Application of Predictive Modeling to the Lower Cretaceous Sedimentary Sequences of the Central Scotian Basin

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Summary

“Source to sink” studies and numerical modeling software have been used to better assess the evolution of sedimentary basins and predict the location of sandstone reservoirs in petroleum basins around the world. Such studies integrate sedimentological and geophysical research with forward stratigraphic modeling techniques to generate predictive facies models of complex depositional settings. This study applies these methods to the Lower Cretaceous delta system of the central Scotian Basin in order to attempt to better understand the distribution and deposition of reservoir sandstone intervals within this area.

Figure 1: Isopach map of offshore Nova Scotia, showing the study area and distribution of reference wells used. Map modified from Wade and MacLean (1990).
Introduction

The distribution and quality of the Lower Cretaceous reservoir sandstone units of the Nova Scotia offshore (Fig. 1) is poorly understood, particularly in the deep basin, where few wells have been drilled. Exploration is further complicated by the widespread salt tectonism and the strong influence of diagenesis on reservoir quality. This project uses forward stratigraphic models of the central Scotian Basin and tests their sensitivity to changes in supply of sediment and subsidence. This study focuses on two Lower Cretaceous reservoir units and an intervening seal: the Upper Missisauga Formation (Late Hauterivian and Barremian), the Naskapi Member (Aptian), and the Cree Member (Albian). These units were supplied with sediments by three main river systems: local rivers from the Meguma Terrane, the Sable River, and the Banquereau River (Zhang et al. 2014). This study uses the forward stratigraphic modeling to: 1) test if provenance pathways proposed in the literature can recreate the sedimentation of the Early Cretaceous; 2) determine the distribution and extent of sands in the Scotian Basin and whether they are trapped on the slope or bypass to the deep ocean floor; and 3) determine the factors which control the distribution of sands within the study area.

Methods

This project uses DionisosFlow™, a forward stratigraphic modeling software, and CougarFlow™, statistical analysis software, to produce predictive stratigraphic models of the central Scotian Basin, and test the sensitivity of produced models. DionisosFlow™ is a deterministic 4D multi-lithology forward stratigraphic modeling software that simulates basin infill over geological time scales (Granjeon 1996). This software reconstructs geological processes in a sequence of time steps with the intention of quantifying the average geometries and facies of sedimentary units (Granjeon and Joseph 1999), reproducing the net result of sediment supply, transport, and accommodation with regards to uplift, subsidence, and sea level fluctuation. DionisosFlow™ uses a sediment diffusion equation that simulates sediment transport with regards to water discharge, sediment load, and slope for particles with differing grain properties, which are tracked during the evolution of the basin. Model results are calibrated against well logs, facies, and seismic interpretations of the study area to produce predictive stratigraphic models. Once the reference case models are calibrated, CougarFlow™ is used to determine the relative contribution of different parameters to simulation results. This is achieved by running large numbers of DionisosFlow™ simulations and altering the parameters. The results from these simulations are used to generate a response surface, upon which statistical analyses are run. Subsidence, water discharge, sediment load, and mud content have been tested to determine their influence on the models.

Examples

1. Simulation Parameters

In order to produce stratigraphic models using DionisosFlow™, data on sea floor bathymetry, sea level, sediment source locations, water discharge, sediment supply, and sediment properties (i.e. grain size and density) are required. These parameters are drawn from previous research conducted in the study area. The study area is 185 km x 215 km and is simulated using a cell size of 5 km x 5 km, with time steps of 0.25 Ma over a period of 30 Ma.

DionisosFlow™ requires a starting configuration in order to simulate basin infill: this is the initial bathymetry. Bathymetric maps were produced on the basis of facies interpretations from palynological studies (Gould et al. 2012), shelf edge interpretations from seismic, and published studies of general slope morphology. The Miller et al. (2005) sea-level curve has been applied. Drainage basins supplying sediment to the study area are identified on the basis
of mineralogical provenance studies conducted in the region. Three sources have been selected to simulate the Upper Missisauga Formation and Cree Members, with only a single source for the Naskapi Member, based on inferred effects of tectonics on river patterns. Initial sediment supply and water discharge values supplied by these sources are based on estimates of the catchment areas and relief, which are compared with water and sediment loads of modern systems. The ranges in sediment grain size supplied to the central Scotian Basin by these sources are based on point counting of sandstones from throughout the study area.

2. Provenance Model

Reference case models were generated for all three units and were initially calibrated against unit thickness from seismic picks and at wells with >75% match. This suggests that the proposed provenance model can be used to generate realistic predictive models of the central Scotian Basin.

However, attempts to calibrate against lithofacies distribution in wells were less successful, with only 80% similarity in some cases. In the Upper Missisauga Formation the Cohasset L-97 and Venture B-52 wells (Fig. 1) show a low calibration on the basis of lithofacies, and the Venture B-52 well continues to be an issue in the Cree Member. The Cohasset L-97 well has a relatively muddy composition, however detailed correlations in the area of this well show that within three cells of the simulated grid other wells show 35% more sand (Gould et al., 2012). Seismic and core studies show that abundant channels were active during the Early Cretaceous, particularly in the eastern Sable Sub-basin, where the Venture B-52 well is located. These channel systems are commonly less than the size of the cells used during simulations, and can be infilled with either sand or shale depending on the depositional environment at their time of formation (Cummings and Arnott, 2005). Local autocyclic variability in sand and mud deposition in estuarine and tidal flat depositional systems takes place on a spatial scale that cannot be captured by a model with a 5 km grid.

In the Naskapi Member the Banquereau C-21 (Fig. 1) well also shows a low calibration of lithofacies. This well contains intervals which are composed of coarser sediment than in other wells of the same age. The mud rich Naskapi Member has been suggested to have formed as a result of the diversion of major rivers to the Scotian Basin. The decreased level of calibration, and increase in coarse sediments in this well may indicate an occasional return of the Banquereau River to the region. Alternatively, the stratigraphic pick on the base of the Naskapi Member in this well may be wrong.

3. Sand Distribution

Model results indicate that the style of sand deposition changed through time. In the Upper Missisauga Formation (Fig. 2a), sand was trapped dominantly on the shelf, with lesser deposition in minibasins along the slope and basin, and transport into the deep basin along salt evacuation corridors. This system became shale dominated in the Naskapi Member (Fig. 2b), as a result of changed input of riverine sediment, with minor sands trapped dominantly on the shelf and very limited transport into the basin. In the Cree Member (Fig. 2c) sand deposition returned to a similar style as the Upper Missisauga Formation, with greater transport deep into the basin along salt corridors and accumulation in minibasins along the slope. The extent to which sand is transported into the deep basin is important for exploration. Simulation results suggest that sand is transported into the basin, accumulating in minibasins in three areas: the western part of the basin downslope from the Alma F-67 well, the central basin proximal to the Annapolis G-24 and Crimson F-81 wells, and the eastern part of the basin downslope from the Tantallon M-41 well. The eastern basin shows the largest concentration of sand of these areas. The model also
suggests that the salt corridors are capable of delivering sediment to the deep basin (Fig. 2a,c), suggesting that a small amount of sand is bypassing the slope and may be transported to deep water.

Figure 2: Weighted average sand proportion maps for the a) Upper Missisauga Formation, b) Naskapi Member, and c) Cree Member.

4. Controls on Sand Distribution

Sensitivity analysis of the reference case models suggests that sand distribution is most sensitive along the upper slope and near salt bodies. However, sand rich minibasins in the basin, and salt corridors leading to the deep basin show lower variation, suggesting that locations of minibasins and salt corridors are likely correct. Statistical analysis shows that the composition of the source rivers and salt movement are the dominant parameters controlling sand distribution within the basin.

Conclusions

Simulation results show that proposed provenance pathways for the Early Cretaceous can be used to generate predictive stratigraphic models which simulate the overall sediment distribution for the central Scotian Basin. Modelling confirms that the shaly nature of the Naskapi Member is the result of tectonic diversion of the Sable River. Sand is dominantly trapped on the shelf in all units, with transport into the basin along salt corridors occurring in the Upper Missisauga Formation and Cree Member. This led to sand accumulation in minibasins with a large deposit seaward of the Tantallon M-41 well. Sand also appears to by-pass the basin via salt corridors which lead to the down-slope edge of the study area. Sensitivity analysis suggest that source composition and salt mobility are the controlling factors of sand distribution in the central Scotian Basin.

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References


