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CONTINUATION PROGRESS REPORT

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TITLE: Testing the correlation between seismic stratigraphy, diagenesis and physical rock properties: Evaluation of fluid flow during early and Late diagenesis

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OBJECTIVES:

This project, being conducted in collaboration with G. Eberli and P. Swart of the University of Miami, is designed to test the conceptual models of diagenesis developed by those researchers with numerical modeling of fluid flow through the Great Bahama Bank.

PROJECT DESCRIPTION:

The finite difference code HST3D is being used to simulate fluid flow, heat transport and solute transport through the Great Bahama Bank. Initial simulations are focussed on a 2-D profile for which the major hydrologic units and properties were chosen based on available seismic and core data provided by the Miami collaborators. The model is being used to assess the sensitivity of flow patterns and flow rates to variations in hydraulic, thermal and density gradients and boundary conditions. The numerical model will also be used to study the effects of sea level fluctuations and changes in permeability due to diagenesis. This will involve modification of the boundary conditions and permeability distribution to reflect conditions that are inferred to have existed during earlier diagenetic periods or as a result of sea level change.

RESULTS:

This project was initiated in April 1994. Simulations of fluid flow for isothermal conditions were used to investigate the sensitivity to variations in permeability within the bank created by five major permeability zones. These zones consist of carbonate deposited 1) in the Straits of Florida, 2) on the Bimini Bank, 3) in the Straits of Andros, 4) on the Andros Bank and 5) during Holocene time, draping the upper surface of the bank. These simulations also assessed the sensitivity to variations in head between Andros Island, the western portion of the bank extending to the Straits of Florida, and the eastern Tongue of the Ocean. Anisotropy of permeability, which is consistent with large vertical variations of permeability measured in core studies, tends to promote fluid flow across the bank, while isotropic conditions lead to a divide beneath Andros Island. Large permeability contrasts between the Holocene carbonate and the underlying bank and straits permeability zones results in strong horizontal flow in the upper portion of the bank and weaker vertical flow at the boundaries between the bank and straits units (see Figure 1).

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Coupled fluid flow and heat transport simulations are being used to examine the potential for Kohout convection in a heterogeneous bank and to compare the significance of head variations across the bank with temperature variations and geothermal heat flux along the lateral and basal boundaries as driving forces for fluid circulation. In the absence of heterogeneity and for bank permeabilities ranging from 10-15 to 10-12 m²/sec, flow patterns appear to be dominated by convection cells (see Figure 2). For a heterogeneous permeability distribution, rapid flow occurs through the upper bank and Kohout convection is simulated for contrasts in horizontal permeability of one order of magnitude or more between bank and straits deposits and anisotropy ratios of 100 to 1000 (see Figure 3). Simulations show some evidence of convection cells persisting in the central portion of the bank. We are now attempting additional grid refinement in order to determine whether these convection cells are physically realistic or controlled in part by the grid of the numerical model.

Preliminary conclusions of the coupled heat and fluid flow modeling include the following. Temperature gradients and heat flow appear to dominate head differences as a driving force for circulation in the Bahama Bank under present day boundary conditions. Flow patterns and temperature distributions are sensitive to bank scale heterogeneity and to the magnitudes of permeability and anisotropy. Higher permeabilities generally result in lower temperature gradients with depth and in increased areas of low temperature near the lateral boundaries resulting from Kohout convection. Vertical gradients of temperature along the steep edges of the bank are particularly sensitive to permeability magnitudes and contrasts within the bank. This suggests that temperature measurements in holes drilled in these areas, as proposed for an upcoming leg of the Ocean Drilling Program, may provide better constraints on permeability than measurements in holes through the top of the platform.

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Figure 1 - Velocity vectors and flow patterns for isothermal flow in a heterogeneous bank. Holocene deposits (facies I) are modeled as isotropic with permeability of 10^{-14} m². Facies II and III are modeled as anisotropic with horizontal permeabilities of 10^{-12} m² and 10^{-13} m² respectively. Horizontal permeabilities are 1000 times vertical permeabilities for these two facies. Cross bank flow is generated by a head difference of 30 cm between the Florida Straits and the Tongue of the Ocean.

Homogeneous, and Isotropic
 $k = 10^{-14} \text{ m}^2$

Temperature Distribution

Velocity Vectors

Figure 2 - Temperature distribution and velocity vectors for simulation of coupled heat and fluid flow in a bank with homogeneous permeability distribution.

$$\begin{aligned}
 k_{lx} &= 10^{-11} \text{ m}^2 & k_{llz} &= 10^{-11} \text{ m}^2 \\
 k_{lix} &= 10^{-12} \text{ m}^2 & k_{llz} &= 10^{-15} \text{ m}^2 \\
 k_{llx} &= 10^{-13} \text{ m}^2 & k_{llz} &= 10^{-16} \text{ m}^2
 \end{aligned}$$

Temperature Distribution

Velocity Vectors

Figure 3 - Temperature distribution and velocity vectors for simulation of coupled heat and fluid flow in a bank with heterogeneous permeability distribution. Facies I, II and III are as shown on Figure 1. Horizontal permeability is k_x and vertical permeability is k_z .