

## The role of sea-level fluctuations in early diagenetic carbonate cementation and impacts on shallow-marine clastic reservoir quality: A perspective from the Hibernia field, offshore Newfoundland.

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### Summary

Carbonate cements filling intergranular pore space in siliciclastic reservoirs represent low-perm intervals that impact reservoir performance and drilling operations. Understanding the origin of pore fluids that lead to carbonate cementation during diagenesis allows for deciphering and predicting carbonate-cemented sandstone distribution. The Lower Cretaceous Hibernia formation at the Hibernia field records the transition from a deltaic environment to an estuarine environment where carbonate-cemented intervals are common. The early diagenetic carbonate cementation of the Lower Hibernia zone evidences a strong stratigraphic control that contributes to predicting low-perm intervals in shallow marine systems. During the early stages of diagenesis, sea-level fluctuations settled the physicochemical conditions for pore fluids to precipitate calcite and dolomite in sandstones that exhibit high intergranular volumes and phreatic cementation textures. Furthermore, stable isotope composition ( $\delta^{13}\text{C}$  and  $\delta^{18}\text{O}$ ) of early carbonate cements suggest that parent fluids were likely a mixing of marine and meteoric pore waters evolving from oxic to suboxic conditions at shallow depths. Regression episodes during the Hibernia formation deposition are linked to pore fluids that precipitated dolomite cements in delta front and offshore marine facies. The basinward migration of the meteoric wedge, massive meteoric influx, and less seawater contributions represent the main mechanism for dolomite cementation. Conversely, transgressions are lined with calcite cementation in tidal, tidal-fluvial and offshore marine facies associations. A significant marine water flux during sea level rise and landward migration of the meteoric wedge facilitated the formation of pore-filling calcite in recently deposited sediments.

### Theory

Carbonate cement intervals impact reservoir performance during water injection as they act as barriers or baffles for fluid flow. Additionally, carbonate cemented sandstones pose challenges during drilling operations, when increasing the well path inclination to reach a near-horizontal position. Carbonate-cemented strata in the Hibernia formation have been reported at the Hibernia field. Calcite, dolomite, and ferroan calcite layers occur in reservoir intervals of the Hibernia formation (Brown et al., 1989; Hesse

and Abid, 1998). However, the mechanisms that led to carbonate cementation and links to the reservoir stratigraphy remain elusive. Understanding these mechanisms is crucial for improving the reservoir quality prediction in the Hibernia formation, also serving as foundation for predicting carbonate cements in shallow marine siliciclastic reservoirs worldwide.

The Lower Cretaceous Hibernia formation is one of the primary siliciclastic reservoirs at the Hibernia field, Jeanne d'Arc basin, Offshore Newfoundland. Sinclair et al. (2005) subdivided the Hibernia formation into two stratigraphic members: the Lower zone, where the reservoir intervals occur and the upper zoner (Sinclair et al., 2005). The lower zone was deposited in a delta plain environment, while the upper zone is linked to a delta front environment. The lower zone is assigned to Lower Hibernia zone in this study. The depositional environments, pore water evolution and facies associations most likely exert control influence over the early carbonate cementation of the Lower Hibernia zone. Analyzing the facies associations and proposing links between early carbonate cementation, sea level changes and pore water evolution elucidated how pervasive calcite and dolomite cementation occurred during early diagenesis.

## Method / Workflow

Drill cores of the Lower Hibernia acquired from development and delineation wells were logged to describe the sedimentary facies (i.e., lithology, bedding, stratification) and macromorphologies of carbonate-cemented intervals. In addition, the stratal evolution and the sequence stratigraphy framework of the Lower Hibernia zone were proposed in order to suggest links to early carbonate cementation. Optical petrography was performed in forty-four and seven samples, respectively, to characterize microscopic features of carbonate cements and cross-cutting relationships. The mineral liberation analysis (SEM-BSE-MLA) was performed using a FEI MLA 650F and a FEI Quanta 400 scanning electron microscope equipped with an energy dispersive X-ray (EDS) microanalytical system (Bruker AXS, XFlash Detector 4010) at Memorial University of Newfoundland.

The  $\delta^{18}\text{O}$  of carbonate cement is helpful in constraining the origin of carbonate-bearing fluids (e.g., marine, meteoric, and marine-meteoric waters; Hoefs, 2006). The  $\delta^{13}\text{C}$  is employed to constrain the carbon origin of carbonate cement, and the biogenic and abiogenic reactions that occur during diagenesis (e.g., organic matter oxidation, bacterial fermentation, thermal decarboxylation of kerogen; Irwin et al., 1977). The isotopic composition of carbonate cement was measured employing 75  $\mu\text{g}$  micro-drilled cement. Carbon dioxide was generated through a reaction with phosphoric acid employing a Thermo Scientific Kiel IV Carbonate Device, which was then interfaced to the inlet of a ThermoFinnigan MAT 253 dual inlet mass spectrometer for stable isotope analysis. Additionally, minor and trace elements were analyzed using LA-ICP-MS, with laser sampling facilitated by a GEOLAS 193 nm laser system. Sampling spots of 20 – 40  $\mu\text{m}$

on carbonate cements were selected under SEM. Trace elements such as Mn, Mg, Fe and Sr provide insights about the redox conditions of precipitation and contributions marine water contributions to the carbonate-bearing fluids.

## Results, Observations, Conclusions

The vertical facies succession of the Lower Hibernia zone records the transition from a deltaic-dominated succession to an estuarine succession punctuated by two regressive sequence boundaries. Facies associations are mainly delta front (FA1), braided fluvial (FA2) marginal marine tidal-fluvial channels (FA3), tidal flats (FA4), open marine offshore (FA5) and tidal bars (FA6). The delta-dominated succession starts with the coarsening-upward sequences of the Fortune Bay formation underlying the FA1 (Layer 4) and FA2 strata (Layer 3 lower) of the Lower Hibernia zone. The erosive surface separating FA1 and FA2 is interpreted as a Sequence Boundary and indicates erosion of the delta front strata and a forced regression before the onset of fluvial sedimentation. The tidal-fluvial and tidal facies associations FA3 and FA4 (Layer 3 Upper) represent the transition from a deltaic to an estuarine environment as the sea level progressively raised. The transition from tidal-fluvial to an offshore marine sedimentation of FA5 in the Medial Shale was triggered by increased rates of subsidence that led to a progressive transgression and retrogradation of the fluvio-deltaic system. An abrupt sea-level fall was recorded by the erosive surface that separates the Medial Shale and the FA3 strata of Layer 2. Subsequently, fluvial-tidal deposition characterized by fining-upward successions of marginal marine channels (FA3) and tidal flats (FA4) occurred and composing Layer 2. The final sedimentation episode is marked by a rise in sea level, evidenced by coarsening-upward successions of subtidal sand bars (FA6) in Layer 1 (L1).

The strata of the Lower Hibernia zone exhibit both non-pervasive and pervasive carbonate cements, indicating diverse stages of cementation during diagenesis. The main pervasive cement phases of the Lower Hibernia zone include calcite, dolomite and ferroan calcite. Calcite and dolomite cements exhibit petrographic textures which are commonly linked with early cementation (e.g., blocky mosaics, high intergranular volumes). Additionally, the stable isotopic composition ( $\delta^{13}\text{O}$  and  $\delta^{13}\text{C}$ ) of calcite and dolomite indicates that the parent fluids likely originated from a mixture of marine and meteoric pore waters, evolving from oxic to suboxic conditions at shallow depths. Regression episodes of the Lower Hibernia zone are linked to dolomite cementation in the delta front (FA1) and offshore marine facies (FA5). The basinward migration of the meteoric wedge and shoreline during regressions, accompanied by a significant influx of meteoric water and reduced seawater contributions, represents the primary mechanism for dolomite cementation (e.g., the Dorag model; Badiozamani et al., 1973). In contrast, transgressive events are linked to calcite-cemented sandstones in tidal-fluvial (FA3) and tidal facies (FA4-FA6), indicating a predominant marine influence in the early diagenetic carbonate-bearing fluids. The landward migrations of the shoreline and meteoric wedge

facilitated a significant marine water flux in the recently deposited sediments and supersaturating pore fluids with respect to calcite. The early diagenetic carbonate cementation of the Hibernia formation evidences a stratigraphic control related to sea-level fluctuations and environments of deposition, which aids in predicting carbonate cemented intervals in shallow marine systems.

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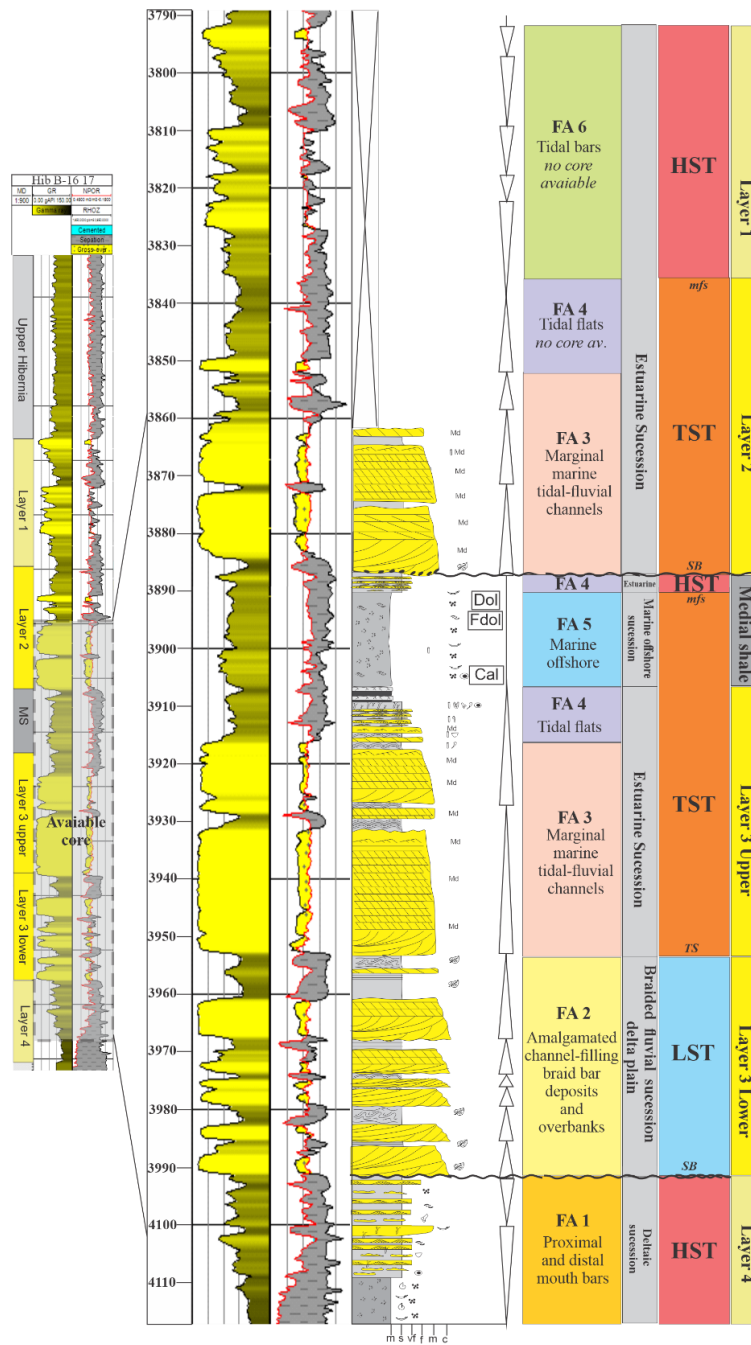


Figure 1. The vertical distribution of facies association in Layer 4 and Layer 3, Medial Shale and Layer 2 of the Lower Hibernia zone. Hibernia B-16 17 is located in a distal area, developing more tidal bars in Layer 1 and marginal marine channels in L3U and L2.