Taphonomy of the Late Pleistocene Key Largo Limestone: A Comparison of Modern and Ancient Coral Reef Ecosystems

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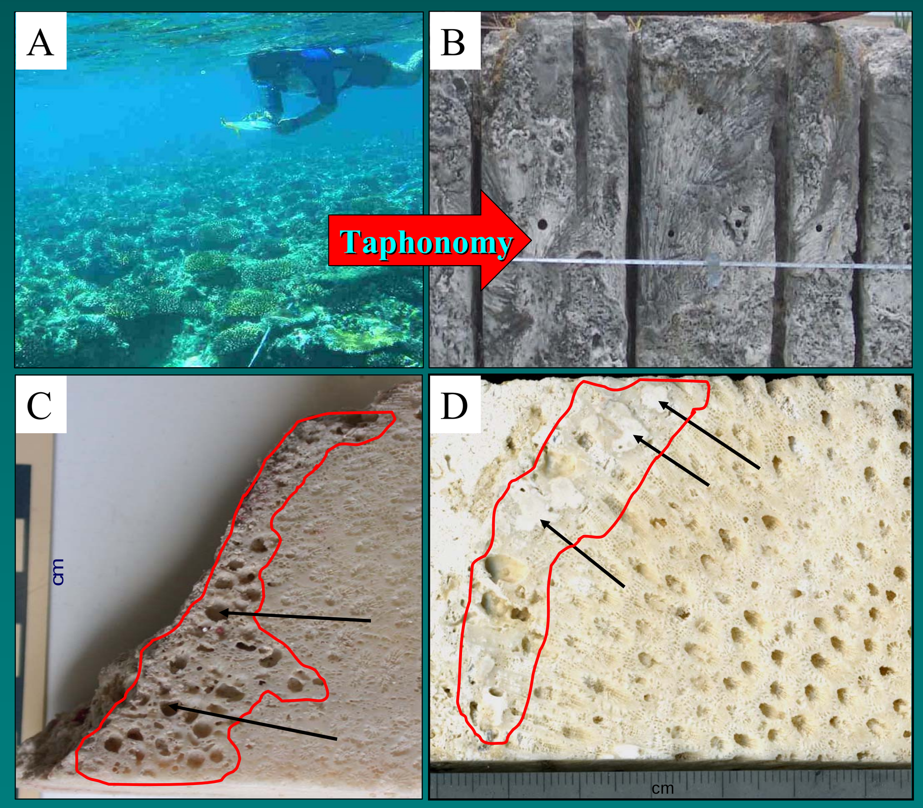
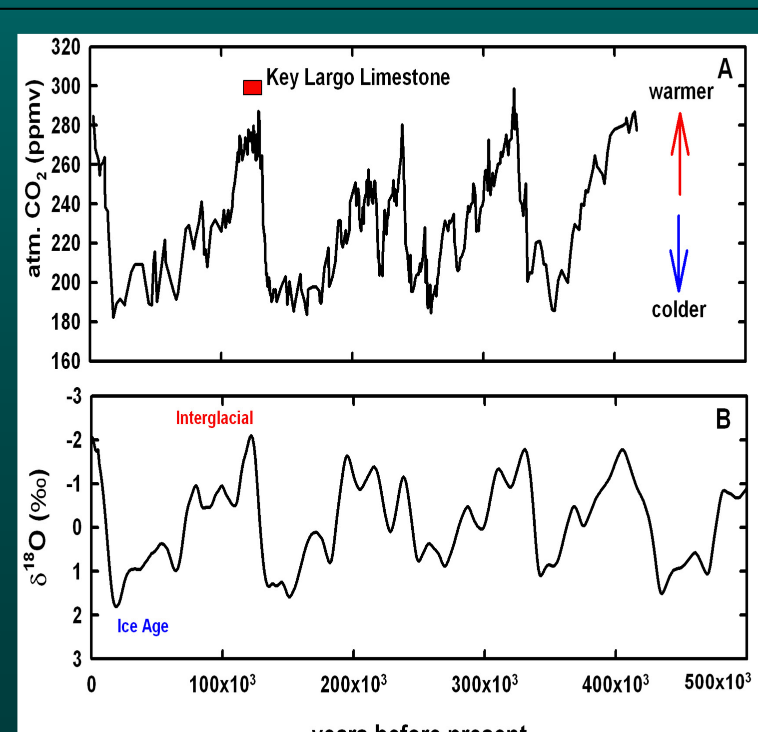


Figure 1: The primary objective of this research is to evaluate the difference in coral coverage between a living coral reef (A) and its fossilized counterpart (B). Coral alteration is induced primarily by bioerosion and also by physical processes, early diagenesis, and chemical interactions. The circled bioerosion zone on the *Montastraea annularis* rubble (C) from Biscayne Bay is analogous to the circled zone on a slice of fossilized *Montastraea annularis* (D) from the Key Largo Limestone. Arrows point to examples of bore holes (which are filled by fine-grained internal sediment for the fossilized sample).

ABSTRACT

Understanding the transformation of unconsolidated sediments into their lithified equivalents is an essential concept in geology, and is especially complex for coral reef deposits accumulating at marine and terrestrial interfaces. Because corals are used as paleoclimatic and paleoenvironmental proxies, it is important to identify the extent of alteration to their skeletons. The geographic proximity of ancient limestone reefs and modern reefs in southern Florida provides an ideal location to study coral taphonomy in similar systems separated by over 100,000 years. Linear transects measuring *in-situ* coral from living Florida Keys patch reefs (representing the once-living Key Largo Limestone reefs) and *in-situ* fossilized coral from patch reefs in the Pleistocene Key Largo Limestone at Windley Key, Florida were compared to gauge the extent of alteration with time. The Key Largo Limestone *in-situ* coral covered ~21% of the formation while the modern *in-situ* coral counterparts covered ~33%, suggesting that taphonomic processes reduced coral coverage by ~38%. Ultimately, bioerosion of coral skeletons is most likely the largest cause of alteration and loss of *in-situ* coral coverage. Fine scale X-ray diffraction and carbon and oxygen isotopic analysis of a serially sectioned fossilized coral sample were used to demonstrate biological "vital" effects of coral calcification similar in both modern and ancient examples. These analyses were also used to evaluate the extent of alteration of the fossilized coral due to interactions between seawater and meteoric fluids, which flushed through the deposit when exposed during sea level regressions. The influence of meteoric water caused the dissolution and re-precipitation of carbonate material, mediating mineralogical and isotopic transformations. The slices were also used to create a 3-D textural map of primary and secondary phases associated with coral taphonomy. The results of this integrated taphonomic study of an ancient coral reef may be used to help calibrate coral-based paleoenvironmental proxies.

Figure 2: This study assumes that the Pleistocene Key Largo Limestone was a series of patch reefs ecologically, volumetrically, and spatially analogous to present-day Florida patch reefs. Climatic, biologic, and morphologic similarities between the reef systems validate the assumption. (A) Records of atmospheric CO_2 concentration from the Vostok ice core in Antarctica (Petit et al., 1999) and the history of global ice volume (B), based on benthic foraminiferal $\delta^{18}O$ values from SPECMAP (Imbrie et al., 1989; McIntyre et al., 1989), provide an estimate of sea level. During the last glacial maximum, sea level may have dropped >150 m relative to today. The Key Largo Limestone accumulated during the prior interglacial, when temperatures were similar to today, with slightly higher sea level.



SAMPLE COLLECTION AND REEF – SCALE ANALYSIS

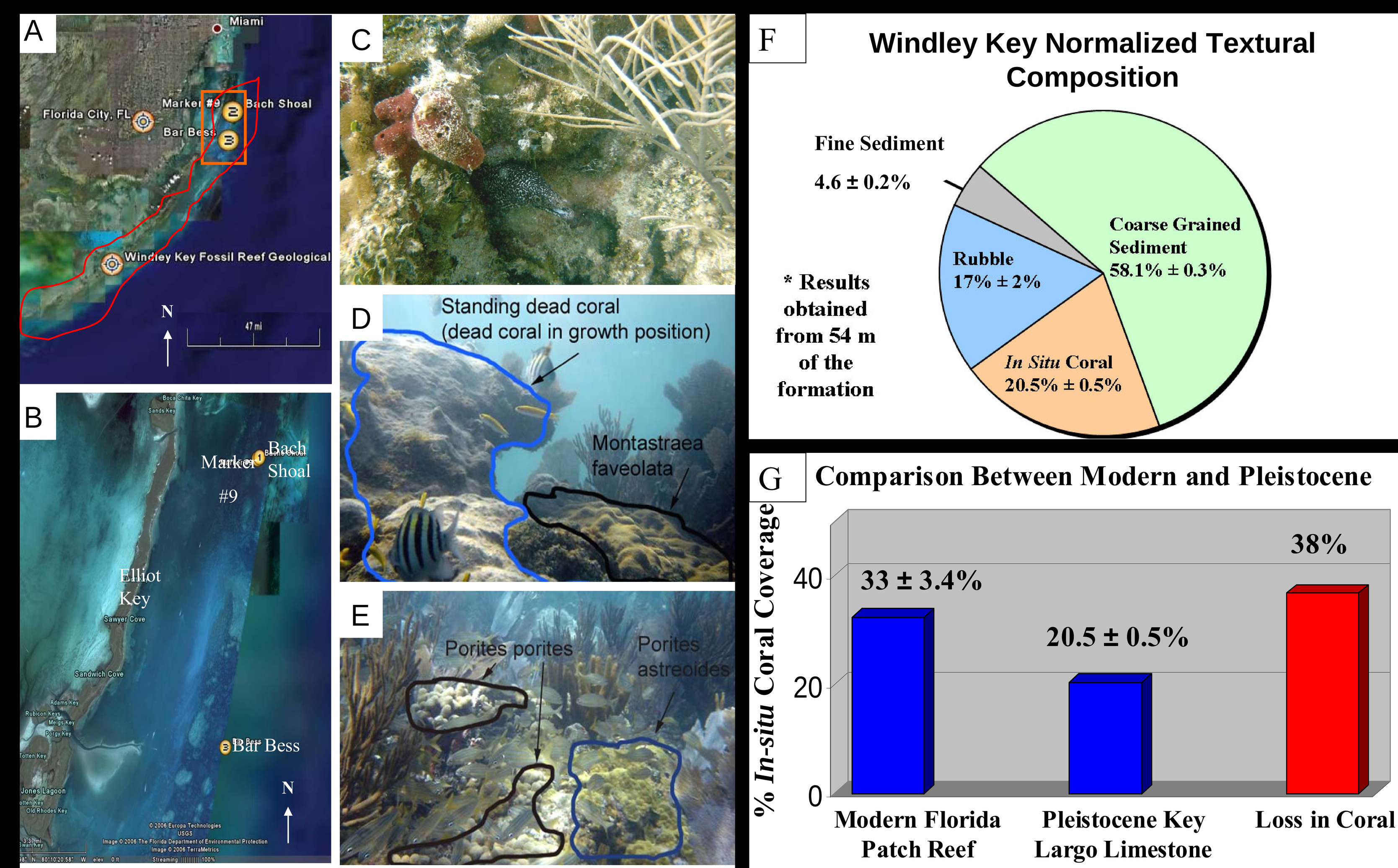


Figure 3: (A) Map identifies Windley Key and Florida City field sites (for Pleistocene coral analysis). Red enclosure marks the extent of Key Largo Limestone surface exposures. Orange box shows position of map B, which indicates sites (orange numbered points) for modern coral collection. Modern patch reef track observed to the west of Bar Bess site. Modern coral samples were collected from Bach Shoal (C), Bar Bess (D), and Marker #9 (E). Pleistocene Key Largo Limestone research, conducted at Windley Key, used seven linear transects to measure the textural composition of 69.1 m of the formation. (F) Normalizing the data by factoring out unidentifiable textures allowed for the identification of the *in-situ* coral coverage preserved at Windley Key. (G) Windley Key results were compared to the modern Florida patch reef coral coverage data, obtained from AGRRA, to estimate *in-situ* coral coverage loss due to taphonomy.

FINE – SCALE ANALYSIS

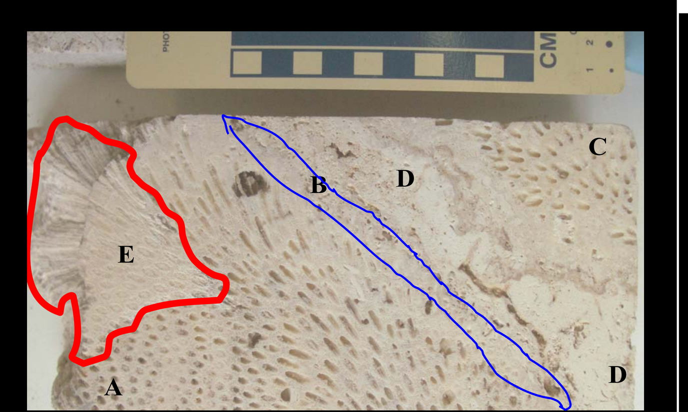
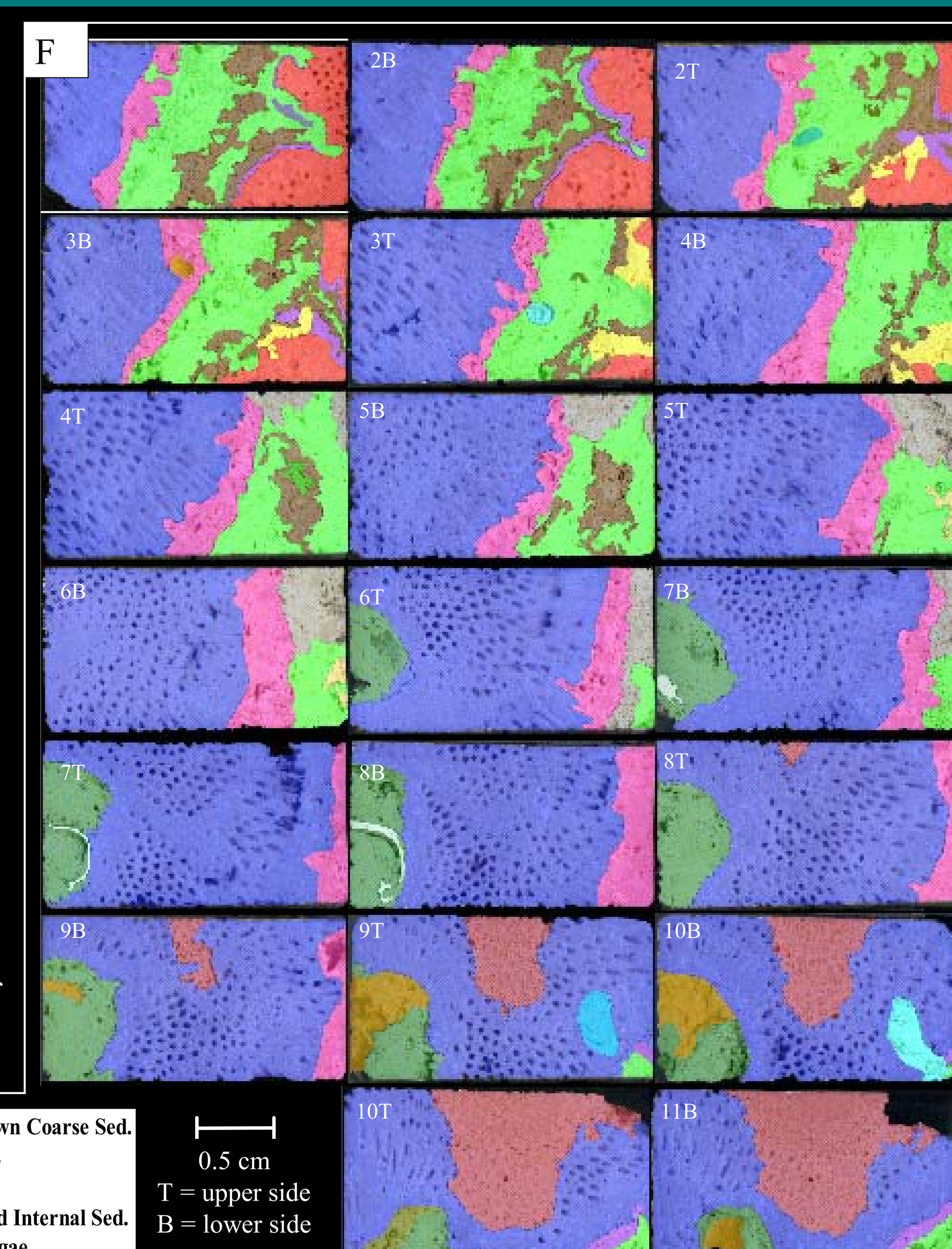


Figure 4: Representative Florida City sample used for fine-scale analysis. Two different fossils of *Montastraea annularis* (A, C) were determined to be 100% calcite. Fossil "A" is bounded by a bioerosion zone enclosed in blue (B). Corals are separated by calcareous sediment (D). The "bleached zone" enclosed in red (E) was determined by XRD to be 100% aragonite. The sample was serially sectioned into 10 slices (F). Superimposed colors on the slices represent various observed textural features. Slices were also used for isotopic and volumetric analysis. Distance between the bottoms of each slice to the top of the next slice is 0.2 cm. Slices were slightly different thicknesses.



ISOTOPIC ANALYSIS AND DISCUSSION

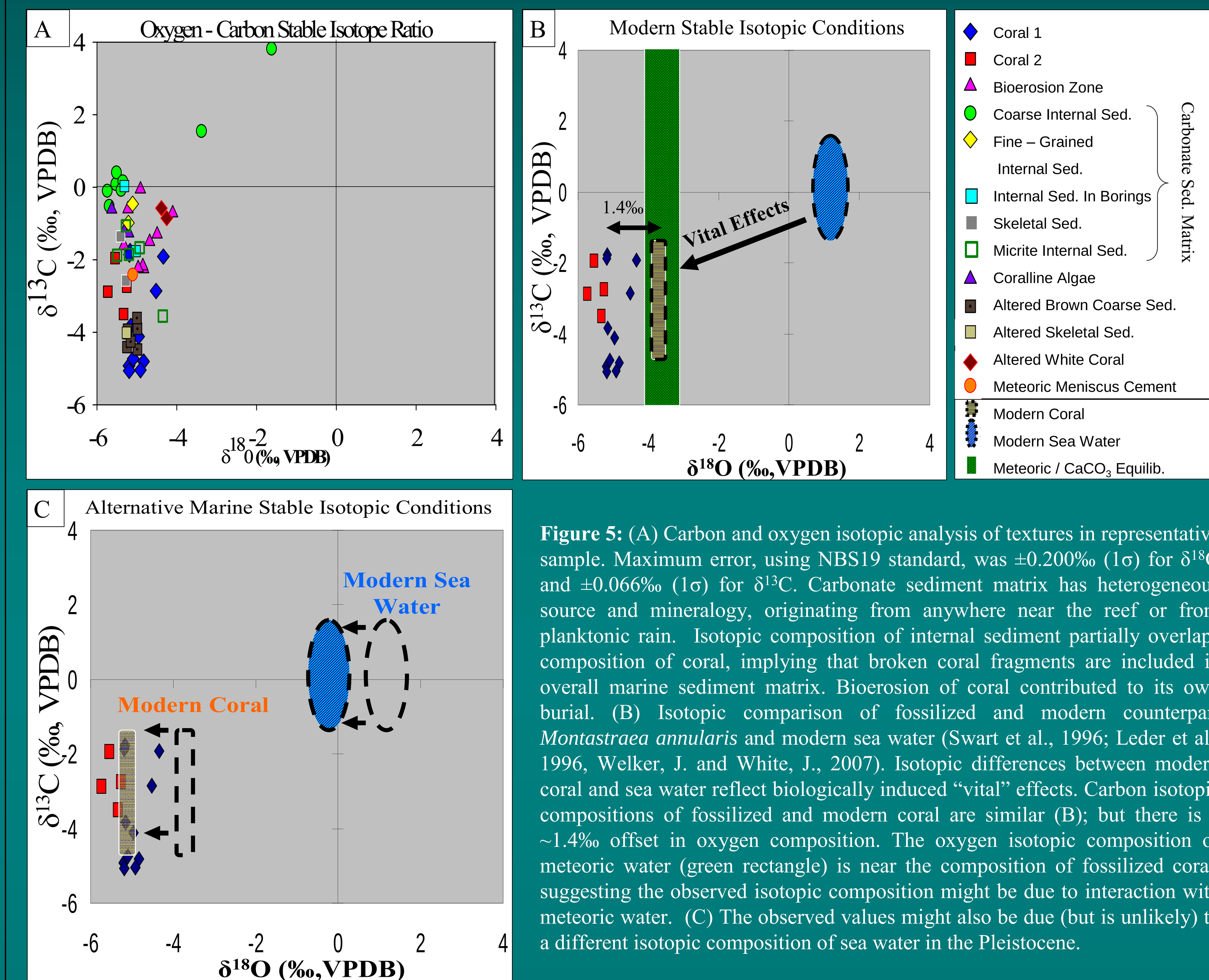


Figure 5: (A) Carbon and oxygen isotopic analysis of textures in representative sample. Maximum error, using NBS19 standard, was ±0.200‰ (1σ) for $\delta^{18}O$ and ±0.066‰ (1σ) for $\delta^{13}C$. Carbonate sediment matrix has heterogeneous source and mineralogy, originating from anywhere near the reef or from planktonic rain. Isotopic composition of internal sediment partially overlaps composition of coral, implying that broken coral fragments are included in overall marine sediment matrix. Bioerosion of coral contributed to its own burial. (B) Isotopic comparison of fossilized and modern counterpart *Montastraea annularis* and modern sea water (Swart et al., 1996; Leder et al., 1996, Welker, J. and White, J., 2007). Isotopic differences between modern coral and sea water reflect biologically induced "vital" effects. Carbon isotopic compositions of fossilized and modern coral are similar (B); but there is a ~1.4‰ offset in oxygen composition. The oxygen isotopic composition of meteoric water (green rectangle) is near the composition of fossilized coral, suggesting the observed isotopic composition might be due to interaction with meteoric water. (C) The observed values might also be due (but is unlikely) to a different isotopic composition of sea water in the Pleistocene.

CONCLUSION

- A comparison of preserved *in-situ* coral coverage at Windley Key with the coral coverage of living and standing dead coral in the modern Florida Keys patch reefs indicate that ~38% of *in-situ* coral coverage is lost in the preservation process.
- The largest major factor for coral loss is a high degree of bioerosion. The process creates sediment that ultimately buries the corals, and amplifies an already highly porous framework for fluid flow through the fossilized reef.
- The interaction of meteoric water with fossilized coral and sediment constitutes a major contributor to coral reef taphonomy and is the dominant process responsible for chemical and mineralogical changes. The bioerosion-induced increase in permeability aids the transformation of aragonite to calcite by the process of dissolution and re-precipitation.
- Loss of coral coverage is also recorded because branching coral observed in the modern patch reefs are sparsely preserved as *in-situ* fossilized coral in the quarry.
- A detailed history of taphonomic reduction should accompany studies of ancient reefs to better calibrate scientific results.

REFERENCES

Imbrie, J., McIntyre, A., and Mix, A.C., 1989, Oceanic Response to Orbital Forcing in the Late Quaternary: Observational and Experimental Strategies, *in* Berger, A., Schneider, S.H., and Duplessy J.C., eds., Climate and the Geosciences: Kluwer Academic Publishers, Boston, p. 121-164.

Leder, J.J., Swart, P.K., Szmant, A.M., and Dodge, R. E., 1996, The origin of variations in the isotopic record of scleractinian corals: I. Oxygen: Geochimica et Cosmochimica Acta, v. 60(15), p. 2857-2870.

McIntyre, A., Ruddiman, W.F. Karlin, K. and Mix, A.C., 1989, Surface water response of the equatorial Atlantic Ocean to orbital forcing: Paleoceanography v. 4, p. 19-55.

Petit, J.R., Jouzel, J., Raynaud, D., Barkov, N.I., Barnola, J.M., Basile, I., Benders, M., Chappellaz, J., Davis, M., Delayque, G., Delmotte, M., Kotlyakov, V.M., Legrand, M., Lipenkov, V.Y., Lorius, C., Pépin, L., Ritz, C., Saltzman, E., and Stievenard, M., 1999, Climate and atmospheric history of the past 420,000 years from the Vostok ice core, Antarctica: Nature, v. 399, p. 429-436.

Swart, P.K., Leder, J.J., Szmant, A.M., and Dodge, R.E., 1996, The origin of variations in the isotopic record of scleractinian corals: II. Carbon. Geochimica et Cosmochimica Acta, v. 60(15), p. 2871-2885.

Welker, J. and White, J., Natural Resource Ecology Laboratory, Colorado State University, United States Network for Isotopes in Precipitation (USNIP), http://www.nrel.colostate.edu/projects/usnip/usnip/fl11.htm. Checked March, 2007.