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Sizes, Shapes, and Patterns of Sediment Accumulations on a Modern Tidal Flat and Stratigraphic Implications: Three Creeks Area, Andros Island, Bahamas

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Construction of realistic geologic and simulation models of subsurface reservoirs requires data on the geometry and continuity of flow units, baffles, and barriers, parameters commonly constrained by log, core, seismic, and production data. If the minimum horizontal dimensions of facies bodies is less than the typical well spacing, however, properties will not be accurately described using either deterministic or stochastic methods. In these situations, seismic or production data can provide insights, yet still may include ambiguous characterization.

Analysis of modern analogs is one of the few other means by which high-resolution spatial complexity of stratigraphic systems can be described. This study integrated remote sensing, GIS, and sedimentology to analyze the spatial complexity and morphology of the modern tidal flats at Three Creeks, Andros Island, Bahamas. Landsat TM data were classified to create a thematic map of eight spectrally distinct classes and compared with published maps, aerial photos, and ultra-high resolution remote sensing images for sedimentologic interpretation (Figure 1). The spatial statistics of the interpreted map then were analyzed to characterize the sizes, shapes and patterns of sediment accumulations.

The results of these analyses show that:

1) Landsat data can be used to map sedimentary facies that are consistent with ground observations and existing maps, although the 28.5 m^2 pixel size precludes resolution of very small features;
2) Different facies have different mean size, ranging from 1539 m^2 (high algal marsh) to 5501 m^2 (marginal inland algal marsh) (Figure 2A);
3) Different facies have different shape complexities (low algal marsh = least complex and exposed levee/beach ridge = most complex) (Figure 2B). Shape can be analyzed through SqP, a dimensionless measure that compares each shape complexity to that of a square (Frohn, 1998). SqP is calculated as: $SqP = 1 - (4 * A^{1/2} / P)$, where: A = total area of a patch, P = perimeter of the patch. SqP can be

thought of as a measure of how much a shape deviates from that of a perfect square, with 0.0 being a square and 1.0 being maximum deviation from a square. Another measure of shape complexity is the ratio between the longest axis of the patch and the shortest axis of the patch. With this dimensionless metric, a higher ratio suggests that the patch is more elongate; a lower ratio suggests a more equant shape. Comparison among classes reveals that the mean ratio for all patches of exposed levee/beach ridge is highest (2.90, more elongate); lowest mean ratios are in patches of low algal marsh (2.25, more equant) and mangrove pond (2.20, more equant).

4) Mean area for each facies is related to entropy in lateral transitions (Hattori, 1976) and the total abundance of facies in the landscape (R^2=0.78; RMSE = 990m^2) (Figure 2C). With additional testing, this model may serve as a predictor of mean facies size in ancient successions;
5) Subfacies area-frequency (Figure 2D) and lacunarity (gap size distribution) data exhibit power law relationships over several orders of magnitude, indicating fractal characteristics (Plotnick et al. 1993);
6) Embedded Markov chain analysis of lateral transitions (chi-squared > 55,000) between different facies suggests that the tidal flat is an extremely ordered system; and
7) Mean patch size is highly correlated with proximity to tidal channel (R^2=0.87). This correlation may reflect influence of the more pronounced topographic changes nearer the tidal channels that leads to more rapid lateral facies changes that in turn lead to smaller patches.

The fractal nature of subfacies area and gaps between facies illustrate that this modern tidal flat has statistical behavior of a self-organized system. The high level of self-organization might be the statistical expression of ‘autogenic’ processes and are interpreted to be controlled by the subtle topographic gradients on the tidal flat (which may in turn also be fractal). These results are inconsistent with models suggesting that tidal flats include a migrating complex of randomly distributed, randomly sized subenvironments. Ancient successions that include random patterns may reflect the more pronounced influence of forces external to the sedimentary system, instead of an absence of those forces.

This study includes the some of the first systematic, quantified measures of high-resolution spatial heterogeneity in a modern carbonate depositional system (cf. Wilkinson et al. 1999), and the results may have pronounced implications for the large-scale processes and patterns of sediment accumulation, for prediction of facies dimensions and shape, for interpretation of the controls on vertical and lateral heterogeneity in the stratigraphic record, and for techniques of spatial analysis of sedimentary systems.

Works Cited

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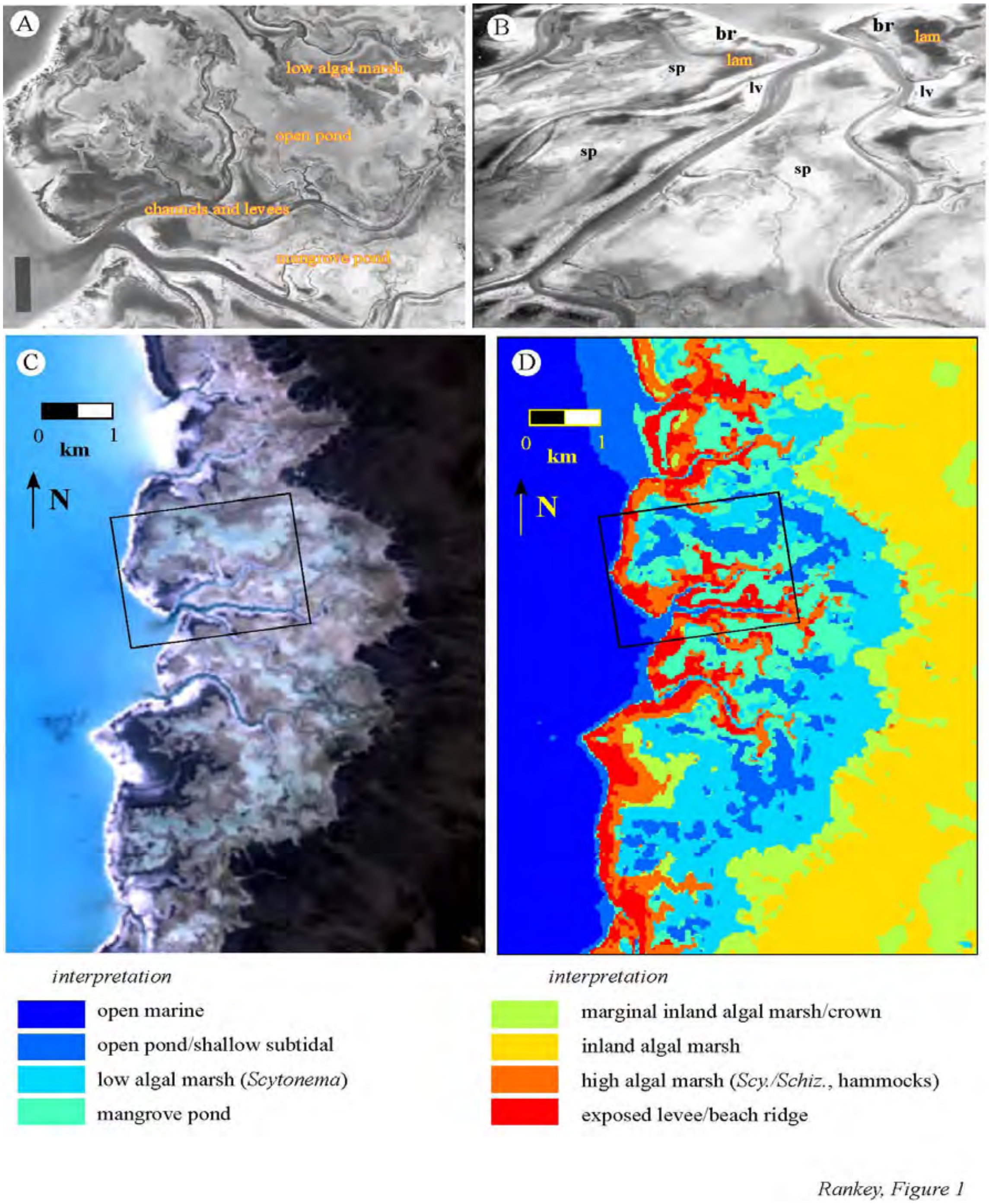
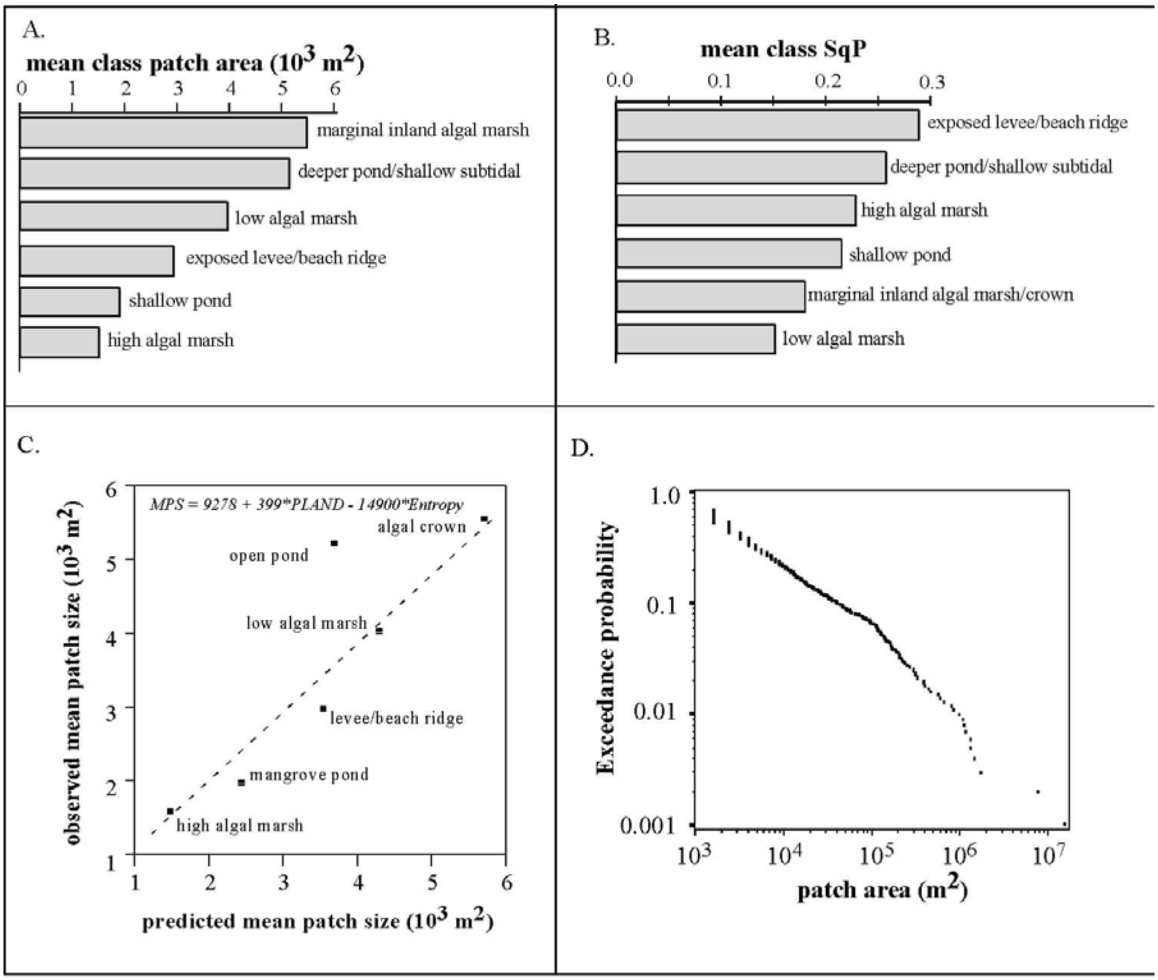


Figure 1. A). Aerial photograph of part of Three Creeks area. Some tidal flat subenvironments are labelled. B) Oblique aerial photograph of part of the Three Creeks area. Some tidal flat subenvironments are labelled. Sp = mangrove pond, br = beach ridge, lv = levee, lam = low algal marsh. C) Landsat TM rgb color image of study area. Black rectangle encloses the area of upper left aerial photo. D) Classified image from study area. Each color represents a spectrally distinct class. Black square is area of upper left aerial photo. Note that there is a good relationship between spectral classes and subenvironments observed on aerial photographs.



Rankey, Figure 2

Figure 2. Statistical characterization of facies and facies patterns, Three Creeks area, as assessed from Landsat data and GIS. A) Mean size of facies, not including the inland algal marsh and open marine facies. B) Mean class shape complexity (SqP). C) Multiple linear regression model between mean patch size for each class (in m^2, dependent variable) and percentage of class in landscape and entropy (independent variables). Class numbers are labelled. [For this analysis, class 1 and class 6 were not used, because of possible edge effects.] For this regression, R^2 = 0.78 and RMSE = 990 m^2. Note that mean patch area is well predicted using these variables that might be quantifiable from ancient peritidal successions. D) Plot of exceedance probability versus patch area, illustrating a power-law relationship between the two. This relationship illustrates that fractal nature of facies area and a fractal dimension of 1.21.