Holocene Sediment Accumulations of the South Florida Shelf Margin

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ABSTRACT

The carbonate shelf-margin depositional model is fundamental to understanding carbonate rocks and to petroleum exploration in carbonate rocks. The sedimentary package is normally thick and permeable, trends and facies patterns are inherently predictable, and a variety of diagenetic environments are encountered. The south Florida shelf margin is one of the few currently active carbonate shelf margins and a large area where the surface sediments are relatively well known. The Holocene-Pleistocene package, the latest chapters in a long history of shallow-water carbonate deposition, is prograding seaward toward the edge of the continental shelf. The Holocene sedimentary sequence was dissected in the third dimension to study accumulation patterns, variations in the patterns, sediment sources, and pore-space characteristics. A compact, high-resolution seismic profiler, a core driver for underwater coring of sandy sediments, and a permeameter for measuring flow rates through sediment cores were essential tools in this study.

Natural subdivisions of the south Florida shelf are the restricted inner shelf (Florida Bay), the slightly restricted inner shelf margin, the outer shelf margin where circulation and turbulence are maximum, and the shallow slope seaward of the shelf break. Water turbidity, temperature variations, and salinity variations generally increase landward from the shelf break. Substrate is a primary control on the organism habitat communities; organisms, in turn, produce virtually all the sediment of the substrate. Other important controls are bottom morphology and restriction of circulation. Mappable habitat communities and their sedimentologically important inhabitants on the south Florida shelf are:

1. Rock or dead reef

2. Mud
   a. grass covered — turtle grass (*Thalassia*), green algae (*Halimeda, Penicillus*) miliolid foraminifera, browsing gastropods, burrowing pelecypods and shrimp (*Calianassa*)
   b. bare — a few green algae, foraminifera
3. Sand
   a. grass covered — *Thalassia, Halimeda,* peneroplid foraminifera, browsing gastropods, burrowing pelecypods
   b. bare — burrowing echinoids
4. Patch reef — head corals
5. Outer reef — corals (*Acropora, Montastrea, Diploria, Porites*), *Millepora, Halimeda opuntia*
6. Forereef muddy sand — pelagic foraminifera
7. Shoal fringe, restricted — finger coral (*Porites*), red algae (*Goniolithon*), *Halimeda opuntia*
8. Reef rubble — few organisms

Relative skeletal productivity by the habitat communities is estimated as $5 > 4 > 7 >> 2a >> 3a > 1a > 1b > 6 >> 2b > 3b > 8$.

Inner shelf, inner shelf margin, outer shelf margin, and shallow slope depositional environments may be distinguished by depositional textures, grain composition, and sedimentary structures. The percentage of fines ($<62\mu m$) is the most sensitive textural indicator of the environments. Fines are absent in much of the outer shelf margin. Inner shelf margin and slope sediments generally contain 10 to 50 percent fines; inner shelf sediments are muddier still. All major skeletal components of the sand-sized fraction are useful in distinguishing the four major depositional environments. Mollusks increase steadily in abundance from shallow slope to inner shelf. Corals are most abundant at the shelf break and decrease to zero in the inner shelf. *Halimeda* is the most abundant constituent throughout the shelf margin. Foraminifera increase in abundance from the outer shelf margin to the inner shelf and also on the shallow slope where pelagic forams appear. Coralline algal fragments are most numerous on the shallow slope and decrease to zero in the inner shelf.

Aragonite comprises 73 percent of shelf-margin surface sediments; Mg calcite and calcite increase to total 41 percent in inner shelf sediments. Sedimentary structures formed by waves and currents characterize outer shelf margin sediments. Angle-of-repose depositional slopes occur in outer reef rubble. Inner shelf-margin sediments are bioturbated. Permeabilities of outer shelf-margin skeletal sands are as great as 34 darcys with 45 percent porosity. Inner shelf-margin sediments are about 65 percent pore space with permeabilities of 30 to 300 millidarcys. Early diagenesis at the sediment surface involves a complex of organic and inorganic, physical and chemical, constructive and destructive processes whose most important products are fecal pellets, crypto-crystalline grains, bioturbation, and bored rocks and shells.

Prominent features of the Pleistocene rock surface that underlies the Holocene sediments are (1) a shelf break at about the position of the present shelf break; (2) a gently inclined shelf from the shelf break to the Florida Keys; (3) a narrow, discontinuous high that forms the Keys; and (4) a very flat floor that underlies the inner shelf embayments. Features such as reef buttresses can be interpreted from profiles and maps leading to the inference that the Pleistocene rock surface is largely a depositional surface. Small-scale erosion is inferred from features interpreted as shoreline notches at about −9 m and −25 m (−30 ft and −80 ft) and as solution depressions at −8 m (−25 ft).

Holocene sediment is thickest in three discontinuous linear accumulations parallel to the shelf break. The most extensive and thickest accumulations (up to 14 m) are along the outer reefs. Behind the outer reefs, a second belt is formed by sand shoals up to 40 km (25 mi) long or by discontinuous patch-reef banks. The belt of sediment accumulations on the shallow slope is a seaward-thinning wedge up to 12 m (40 ft) thick. Sediment accumulation in the inner shelf margin is thickest in patch-reef banks, tidal deltas (up to 8 m), and broad flat-topped wedges near the Keys (up to 7 m). The belts of thick sediment vary along depositional strike, parallel to the shelf break, in thickness, width, and continuity. This is particularly striking with the sand shoals that disappear to the southwest and are replaced to the north-northeast by discontinuous patch-reef banks. Areas of maximum development of all three belts tend to coincide, as do areas of minimum development. Accordingly, strong contrasts exist in the degree to which a given area has been "filled" up to sea level with sediment. Some areas of the outer shelf margin are over 50 percent filled, with sedimentation rates of 1 m/1,000 yr. In areas of minimum sedimentation, the inner shelf margin is 10 percent filled with accumulation rates as low as 0.18 m/1,000 yr.

Three core profiles demonstrate that the Holocene sedimentary record is transgressive. The sequence of textures, structures, and grain composition encountered from the shelf break to the inner shelf is generally reproduced from the surface downward in cores, in accordance with Walther's law. Sediments at depth are finer, more bioturbated, and contain fewer skeletal fragments of typical outer shelf-margin habitat communities.

Outer reefs are generally located along the Pleistocene slope break or slightly behind it. The abundance of unbound sediment in cores through the outer reefs indicates that reef growth at any one location has not been continuous since the Pleistocene. It is hypothesized that reef development may be in a long-term steady state with loci of growth shifting along the shelf break and, in some cases, to new positions behind the shelf break.

Shelf-margin sand shoals probably originated through wave and current concentration of sediment produced in the outer reefs; this was muddy sediment in the early stages of shelf-margin transgression. This origin would account for the correlation between maximum reef development and sand-shoal location and for the parallels in setting with Bahaman oolite shoals which are localized by hydrodynamic forces.

Patch-reef–bank locations show some correlation with Pleistocene rock-floor highs, but the reefs actually originated on antecedent mud banks formed by mechanical concentration of sediment. The bank origin parallels that of the shelf-margin sand shoals, but later development favored patch reefs where the ecological conditions for coral growth were met, wave energy was not excessive, and external sediment supply was not overwhelming. Inner shelf-margin sediment wedges are miniature shelf margins built in equilibrium with local wave base, largely through local sediment production. Tidal deltas mark the boundary between shelf margin and inner shelf where tidal currents are channeled through the Florida Keys. Their locations are controlled by relative strengths of ebb and flood currents, by protection from large waves, and by sediment supply, much of it of local origin. Inner shelf-margin bank locations may be determined by the ability of the shoal-fringe community to exploit small breaks in the slope of the rock floor.

Skeletal productivity appears to be the most important control of sediment accumulation patterns. Variations in productivity by the outer-reef "factories" correlate with lateral variations in volume of shelf-margin sand shoals and shallow-slope sediments. Mechanical redistribution of sediment, topography of the lithified rock floor, and the evolving contemporary depositional topography are other important controls on sediment accumulation patterns.

The Holocene transgressive sedimentary sequence is an incomplete cycle comparable to the five Pleistocene stratigraphic units of Perkins (Part II). The Holocene shelf margin is essentially stacked on the late Pleistocene margin, but the Holocene belt of coarse, grainy, coralline sediment is much narrower, and the crest of the Holocene depositional topography is at the shelf break, not at the Florida Keys.

INTRODUCTION

The shelf of the southeastern Florida peninsula between Miami and Dry Tortugas is the only area of the continental United States and one of relatively few areas in the world where shallow-water marine carbonate sediments are actively being deposited on a large scale. The shallow carbonate shelf is 360 km (225 mi) long, 6 to 35 km (4 to 20 mi) wide, and generally less than 12 m (40 ft) deep. The seaward margin of this shelf, where carbonate sedimentation is most active, is about 8 km (5 mi) wide. A spectrum of carbonate sediments, modern correlatives of many familiar carbonate rocks, is present in this narrow belt. The south Florida carbonate shelf, like other modern depositional environments, presents a time horizon upon which facies patterns, relationships of sediment source and accumulation, and initial porespace characteristics can be studied.

Carbonate shelf margins have long attracted the interest of geologists for economic as well as academic reasons. Shelf margins present some of the most inherently predictable trends and facies patterns among carbonate rocks. Many ancient shelf margins are recognizable by seismic or other geophysical techniques or with limited well control. Shelf-margin sedimentary sequences in many examples, modern and ancient, are thick and permeable. The sediments are chiefly of shallow marine origin, and in many carbonate examples, the shelf margin is topographically higher than much of the inner shelf. Subaerial exposure may therefore be more frequent and prolonged than in other marine environments, and subaerial diagenesis, which may either reduce or enhance porosity and permeability, should be at a maximum. Submarine diagenesis also appears to be most active in shallow areas with open circulation.

Extensive work has been done on the surface sediments of the south Florida shelf. Texture and constituent grain composition of the surface sediments were reported by Ginsburg (1956) and Swinchatt (1965). Stehli and Hower (1961), Siegel (1961), and Taft and Harbaugh (1964) studied the mineralogy and chemistry of the surface sediments. Sedimentary structures were examined by Shinn (1968a, 1968b). Pleistocene facies patterns along the same shelf margin trend are described in Perkins' study (Part II) of south Florida Pleistocene stratigraphy.

The primary objective of this report is to examine patterns of Holocene carbonate accumulation in three dimensions. This emphasis reflects the current focus of carbonate research on diagenesis and some technological developments that facilitate study of the third dimension of sediments. The study of diagenesis depends on some knowledge of the starting material — sedimentary facies, mineralogy, pore space, permeability, and alteration in the depositional environment. The new tools are a compact, high-resolution reflection profiler suitable for use in shallow water, a system for taking cores of sandy sediment, and a