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Slope Sedimentation and Organic Carbon Content in the Late Quaternary West Florida Slope Sediments

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Slope sedimentation on the modern west Florida continental margin is controlled by pelagic carbonate accumulation and off-shelf sedimentation of neritic carbonates and terrigenous fines. Production and deposition of pelagic carbonates by planktonic foraminifera and coccoliths have played a significant role in the total slope sedimentation and are mainly promoted by sea-surface productivity. Organic carbon data reflect the relatively high biological productivity in surface waters, indicating high accumulation of biogenic calcareous sediments. The surface-water productivity in the study area is supported by the relation among microfossil assemblages, carbonate mineralogy and sedimentary organic carbon.

INTRODUCTION

The Gulf of Mexico, a semi-enclosed sedimentary basin, has been intensively studied due mainly to hydrocarbon exploitation, especially along the Texas, Louisiana and Mississippi continental margins. The continental margins in the northern Gulf of Mexico have high rates of sedimentation resulting from a significant supply of terrigenous sediments. In contrast, in the eastern Gulf of Mexico, the west Florida continental margin (Fig. 1) is characterized by carbonate sediments.

Carbonate sediments normally occur in shallow warm-water regimes and in the deep ocean above the calcium carbonate compensation depth (CCD). They are chiefly formed by carbonate-secreting marine organisms and are deposited near or in the place where they are produced. Accumulation of carbonate particles is primarily controlled by a supply of terrigenous sediments, which usually carries terrigenous organic matter.

The west Florida continental margin bordering the Florida peninsula is known as one of the most active carbonate depositional systems and is characterized by a broad, non-rimmed open shelf (Ginsburg and James, 1974; Tucker, 1985). Generally, Late Quaternary west Florida slope sedimentation is a combination of carbonate accumulation and supply of terrigenous material. Sedimentation rates recorded in modern sediments of the west Florida continental slope are unusually high at 20–60 cm/ 1000 years (Doyle and Holmes, 1985), compared with other modern carbonate and deep-sea environments. The high rates of sedimentation on the west Florida slope as a deep-water setting (>500 m) as well as a modern carbonate system deserve further investigation: what are the biogenic carbonate components and how significant has carbonate sedimentation been on the modern west Florida slope?. This paper aims to determine sediment composition and to describe the relationship between slope sedimentation and organic carbon content in the west Florida slope sediments.

BACKGROUND AND OCEANOGRAPHIC SETTING

Initial rifting and subsequent separation of the North America, Yucatan and African plates led to the development of the west Florida continental margin during the middle Mesozoic (Buffler *et al.*, 1980; Buffler and Sawyer, 1985). Modern sedimentary patterns on the west Florida margin were initiated in response to the closure of the Central American Seaway and increased climate gradients in the middle Miocene (Mullins *et al.*, 1987, 1988).

The west Florida continental slope can be divided into two regions: the upper slope and the lower slope (the Florida Escarpment). The upper continental slope is separated from the broad shelf by the shelfbreak with a 1–2° gradient, gradually deepening seaward and extending to the steep escarpments (Walker, 1984). The water depth at the shelfbreak ranges from 100 m near the DeSoto Canyon in the north to 200 m in the south (Holmes, 1981).

Foraminifera and coccoliths have been recognized as major constituents in west Florida slope sediments (Mitchum, 1978; Doyle and Holmes, 1985; Gardulski *et al.*, 1990). The carbonate mineralogy is dominated by low-Mg calcite, which is derived primarily from planktonic foraminifera and coccoliths, ranging from about 60% in glacial times to 98% in interglacial stages (Gardulski *et al.*, 1986). Aragonite and high-Mg calcite are contributed by benthic foraminifera, echinoids, coralline algae, and pteropods. Mass movement events such as creep, turbidites and massive slides have been documented on the Late Quaternary west Florida slope deposits (Mitchum, 1978; Walker, 1984; Doyle and Holmes, 1985; Mullins *et al.*, 1986). These massive redepositional processes were interpreted to have been induced by high rates of sediment accumulation when sea-level was low (Doyle and Holmes, 1985).

In the eastern Gulf of Mexico, oceanic circulation is dominated by the Loop Current (Fig. 1). The Loop Current originates from the Caribbean Current which flows into the Caribbean Sea through the Lesser Antilles Passages and finally enters the Gulf of Mexico through the Yucatan Strait (Nowlin, 1972; Morrison and Nowlin, 1982). This current flows clockwise along the west Florida margin and exits through the Straits of Florida as the Florida Current (Nowlin, 1972). This current then joins the Antilles Current to form the Gulf Stream. The Loop Current circulation pattern is quite variable; intrusion into the Gulf of Mexico ranges between 24°N and 28°N (Vukovich *et al.*, 1979). The northernmost observation (about 29°N) has been documented around the DeSoto Canyon and the northwest Florida continental shelf (Huh *et al.*, 1981). Cyclic eddies induced from the Loop Current circulation promote upward flux of nutrient-rich subsurface waters, enhancing primary production on the southwest Florida shelf (Paluszkiewicz *et al.*, 1983). Tropical storms also influence the Loop Current; eddies can be transported onto the shelf when winds blow onshore.

METHODS

Two piston cores, taken as part of the G80-6 cruises for a 5-year program between the U.S. Geological Survey and the University of South Florida on the west Florida continental slope, were used for this study (Fig. 1). Sediment subsamples from the piston cores (cores N5 and C6) were analyzed to determine grain size, sediment constituents, organic carbon, and carbonate mineralogy.

For grain-size analysis, subsamples were wet-sieved through a 63 μm mesh to separate mud and sand

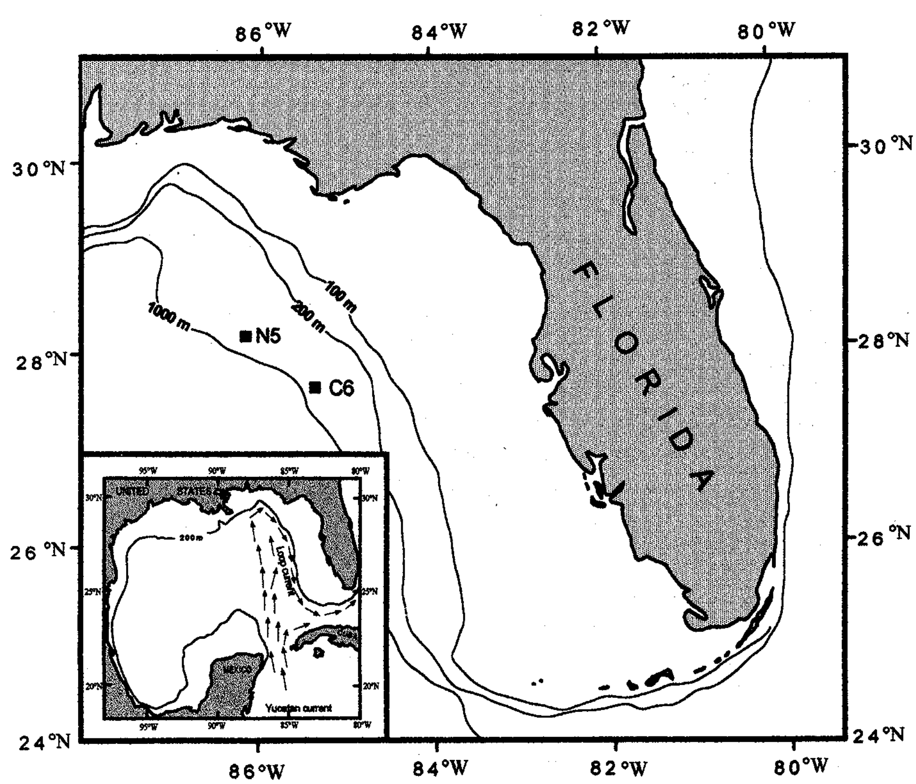

Fig. 1. Map of the study area, showing core sites, bathymetry and Loop current circulation.

(Folk, 1980). Sediment composition in the sand fractions was examined by point-counting (Carver, 1971). Sand fractions were divided into two size classes (63–250 μm and >250 μm). One hundred grains were counted under a light microscope. Mud-fractions of selected samples were observed with a Scanning Electron Microscope (SEM). X-Ray diffractometry (XRD) was used to identify carbonate minerals. XRD analysis was focused on a scan range from 2 to 40 degrees. Relative percentages of calcite, high-Mg calcite and aragonite were determined by the ratio of peak areas between samples and standards. Standard slides of pure calcite and aragonite and mixtures of calcite and aragonite (75% calcite, 50% calcite, 25% calcite) were prepared for comparison to samples. Calcium carbonate content was estimated by acid addition. Organic carbon contents for the dry samples were determined by the CHN analyzer. About 2–3 mg of dry sample was taken and then combusted at temperatures exceeding 1000°C.

RESULTS AND DISCUSSION

Slope Carbonate Sediments

Grain-size analyses show the variations in relative abundance between sand and mud. Mud content (ranging from 36% to 96%) is generally higher than sand content in the slope sediments. Sand percentages are between 4% and 64%.

Sediment composition data provide semiquantitative estimates for sediment constituents in sands. The Late Quaternary sediment composition in the coarse fraction of west Florida slope sediments is very homogeneous and is composed of biogenic calcareous skeletal particles and fragments, as documented in previous works (Mitchum, 1978; Doyle and Sparks, 1980; Doyle and Holmes, 1985; Gardulski *et al.*, 1990). In particular, planktonic foraminifera (varying from 55% to 96%, 83% on average) always predominate in sand fractions regardless of the relative proportion of sand and mud. Additionally, planktonic foraminiferal abundance increases with increasing sand content throughout cores (Figs. 2 and 3). The planktonic foraminifera identified in two core sediments are mostly "warm water" faunas, including the genus *Globigerinoides (G.ruber* and *G.sacculifer*), the genus *Globorotalia* (*G.menardii, G.truncatalinoides, G.crassaformis, G.tumida, and G.inflata*), *Neogloboquadrina dutertrei*, and *Orbulina universa*.

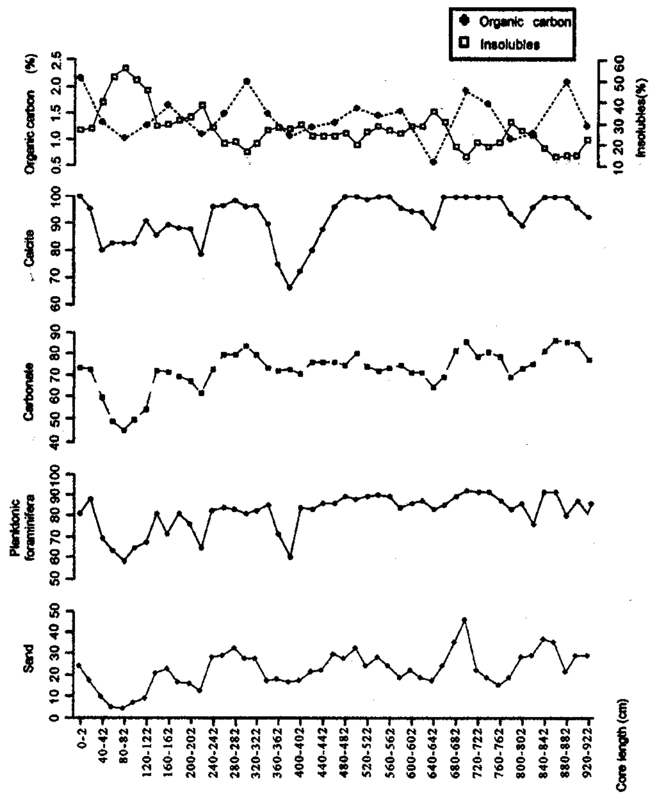

Fig. 2. Comparable trend in percent sand, planktonic foraminiferal numbers, carbonate content, percent calcite, organic carbon concentrations, and insoluble content in Core N5.

The unidentified components are rare and also seem to be fragmented skeletal remains. Quartz grains and biogenic siliceous material are not identified in sand fractions. The fine-grained sediments examined with SEM contain abundant coccoliths, with some smaller foraminifera and associated fragments. Sediment examination of both sand and mud indicates that coarse-grained foraminifera and fine coccoliths are major biogenic carbonate components in modern west Florida slope sediments.

Examination of bulk mineralogy in the slope cores revealed them to be dominated by carbonate minerals. "Low-Mg" calcite, referred to as calcite, predominates in all slope samples. Aragonite and high-Mg calcite were also identified as important sources of carbonate minerals. Their maximum values are about 10% and 30%, respectively. Distinct peaks of quartz occur throughout the cores. Clay minerals are also present, but are seemingly rare in bulk sediments. The relative abundance of calcite in carbonate minerals varies from 60% to almost 100%, averaging 91% (Figs. 2 and 3). Aragonite and high-Mg calcite of neritic origin generally increase in the core layers where calcite percentage decreases. Calcite normally

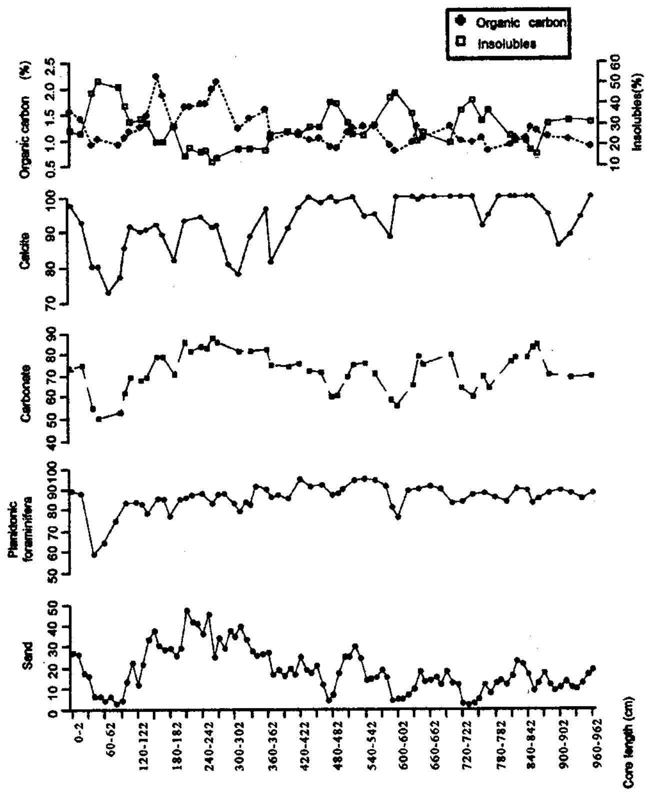

Fig. 3. Comparable trend in percent sand, planktonic foraminiferal numbers, carbonate content, percent calcite, organic carbon concentrations, and insoluble content in Core C6.

increases with increasing sand content, reflecting the contribution of sand-sized planktonic foraminifera to calcite enrichment.

Calcium carbonate content in bulk sediments ranges from 57% to 88%, 75% on average. Carbonate values in mud are also high (37%–67%), indicating the abundance of biogenic calcareous material. Usually, carbonate-rich layers correspond to higher percentages of coarse-grained sediments, composed predominantly of planktonic foraminifera. Weight percent insoluble (25% on an average) is estimated by direct subtraction of carbonate content from bulk sediment. Quartz and clay minerals, as major insolubles, were identified with XRD. The amount of insolubles generally increases with increasing mud content.

Calcite enrichment combined with dominant planktonic foraminifera and coccoliths indicates that calcareous pelagic deposition prevails on the modern west Florida continental slope, compared with neritic carbonate transport and terrigenous sedimentation.

Organic Carbon

Organic carbon values in the study area range from 0.41% to 2.58% (an average of 1.4%), higher than those (0.1–0.3%) in most modern open-ocean environments (Heath *et al.*, 1977; Stein, 1990). The downcore variations in organic carbon are generally similar between two cores. The organic carbon data indicate that the core layers with high insoluble content (mainly silt-sized quartz and clays) usually contain low organic carbon values, while the core sections with low percent insolubles show relatively high organic carbon content (Figs. 2 and 3). In addition, organic carbon content is positively correlated with calcium carbonate content, which is primarily derived from planktonic foraminifera and coccoliths.

There is a general relation between organic carbon content and lithology (Gautier *et al.*, 1985). Unlike coarse grains, fine-sized particles have a higher ratio of surface area to volume and may readily absorb and aggregate with various material (Seibold and Berger, 1993). Clay minerals tend to incorporate organic material to form aggregates in the water column (Weaver, 1989). In fact, most clay minerals are transported to deep-sea sediments in the form of large aggregates. Furthermore, Ibach (1982) documented that weight percent organic carbon increases from calcareous sediments to mixed calcareous/siliceous sediments to siliceous sediments.

However, the organic carbon data from the west Florida slope are not consistent with these general trends in marine sediments. Sand-rich intervals with abundant planktonic foraminiferal numbers in cores have relatively higher organic carbon content (Figs. 2 and 3). This discrepancy may be explained by the input of autochthonous organic matter, associated with the production and accumulation of slope carbonate sediments and the relatively little terrigenous clays in fine sediments.

In general, sedimentation rates are enhanced by terrigenous influx, which usually bears more terrigenous organic matter. The close correlation between organic carbon content and sedimentation rate has been widely investigated in modern and ancient deposits (Heath *et al.*, 1977; Ibach, 1982; Jones, 1983; Muller and Suess, 1979). Recently, Stein (1990) combined organic carbon data collected from different depositional settings (Fig. 4), and particularly emphasized the relation between (marine) organic carbon and sedimentation rates ("OCSR" diagram). In open-ocean oxic environments, the positive correlation can be explained by high sedimentation rates, including better preservation of (marine) organic matter by reducing its residence time in oxidizing conditions.

In (coastal) upwelling zones, high sedimentation rates (of biogenic components) may have been influenced by high biological productivity, promoted by a supply of nutrients and dissolved carbon dioxide from deeper water. This means that marine organic carbon content is mainly controlled by primary production in the surface-water and/or preservation of organic matter, related to sedimentation rates. The typical open-ocean environments are commonly characterized by low organic carbon content (<0.4%) and low sedimentation rates (0.2–1 cm/1000 years). In coastal upwelling zones, high concentrations of organic carbon (up to 20%) and high sedimentation rates (up to 100 cm/1000 years) have been recorded. The "OCSR" diagram (Fig. 4) of the west Florida slope has been made, based on the combination of organic carbon data(ranging from 0.413% to 2.580%) with about 1.40% on average and sedimentation rates (from 16 cm/1000 years to 65 cm/1000 years) with an average of 30 cm/1000 years (Doyle and Holmes, 1985). The sedimentation rate data mentioned the above were acquired in the study area where modern slope sedimentation has continued with limited terrigenous influx. This diagram indicates that the west Florida slope is a moderately high surface-water productivity area, much higher than typical open-ocean environments, but lower than the upwelling zones.

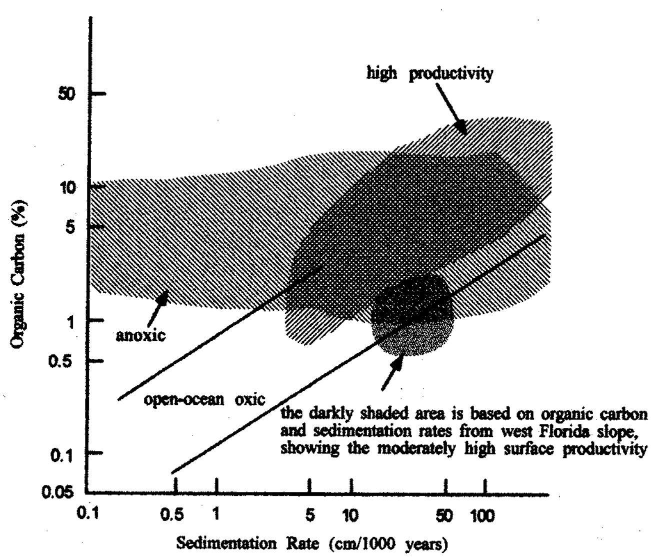

Fig. 4. The "Organic Carbon/Sedimentation Rate" diagram added (from Stein, 1990) with organic carbon data and sedimentation rates from the west Florida slope. This generalized pattern shows that high accumulation of biogenic components in nutrient-rich upwelling areas may primarily be caused by high biological productivity of sea-surface. According to this diagram, the west Florida slope can be classified as a moderately high productivity area.

Additionally, the estimated chlorophyll pigment concentrations (about 0.5 mg/m^3) on the west Florida continental terrace support the relatively high surface productivity (Hallock *et al.*, 1993). On the west Florida slope, both marine and terrigenous organic carbon may have contributed to the slope sedimentation. However, most of the organic carbon in the study area is of marine origin, based on the relation among sand content, percent carbonate, calcite content, and organic carbon concentration.

Organic carbon was mentioned as an indicative of relatively high pelagic primary production in the study area. The production and deposition of pelagic calcareous sediments (mainly planktonic foraminifera and coccoliths) on the west Florida continental margin is explained by nutrient influx into the surface waters. Based on different temperature and salinity, modern neritic carbonates are divided into four assemblages: chlorozoan, chloralgal, foramol, and bryomol (Lees, 1975; Nelson *et al.*, 1988). The chlorozoan and chloralgal carbonate facies usually occur in warm, tropical seas. The foramol and bryomol assemblages are present in high nutrient tropical shelves, and more commonly on temperate shelves. Lees (1975) predicted "chlorozoan" sediment composition on the west Florida continental shelf, based on temperature and salinity. However, the shelf sediments are characterized by classic "foramol" assemblage, composed of benthic foraminifera and mollusks (Doyle and Sparks,1980: Doyle *et al.*, 1996). Hallock and Schlager (1986) and Hallock (1988) suggest that moderately high nutrient flux to waters over the west Florida shelf stimulates growth and activity of bioeroding organisms in carbonate substrates, accelerating intense bioerosion processes. Subsequently, this prevents carbonate framework buildup. Thus, mesotrophic flux allows predominance of "foramol" type particles rather than "chlorozoan" assemblages which are typical in oligotrophic, shallow-water carbonate systems. The absence of biogenic siliceous sediments such as diatoms or radiolarians also indicates that nutrient influx is mesotrophic, not truly eutrophic. Dinoflagellate blooms on the west Florida shelf are common (Vargo *et al.*, 1987). The potential for diatom blooms was also hypothesized on the basis of the high Coastal Zone Color Scanner (CZCS) signals (Gilbes *et al.*, 1996), but has not been confirmed. Although sporadic blooms of siliceous organisms are assumed to take place, indicating pulses of nutrients, they are not sufficient enough for deposition of siliceous sediments in the study area. Therefore, this fertility is critical for production and sedimentation of carbonates. Organic carbon data in this study reflect the moderately high biological productivity in surface waters, resulting in high accumulation of biogenic calcareous sediments.

CONCLUSIONS

Marine microfossils, mostly planktonic foraminifera and coccoliths, are the dominant sediment types in west Florida slope sediments. Their productivity in surface water promotes rapid pelagic carbonate sedimentation and marine organic carbon input on the west Florida continental slope where terrigenous sedimentation is limited. It also causes marine organic carbon input in the slope sediments, showing a positive correlation between organic carbon content and sand-sized planktonic foraminiferal numbers. Finally, this relation between organic carbon content and sedimentation rates in marine sediments can be applied to depositional systems that are characterized by a limited supply of terrigenous sediments, even in the mid and high latitudes.

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REFERENCES

Buffler, R.T., J.S. Watkins, F.J.Shaub and J.L. Worzel, 1980. Structure and early geologic history of the deep central Gulf of Mexico Basin. In: The Origin of the Gulf of Mexico and the Early Opening of the Central North Atlantic Ocean, edited by Pilger, R.H., Jr., Louisiana State University, Baton Rouge, pp. 3 – 16.

Buffler, R.T. and D.S. Sawyer, 1985. Distribution of crust and early history, Gulf of Mexico basin. *Gulf Coast Assoc. Geol. Sci. Trans.*, **35**: 333 – 344.

Carver, R.E., 1971. Procedures in Sedimentary Petrology. Wiley-Interscience, New York, 653 pp.

Doyle, L.J. and C.W. Holmes, 1985. Shallow structure, stratigraphy, and carbonate sedimentary processes of west Florida upper continental slope. *American Assoc. Petrol. Geol. Bull.*, **69**: 1133 – 1144.

Doyle, L.J. and T.N. Sparks, 1980. Sediments of the Mississippi, Alabama, and Florida (MAFLA) continental shelf. *J. Sed. Petrol.*, **50**: 905 – 916.

Doyle, L.J., G.R. Brooks and E. Lee, 1996. Analyses of the sedimentary parameters, carbonate mineralogy and constituents of vibra-cores and surface samples taken from the inner west Florida continental shelf part B. In: West-Central Florida Coastal Studies Workshop, edited by Gelfenbaum, G., USGS Center for Coastal Geology, St. Petersburg, Florida, pp. 13 – 31.

Folk, R.L., 1980. Petrology of Sedimentary Rocks. Hemphill Publishing Co., Austin, Texas, 183 pp.

Gardulski, A.F., H.T. Mullins, B. Oldflield, J. Applegate and S.W. Wise, 1986. Carbonate mineral cycles in ramp slope sediment, eastern Gulf of Mexico. *Paleoceanogr.*, **1**: 555 – 565.

Gardulski, A.F., H.T. Mullins and S. Weiterman, 1990. Carbonate mineral cycles generated by foraminiferal and pteropod response to Pleistocene climate: west Florida ramp slope. *Sedimentol.*, **37**: 727 – 743.

Gautier, D.L., Y.K. Kharaka and R.C. Surdam, 1985. Relationship of organic matter and mineral diagenesis. Society of Economic Paleontologists and Mineralogists Short Course No. **17**, 279 pp.

Gilbes, F., C. Tomas, J.J. Walsh and F.E. Muller-Karger, 1996. An episodic chlorophyll plume on the west Florida shelf. *Cont. Shelf Res.*, **16**: 1201 – 1224.

Ginsburg, R.N. and N.P. James, 1974. Holocene carbonate sediments of continental margins. In: The Geology of Continental Margins, edited by Burke, C.A. and C.L. Drake, Springer-Verlag, New York, pp. 137 – 155.

Hallock, P., 1988. The role of nutrient availability in bioerosion: consequences to carbonate buildup. *Palaeogeogr. Palaeoclimat. Palaeoecol.*, **63**: 275 – 291.

Hallock, P. and W. Schlager, 1986. Nutrient excess and the demise of coral reefs and carbonate platform. *Palaios*, **1**: 389 – 398.

Hallock, P., F.E. Muller-Karger and J.C.Halls, 1993. Coral reef decline. *Natl. Geogr. Res. and Explor.*, **9**: 358 – 378.

Heath, G.R., T.C. Moore and J.P. Dauphin, 1977. Organic carbon in deep-sea sediments. In: The Fate of Fossil Fuel CO_2 in the Oceans, edited by Anderson, N.R. and A. Malahoff, Plenum Press, New York, pp. 605 – 625.

Holmes, C.W., 1981. Late Neogene and Quaternary Geology of the Southwestern Florida Shelf and Slope. U.S. Geological Survey Open-File Report 81 – 79, 44 pp.

Huh, O.K., W.J. Wiseman and L.J. Rouse, 1981. Intrusion of Loop Current waters onto the west Florida continental shelf. *J. Geophys. Res.*, **86**: 4186 – 4192.

Ibach, L.E.J., 1982. Relationship between sedimentation rate and total organic carbon content in ancient marine sediments. *American Assoc. Petrol. Geol. Bull.*, **66**: 170 – 188.

Jones, R.W., 1983. Organic matter characteristics near the shelf-slope boundary. Society of Economic Paleontologists and Mineralogists Special Publication No. 33, Tulsa, pp. 391 – 405.

Lees, A., 1975. Possible influence of salinity and temperature on modern shelf carbonate sedimentation. *Mar. Geol.*, **19**: 159 – 198.

Mitchum, R.M., 1978. Seismic stratigraphic investigation of west Florida slope, Gulf of Mexico. American Association of Petroleum Geologists Studies in Geology No. **7**, pp. 193 – 224.

Morrison, J.M. and W.D. Nowlin, Jr., 1982. General distribution of water masses within the eastern Caribbean Sea during the winter of 1972 and fall of 1973. *J. Geophys. Res.*, **87**: 4207 – 4229.

Muller, P.J. and E. Suess, 1979. Productivity, sedimentation rate, and sedimentary organic matter in the oceans - I. organic carbon preservation. *Deep-Sea Res.*, **26A**: 1347 – 1362.

Mullins, H.T., A.N. Gardulski and A.C. Hine, 1986. Catastrophic collapse of the west Florida carbonate platform margin. *Geology*, **14**: 167 – 170.

Mullins, H.T., A.N. Gardulski, S.W. Wise and J. Applegate, 1987. Middle Miocene oceanographic event in the eastern Gulf of Mexico: implications for seismic stratigraphic succession and Loop Current/Gulf Stream circulation. *Geol. Soc. America Bull.*, **98**: 702 – 713.

Mullins, H.T., A.N. Gardulski, E.J. Hinchey and A.C. Hine, 1988. The modern carbonate slope of central west Florida. *J. Sed. Petrol.*, **58**: 273 – 290.

Nelson, C.S., S.L. Keane and P.S. Head, 1988. Non-tropical carbonate deposits on the modern New Zealand shelf. *Sed. Geol.*, **60**: 71 – 94.

Nowlin, W.D., Jr., 1972. Winter circulation patterns and property distribution. In:Contributions on the Physicall Oceanography of the Gulf of Mexico, edited by Capurro, L.R.A. and J.L. Reid, Texas A&M University Oceanographic Studies, Volume 2, Gulf Publishing Co., Houston, pp. 3 – 51.

Paluszkiewicz, T., L.P. Atkinson, E.S., Posmentier, and C.R. McClain,1983. Observations of a Loop Current frontal eddy intrusion onto the west Florida shelf. *J. Geophys. Res.*, **88**: 9639 – 9651.

Seibold, E. and W.H. Berger, 1993. The Sea Floor, Springer-Verlag, New York, 356 pp.

Stein, R., 1990. Organic carbon content/sedimentation rate relationship and its paleoenvironmental significance for marine sediments. *Geo-Mar. Let.*, **10**: 37 – 44.

Tucker, M.E., 1985. Shallow-marine carbonate facies and facies models. In: Sedimentology: recent developments and applied aspects, edited by Brenchley, P.J. and B.P.J. Williams, Special Publication of Geological Society of London No. 18, London, pp. 147 – 169.

Vargo, G.A., K.L. Carder, W. Gregg, E. Shanley and C. Heil, 1987. The potential contribution of primary production by red tides to the west Florida shelf ecosystem. *Limnol. Oceanogr.*, **32**: 762 – 767.

Vukovich, F.M., B.W. Crissman, M. Bushnell and W.J. King, 1979. Some aspects of the oceanography of the Gulf of Mexico using satellite and in situ data. *J. Geophys. Res.*, **84**: 7749 – 7768.

Walker, S.T., 1984. Sedimentary structures of the west Florida slope and eastern Mississippi cone: distribution and geologic implications. Unpublished M.S. thesis, University of South Florida, 148 pp.

Weaver, C.E., 1989. Clays, Muds, and Shales: Developments in Sedimentology **44**, Elservier, New York, 819 pp.

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