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Depositional Interpretation and Reservoir Characterization of the Tithonian in Mizzen F-09, Flemish Pass Basin, Canada

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Introduction

The Mizzen structure is located in the Flemish Pass Basin, approximately 450 km east of St. John's Newfoundland, and adjacent to the Flemish Cap (Figure 1a and b). The northern Flemish Pass encompasses an area of 13,500 km^2, and is a relatively under-explored basin with only 4 wells drilled to date, 3 of which are drilled into the Mizzen structure itself.

The Mizzen Field was discovered in 2010 during the drilling of Mizzen O-16 by Statoil Canada Ltd. and Husky Energy. The structure is defined as a fault-bounded, doubly-plunging horst block, and represents the first significant hydrocarbon accumulation in the Flemish Pass. Mizzen O-16 was drilled near the crest of the structure, and encountered an oil-down-to in sandstone reservoirs of Upper Jurassic (Tithonian) age. This package is informally termed the "Bodhrán Formation", and is time and depositionally equivalent to the Jeanne d'Arc Formation in the Jeanne d'Arc Basin. In mid-2011 Mizzen F-09 was drilled down the north flank to delineate the extent of the oil leg. The F-09 data acquisition program was designed to obtain a full-diameter core in the Ti-3 member (primary reservoir interval) of the Bodhrán Formation, to obtain data to aid in determining the lateral distribution of the reservoir, characterizing the petrophysical parameters, and to provide insights into the nature of the depositional environment. To date, 5 clastic reservoir members (from base to top Ti-0 to Ti-4) have been identified in wells drilled in the Mizzen Field (Figure 1c).

Core Description and Environmental Interpretation

A 63 metre x 5¼" full diameter core from the uppermost Bohdrán Formation (3327 to 3390 m MD) was obtained during drilling of the Mizzen F-09 well (Figure 2). The core was acquired across the entire Ti-3 member and TD's in 2 meters of lime mudstone. The basal contact of the Ti-3 member is an erosional unconformity across the top of the lime mudstone by poorly sorted conglomerates and coarse sandstones.

Six main lithofacies have been identified in the core:

I. Lime mudstone, medium grey, poorly laminated, with slightly reactive shales, and minor pyritized beds (1-2 cm thick) and pyrite nodules.

II. Matrix-supported gravel to cobble conglomerate (rounded quartz and lithic clasts, occasional coal rip-ups and pyrite nodules) in a well-sorted, medium to coarse sand matrix. Beds are typically 15-50 cm thick, amalgamated, and defined by sharp-based scour surfaces. Often pervasively calcite cemented.

III. Planar cross-stratified sandstone, fine to coarse-grained,containing isolated, well-rounded conglomerate pebbles and siltstone rip-up clasts. Beds are up to 1.2 m thick, with a maximum dip angle of 35° defined by carbonaceous laminae. Associated with Lithofacies II and IV, and often pervasively calcite cemented.

IV. Horizontally stratified sandstones, fine to medium-grained, salt and pepper texture, minor siltstone rip-ups. Bedding is poorly defined by carbonaceous laminae, dipping 10° or less. Rare vertical to sub-vertical fractures filled with white calcite are observed in cemented sandstone beds.

V. Ripple cross-laminated sandstones, fine-grained, with occasional mudstone drapes. Ripple types observed include climbing, flaser, wavy and lenticular. Carbonaceous laminae are common, with minor coal clasts, and very rare *Planolities* burrows. Calcite cementation is a minor component.

VI. Interbedded shale, siltstone and fine-grained sandstone. High frequency laminated planar and rippled sedimentary structures are overprinted by soft sediment deformation/dewatering structures, and very rare *Planolities* burrows. Other components include minor amounts of swelling clay beds, and rare, thinly bedded cemented sandstones.

Combining observations on the overall fining-upward hierarchy, predominantly unidirectional current flow sedimentary structures in the lower half of the core, the coarseness and roundness of the gravel clasts, the high net to gross (>75%) ratio, the blocky nature of the gamma-ray log signature, and an extremely low abundance and diversity of trace fossils, the Ti-3 member is interpreted as dominantly braided fluvial in nature, with an increased influence of tidal processes towards the top of the unit. The F-09 core can be subdivided into amalgamated braided channel deposits in the lower section of the core (represented by Lithofacies II, III and IV); gradually fining upwards into restricted nearshore marine deposits (estuarine) represented by Lithofacies V and VI. Biostratigraphic slides were prepared from various lithofacies throughout the Tithonian interval in the Mizzen wells, and interpreted palynofacies provide evidence of freshwater run-off into a marginal marine environment.

The Upper Jurassic marked the initiation of regional extension in the Flemish Pass Basin. The rapid subsidence of structural blocks was conducive for the accumulation of fine-grained clastic sediments (Lithofacies I) into anoxic/restricted basins. These basins also provided a catchment area for periodic runoff of siliciclastic sediments derived from fluvial systems controlled by nearby fault scarps. Extension and change in base level in the Mizzen area increased accommodation space for conglomerate lag deposits and overlying sands to form laterally extensive, syntectonic channel belts (i.e. the Ti-3 member) comprised of amalgamated, braided fluvial deposits.

Reservoir Characterization

The Ti-3 member represents a high N:G conglomeratic sandstone reservoir, with average porosities greater than 20%, and measured permeabilities in the multi-Darcy range. The Ti-3 reservoir is correlated over 5 km lateral distance between the Mizzen F-09 and O-16 wells, and correlations of additional Bodhrán members (Ti-2, Ti-1) demonstrate that amalgamated braided fluvial belts are present across the crest of the main Mizzen structure. Mapping and seismic geomorphology tied to the Mizzen wells suggest that although variation in reservoir quality across the field can be expected, the high N:G and world-class reservoir parameters encountered to date will support field development.

The main impediment to reservoir quality in the F-09 core is an early-phase calcite cement. In thin section, the cement is commonly observed to completely fill any original porosity, particularly in the stratigraphically lower, coarser clastic Lithofacies (II, III, and IV). Thin sections from samples that are strongly cemented document originally high porosities, and have nearly identical primary mineralogy to non-cemented samples. Primary grains (quartz-rich) form an open framework in both cemented and non-cemented samples, indicating early stage calcite cementation. The calcite is interpreted to be derived from fragments of bivalves, brachiopods, echinoderms, forams, and calcite ooids. The cements in the F-09 core often occur as large concretions (larger than core diameter), which likely nucleated from fossil fragments that were eroded from the source drainage area, and redeposited with the coarsest clastic fraction of the fluvial deposits. Similar deposits of early calcite cemented zones in fluvial sands at the analogue Terra Nova Field in the Jeanne d'Arc Basin have not had a significant impact on field production.

Conclusions

The core obtained from the Bohdrán Formation Ti-3 member in Mizzen F-09 is representative of the thickness and quality of the Tithonian reservoir sandstones that exist in the Flemish Pass and adjacent Orphan Basins. Core observations and data provide strong evidence that these deposits were the product of synrift braided fluvial channel belts. The petrophysical parameters from this core can be linked to wireline logs from wells in the region as evidence that these reservoir sands are capable of providing high-rate, sustained production. The discovery of the Mizzen Field has established a proven hydrocarbon accumulation in the Flemish Pass, and may signal the opening stages of a new oil province in an underexplored Canadian frontier basin.

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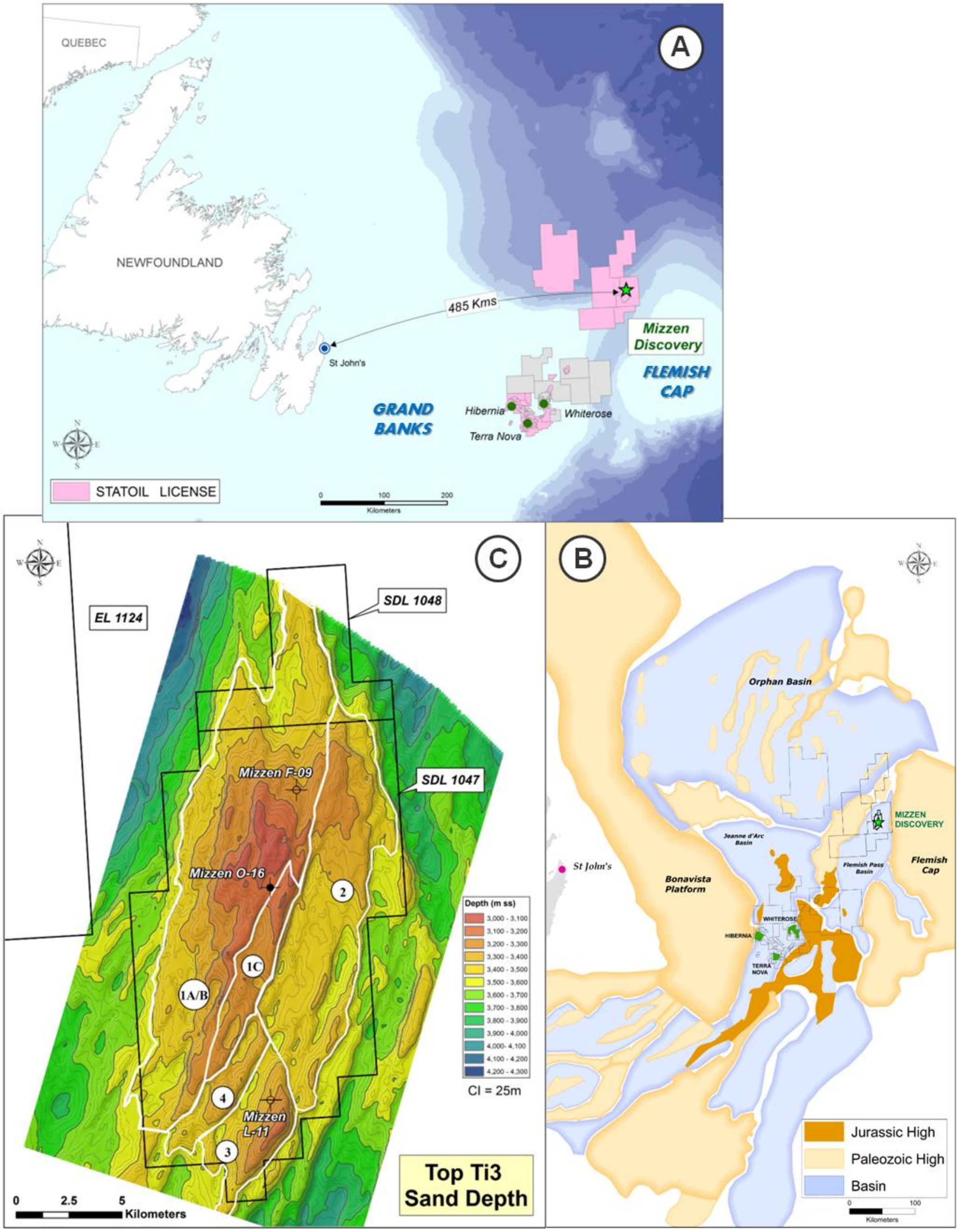

Figure 1. Maps of the Mizzen field; a) Location map showing licenses in pin, b) Tectonic elements map with location of the Flemish Pass Basin in relation to basement structures, c) Top reservoir structure map of the top Ti-3 sandstone.

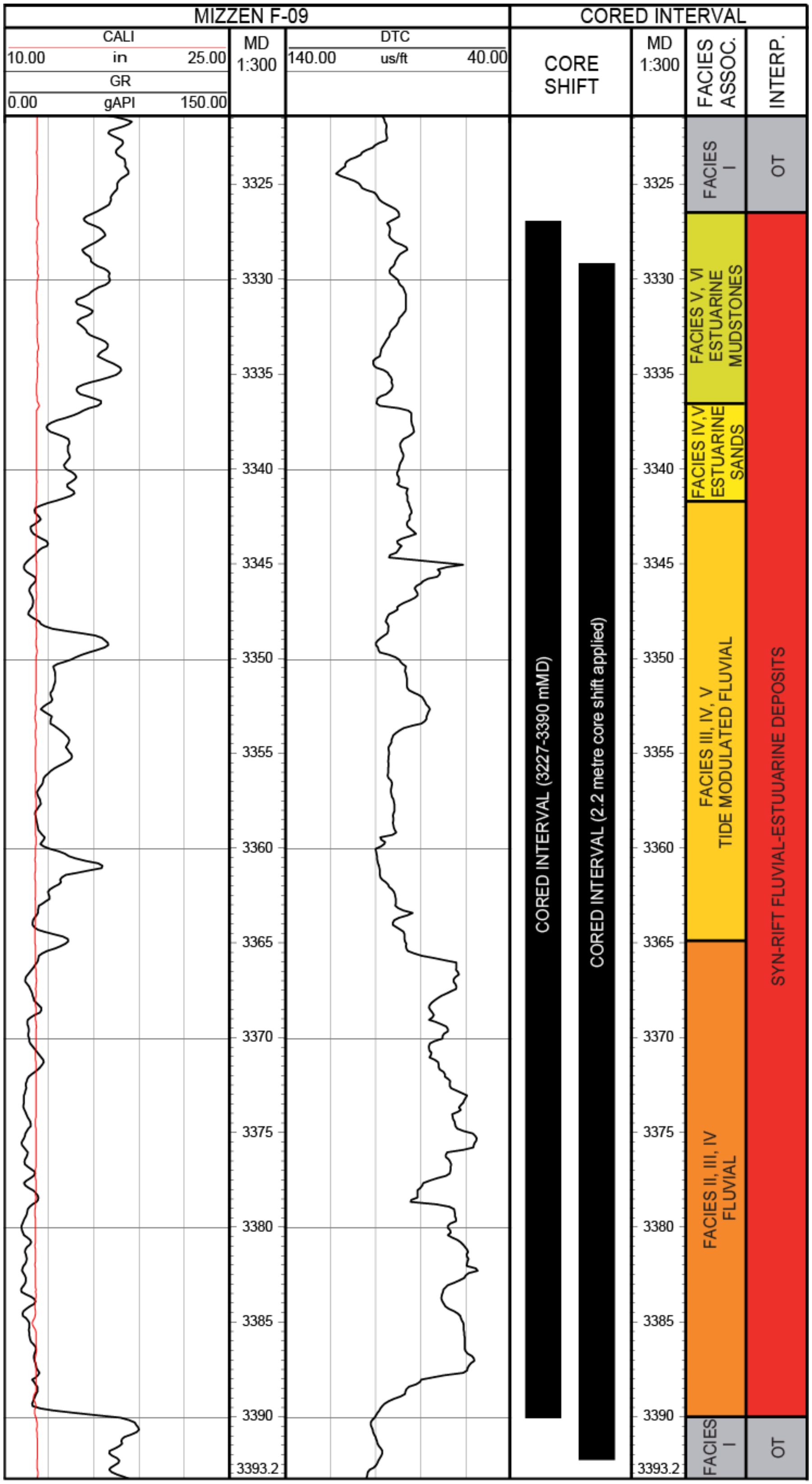

Figure 2. Gamma and sonic logs with over the Mizzen F-09 Ti-3 core. Location of core in wellbore (and shifted to match logs) in black, facies and interpretations in colour on right.

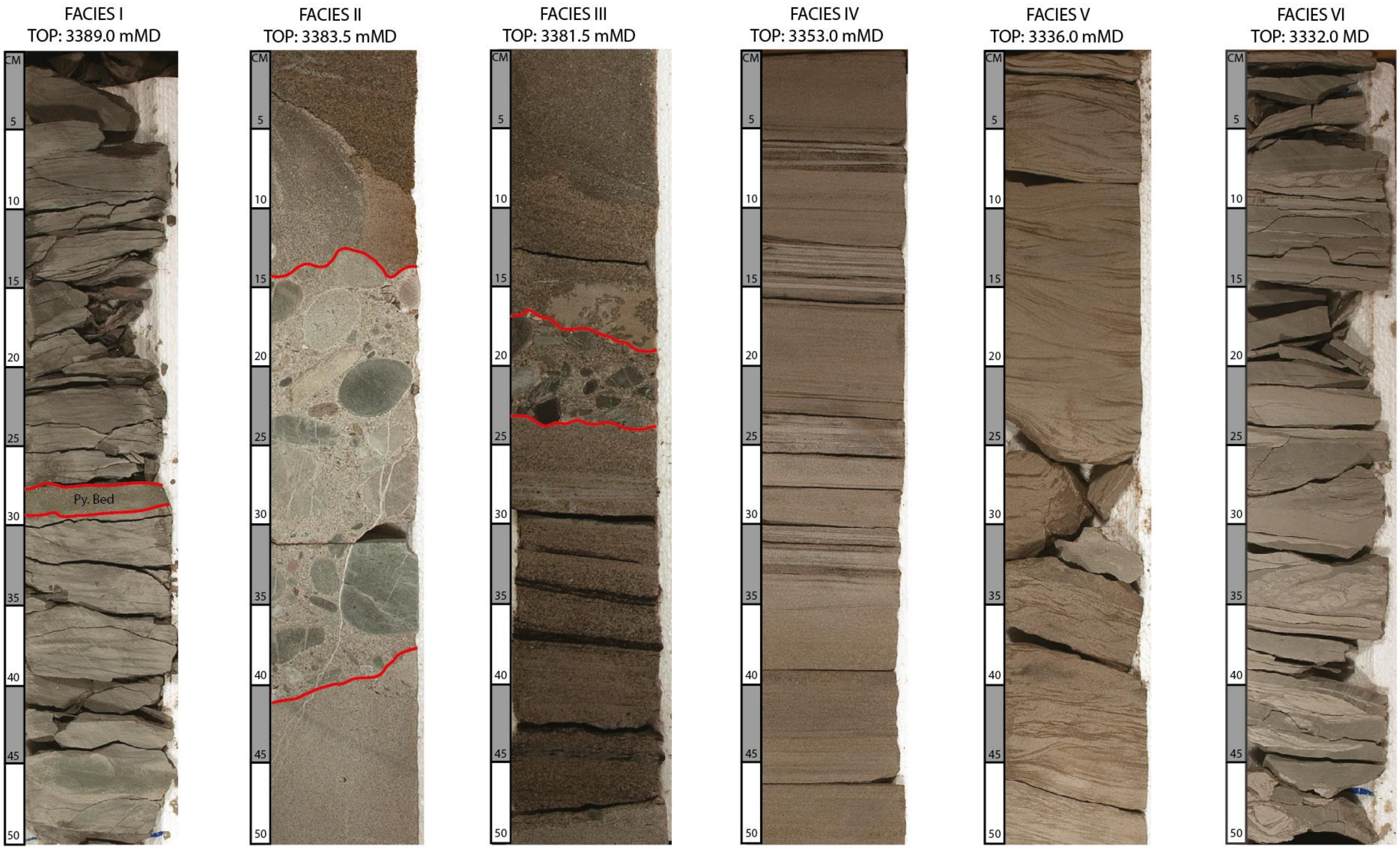

Figure 3. Lithofacies observed in the Mizzen F-09 core. From left to right, i) Facies I – lime mudstone (offshore transition), ii) Facies II – matrix supported gravel/cobble conglomerate in coarse sandstone, iii) Facies III – planar x-stratified med-coarse sandstone, with pebble

lags and carbonaceous laminae, iv) Facies IV – horizontally stratified fine-med sandstone with carbonaceous laminae, v) Facies V – ripple cross laminated sandstone and siltstone, and vi) Facies VI – interbedded fine sandstone, siltstone and shale displaying soft sediment deformation. Facies II through VI represent an overall transition of fluvial through estuarine deposits in a syn-rift system.