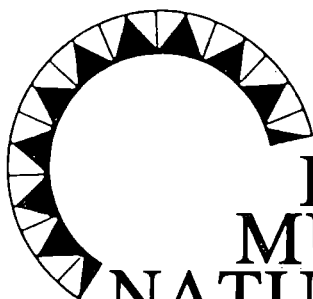


BULLETIN

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**OCCURRENCE OF PLIO-PLEISTOCENE
PHOSPHATIZED MACRO-INVERTEBRATES
FROM THE UPPER WEST FLORIDA SLOPE,
EASTERN GULF OF MEXICO**

**Craig W. Oyen, Kendall B. Fountain, Roger W. Portell,
and Guerry H. McClellan**

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OCCURRENCE OF PLIO-PLEISTOCENE PHOSPHATIZED MACRO-INVERTEBRATES FROM THE UPPER WEST FLORIDA SLOPE, EASTERN GULF OF MEXICO

Craig W. Oyen¹, Kendall B. Fountain², Roger W. Portell^{3*},
and Guerry H. McClellan²

ABSTRACT

Numerous phosphatized internal molds of an articulate brachiopod, along with fossils from four other phyla (Cnidaria, Mollusca, Annelida, and Echinodermata), were collected from several dredge sites in the Gulf of Mexico. The samples were collected during two cruises aboard the *RV Suncoaster* in December 1989 and May 1993, approximately 250 km west-southwest of Tampa, Florida. These cruises were not designed to collect fossils, rather they were aimed at studying the origin of phosphorite nodules and hardgrounds developing in response to marginal upwelling of the Gulf of Mexico Loop Current along the western margin of Florida. The invertebrate fossils were collected as part of the phosphorite nodule dredge hauls and are the focus of this study.

Mineralogical analysis of these internal molds, including a brachiopod and the largest of the three echinoid specimens, indicates they are composed of francolite, low-magnesium (Mg) calcite, aragonite, and variable amounts of quartz, which is consistent with nonferruginous nodules recovered from the same areas. Petrographic examination also identified glaucony and iron-oxyhydroxides (FeOOH) within the phosphatic molds. The timing of phosphogenesis associated with the fossils and nonferruginous nodules has been identified as occurring after a late Miocene (Tortonian) sea level lowstand, most likely during Plio-Pleistocene sea level highstands that favored marginal upwelling over the west Florida slope.

We interpret the paleoecology of the fauna to represent a continental shelf environment of shallower depth than where the fossils were collected (511-520 m) along the west Florida slope. Though all the taxa have ranges of depth from which they have been recorded, the best synthesis using all the fossils indicates an environment of less than several hundred meters depth. It is likely that some transportation of the organisms occurred after death. Also, significant exposure effects (such as encrusting organisms and borings) are present on the fossils. Therefore, some mixing of the shallower water and deeper water fauna possibly occurred prior to their ultimate inclusion within the limestone outcrops on the west Florida slope.

RESUMEN

Se colectaron numerosos moldes internos fosfatizados de un braquiópodo articulado provenientes de diferentes lugares en el Golfo de México, junto a fósiles de cuatro otras phyla (Cnidaria, Mollusca, Annelida y Echinodermata). Las muestras fueron obtenidas durante dos cruceros a bordo del *RV Suncoaster* en Diciembre de 1989 y en Mayo de 1993, aproximadamente 250 km oeste-sudoeste de Tampa, Florida, USA. Los mencionados viajes de colecta no fueron ideados para coleccionar fósiles, sino para estudiar el origen de

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nódulos de fosforita y el desarrollo de sustratos duros en respuesta al flujo marginal de la corriente del Golfo de México a lo largo de la costa oeste de Florida. Los fósiles invertebrados fueron colectados como parte del dragado de nódulos de fosforita y son el foco de este estudio.

Análisis mineralógico de los moldes internos de un braquiópodo y el mayor de tres especímenes equinóideos indica que están compuestos por francolita, calcita con poco magnesio, aragonita y cantidades variables de cuarzo, siendo estos resultados consistentes con nódulos no-ferrugíneos recuperados en la misma área. Exámenes petrográficos también identificaron glauconita variable (*glaucony* en el original) y oxihidróxidos de hierro en los moldes fosfáticos. Se estimó que la fosfogénesis asociada con los fósiles y nódulos no-ferrugíneos ocurrió después del período bajo de las aguas del Mioceno (Tortoniano), probablemente durante los niveles altos del mar en el Plio-Pleistoceno que favorecieron flujos marginales en la vertiente oeste de Florida.

Nuestra interpretación paleoecológica de la fauna indica que se trataría de un ambiente en la plataforma continental a lo largo de la pendiente oeste de Florida menos profundo que los sitios de donde se colectaron los fósiles (511-520 mts). Si bien las taxa tienen un rango de profundidad conocido, la mejor síntesis utilizando todos los fósiles indica un ambiente con profundidades menores a cientos de metros. Muy probablemente ocurrió cierto grado de transporte *post mortem* de los organismos. También, se evidencia en los fósiles, efectos de exposición a organismos incrustantes o penetrantes. Sugerimos que la mezcla de faunas de aguas poco profundas con faunas de aguas profundas ocurrió antes de la inclusión de estos organismos dentro de la matriz limolítica del afloramiento en la pendiente oeste de Florida.

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INTRODUCTION

Areas of phosphorite formation and accumulation are representative of unique conditions of paleoenvironment and sedimentation, often in response to global factors such as sea level fluctuation and plate tectonics (Cook and McElhinny, 1979; Sheldon, 1980). The upper west Florida slope (WFS) is just such a region, possessing accumulations of ferruginous and nonferruginous phosphorite nodules and hardgrounds outcropping at water depths of between 450 and 600 m (Fountain and McClellan, in press). These phosphorites are associated with middle Miocene (12-15 Ma) to Recent carbonate-rich sediments exposed along the upper WFS in response to Loop Current winnowing and non-deposition.

Periods of phosphogenesis commonly are associated with increased biological productivity (Compton et al., 1993). It is not unusual to find a diverse fossil assemblage associated with nodular or hardground phosphorites, especially with boring or encrusting faunas (Soudry and Lewy, 1988). Such is the case on the upper WFS, where numerous phosphatized fossil molds of invertebrates were recovered during dredging operations aimed at studying the origin of these phosphorites. The molds collected are dominated by the brachiopod *Tichosina* sp. Also present are ahermatypic scleractinian corals, two species of gastropods (one indeterminate and one *Onustus* sp.), three species of bivalves (one ostreid and two lucinids), annelid tubes, and possibly three species of echinoids (*Pericormus* spp. and an unidentifiable brissid).

Interest in the phosphorite deposits found along the upper WFS originated with the work of Dix et al. (unpublished data) and Mullins et al. (1988b). These groups were the first to identify phosphatic materials recovered during dredge hauls and correlate their occurrence to eustatic sea level fluctuations since the mid-Miocene. Subsequent interest at the University of Florida Department of Geology began when Dr. A. Hine of the University of South Florida sent a sample to the authors, concerned with their origin and stratigraphic significance. After careful study of the sample, a proposal for ship-time with the Florida Institute of Oceanography was submitted and the first cruise proceeded in December of 1989.

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West Indies, Jamaica) assisted with the identification of the brachiopods and corals, respectively. Richard Petit (North Myrtle Beach, South Carolina) and Harry Lee (Jacksonville, Florida) are acknowledged for providing gastropod references. Stephen Donovan and Sherwood Wise (Department of Geological Sciences, Florida State University) kindly reviewed an earlier draft of this paper. This is University of Florida Contribution to Paleobiology number 506.

GEOLOGICAL SETTING

Active carbonate sedimentation and erosive conditions controlled by positioning of the Gulf of Mexico Loop Current have dominated deposition on the continental slope west of peninsular Florida. The general geology of the upper WFS and the details of the Neogene stratigraphy have been summarized by Mullins et al. (1987, 1988a, b, and references therein). The slope forms the edge of a Jurassic-to-Holocene sequence of marine carbonates intercalated with evaporites, producing a modern carbonate ramp environment (Doyle and Holmes, 1985). These deposits (more than 5 km thick) record the isolation of the Florida peninsula from terrigenous sediment input until the early Miocene (24 Ma), when increased contents of siliciclastic sediments, including quartz sands, silts, and clays, are recorded in upper WFS sediments (Mullins et al., 1988b). Prior to this time, the siliciclastic sediment supply from the north (the Appalachians) was either limited or transported away from the Florida Platform by currents in the northeast-southwest oriented Gulf Trough and/or Suwannee Strait located in northern Florida and southern Georgia (Scott, 1992). During the late Oligocene to early Miocene, renewed uplift of the Appalachians (Stuckey, 1965) led to a replenished supply of siliciclastics flooding the southeastern North American coastline. This massive influx of sediments eventually filled the Gulf Trough, permitting siliciclastic encroachment onto the Florida Platform.

The study area is located south of the DeSoto Canyon, along the continental shelf-slope transition, in a complicated series of breaks with steps in between (Doyle and Holmes, 1985). Between the steps, which represent outcrops or reefs, lie gently sloping areas of unconsolidated carbonate sediments. In this region, the continental margin forms a distally steepened carbonate ramp with gentle slopes ($1-2^\circ$) extending to water depths as great as 2000 m (Uchupi, 1967). Below 2000 m, the sea floor drops at a sharp angle ($20-30^\circ$) to the abyssal depths of the Gulf of Mexico basin along the Florida Escarpment.

West Florida slope phosphorites are oriented approximately north-south along the upper slope in water depths of 450 to 600 m (Figure 1). In the northern portion of the study area (OTB8, OTB5, and WFS1), ferruginous and nonferruginous phosphorites cap lower to middle Miocene shelf-margin carbonates and clays which form seaward-prograding clinoforms (Mullins et al., 1988b). Sediments located between local outcrops of these phosphorites are a relatively coarse-grained, winnowed foraminiferan-sand facies (Mullins et al., 1988a). A basal unconformity underlies the phosphorites, which is the result of a depositional hiatus of middle Miocene age (Serravallian; 12-15 Ma). A landward unconformity stratigraphically correlated to the ferruginous phosphorites is associated with a late Miocene (Tortonian) age eustatic sea

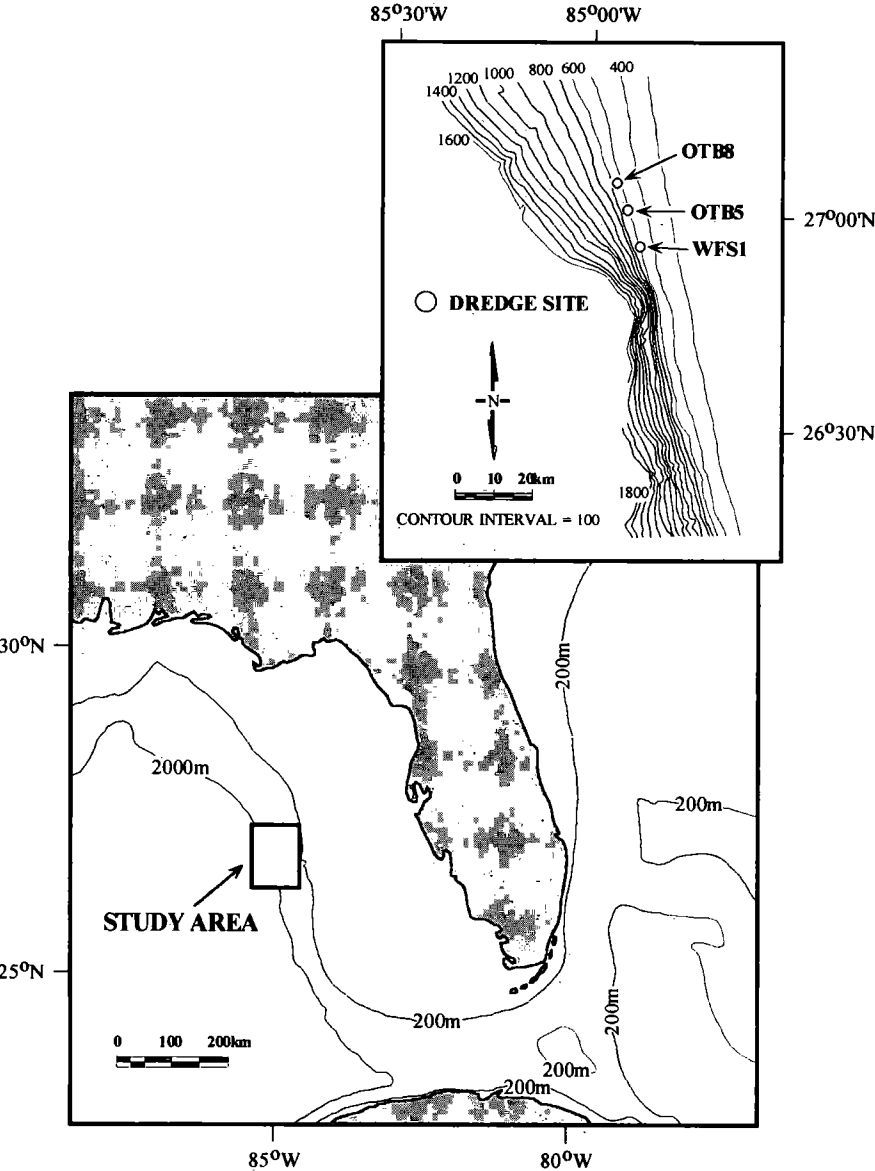


Figure 1. Location of the study area on the upper west Florida slope illustrating the bathymetric characteristics of the shelf-slope transition and the location of the dredge sites (OTB8, OTB5, and WFS1) employed in this study.

level lowstand beginning at 10.2 Ma (Mullins et al., 1987). Post-late Miocene sedimentation was dominated by the vertical accumulation of pelagic sediments, resulting in the development of a gently-dipping aggradational ramp that has withstood Quaternary environmental fluctuations (Gardulski et al., 1991). It is from these overlying late Miocene to Holocene sediments that the phosphatized invertebrate fossil molds were collected.

Oceanic circulation in the eastern Gulf of Mexico is dominated by clockwise flow of the Loop Current, which enters the Gulf through the Straits of Yucatan as the Caribbean Current and exits via the Straits of Florida as the Florida Current (Mullins et al., 1988b). The Loop Current presently extends to the sea floor and has produced a swath of winnowed foraminiferal sand at 400 to 600 m depth, reportedly inhibiting off-platform transport of shallow-water grains (Mullins et al., 1987; Gardulski et al., 1991). Upwelling occurs along the margin of the Loop Current in association with eddies that commonly break away from the current and migrate either westward or eastward over the outer shelf of west Florida (Elliot, 1982), enhancing primary production (Jones, 1973).

METHODS

Phosphatized internal molds of fossil invertebrates from five phyla (Cnidaria, Brachiopoda, Mollusca, Annelida, and Echinodermata) were collected during two cruises aboard the *RV Suncoaster* in December 1989 and May 1993, approximately 250 km west-southwest of Tampa, Florida (Figure 1). The corals, brachiopods, mollusks, annelids, and two echinoid fossils were recovered by dredge hauls in the northern portion of the study area (OTB8 and OTB5) during the 1989 cruise, while the third and largest echinoid fossil (*Pericosmus* sp.) was collected during the 1993 cruise, south of the previous locations (WFS1). Representative specimens of these fossils are deposited in the Invertebrate Paleontology Division, Florida Museum of Natural History (FLMNH), University of Florida, Gainesville, Florida (collection acronym UF).

In order to define the timing of phosphatization, and thereby estimate the age of the invertebrate fauna, mineralogical and petrographic analyses were performed to correlate the fossils to phosphorite nodule data compiled by Fountain and McClellan (in press). Mineralogy was determined by X-ray diffraction (XRD) using a Philips Electronics Instruments x-ray diffractometer with Cu K α radiation operated at 40 KV and 30 mA, with a step size and time constant of 0.02° and 1 second. Petrographic analysis of thin sections using polarized light microscopy (PLM) was performed using an Olympus Model BHS System binocular petrographic microscope.

FOSSIL MINERALOGY AND PETROGRAPHY

X-ray diffraction analyses performed on one brachiopod specimen (uncataloged; *Tichosina* sp.) from the OTB5 dredge site and one fragment of echinoid (UF 66566;

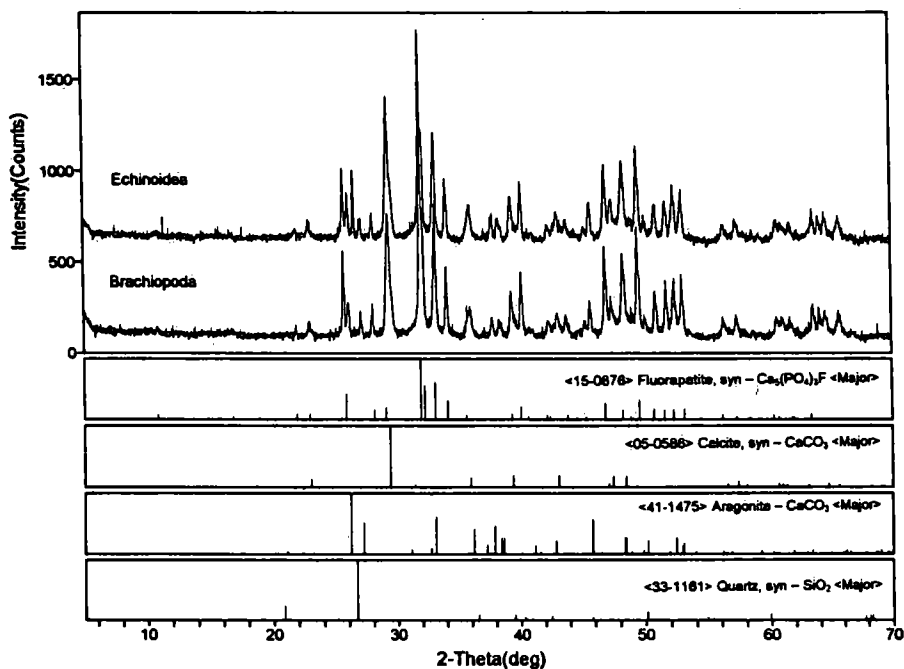
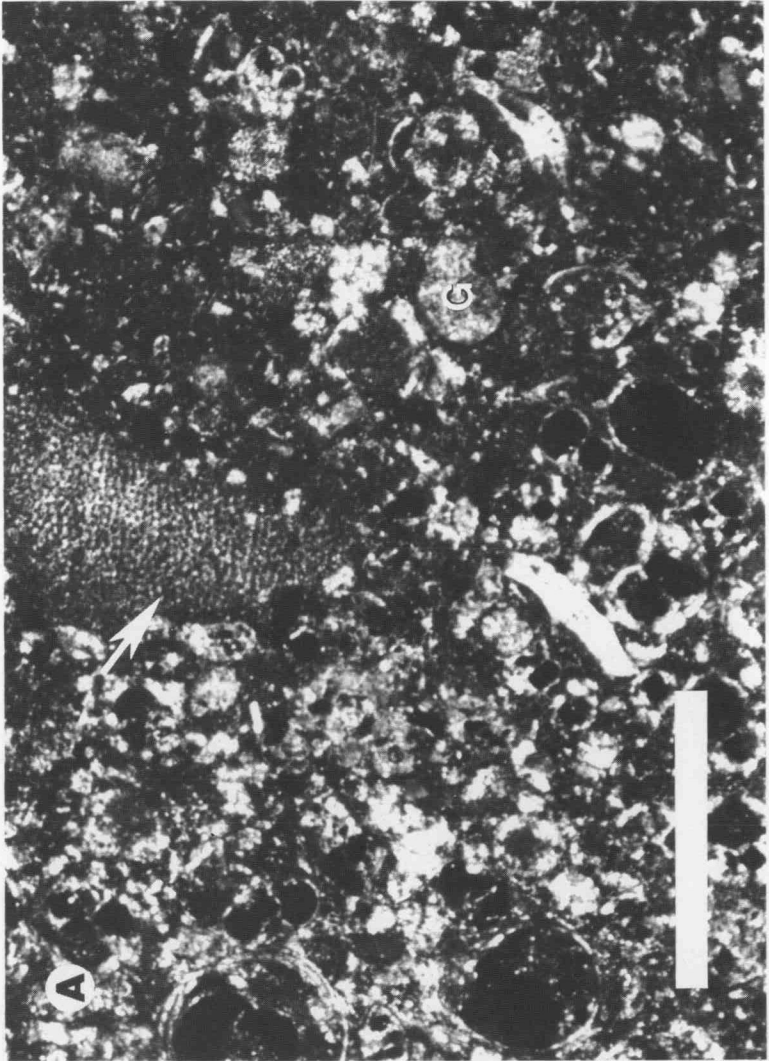


Figure 2. XRD diffractograms of phosphatic fossil molds of echinoid (UF 66566 – *Pericosmus* sp.) from dredge site WFS1 and brachiopod (uncatalogued; *Tichosina* sp.) from dredge site OTB5, both from the upper west Florida slope.

Pericosmus sp.) collected from the WFS1 dredge site indicate francolite (carbonate fluorapatite) as the principal apatite mineral, along with low-Mg calcite and aragonite (Figure 2). Quartz, an indicator of detrital flux to WFS sediments, was present only in the echinoid specimen. The presence of aragonite and the lack of high-Mg calcite in these samples permits their correlation to the BI nonferruginous nodule lithotype identified by Fountain and McClellan (in press).

Petrographically, the fossil molds are phosphatic biomicrite with allochems of fragmented or nonfragmented planktic (globigerinids, globorotalids, and *Orbulina* sp.) and benthic foraminifera. Additionally, echinoid fragments and gastropods, with granular and test infilling glaucony and detrital quartz in a micrite and francolite matrix, are present (Figure 3). As also observed in the BI nodules (Fountain and McClellan, in press), iron-oxyhydroxide (FeOOH) exhibits variable enrichment, replacing micrite, francolite, and glaucony, as well as replacing and/or infilling matrix and foraminiferal tests. Glaucony and FeOOH were not detected by XRD due to their low abundance (glaucony) and X-ray amorphous nature (FeOOH).



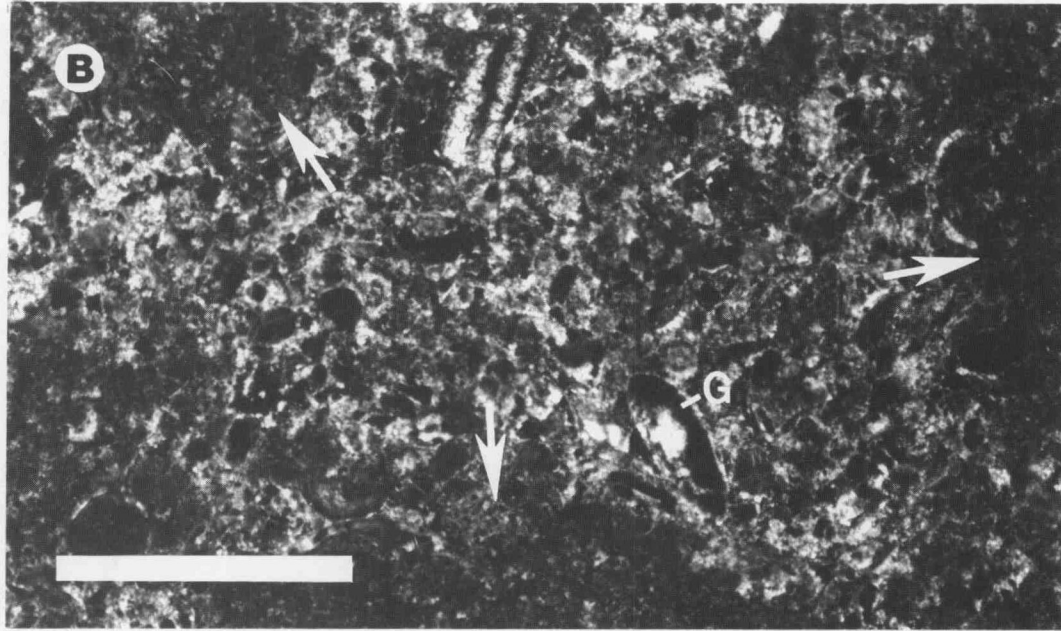


Figure 3. (A, B) Photomicrographs of phosphatic fossil mold of *Tichosina* sp. (scale bars in PLM photomicrographs = 0.5 mm). (A) Phosphatic biomicrite mold recovered from OTB5 illustrating the abundance of fragmented and nonfragmented foraminiferal tests, as well as echinoid fragments (arrow) in a matrix dominated by francolite and micrite. Note the glaucony grain (G) possessing minor FeOOH alteration along the edges. (B) Example of a mold possessing greater FeOOH enrichment (arrows) at the expense of matrix and allochems. Note more advanced FeOOH alteration of glaucony grain (G).

SYSTEMATIC PALEONTOLOGY

Phylum CNIDARIA Hatschek
Class ANTHOZOA Ehrenberg
Order SCLERACTINIA Bourne
Scleractinia, gen. et sp. indet.
(Figure 4A, B)

Material—Two partial internal molds of coralla (UF 57742 and UF 97924). Both dredged from approximately 511 m, December 19, 1989, at OTB5 (27° 01'N, 84° 56'W) (UF locality 3784).

Discussion—The coral specimens were incompletely and imperfectly preserved. Preliminary identifications were not attempted given the large number of ahermatypic corals known from the Western Atlantic and Gulf of Mexico. See Cairns (1979) for a discussion of the Recent deep-water ahermatypic scleractinia of the Western Atlantic and Gulf of Mexico.

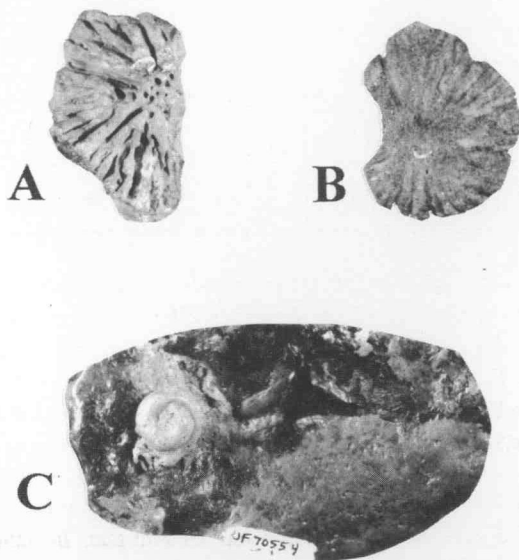


Figure 4. (A-C) Examples of phosphatized fossil invertebrates from the upper WFS dredge site OTB5. (A, B) Partial internal molds of coralla from ahermatypic corals gen. et sp. indet. (left specimen UF 97924; right specimen UF 57742). (C) Internal mold of annelid tube gen. et sp. indet. (UF 70554) on the left portion of phosphorite nodule. All specimens are at natural size (1x).

Phylum BRACHIOPODA Dumeril
 Class ARTICULATA Huxley
 Order TEREBRATULIDA Waagen
 Family TEREBRATULIDAE Gray
 Genus *Tichosina* Cooper
Tichosina sp.
 (Figure 5)

Material—One hundred seventeen internal molds, UF 57741, UF 57744, UF 57746, UF 70551, UF 70552, UF 90721, UF 90723, UF 90726, and UF 101882, dredged from approximately 511 m, December 19, 1989, at OTB5 (27° 01'N, 84° 56'W) (UF locality 3784).

Measurements—Biometric values all in millimeters (mm). UF# = Florida Museum of Natural History lot number; SLPV = sagittal length of pedicle valve; SLBV = sagittal length of brachial valve; MWI = maximum width; THCK = maximum thickness of articulated valve pair.

UF #	SLPV	SLBV	MWI	THCK
70551a	31.5	27.6	28.7	16.6
70551b	40.1	34.9	34.5	22.3
90721	34.1	29.8	30.9	19.4
90726a	39.4	35.6	34.5	23.7
90726b	41.0	36.9	36.0	22.5
90726c	31.3	27.8	28.5	17.3
90726d	33.1	29.4	26.9	13.5
90726e	37.1	32.2	29.5	23.7

Discussion—Identification of internal molds of brachiopods can be very difficult. However, the fossil brachiopods from the upper WFS are exceptionally well preserved. Morphologically, the specimens appear to represent the large, smooth-shelled, terebratulid genus *Tichosina*. The placement of our specimens in this genus was based on their general shape, size, and modified anterior commissure (Figure 5).

The stratigraphic range of *Tichosina* in the Caribbean is Eocene through Recent. In Cuba, Cooper (1979) reported the genus as occurring in the Eocene Taguasco Formation and the Miocene Yumuri Limestone. He also reported occurrences in the Eocene of Trinidad and the upper Oligocene of Antigua. In Jamaica, *Tichosina* is known from the lower Miocene Montpelier Formation and the lower Pleistocene Manchioneal Formation (Harper et al., 1995, 1997). In the Dominican Republic, Logan (1987) reported the genus from the Miocene Gurabo Formation and the Pliocene Mao Formation. Harper and Donovan (in press) have also reported middle Pleistocene *Tichosina* from Barbados.

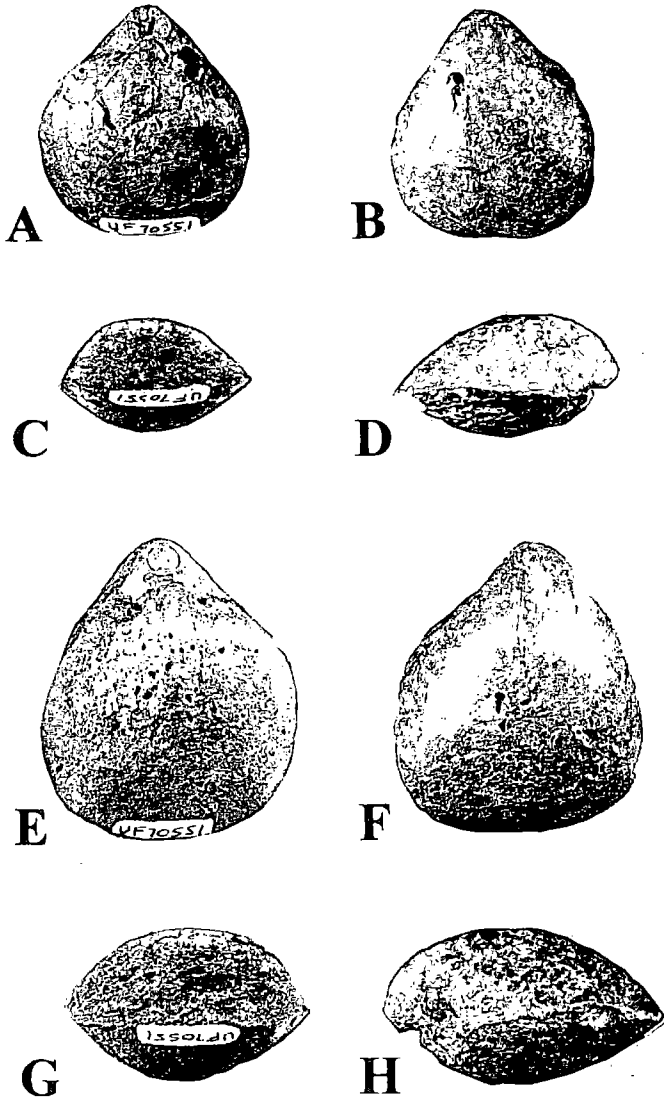


Figure 5. (A-H) Internal molds of two phosphatized *Tichosina* sp. (both UF 70551) from upper WFS dredge site OTB5. (A-D) Dorsal, ventral, anterior, and side view of one specimen. (E-H) Dorsal, ventral, anterior, and side view of second specimen. All specimens at natural size (1x).

Tichosina fossils have not previously been recorded from Florida. However, the known Cenozoic brachiopod taxa from Florida include the inarticulates *Discradisca aldrichi* (Gardner, 1928) from the middle Miocene Shoal River Formation and *D. lugubris* (Conrad, 1834) from the Pliocene Tamiami Formation, Jackson Bluff Formation, and Pinecrest Beds and the Plio-Pleistocene Caloosahatchee Formation. Additionally, Portell and Oyen (1997) and Campbell et al. (1997) reported *Glottidia inexpectans* Olsson, 1914, from the Pliocene Tamiami Formation and the Bone Valley Member of the Peace River Formation. Articulate brachiopods recorded from Florida include *Terebratulina lachryma* (Morton, 1833) from the upper Eocene Crystal River Formation (see Toulmin, 1977 and references therein), and *Terebratula* sp. and *Argyrothea schucherti* Dall, 1903, both from the upper Pliocene Jackson Bluff Formation.

Today *Tichosina* occurs throughout the Caribbean and Gulf of Mexico, and exhibits extreme morphological variation (Cooper, 1977).

Phylum MOLLUSCA Cuvier
Class GASTROPODA Cuvier
Gastropod, gen. et sp. indet.
(Figure 6A)

Material—One internal mold embedded in slab (UF 70553) dredged from approximately 511 m, December 19, 1989, at OTB5 (27° 01'N, 84° 56'W) (UF locality 3784).

Measurements—Maximum length = 19.5 mm and maximum width = 8.5 mm.

Discussion—The poor preservation of this specimen does not permit a confident generic or familial assignment.

Family XENOPHORIDAE Philippi
Genus *Onustus* Swainson
Onustus sp.
(Figure 6B)

Material—Partial internal mold consisting of four whorls (UF 101884) dredged from approximately 511 m depth, December 19, 1989, at OTB5 (27° 01'N, 84° 56'W) (UF locality 3784).

Measurements—Maximum width of incomplete internal mold = 53.4 mm and maximum height of incomplete internal mold = 28.1 mm.

Discussion—The family Xenophoridae is remarkable for its habit of attaching foreign objects, such as shells, pebbles, and corals, to the exterior of its shell. Today, three species are known to exist in the Western Atlantic and Gulf of Mexico. These are *Xenophora conchyliophora* (Born, 1780), *Onustus caribaeus* (Petit de la Saussaye, 1857), and *Onustus longleyi* (Bartsch, 1931).

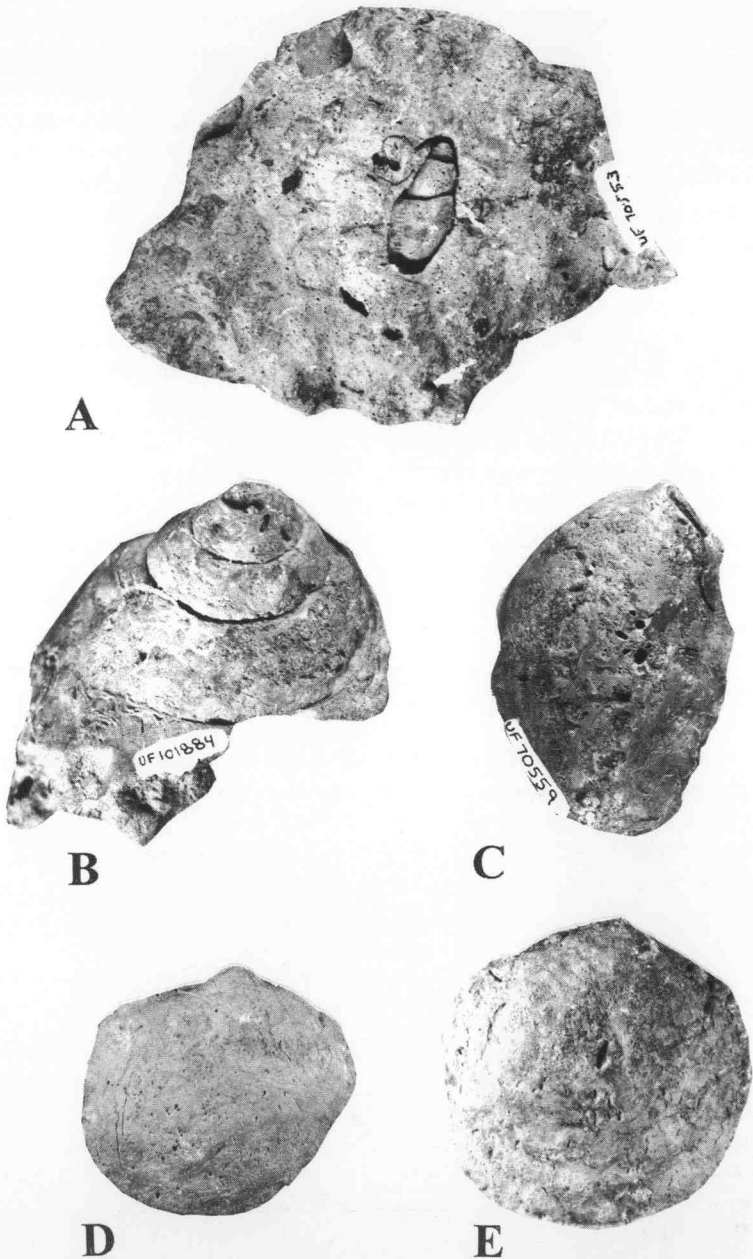


Figure 6. (A-E) Additional examples of phosphatized fossil invertebrates from the upper WFS dredge site OTB5. (A) Internal mold of gastropod gen. et sp. indet. in phosphorite nodule (UF 70553). (B) Incomplete internal mold of gastropod *Onustus* sp. (UF 101884). (C) Internal mold of single ostreid valve (UF 70559). (D) Internal mold of lucinid gen. et sp. indet. A. (UF 97925). (E) Internal mold of lucinid gen. et sp. indet. B (UF 101883). All specimens at natural size (1x).

As reported by Ponder (1983) and Kreipl and Alf (1999), *X. conchyliophora* has a geographic range from North Carolina south to Brazil and from the Gulf of California to the Gulf of Panama. It averages 47 mm in diameter at its base (excluding foreign attachments) and is known to attach considerable rubble, shells, and shell fragments to nearly its entire shell surface. *Onustus caribaeus* has a geographic range from Florida to Brazil and averages 60 mm in diameter at its base (excluding foreign attachments). *Onustus longleyi* occurs from North Carolina to Barbados and averages 130 mm in diameter at its base (excluding foreign attachments). The latter two species are deeper water taxa that attach far fewer foreign objects to their shell than does the typically shallower water *X. conchyliophora* (see Abbott [1974], Clench and Aguayo [1943], Ponder [1983], and Kreipl and Alf [1999] for further discussion of modern taxa).

Comparisons were made of the incomplete internal mold (UF 101884) to the three above-mentioned Recent species and all Florida fossil species of Xenophoridae housed in the Invertebrate Paleontology Division (IP) of the Florida Museum of Natural History (FLMNH). The entire collection of fossil *X. conchyliophora* from the Plio-Pleistocene shell beds were considerably smaller than the phosphatized incomplete internal mold. Similarly, the early Miocene species *Xenophora textilina* Dall, 1892 from the Chipola Formation was also considerably smaller. Only one specimen of *Xenophora* sp. (UF 9000) in the IP collection even approached the estimated total base width for the upper WFS Florida slope specimen. It is a nearly complete internal mold from the early Oligocene Suwannee Limestone. However, all the examined fossil species exhibited angled ("stair-stepped") rather than smooth, sloping, whorls as seen in UF 101884. The only specimens exhibiting such smooth, sloping whorls were the two Recent, deeper water taxa, *O. caribaeus* and *O. longleyi*.

Therefore, due to the overall large size of the four whorls of the incomplete internal mold and the smooth slope of the mold's whorls (with few and only minor impressions of foreign attachments), we concluded that this specimen represents a member of the genus *Onustus*, a typically deep-water taxon. However, because the critical characters that could further facilitate identification of this specimen, such as the presence of an umbilicus, the shape of the aperture, and the presence of a cape or palatal extension were not preserved, specific taxonomic identification was not attempted. The only other known fossil occurrence of *Onustus* from the Gulf of Mexico or Western Atlantic is from Miocene deposits of the Dominican Republic (Ponder, 1983).

Class BIVALVIA Linnaeus
Order OSTREOIDA Férussac
Family OSTREIDAE Rafinesque
Ostreid, gen. et sp. indet.
(Figure 6C)

Material—One internal mold of a single valve (UF 70559) dredged from approximately 511 m, December 19, 1989, at OTB5 (27° 01'N, 84° 56'W) (UF locality 3784).

Measurements—Maximum length = 50.3 mm and maximum width = 34.0 mm.

Discussion—Based on its size and shape, the single, bored, worm tube-incrusted valve infilling most closely resembles the genus *Ostreola* or *Conradostrea*. However, because of its unexceptional preservation, the size and shape of the impression of the muscle scar is not visible on the internal mold, or is any other landmark such as the impression of marginal crenulations.

Order VENEROIDA H. and A. Adams
Family LUCINIDAE Fleming
Lucinid, gen. et sp. indet. A
(Figure 6D)

Material—Five internal molds of paired valves and one internal mold of a single valve (UF 70557), two internal molds of paired valves (UF 90722 and UF 97925). All dredged from approximately 511 m, December 19, 1989, at OTB5 (27° 01'N, 84° 56'W) (UF locality 3784).

Measurements—Maximum length = 34.6 mm, maximum width = 36.7 mm, and maximum internal mold thickness (paired valves) = 15.3 mm (UF 97925).

Discussion—All specimens appear to represent a single taxon. The outlines of the internal molds are ovate, with the most complete specimens having umbos that are centrally located and moderately projecting above the body of the mold. The molds exhibit moderate compression representative of the original paired valves, but with no visible impressions of shell sculpture, ventral margin crenulation, muscle scars, or hinge teeth. However, on several specimens in UF lot 70557, the slight impression of the pallial line is visible. All molds show varying degrees of borings which obscure internal mold detail. There is a tremendous diversity among lucinids; however, it appears that these specimens are most closely allied to either the genus *Linga* or *Lucina*, based on comparisons to fossil and Recent collections at the FLMNH. Unfortunately, as with most other mollusks collected from OTB5, poor preservation precludes a more confident identification.

Lucinid, gen. et sp. indet. B
(Figure 6E)

Material—One internal mold (UF 101883) dredged from approximately 511 m, December 19, 1989, at OTB5 (27° 01'N, 84° 56'W) (UF locality 3784).

Measurements—Maximum length = 43.4 mm, maximum width = 43.7 mm, and maximum internal mold thickness (paired valves) = 21.2 mm.

Discussion—The single internal mold of paired valves is subcircular in outline and moderately compressed. The umbo is slightly off-center and projecting above the body of the mold. As with most of the mollusks from the upper WFS, a high degree of boring is evident. No impressions of the shell sculpture, ventral margin crenulation, or hinge teeth are visible. However, the strong impression of the pallial line and the faint impressions of the muscle scars are visible. Comparisons to all species of Lucinidae

housed in the Malacology Division of the FLMNH reveal that this specimen is most closely allied to the genus *Lucina*. However, further identification is not possible.

Phylum ANNELIDA Lamarck
Annelid, gen. et sp. indet.
(Figure 4C)

Material—Sixteen phosphorite nodules with internal molds of worm tubes attached, UF 57745, UF 70554, UF 70556, UF90724, and UF 90725, dredged from approximately 511 m, December 19, 1989, at OTB5 (27° 01'N, 84° 56'W) (UF locality 3784).

Discussion—The poor preservation of these internal molds does not permit a generic or familial assignment. Worm tubes and internal molds of worm tubes are very common in Florida rocks of Eocene to Pleistocene age. However, very little has been published as to their identities.

Phylum ECHINODERMATA Leske
Class ECHINOIDEA Leske
Order SPATANGOIDA Claus
Family PALEOPNEUSTIDAE A. Agassiz
Genus *Pericosmus* L. Agassiz
Pericosmus spp.
(Figures 7 and 8)

Material—One partial, phosphatized test with nearly complete internal mold (UF 101885) dredged from approximately 511 m, December 19, 1989, at OTB5 (27° 01'N, 84° 56'W) (UF locality 3784). One internal mold of test (UF 66566) dredged from approximately 520 m, May 4, 1993, at WFS1 (26° 56.29'N, 84° 55.75'W) (UF locality 3810).

Description—One fossil, UF 101885, test outline is subcircular, with maximum width slightly anterior of ambitus. Specimen somewhat compressed at apical system, although overall shape is not distorted significantly. Unfortunately, this compaction and the remnant sediment cemented to the surface has inhibited identification of apical system morphology. Periproct and peristome are nearly intact and largely unaffected by diagenesis or fragmentation. Peristome has elevated labrum, and is located slightly anterior of the test center and distinctly posterior of the anterior sulcus termination on adoral surface. Anterior sulcus is modestly developed and approximately half as deep as wide. Adoral surface is generally flat while aboral surface originally was dome-shaped (though presently collapsed). Test margins are broadly rounded. The anterior half of both adoral and aboral surfaces show well-preserved molds of tubercles, both large and small, and relict plate sutures are visible in various areas of the specimen. Ambulacrum I and IV petals are partially preserved, with pore-pairs present. Petals are closed, lanceolate, and terminate approximately midway between former apical system and ambitus.

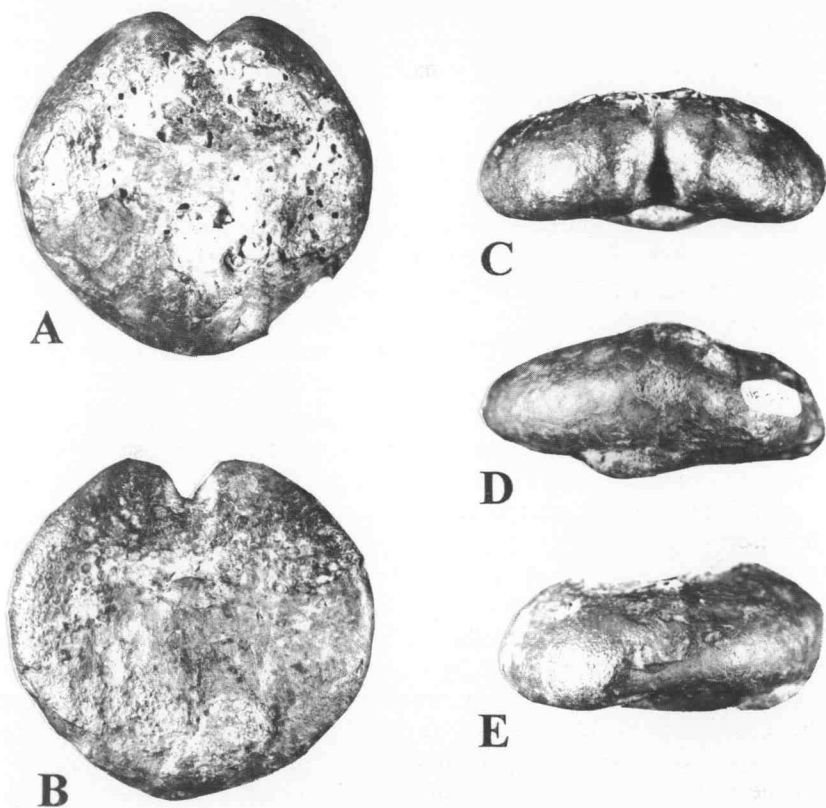


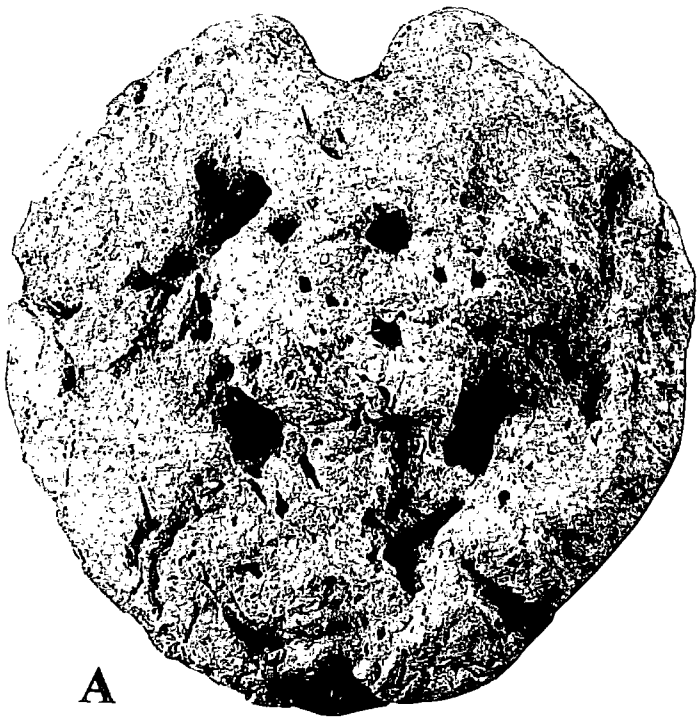
Figure 7. (A-E) Partial phosphatized test and internal mold of *Pericosmus* sp. (UF 101885) from upper WFS dredge site OTB5. (A) Aboral view. (B) Adoral view. (C) Anterior view with peristome visible. (D) Posterior view with outline of periproct visible. (E) Lateral view. All specimens are at natural size (1x).

The second fossil, UF 66566, test outline subcircular to subpentagonal, with maximum test width located distinctly anterior of ambitus. All surfaces of this internal mold have been bored extensively, but the general shape of the test is preserved. Adoral surface relatively flat, with test margins broadly curved or rounded, and a gently domed aboral surface with a slight peak at the approximate apical system location. No ambulacra, plate sutures, tubercles, or other morphological traits are visible on the mold surfaces. Anterior sulcus is small to moderate in size, with sulcus length subequal in dimension to sulcus width. Peristome visible on adoral surface, positioned distinctly anterior of test center and near the posterior margin of sulcus. Peristome slightly curved and ovate, with elevated labrum. Periproct not preserved.

Measurements—UF 101885 specimen: maximum test length = 47.3 mm, maximum test width = 51.0 mm, anterior sulcus maximum length = 4.3 mm, anterior sulcus maximum width = 10.8 mm, peristome position (anterior peristome margin to anterior test margin) = 14.9 mm; UF 66566 specimen: maximum test length = 97.8 mm, maximum test width = 93.2 mm, anterior sulcus maximum length = 12.3 mm, anterior sulcus maximum width = 14.0 mm, peristome position (anterior peristome margin to anterior test margin) = 19.6 mm.

Discussion—The UF 101885 specimen has undergone phosphatization, but it is apparent that the anterior portion of the test is intact, while only the posterior portion is exclusively an internal mold of phosphatized carbonate sediment. Some micromorphology is visible, such as tubercles and pore-pairs (see description), and overall preservation is the best of the echinoids collected along the upper WFS. Surface borings and epibionts are present, and are located principally on the aboral surface. The only significant preservational effect that limits complete description of the specimen is the slight compaction and collapse of the apical system. Original skeletal composition of echinoids is high magnesium (4-16% Mg^{+2}) calcite, which is relatively stable chemically (Sprinkle and Kier, 1987). Therefore, it is typically uncommon to find fossil echinoid tests completely dissolved or replaced during the preservation process. According to Donovan (pers. comm., 1999), some taxa do seem to be prone to this kind of preservation (e.g., *Brissus* spp. in the Pleistocene of Barbados, Oligo-Miocene in Jamaica, and Miocene in the Cayman Islands). In Florida, several species of Miocene brissids are only preserved as molds; one example is *Lovenia clarki* (Lambert, 1924) from the Chattahoochee Formation.

Preservation quality of the second *Pericosmus* specimen (UF 66566) is better than that of the brissid (UF 57743; see below), but it is a more poorly preserved internal mold than the other *Pericosmus* sp. fossil (UF 101885). Therefore, relatively few diagnostic morphological characteristics could be described. However, in addition to the traits of test length, width, and height, the shape and position of the peristome are evident. The aboral surface of UF 66566 (Figure 8A) is imperfectly preserved and bored, but adorally (Figure 8C) the mold provides a generally good surface for examination. Since the peristome shape and position commonly are used to aid in taxonomic descriptions, this specimen can be identified (tentatively) to generic level. Based on these discernable characteristics, our best placement for this specimen is also within the genus *Pericosmus*.



A



B

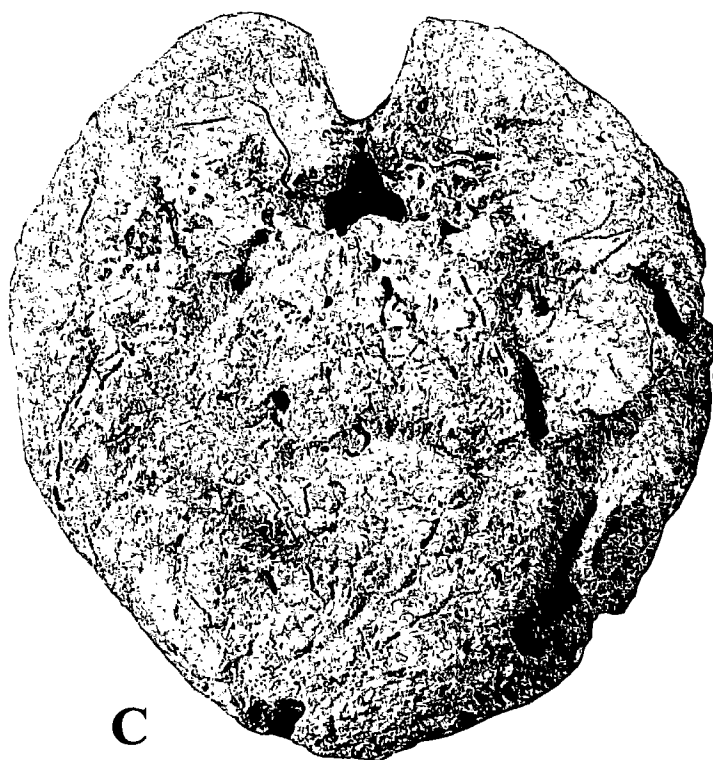


Figure 8. (A-C) Phosphatized internal mold of test from *Pericosmus* sp. (UF 66566) from upper WFS dredge site WFS1. (A) Aboral view. (B) Anterior view with peristome visible. (C) Adoral view. All specimens are at natural size (1x).

Comparison of the two *Pericosmus* specimens from different upper WFS localities indicates morphological differences exist between them, which supports identifying them as two distinct taxa. The position of the peristome relative to both the test center and the anterior test margin is different between the specimens. In the better preserved *Pericosmus* sp. (UF 101885) the peristome is more centrally located, whereas in the other *Pericosmus* sp. (UF 66566) the peristome is distinctly positioned much nearer the anterior portion of the test. Further, the anterior sulcus length-to-width ratio for *Pericosmus* sp. (UF 101885) is approximately 0.40, whereas for the second *Pericosmus* sp. (UF 66566) the ratio is approximately 0.88. Nowhere in the literature referring to species of *Pericosmus* is a size range of over 50 mm listed for any species of the genus. The two upper WFS specimens, herein called *Pericosmus* spp., differ by slightly more than 50 mm in test length. Assuming these specimens are adults, this is not a trivial variation in size and would likely indicate two different taxa. Specific identification of these specimens will be difficult, if not impossible (particularly for UF 66566), but we believe there is a real morphological difference between the specimens and have tentatively identified them as unique varieties of the genus for this study, based on the characteristics listed above.

Both fossil and extant species of *Pericosmus* are known from the Caribbean as well as from other parts of the world. Only three countries in the Caribbean and the Gulf of Mexico region, Cuba, Costa Rica, and Venezuela, have fossil records of this genus. Most of the taxa were originally reported and described by Sánchez Roig from the Eocene through Miocene of Cuba (see Kier and Lawson, 1978, p. 102-103, for taxonomic listing, stratigraphic ages, and associated references), though several were synonymized or transferred to other genera later by Kier (1984). The five Cuban fossil species considered valid by Kier (1984) were the Eocene *Pericosmus atolladosae* (Sánchez Roig, 1951) and the four Oligocene-Miocene species, *P. aguayoi* (Sánchez Roig, 1949), *P. blanquizalensis* Sánchez Roig, 1952, *P. camagueyanus* Sánchez Roig, 1949, and *P. mortenseni* (Sánchez Roig, 1952). It should be noted, however, that Kier expressed concern regarding the validity of all the species attributed to *Pericosmus* in Cuba, since the samples were relatively poorly preserved and had only subtle morphologic variation as the basis for specific differentiation.

Kier also included two additional taxa from the Caribbean and Gulf of Mexico region in his monograph; *P. israelskyi* Durham, 1961, from the Miocene of Costa Rica and *P. stehlini* Jeannel, 1928, from the Miocene of Venezuela. Kier (1984, p. 9) was cautious regarding the Venezuelan species, however, noting its strong similarity to *P. camagueyanus* of Cuba, which he believed may warrant future synonymy. A potential Caribbean record from Jamaica was reported by Donovan (1993), with a tentative generic identification of *Paleopneustes* sp. or *Pericosmus* sp. However, Donovan and Embden (1996) identified this Pleistocene echinoid from the Manchioneal Formation as *Paleopneustes cristatus* A. Agassiz, 1873, rather than a species of *Pericosmus*, thereby eliminating any Jamaican fossil records of the genus.

Other fossil records of *Pericosmus* have been reported from localities including eastern Africa, Madagascar, Italy, Japan, and the Philippines (Kier and Lawson, 1978). In addition to these regions, several fossil taxa are known from New Zealand and

Australia. Henderson (1975) described three new Cenozoic *Pericosmus* taxa from New Zealand and reported the occurrence of two previously described species; therefore New Zealand represents the only area equal to Cuba in fossil species diversity of the genus. The taxa and ages are: *P. crawfordi* (Hutton, 1873), Oligocene-Miocene; *P. borraeus* Henderson, 1975, Miocene; *P. scaevus* Henderson, 1975, Miocene; *P. annosus* Henderson, 1975, Eocene; and a taxon tentatively identified by Henderson as *Pericosmus? altus* (Hutton, 1873), age uncertain but estimated to be Oligocene. Henderson (1975, pp. 56-57) also noted that, until his work, two valid species of *Pericosmus*, (i.e., *P. compressus* [Duncan, 1877] and *P. maccoyi* Gregory, 1890) were present in southeastern Australia. Following closer examination, Henderson determined that both *P. compressus* and *P. maccoyi* only represent slight morphological variations of *P. crawfordi*, and thus are synonyms of the New Zealand species. Therefore, only five fossil species of *Pericosmus* are known from the New Zealand and Australia region.

One point of significance regarding our *Pericosmus* spp. fossils is their age. All the Cuban species were found in Eocene through Miocene age strata. The Venezuelan and Costa Rican species both were collected from the Miocene. Therefore, our specimens represent the youngest fossils of *Pericosmus* in the Caribbean and Gulf of Mexico. In addition, only one other record of a Pliocene species (i.e., *P. schencki* Israelsky, 1933, from the Malubang Formation, Philippine Islands) has been published. In another complication of stratigraphic ranges, Israelsky (1933, p. 301) noted in his paper that the age of the Malubang Formation was uncertain because all taxa but one were extant, so he believed the Malubang may be younger than Pliocene. Rocks collected from the dredge sites along the upper WFS are broadly identified as Plio-Pleistocene age (Fountain and McClellan, in press), and therefore our work may allow a biostratigraphic range extension of the genus. Furthermore, if our identification is correct, this represents the first report of fossil *Pericosmus* from the United States.

Family BRISSIDAE Gray
Brissid, gen. et sp. indet.
(Figure 9)

Material—One internal mold of a test (UF 57743) dredged from approximately 511 m, December 19, 1989, at OTB8 (27° 05'N, 84° 57'W) (UF locality 3811).

Measurements—Maximum internal mold length = 33.5 mm, maximum internal mold width = 30.8 mm, maximum internal mold height = 21.1 mm.

Discussion—Of the three echinoids recovered from the upper WFS Florida slope, this specimen is the most poorly preserved. However, the general test length, width, and height can be distinguished, as well as the slight sulcus along ambulacrum III (Figure 9A-C). The relative proportions of these morphologic characteristics as a reflection of the overall shape suggest a strong affinity to the family Brissidae.

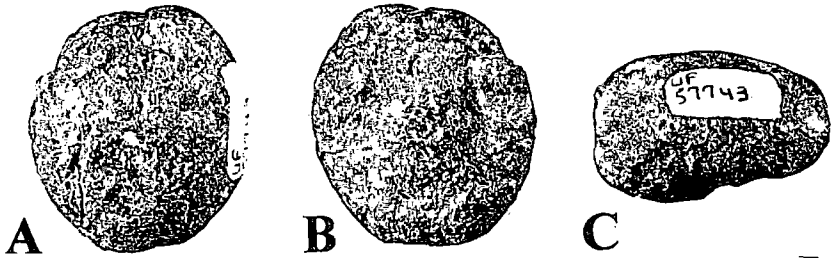


Figure 9. (A-C) Phosphatized internal mold of test from unidentified brissid (UF 57743) from upper WFS dredge locality OTB8. (A) Aboral view. (B) Adoral view. (C) Lateral view. All specimens are at natural size (1x).

The stratigraphic range of brissids extends from the Cretaceous through the Recent (Kier and Lawson, 1978; Smith, 1984), and species of this family are present in Tertiary rocks of North America and the Greater Antilles. Numerous species of brissids have been reported from Cuba in Eocene through Miocene strata (Sánchez Roig, 1953; Kier, 1984), and one species of brissid has been reported from the Pliocene of the Dominican Republic (Kier, 1992). In Jamaica, Donovan (1993) also reported a variety of brissid species in selected units ranging in age from Eocene through Miocene and the Pleistocene. Extant species of the family are present in the marine realm of the Gulf of Mexico, Caribbean, and Western Atlantic, as well as most other major oceans of the world.

PALEOECOLOGICAL INTERPRETATION

Specimens collected from three localities (OTB8, OTB5, and WFS1) along the west Florida slope were examined in the course of this study. Locality OTB5 contained the most taxa, including molds of corals, brachiopods, mollusks, annelids, and one echinoid (*Pericosmus* sp.). Locality OTB8 produced a single brissid echinoid, and at locality WFS1 another echinoid (*Pericosmus* sp.) was collected.

Due to the poor preservation of most of the above-mentioned specimens, and therefore the inability to identify the taxa more specifically, paleoecologic interpretation is rather difficult, although worthwhile. Additionally, we realize that even though the preservation is similar at all three localities, the environmental settings for all three sites may have been different. Therefore, the following provides only the most basic interpretation of the paleoecology.

Present-day articulate brachiopods are always marine and benthic, and there is no reason to suppose that fossil species, particularly in the Tertiary, were otherwise (Logan, 1987). In the Caribbean, extant species of *Tichosina* range to 1000 m depth, but rarely are found at depths of less than 100 m (Cooper, 1977). Therefore, the

Tichosina from the upper WFS, as well as most other brachiopod genera, are typically poor depth range indicators.

Today, three living species of Xenophoridae are known to exist in the Western Atlantic and Gulf of Mexico, *Xenophora conchyliophora*, *Onustus caribaeus*, and *Onustus longleyi*. According to Ponder (1983) and Kreipl and Alf (1999), *X. conchyliophora*, is mostly a shallow-water species. *Onustus caribaeus* is typically found at depths greater than 100 m (down to 640 m). *Onustus longleyi* occurs at depths between 180 and 695 m. As stated above, the single, incomplete, phosphatized mold of *Onustus* sp. from the upper WFS exhibits the characters of the two deeper water taxa mentioned above. We are thus confident that this specimen represents a deep-water taxon; however, without better-preserved material, refinement of a paleobathymetric interpretation is not possible.

The ecological regime inhabited by extant brissids around Florida and the Caribbean includes a range of substrate grain-sizes from mud to coarse sands, and water depth ranges from 0-3200 m (Serafy, 1979; Hendler et al., 1995). Unfortunately, information regarding life habits of extant paleopneustids is not as easy to obtain. No living *Pericosmus* has been observed in its habitat (Kier, 1984), so only indirect interpretations can be made for both the fossil and modern taxa. Related taxa, the schizasterids, found in the same geographic region of the Caribbean and Florida inhabit a substrate grain-size range similar to the brissids noted above and have been reported from depths ranging from 0-1750 m (Serafy, 1979; Hendler et al., 1995).

Extant species of *Pericosmus* are restricted to the Indo-West Pacific region (Mortensen, 1951; Henderson, 1975; Kier, 1984). All species of the family Paleopneustidae are tropical inhabitants of present seas with the exception of two taxa, one of which is *P. cordatus* Mortensen, 1950. This species is found in Japanese seas from Sagami Bay to southwestern Kyushu at depths of 80-200 m (Imaoka et al., 1990, p. 125). Henderson proposed that even though all species in the family inhabit deeper water (70-800 m), temperature appears to control their geographic distribution, so it is likely the tropical-derived waters of the Kuroshio Current sustains the echinoids and other warm water taxa in areas of southern Japan. McNamara (1984) described and reported a single living species, *P. porphyrocardius*, as occurring along the continental slope of Australia at water depths of 309-420 m. Kier (1984) suggested the Cuban fossil species inhabited tropical waters greater than 100 m, based on the fact that modern taxa normally live at depths of 200-500 m, with the shallowest taxa at 18-70 m. Kier also examined the morphological characteristics of the Cuban fossils, and on this basis determined they likely burrowed deep enough infaunally to at least have the dorsal portion of the test covered.

Therefore, based on the limitation of taxonomic resolution for the Florida echinoids, we generalize that they likely inhabited a shallow water depth of less than several hundred meters when living. Furthermore, the variety of brissids in the Caribbean and Florida and paleopneustids in the Indo-Pacific are infaunal (Mortensen, 1951; Hendler et al., 1995), burrowing a few cm under the sediment-water interface to as much as 10 cm deep. Using modern taxa as environmental indicator guides, we feel it is likely the *Pericosmus* species reported herein occupied a similar habitat when alive.

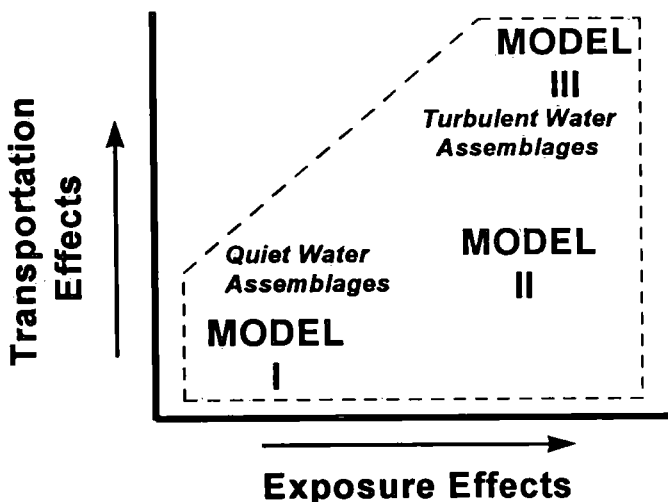


Figure 10. Hypothetical models for fossil assemblage formation. Relationship between duration of exposure of fossils on sea floor and the potential distance of transport of fossils (prior to ultimate burial and incorporation into the rock record) will control assignment of specimens to one of the three models plotted in figure (from Johnson, 1960).

Using the information known about modern species of brissids and schizasterids, we suggest that the echinoids dredged from the upper WFS inhabited an environment similar to that described in the above paragraph. The preservation of the fossil assemblage can be interpreted using fossil assemblage models designed by Johnson (1960). In Johnson's models, an assemblage of fossils can reflect the environmental conditions affecting that assemblage. These include characteristics regarding the relative distance of transport of individual organisms prior to burial and incorporation into the sediment, as well as factors reflecting the amount of exposure on the surface of the sea floor any organisms' remains had prior to burial. An illustration of the relationship between the three fossil assemblage types, and the variation of transportation and exposure effects on the fossil remains, is provided in Figure 10. Examples of features found on fossils that can reflect the degree of transport or exposure on the sea floor include (but are not limited to): density of fossils, size-frequency distribution, fragmentation, surface condition of fossils, chemical and mineralogical composition, orientation, and sediment structure and texture (see Johnson, 1960, for complete discussion of important factors).

Although the fossils in this paper all were collected indirectly via dredging, some generalizations can be made regarding the style of fossil assemblage that is present at the collection localities. The best interpretation for these fossils would be as representatives of Model II assemblages. Since the echinoids probably were shallow,

infaunal inhabitants (as were some of the mollusks), it is likely they died within the substrate and had at least limited shelter from transportation (from their death site to a new assemblage site), except in unusually high sea-floor scour conditions. The fossils do, however, show some evidence of exposure effects. Exposure effects include features such as epibiont encrustation and borings by other biologic entities. The fossils collected along the upper WFS tend to show extensive borings (see figures 7A, 8). Encrusting organisms, such as bryozoans and annelids, can be found on some of the fossils, reflecting exposure to the sediment-water interface on the sea floor prior to burial. Therefore, the moderate presence of exposure effects and the limited presence of transportation effects on the fossils collected tend to support our interpretation of the fossils as part of a Model II assemblage.

AGE AND FACIES INTERPRETATION

Sediments capping ferruginous phosphorite nodules recovered from the northern portion of the study area (OTB8, OTB5, and WFS1) correspond to sequence I of Mullins et al. (1988b), which, in turn, correlates to Vail supercycle TB2 (10.2 Ma) through supercycle TB3 (late-middle Miocene to Holocene) (Haq et al., 1987). Accumulation of ferruginous phosphorites predates subsequent invertebrate fossilization, as well as the development of the BI nonferruginous nodules with which they are associated (Fountain and McClellan, in press; Fountain et al., in prep). Based on a model proposed for the WFS which favors sea level highstand conditions during phosphogenesis (Fountain and McClellan, in press), formation of both phosphatic fossil molds and BI nonferruginous nodules most likely would have occurred during the Plio-Pleistocene (Fountain et al., in prep.).

This interpretation is supported by the age of incorporated planktonic foraminifera. *Globorotalia truncatulinoides*, *Globorotalia inflata*, *Globorotalia menardii*, *Globorotalia tosaensis*, and *Globigerinoides ruber* are found within nonferruginous phosphorite in the northern portion of the study area and constrain the age of the phosphatic sediment to the Plio-Pleistocene (Dix et al., unpublished data). Thus, the macrofauna must have been present during the Plio-Pleistocene, with phosphatization occurring during subsequent sea level highstands.

Sea level highstands associated with Vail supercycle TB3 third order cycles 3.4 through 3.9 (Haq et al., 1987) would have created conditions favorable to francolite and glaucony crystallization, preserving the invertebrate macrofauna present within WFS sediments. It seems likely that the fauna inhabited the area during either transgressive or regressive episodes, which would have favored shallower water depths. The presence of epifaunal and infaunal species tends to suggest increased current velocities generated by a seaward deflection of the Loop Current associated with a lowering of sea level. Subsequent burial associated with increased sea level and a reduction in current velocity would have favored later preservation and phosphatization of the macrofauna (Figure 11).

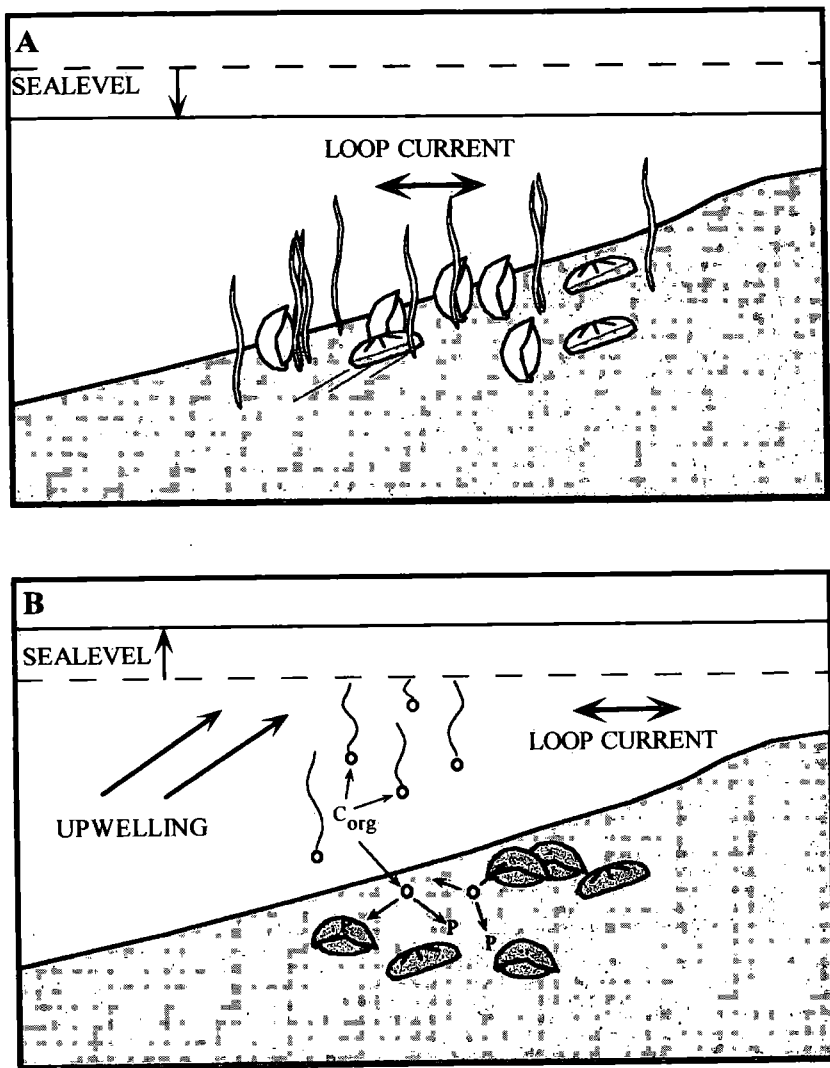


Figure 11. (A, B) Proposed diagenetic model for fossilization of the upper west Florida slope invertebrate macrofauna. (A) Macrofauna most likely inhabited the upper slope during transgressive or regressive sea level episodes. (B) Phosphatic molds are formed during episodes of phosphogenesis associated with sea level highstands and increased C_{org} fluxes to WFS sediments. C_{org} oxidation releases phosphorous (P) to surrounding pore waters, increasing concentrations to levels required for francolite crystallization.

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