Deep Panuke:
The Integration of Geology, Geophysics and Reservoir Engineering for Field Appraisal

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Summary:

In the late 1990's EnCana discovered the Deep Panuke Field some 250 km offshore Nova Scotia. Within the last few years a total of nine wells were drilled to explore the field. In a combined effort of geology, geophysics and reservoir engineering the static and dynamic reservoir characteristics of the Deep Panuke Field were analyzed. This paper discussed the integrated approach, which lead to an improved understanding of the subsurface.

Geological Overview:

The Deep Panuke natural gas field occurs in the carbonate platform (Abenaki Formation) which formed along the East Coast of North America during the opening of the Atlantic Ocean in the Middle to Late Jurassic, approximately 170 to 128 million years ago. The reservoir is made up of limestone and dolomite. The natural gas pool is contained in a combined structural/stratigraphic trap. The general location of the field is shown in figure 1.

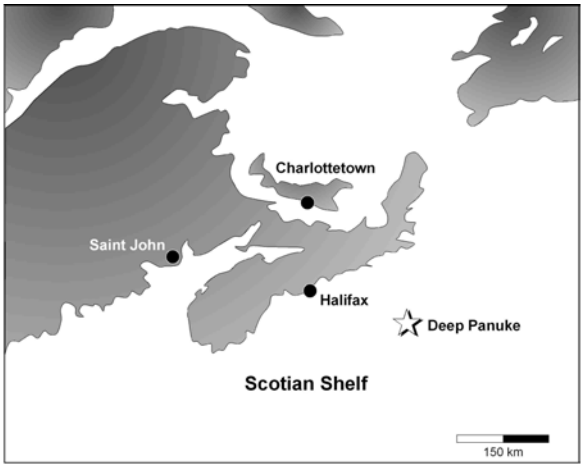


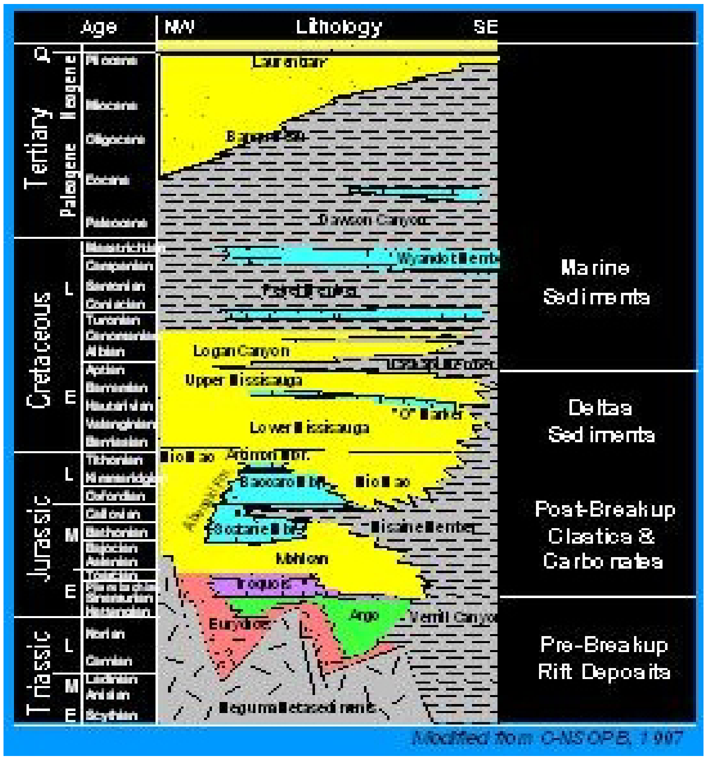
Figure 1: Location of the Panuke

A carbonate ramp was established on the outer edge of the shelf during the Bathonain (Scatarie Member, Abenaki Formation). This ramp was drowned during Callovian and deeper water siliciclastics were again deposited (Misaine Member, Abenaki Formation).

The carbonate system was reestablished from the Oxforidian to Early Berriasian as a thick platform of agrading and prograding carbonate cycles (Baccaro Member, Abenaki Formation). The reservoir occurs in the platform margin which consists of a mixture of deeper water reefs, reef rubble, and foreslope sediments. The Baccaro is capped by the Artimon Member, which consists of deeper water siliciclastics and sponge mounds, and represents deposition during the drowning of the carbonate platform.

Outboard of the carbonate margin, deep-water siliciclastics were deposited (Verrill Canyon Formation). Marginward of the carbonate system, siliciclastics were deposited in a fluvial/deltaic to shoreline setting (Mic Mac Formation). The general stratigraphy of the Scotian Shelf is show in figure 2.

The rocks of the Abenaki formation show indications of early marine cementation and compaction. There is some evidence for exposure and karst, but it is probable probable that the main diagenetic processes are deep burial related. The reservoir is made up of secondary porosity related to dolomitization and dissolution. Reservoir creating diagenesis has been focused primarily along the carbonate margin edge and along lineaments in the platform interior.



Modified from C-NSOPB, 1997

Figure 2: Generalized Stratigraphy, Nova Scotia

Data Base:

A total of nine deep wells were drilled in the vicinity of the field. Most of these wells have a complete set of logs. Shear sonics were acquired in eight of these wells and a few wells have VSP data. Some 450 km2 of 3D seismic were acquired across the study area. High quality seismic processing included PSTM, PSDM, P+S impedances and LMR volumes. The PSDM volume allowed for an optimal picking of the target horizons. The time converted PSDM made a superior depth conversion possible to image the reservoir model in depth. The simultaneous analysis of all processing volumes allowed for an optimized reservoir characterization.

Seismic Reservoir Characterization

The reservoir characterization was conducted in several steps. At first, the distribution of basin - reef – back reef was analyzed with a supervised neural network approach. Training and validation samples were collected from each area and fed into a neural network. Seismic attributes from the PSDM and AVO cubes served as input nodes for the neural network. The output volumes were probabilities for basin, reef, and back (figures 3a-d). The next step focused on the feasibility of porosity prediction. Using sonic, density logs, impedance, and LMR logs the relation between seismic data and porosity was modeled. In the end a set of significant seismic attributes was determined. These attributes were extracted from the 3D seismic volumes in a 3x3 trace area around each well and a neural network was trained to predict porosity. Finally, these attributes were extracted from the full volume and feed into the trained neural network to compute a porosity volume.

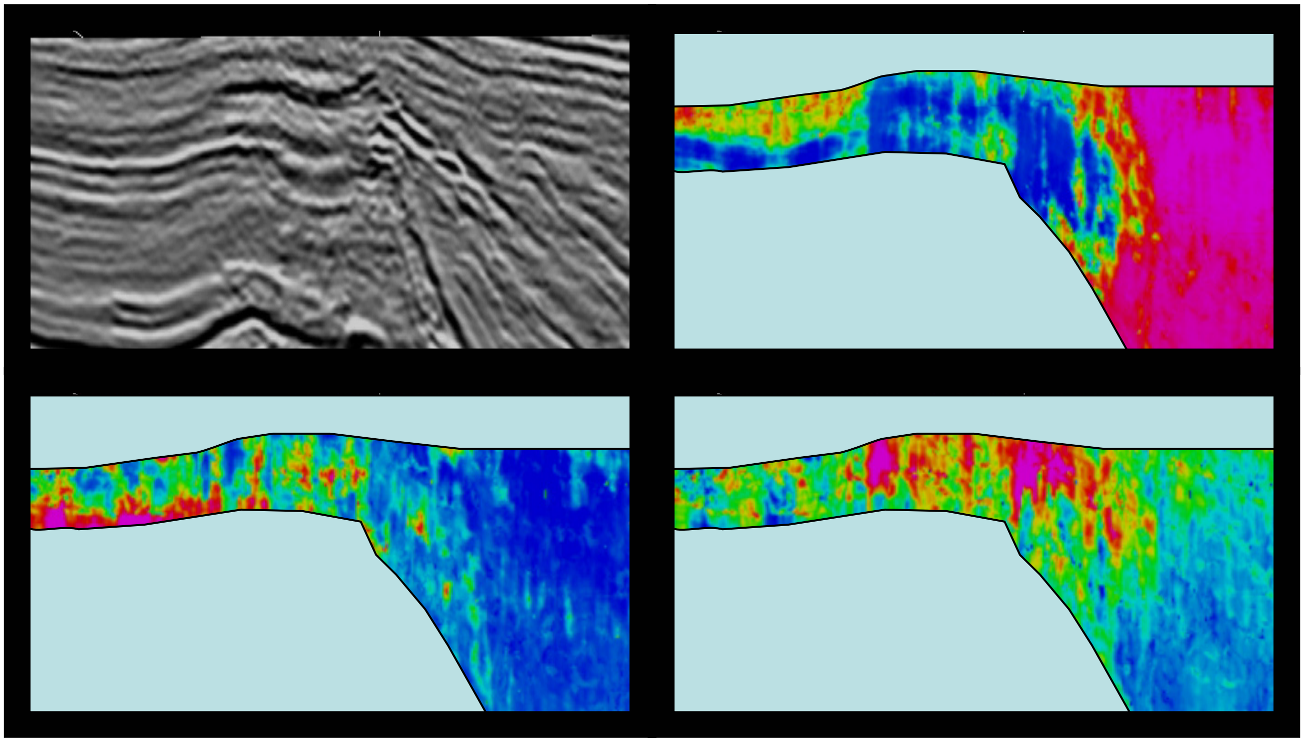


Figure 3:
a) Seismic PSDM Section
Probability for b) Basinal Facis c) Back Reef Facies d) Reef Facies
Hot colors indicate high probability

Static and Dynamic Reservoir Model Integration

The development of the reservoir model was based upon the integration of the geological and geophysical interpretations by the use of geostatistical modeling techniques to develop many field scale porosity and permeability models of the reservoir.

All of the appropriate geophysical, geological and engineering information is integrated into a “shared earth model”, containing the full 3D representation of the reservoir. The structural model is built using the well control and seismic surfaces converted to depth. The property model is generated using seismic attributes, correlated to the available well log and core data. A variety of property models have been tested.
These models were then simulated and compared to well production data to test their validity. The process is iterative and has lead to marked improvements in all facets of the characterization of the reservoir.

Five production well tests have been performed in the Deep Panuke field. These production tests provide significant value and information to guide both the conceptual geologic model and the shared earth model property model. Due to the complex relationship between the rock fabric and permeability, the production test provide an excellent source of large scale permeability values and are critical in reducing the uncertainty in the permeability estimates. All models used in predicting future production performance are history matched to the well tests.

Static uncertainty of the inputs of the modeling workflow was assessed. Integration of stochastic models and history matching has always been a challenge. If the information from the well tests cannot be directly included in the shared earth model, then each realization has to be history matched. This problem has been solved by estimating resource volumes via Monte Carlo techniques, history matching select realizations and using experimental design techniques to assess dynamic uncertainty.

The result of the integration effort has been the generation of reservoir models which honor multi-disciplinary inputs and have a reasonable match to well test results. These models have been used to define the reservoir and permit simulation of future productivity.