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Microbial and Geochemical Characterization of Carbonate Mudbanks from Florida Bay

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Florida Bay is a shallow subtropical bay at the south end of the Florida peninsula. A maze of carbonate mudbanks and small islands has formed over the past 4,000 years on top of the gradually sloping Pleistocence limestone surface 1-4 meters below present sea level. Ancient non-framework carbonate build-ups, such as mud-skeletal rich banks or mud mounds, are potential areas for significant hydrocarbon reservoirs. Mud-skeletal banks are massive elongate bodies that form both parallel and perpendicular to the seaward edge of the platform margin. Sediment in ancient banks of this kind varies from lime mud to fossiliferous sand, is commonly neomorphosed, and may contain cavities filled by sediment and cement. However, they are often characterized by mudstone and wackestone facies with low porosity and permeability. Diagenetic events such as dolomitization can increase the permeability of these deposits and their potential as a hydrocarbon reservoir.

Florida Bay has been used as a modern depositional analog to interpret the middle and upper Wabamun Group on the Peace River Arch, Alberta, Canada. Locating the laterally variable and heterogeneous reservoir grade porosity was improved from 25 to 80% using a depositional/diagenetic model (Saller and Yaremko 1994). Early replacive dolomitization by marine or slightly hypersaline water occurred shortly after deposition and preferentially targeted mudstones and peloidal wackestones and packstones on topographical highs or mound-like structures (Saller and Yaremko 1994). While modern dolomite formation is rare and not completely understood, small amounts of dolomite have been found in Florida Bay typically associated with mud islands (Swart et al. 1989). Understanding factors controlling the distribution of dolomitization and other forms of diagenesis in the modern is important to successful exploration of ancient carbonate mud mounds or mud banks.

Geochemical analysis of sediment pore fluids from Manatee Key, Clive Key and Buoy Key mud banks reveal Florida Bay is undergoing very early stages of diagenesis (Figure 1) Carbonate dissolution and possible recrystallization are occurring as well as sulfate reduction. Numerous bacterial species have been assumed to play a role in the precipitation and dissolution of calcium carbonate in diverse environments. Both the oxidation of organic matter and the reaction by-products influence calcium carbonate saturation by releasing chemicals that interact with the carbonate system. Previous studies have shown sulphate-reducing bacteria can induce the precipitation of dolomite in shallow marine sediments (Vasconcelos et al. 1999). Sulphate reduction through bacterial oxidation of organic matter increases bicarbonate in pore fluids favoring precipitation. On the other hand, oxidation of by-products from sulphate reduction, such as hydrogen sulfide, can lower pH and induce the dissolution of calcium carbonate. Bacterial communities in marine sediments are extremely diverse, but can be sensitive indicators of environmental changes. The spatial distribution of these bacteria within fine grain carbonate mud has not been evaluated. A better understanding of the relationship between bacterial communities and geochemical changes in these sediments will help identify environments where intervals of carbonate production/destruction are occurring.

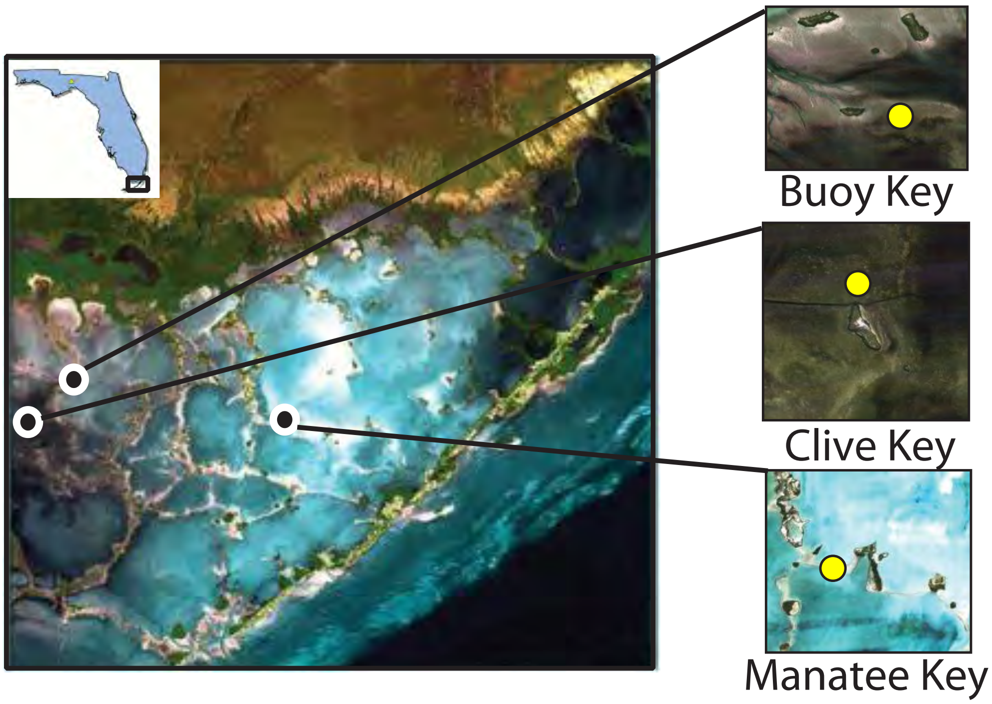

Figure 1. Map of Florida Bay showing the sample locations of cores collected from mudbanks.

In this study, the interstitial water chemistry, sediment chemistry and bacterial community profiles of Florida Bay sediment cores were analyzed at 10cm depth intervals to determine how bacterial communities change along geochemical gradients in relation to carbonate mineralogy. Geochemical analyses of porewaters include alkalinity and chloride titrations, and trace elements such as calcium, magnesium and strontium were measured using standard ICP-OES methods. The inorganic $d^{13}C$ and $d^{18}O$ compositions were measured on the sediments, while the organic $d^{13}C$ and $d^{15}N$ values were analyzed on the co-occurring organic material throughout the cores. Carbonate mineralogy was determined using x-ray diffraction, which quantitatively tracked changes in aragonite, calcite and dolomite down core. Genomic DNA was extracted and the 16S rRNA gene was amplified using polymerase chain reaction (PCR) with universal bacterial primers. Terminal restriction fragment length polymorphism (T-RFLP) analysis of 16S rRNA gene was used track changes in the bacterial communities with sediment depth along the cores and between mud bank locations. Clone libraries were made and the 16S rRNA gene was sequenced to identify dominant populations within the mud cores. The goal of this study was to understand how bacterial communities change along downcore variations in mineralogy and pore fluid chemistry in relation to early diagenesis of mudbank sediments.

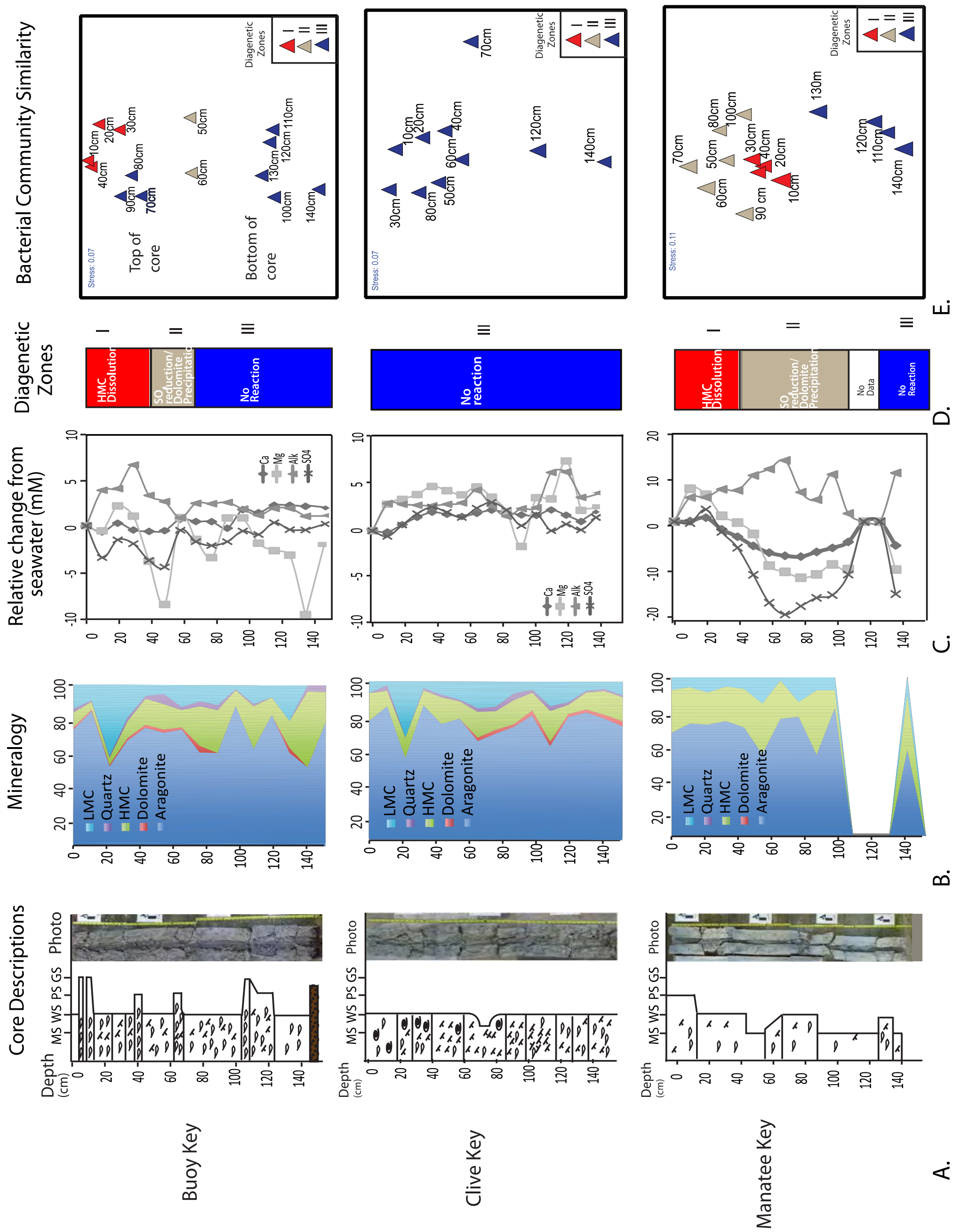

__Figure 2.__ Sediment cores were divided for lithological descriptions (A) and mineralogical analysis (B). Pore fluid concentrations of Ca^{2+}, Mg^{2+}, $SO4^{2-}$, and alkalinity were measured from porewaters squeezed from 10 cm intervals of mud (C). Ion concentration is given in relative mM values above or below the concentration that would be expected if Cl- were behaving conservatively, relative to seawater. Possible zones of diagenesis are inferred based on pore water chemical profiles (D). Nonmetric multidimensional scaling plots shows the results of a similarity analysis (ANOSIM) of bacterial community profiles at each depth interval (E). The greater the amount of shared bacterial species one depth interval has to the other, the closer they will plot.

Consistent with previous studies of mudbanks in Florida Bay, only small changes in ion concentrations occur within these sediments (Burns and Swart 1992), except at Manatee Key. Minor variations were observed at Buoy Key and inferred diagenetic zones were made, but it is possible these values fall within error of the measurement process. Burns and Swart 1992 suggest significant bio-irrigation increases the diffusion from overlying Florida Bay seawater and the Pleistocence bedrock, masking any changes in pore fluid ion concentrations. Manatee Key closely resembles a closed system, where mixing with open seawater did not mask the changes to sulphate, calcium and magnesium concentrations. Despite the strong odor of hydrogen sulfide from all cores, analysis of pore fluid ion ratios suggests sulphate reduction was only occurring at Manatee Key. Despite the Manatee Key pore fluid chemistry profiles suggesting dolomite was precipitating (Fig 2), there was no further geochemical analysis to support that dolomite is currently forming (Fig. 3). HMC dissolution occurred only near the water-sediment interface where sediments likely contain oxygen from biological mixing, suggesting that metabolic activity of aerobic heterotrophic bacteria may favor calcium carbonate dissolution. Both Buoy Key and Manatee key bacterial communities from these zones were similar between cores. Bacterial communities from the inferred diagenetic zones clustered closely together within diagenetic zones at Manatee Key and slightly at Buoy Key. While mudbank sediments appear homogeneous bacterial communities are stratified along geochemical gradients on small spatial scales and may be sensitive indicators of environmental conditions promoting early diagenesis.

References

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