Viviana Díaz was born in Puerto Rico and received her undergraduate degree from the University of Puerto Rico and her Master's at the University of North Carolina. She is currently working on her PhD at the Rosentiel School of Marine and Atmospheric Sciences (RSMC) at the University of Miami.

Effects of depositional and diagenetic heterogeneitites on fluid flow in Plio-Pleistocene reefal carbonates of the Southern Dominican Republic

Project Goal:

The goal of this project is to assess the effects of depositional and diagenetic heterogeneities on reservoir-scale fluid transport in reefal carbonates using hydraulic conductivity measurements obtained from down-hole straddle-packer injection tests in the southern Dominican Republic.

Project Rationale:

The challenge of predicting fluid flow in carbonate aquifers and reservoirs arises from the complex porosity and permeability distribution dependent on both primary matrix porosity related to depositional facies and secondary porosity resulting from diagenesis. However, this complex porosity distribution is reflected in measurements of hydraulic conductivity (K), and the challenge of predicting transport in carbonates can be addressed if variations in K are assessed at a scale that captures depositional and diagenetic heterogeneities.

I propose to conduct in situ straddle-packer measurements of hydraulic conductivity in a series of five existing boreholes, with continuous core. This study will integrate surface and subsurface stratigraphic, depositional, diagenetic and petrophysical data with hydrogeologic data in order to characterize the factors that influence hydraulic properties of Plio-Pleistocene reefal limestones of the Dominican Republic (figure 1). When completed, vertical profiles of hydraulic conductivity will be obtained from short-interval packer tests performed in a transect of five wells drilled perpendicular to the prograding depositional packages. These packer tests provide for calculation of hydraulic conductivity data on both matrix and dissolution zones. The long-term goal of the project is to obtain hydro stratigraphic data from the Plio-Pleistocene carbonates that can be incorporated into a reservoir flow simulation model.

The southern coast of the Dominican Republic is characterized by 6-8 fairly continuous reefal limestone terraces (figure 1). These terraces formed during sea level highstands, and range in age from ~2.5 Ma to 125 Ka. The terraces are preserved by long-term tectonic uplift, such that the youngest deposits are located at the lower elevations and closest to the coast. In the summer of 2010 five core borings were collected along a transect of the southern coast. These cores and associated boreholes provide an unprecedented opportunity to study the petrophysical properties and porosity/permeability evolution of reefal limestones after several stages of post-depositional stabilization related to high frequency sea-level changes. Depositional facies have been established by describing rock textures and faunal description on both core and outcrop, and diagenetic zones have been defined. In the absence of shallow seismic and borehole log data efforts have concentrated on generating the highest resolution age constraints possible for correlation. The age data, combined with depositional lithofacies and faunal indicators has allowed us to better define the internal anatomy and stratal geometry of the individual sigmoids and sigmoid sets (Figure 1). The ages are also important in assessing the progressive evolution of the porosity-permeability system that will be characterize in the hydraulic conductivity study. The link between depositional and diagenetic facies to rock properties has been established by petrophysical properties (porosity, permeability, ultrasonic velocity and electrical resistivity). While the existing data provides an unprecedented characterization of the relationship between rock properties and depositional and diagenetic heterogeneities, it does not provide an adequate characterization of the larger scale porosity development needed to accurately characterize fluid flow. By linking this data with in situ measurements of hydraulic conductivity I hope to establish the link between depositional facies, diagenesis, and fluid flow. I will also assess the ability to predict flow properties based on acoustic data. This study will provide critical new data relevant to groundwater and reservoir flow models in carbonate systems.

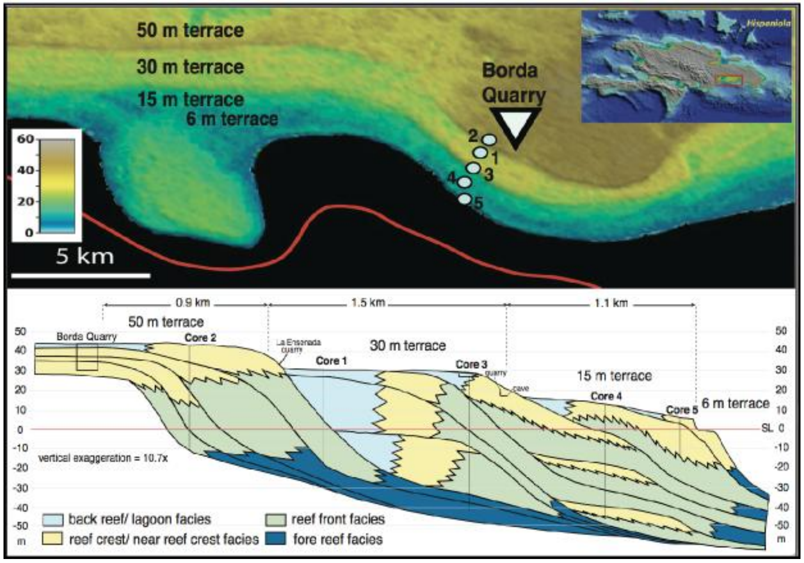


Figure 1: (A.) Location of borehole transect within Plio-Pleistocene prograding terraces of the southern Dominican Republic. (B.) Cross-sectional model of reef sigmoids based on depositional facies and preliminary chrono-stratigraphy of the five drilled borehole cores.

Methodology:

Vertical profiles of hydraulic conductivity, obtained from short-interval (~1 m) packer tests in a transect of five wells drilled across the prograding clinothems will provide a two-dimensional framework of fluid flow in four reef terraces of Plio-Pleistocene age. Packer data are used to calculate hydraulic conductivity from the borehole. Integration of previous core data, mainly depositional and diagenetic facies, and petrophysical data will be correlated with the short-interval packer data.

Vertical and lateral variability in hydraulic conductivity will be calculated from constant-head injection tests performed in five wells from 25 m to 70 m deep. A straddle-packer assemblage (~1 m injection length) will be used for the injection tests at 1.0 m intervals in each borehole. Hvorslev (1951) developed an equation for analyzing steady state, constant-head injection tests. Although designed for saturated zones, the method has applications in unsaturated zones. If L is greater than $5r$, as is the case in all testing proposed here, the equation simplifies to:

$$K = \frac{\left(Q \ln\left(\frac{L}{r}\right)\right)}{2\pi HL}$$

Where K is the hydraulic conductivity, r is the radius of the well, L is the length of the test interval, H is the injection head, and Q is the injection rate. Detailed descriptions of the constant-head injection test procedure are provided in Harlow and Lecain (1993).

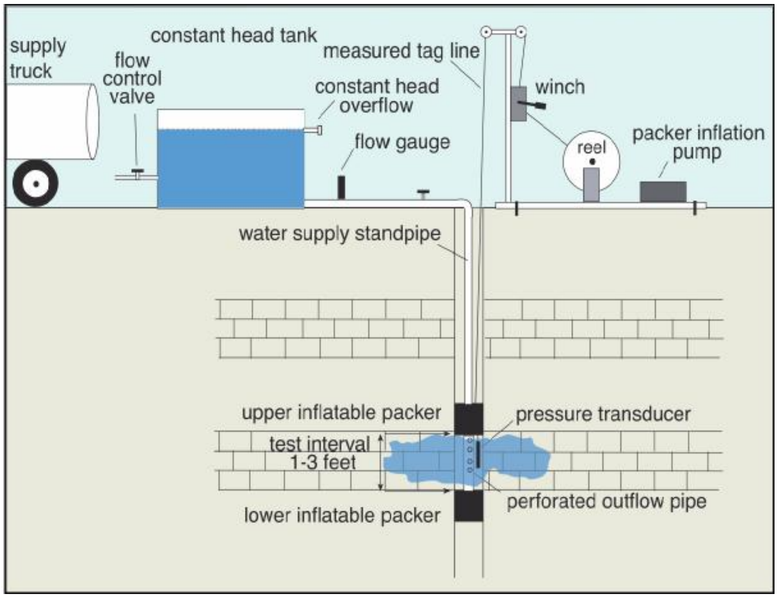
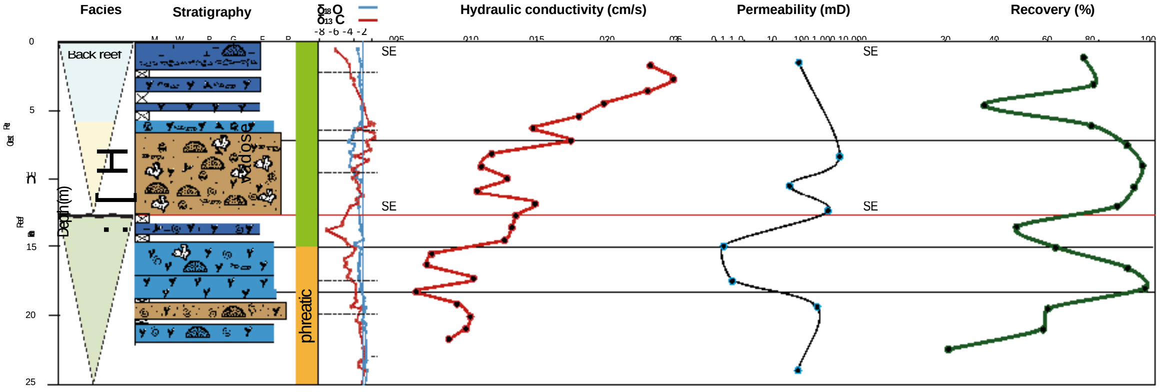


Figure 2. Constant-head injection test setup. A test interval of 1m of pvc pipe is added moving down the borehole. The high water supply needed for this porous carbonates is provided by a water supply truck that sends water to a cistern where a constant head is maintained.

While the short measurement interval was designed to minimize the averaging inherent with most packer tests, this methodology has limitations. Resulting hydraulic conductivities are still averaged over the length of the test interval; for matrix dominated test intervals this is probably appropriate. For fracture or dissolution dominated test intervals, the bulk of the flow is carried through an individual fracture or a cavity despite representing a minor percentage of the overall test-interval length. In order to calculate realistic fracture or cavity transmissivities, it would be necessary to know the number and apertures of these structures. These data are not available.



Preliminary results obtained this past summer 2012 from 22 m of core 3 show hydraulic conductivity (*K*) changes through two shallowing-upward sequences. The hydraulic conductivity trend shows a relationship with 1) facies control and 2) diagenetic overprint related to secondary dissolution and cementation in the meteoric environment. The characteristic fringing cements of the phreatic zone in the lower sequence overprint original primary porosity and occlude pore connectivity resulting in low K values. In the upper sequence facies controls porosity and permeability distribution with lower K in facies where high -energy water flux increases cementation (i.e. reef crest).

Figure 3. Plot showing hydraulic conductivity with depth in core 3. Measurements span two highstand reef sequences separated by a subaerial exposure surface. Stable isotope data and permeability data from petrophysical cores is included for comparison. Core recovery is used as as a proxy for secondary macro-porosity.

Key Deliverables:

Vertical profiles of hydraulic conductivity obtained from the short-interval (~1 m) packer tests will provide a two-dimensional framework of fluid flow in four reef terraces of Plio-Pleistocene age. When completed, the study will provide a facies/diagenesis/acoustic-based correlation of permeability (hydraulic conductivity) data after several stages of post-depositional stabilization. These correlations will then be used (in a later phase) as formation properties in fluid-flow simulation models for shallow-water carbonates.

Bibliography:

Hvorslev M.J. 1951, Time-lag and soil permeability in groundwater observations. US Army Corps Eng Waterways Exp Stat Bull 36, 50 pp.

Harlow G.E., and Lecain G.D. 1993, Hydraulic characteristics of, and Ground-water flow in, coal-bearing rocks of southwestern Virginia. US Geol Surv Water-Supply Paper 2388, 36 pp.