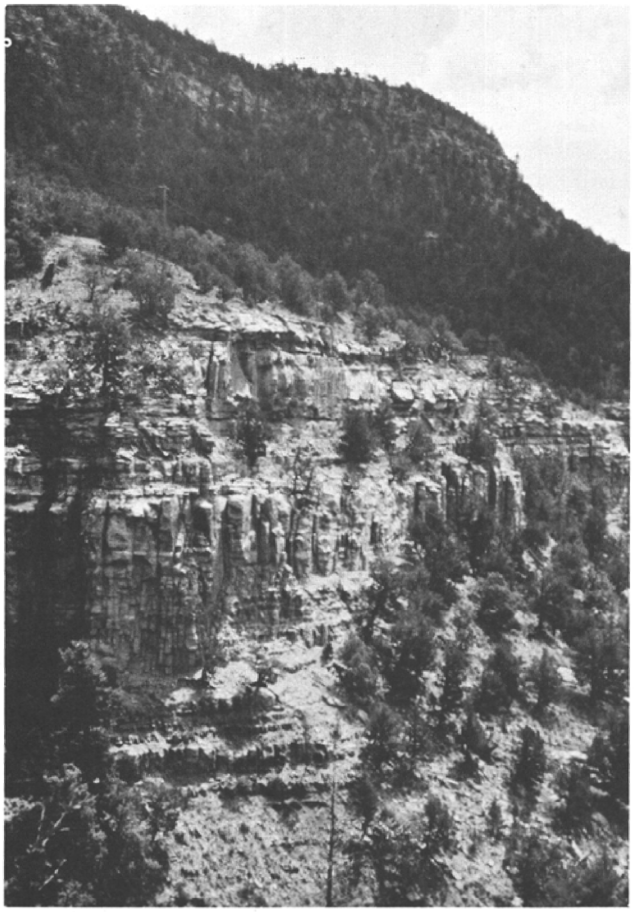

Figure 2. Trinidad outcrop at Vermejo Park, New Mexico. Sharp contact with Vermejo Formation at upper left. Transition zone with Pierre Shale forms slope beneath sandstone cliff.

however, is gradational through a transition zone several meters thick.

ENVIRONMENTS OF DEPOSITION

The Trinidad Sandstone was deposited on an eastward-prograding shoreline during the final retreat of the Cretaceous sea from northern New Mexico and southern Colorado. Deposition of the Trinidad occurred in shallow neritic and beach environments during the transition from marine to continental conditions (Fig. 3). Progradation of the shoreline is recorded in a sequence of four lithofacies: shales and mudstones of the Pierre; mudstone, siltstone, and very fine-grained sandstone of the lower Trinidad; cross-stratified to laminated sandstone of the main body of the Trinidad; and marginal-marine coal, sandstone, siltstone and carbonaceous shale of the basal Vermejo Formation.

The shale-and-mudstone lithofacies was deposited in a lower offshore marine environment. Shales and mudstones coarsen upward into mudstone, siltstone and very fine grained sandstone of the offshore-shoreface transition zone. Upper offshore marine siltstone and sandstone were intensively bioturbated. Body fossils are uncommon throughout the Trinidad. Trace fossils are common and vary from indistinct grazing trails in the lower part to large distinct burrows in the upper part. Black, pyritic, thinly laminated shale and the presence of *Asterosoma, Teichichnus* and *Aulichnites* in sandy laminae of the lower Trinidad suggest a sublittoral, quiet-water environment.

The cross-stratified to laminated sandstone lithofacies makes up the principal, cliff-forming part of the Trinidad (Fig. 2). Three subfacies are commonly present: a lower laminated subfacies that contains abundant small- and medium-sized *Ophiomorpha* and represents the lower shoreface of offshore-shoreface transition environment; a planar- to cross-bedded subfacies that forms high, rounded ledges and cliffs, contains abundant, large *Ophiomorpha,* and represents the middle shoreface environment; and an upper laminated to cross-bedded subfacies that is coarse-grained, sugary in texture, light colored, barren of trace fossils and generally strongly cross-bedded, representing a beach-and-dune environment.

Coal, carbonaceous shale, siltstone and sandstone of the marginal-marine lithofacies were deposited in coastal swamps, lagoons, estuaries and tidal flats behind the Trinidad beach. *Planolites* and a shipworm-type trace fossil, which occur only in carbonaceous sandstone interbeds, are the sole trace fossils found in these marginal-marine rocks.

DESCRIPTIONS OF TRINIDAD TRACE FOSSILS

Trace fossils found in the various lithofacies of the Trinidad Sandstone and in the underlying transition zone with the Pierre Shale include *Diplocraterion, Ophiomorpha, Asterosoma, Teichichnus, Aulichnites, Desmograpton* and *Thallassinoides.*

Diplocraterion occurs only at the very top of the formation, and only in two areas known to us in the New Mexico portion of the Raton Basin—the southeast part of Vermejo Park and the Vermejo River valley north of Dawson. This trace has a distinct "ladder" shape formed by a vertical "U"-shaped tube with spreite linking the two edges of the tube (Fig. 4A). As seen on bedding planes, the trace resembles two small circles joined together by a small rod (Fig. 4B). The fossils are about 4-6 cm in width, and their "ladders" attain lengths of nearly a meter. The trace also occurs in the Colorado part of the basin, near Ludlow, about 20 km north of Trinidad (Fig. 1) (C. D. Manzolillo, oral commun., 1976); but there, the "ladders" are much shorter, averaging about 0.3 m. The traces were the living and feeding burrows of the *Diplocraterion-producing* animal. At Vermejo Park, *Diplocraterion* is extremely abundant in a hard, yellowish-brown, bioturbated sandstone bed at the top of the upper crossbedded subfacies (Fig. 5). The subfacies is 8.2 m thick at this locality. *Ophiomorpha* is also found in the top 2-3 m; its presence indicates a brief return to marine foreshore conditions in that area. According to R. W. Frey (written commun., 1976), the presence of *Diplocraterion* indicates conditions of relatively high energy, entailing shifting sediments and abrupt erosion or deposition in littoral or very shallow sublittoral zones. This interpretation is substantiated by the presence of *Ophiomorpha* in this interval.

Ophiomorpha occurs throughout all the lithofacies of the Trinidad, with the exception of the upper laminated to cross-bedded dune subfacies. It is present in every section examined and remains the best means of identifying the formation in drill cores. *Ophiomorpha* has a wall with a smooth interior surface and a knobby, pustulous (corncob texture) exterior (Figs. 6A, 6B). The tubes are usually inclined, but may be perpendicular to bedding surfaces; are generally 2-3 cm in

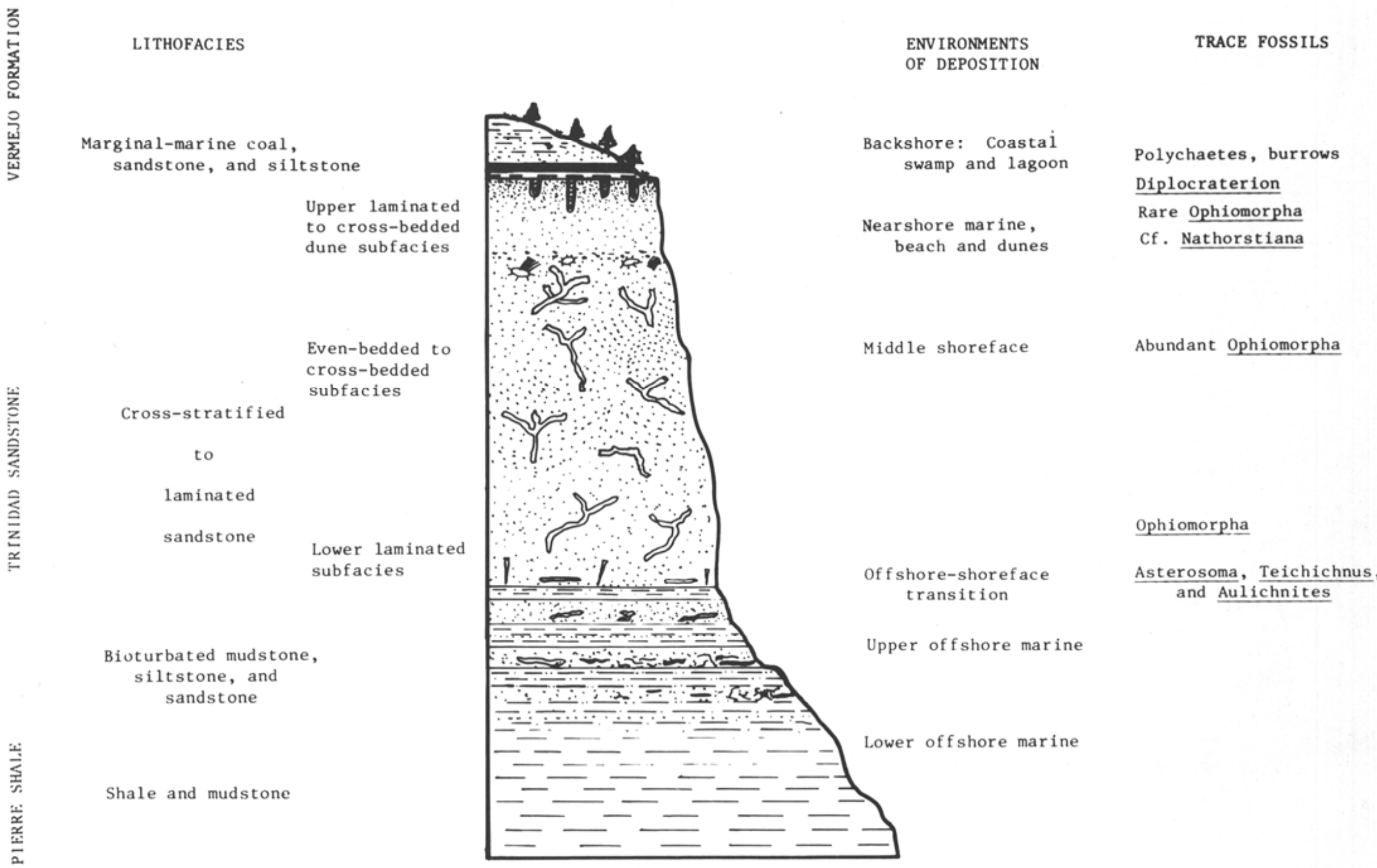

Figure 3. Schematic diagram showing lithofacies, environments of deposition and trace fossils of the Trinidad Sandstone (modified from Ryer, in press).

diameter; and are usually less than 0.5 m in length. *Ophiomorpha* are the dwelling burrows of suspension-feeding decapod crustaceans. Sandstone beds containing especially abundant *Ophiomorpha* crop out along the irrigation canal next to the road at the west exit from Vermejo Park. Large numbers of *Ophiomorpha* indicate littoral or shallow sublittoral environments in which energy conditions ranged from low to high (R. W. Frey, written commun., 1976).

Figure 4A. Diplocraterion *showing the "U"-shaped tubes and spreite forming the "ladder" shape.*

Figure 4B. Diplocraterion *trace on bedding surface; certain "rods" (spreite) were darkened to make them more distinct.*

Figure 5. Diplocraterion *bioturbidite, close-up view.*

Asterosoma burrows occur in orientations ranging from parallel to perpendicular to bedding (Figs. 7A, 7B), and are common in thin- to medium-bedded, fine-grained sandstones below the zones of greatest abundance of *Ophiomorpha.* Burrows that are nearly parallel to bedding occur in very fine grained, carbonaceous sandstone. The sandstone that fills the burrows is clean and devoid of carbonaceous debris. This cleanness and the morphology of the burrows indicate a random grazing search for food by a deposit-feeding organism. Burrows oriented at high angles to bedding are found in clean, well-sorted sandstone that is devoid of carbonaceous material.

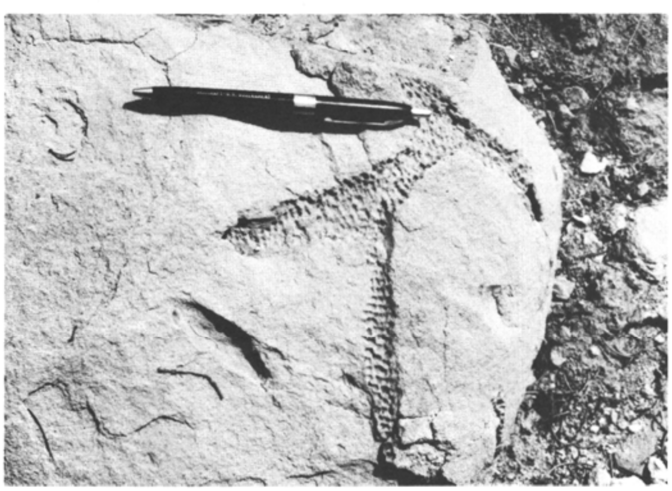

Figure 6A. Ophiomorpha *in Trinidad Sandstone.*

Figure 6B. Ophiomorpha, *showing burrow filling and detail of exterior.*

The high-energy environment in which this type of sediment was deposited was unsuitable for the organisms that produced *Asterosoma.* The high-angle burrows probably represent escape structures formed as the organisms migrated upward through the rapidly accumulating sand. High-angle *Asterosoma* burrows

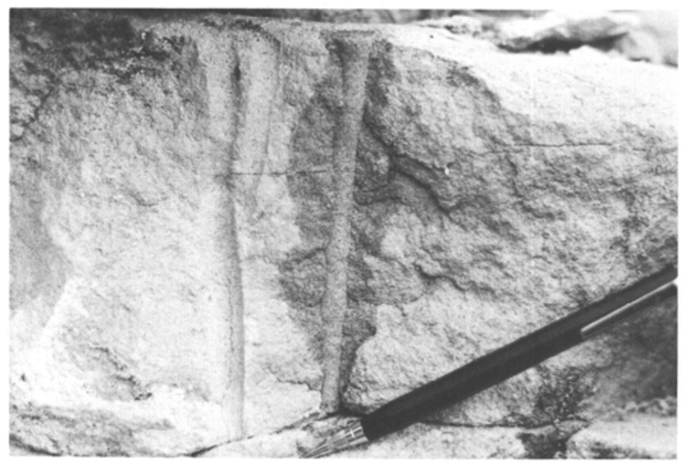

Figure 7A. Asterosoma *perpendicular to bedding in the lower part of the Trinidad Sandstone.*

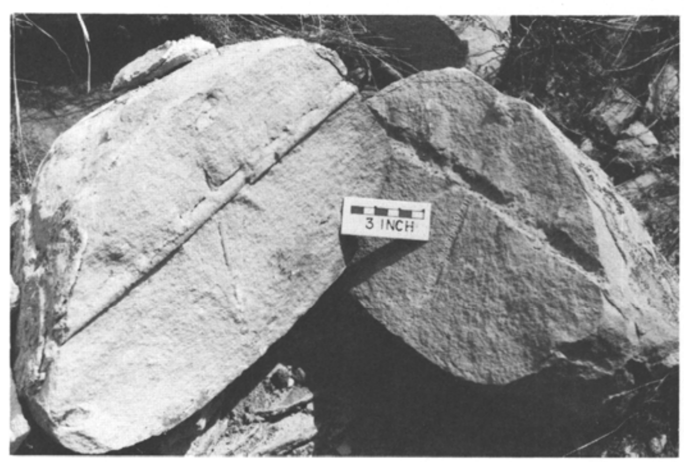

Figure 7B. Asterosoma *lying parallel to bedding.*

are associated with small *Ophiomorpha* and indicate littoral to sublittoral environments of moderately high current velocity. Low-angle burrows indicate deeper littoral environments.

Teichichnus, A Aulichnites and *Thalassinoides,* all indicators of shallow neritic environments of deposition, are less common than *Ophiomorpha* and *Asterosoma.* They are smaller, less well-preserved and partially destroyed by later bioturbation. *Teichichnus* is a form consisting of a series of burrows laid one atop the others to form a scimitar-shaped trace (Fig. 8). It was built as the animal burrowed back and forth through the sediment, juxtaposing each new trail immediately above or below the previous one. *Aulichnites* is a simple, bilobate grazing trail found on the bedding planes. It was probably made by a gastropod. *Thallassinoides* is a series of Y-shaped branching tubes that are intimately interwoven but do not interconnect. Bioturbation of the lithofacies in which these traces occur has been described by R. W. Frey (written commun., 1976) as a "mixture of subconcentric swirls and short, curved and straight biolaminae that are defined mainly by dark shale wisps and by alteration of sand-silt and shale."

A distinctive fossil occurs at the top of the middle shoreface zone of the Trinidad, at exposures in the valley of the Vermejo River. The morphology is suggestive of a sea urchin with spines still in place. We sent specimens of the fossil to Professor Adolph Seilacher of West Germany, who passed them to Professor K. Mägdefrau at Universität Tübingen. Professor Mägdefrau likened the fossils to *Nathorstiana,* a root stock of a palm-tree bole. *Nathorstiana* consists of an oblate, hemispherical core with curving, subparallel spines or tubes, which may or may not be attached, radiating outward from the core (Fig. 9). We were unable to establish that any of the *Nathorstiana*-like fossils occurred in living position. We speculate that they were transported to their present location, perhaps by storm-induced waves and currents.

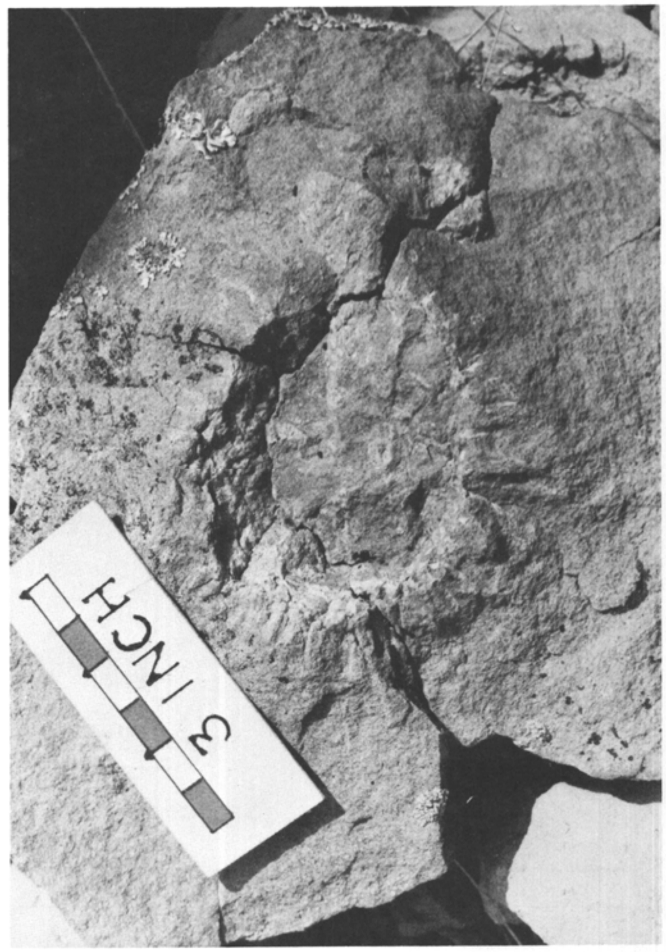

Figure 9. Oblate, spiny form identified as Nathorstiana, *a root stock of a palm-tree bole.*

Figure 8. Curved blades of Teichichnus *in the lower part of Trinidad Sandstone.*

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