# Heavy Mineral Provenace of Prospective Reservoir Sandstones in the Flemish Pass and Orphan Basins

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## Summary

The Orphan and Flemish Pass basins are frontier offshore deep water basins, located approximately 400 km northwest of the Avalon Peninsula, Newfoundland. Mesozoic sandstone intervals from three wells (Mizzen L-11, Baccalieu I-78 and Blue H-28) were studied for provenance analysis using heavy minerals. Three techniques were used for provenance analysis and correlations of units: detrital zircon geochronology, heavy mineral ratios and detrital tourmaline geochemistry.

In the Northern Flemish Pass Basin, a change in sediment source occurred between the Late Jurassic and Early Cretaceous from dominantly Paleozoic with minor Mesozoic and Early Neoproterozoic sources to dominantly Early Neoproterozoic sources. This is interpreted to represent an switch from sediment derived from the south (Avalon Uplift area) to locally derived sediment (local Avalon zone basement). In the West Orphan basin, sources from a Cretaceous sandstone interval are dominantly Paleozoic with subordinate Early Neoproterozoic and a minor Grenville component, representing probable northeast-derived mixed with locally-derived sediments.

Provenance-sensitive heavy mineral ratios were calculated for all intervals, and proved useful in defining units based on differing provenance. These ratios proved useful in correlating contemporaneous units in the Flemish Pass Basin.

## Introduction

Three regional rifting stages occurred in the Grand Banks and Northeast Newfoundland shelf region during the Mesozoic that affected the tectono-stratigraphic evolution of the Flemish Pass and Orphan Basins (Enachescu 1987). Recent regional geophysical studies suggest these basins may have been in syn-depositional communication with the oil and gas producing Jeanne d'Arc basin during syn-rift sedimentary deposition, and therefore potentially contain similar large oil and gas fields. Exploration of these areas over the past thirty years has provided strong evidence for the presence of petroleum systems. The Flemish Pass Basin is known to contain Kimmeridgian-aged source rocks and Late Jurassic to Early Cretaceous reservoir-quality sandstones, and it has been postulated that these strata may continue into the East Orphan Basin.

Sources and paleo-transport pathways of detritus into these frontier basins are poorly constrained, which limits stratigraphic correlations, hydrocarbon exploration and paleo-geographic reconstructions. Foster and Robinson (1993) identified three major sequences in the Flemish Pass basin, which in general record periods of rifting followed by progradation first from the north or south and then from the southeast. Potential proximal sources of detritus in the Flemish Pass Basin include the dominantly Neoproterozoic Avalon zone to the north, west and east, the Cambrian-Ordovician Meguma zone with Silurian-Devonian granitic intrusions to the south, A large Neoproterozoic granitic intrusion to the west (on the Flemish Cap) and minor Mesozoic volcanic which have also been encountered to the south (on the Avalon uplift).

The Purpose of this project is threefold; (1) to determine the provenance of Jurassic and Cretaceous reservoir sandstones and interpret regional paleo-drainage, paleo-geography, and basin configurations during rifting, (2) to make regional correlations between potential reservoir sandstones, and (3) to test the application of heavy mineral analysis and the analytical methods used (MLA and ICP-MS) to industry-related frontier exploration efforts.

**Theory and/or Method**

Three heavy mineral approaches were used to determine provenance and make correlations: (1) U-Pb geochronology of detrital zircons, (2) detrital heavy mineral grain counts and ratios, and (3) geochemistry of detrital tourmalines. Three industry exploratory wells were used for this project: Mizzen L-11 and Baccalieu I-78 in the Flemish Pass basin, and Blue H-28 in the Orphan basin. Three stratigraphic units were analyzed from Mizzen L-11: the two late Jurassic sandstones and the Early Cretaceous Baccalieu Sandstone. From Baccalieu I-78, the Late Jurassic to Early Cretaceous Hibernia Formation equivalent and the Early Cretaceous Avalon Formation equivalent were used for provenance analyses. Some lesser quality Jurassic sandstones were present in Baccalieu I-78; however, they proved inadequate for heavy mineral sampling owing to their poor mineralogical maturity. A Cretaceous sandstone of unknown affinity was sampled from Blue H-28.

Samples ranging from 50 to 500g were obtained from the Canada-Newfoundland Offshore Petroleum Board and/or well operators. Heavy minerals and detrital zircon fractions were extracted from the samples by gravity separation using heavy liquids. Heavy minerals and picked zircons were mounted in epoxy for imaging and analysis.

Concordia ages of single detrital zircons were calculated and plotted on an age histogram to reveal detrital age groups and identify sources and regional paleotransport directions. Detrital zircon grains were picked from heavy factions of sedimentary samples for single-grain U-Pb geochronology. They were then mounted in epoxy and imaged with reflected light and a scanning electron microscope to reveal grain morphology and compositional zoning. U-Pb ages of 40-85 zircons per sample were determined by laser ablation and inductively coupled plasma mass spectrometry (LA-ICPMS) at the INCO Innovation Centre Laboratory at The Memorial University of Newfoundland. The type of in-situ U-Th-Pb dating technique used in the laboratory is described in detailed by Kosler et al. (2002).

Grain ratios of detrital heavy minerals were used to detect differences in sedimentary provenance laterally and through time, and to make stratigraphic correlations, as in the methods utilized by Morton and Hallsworth (1999). The mineral ratios are considered to be sensitive to provenance and not reflective of differences caused by differential sedimentary sorting or diagenetic stability; that is, ratios of two minerals with similar densities (thus reacting similarly to hydraulic processes) and similar diagenetic stabilities, such as zircon and rutile or apatite and tourmaline, are used. These ratios were measured for heavy minerals within the 63-177 µm size range, in which all of the heavy minerals are ubiquitous, to avoid any biasing created by grain size sorting during transport and deposition. Mineral identification and quantitative estimates of the proportions, and sizes and shapes of grains in the mounts have been made in automated fashion using a scanning electron microscope (SEM) equipped with and energy dispersive x-ray (EDX) spectrometer mineral liberation analysis (MLA) software.

Major element chemistry of detrital tourmalines was used to identify the composition of the source rock of the tourmalines, following the methods of Henry and Guidotti (1985). Detrital tourmalines were identified using the SEM-MLA method described above, then imaged with a scanning electron microscope to reveal grain morphology and compositional zoning. Chemical analyses were obtained using an electron microprobe at Dalhousie University.

## Conclusions

1) The three sampled units in Mizzen L-11 record a change in source over time from dominantly Paleozoic sources to dominantly Early Neoproterozoic sources (Avalonian affinity), representing a change in source from the Avalon Uplift to the south to more proximal Avalon zone basement sources from the Late Jurassic to early Cretaceous.

2) In Baccalieu I-78, the Hibernia Formation was derived from a mixture of Avalon zone and Late Paleozoic sources, probably representing a mix of distal sources to the south as well as local sources. The Avalon Formation appears to be mainly sourced from the Neoproterozoic Avalon Zone, representing a switch from input from distal southward lying sources to dominantly local sources.

3) The Cretaceous sandstone in Blue H-28 is dominated by Paleozoic sources, with subordinate Neoproterozoic (Avalon zone) and minor Late Mesoproterozoic (Grenville) aged sources. The Paleozoic sources are most likely derived from the Gander and Dunnage subzone basement located in Central Newfoundland and to the northwest of Blue H-28. This, along with a small Grenville source input, is indicative of sourcing from the northeast with minor input from local Avalon Zone basement sources.

4) Heavy mineral ratios proved efficient for detecting differences in provenance, and in one case, for making a direct correlation.

5) Early Cretaceous shallow marine turbidites from Baccalieu I-78 are correlated to the Baccalieu Sandstone interval from Mizzen L-11 using provenance-sensitive heavy mineral ratios. The Baccalieu Sandstone in Mizzen does not show a strong correlation to the fluvial-deltaic Early Cretaceous Hibernia Formation equivalent, which therefore puts constraints on the lateral extent of this prospective reservoir in the Flemish Pass Basin.

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