Facies analysis of the Clearwater Formation in Marten Hills and Nipisi, north-central Alberta

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Summary:

The Lower Cretaceous Clearwater Formation represents a range of depositional settings including marginal marine, shallow marine, and non-marine environments (Minken 1974, Putnam and Pedskalny 1983, McCrimmon 1996, McCrimmon and Arnott 2002, Feldman et al 2008, Currie 2011). Within the Marten Hills and Nipisi regions of north-central Alberta (Tsp 71-78, Rge 21W4-8W5), a rapid increase in exploration efforts by oil and gas companies over the past 5 years has sparked interest aimed at better understanding the Clearwater geology. Through the use of multilateral horizontal drilling, cold flow production (the leading production method in Marten Hills and Nipisi) is being successfully utilized. The use of this drilling technique places emphasis on the establishment of a strong geologic framework to optimize well performance. Although production efforts have yielded successful results, the study region is void of academic work aside from regional generalizations by Jackson (1984) and Smith et al. (1984), as well as a brief mention of Marten Hills Clearwater geology by Bradley and Pemberton (1992). The Clearwater Formation was previously believed to consist predominantly of interbedded marine siltstones and mudstones, resulting from the transgression of the Boreal Sea throughout the (lower) Albian. However, reservoir-quality sandstones within the Clearwater Formation, hosting medium-light oil reserves, were initially bypassed during the exploitation of the Wabiskaw Member (a low member of the Clearwater Formation), and equivalent Bluesky Formation. These Clearwater sandstones have recently been recognized as significant exploration opportunities. An interpretation of the sedimentology and ichnology within these reservoir-quality sandstones has yet to be established and are the primary goals for this research.

In the study area, Clearwater sandstones range in thickness from 5 to >25m and extend laterally along depositional strike throughout much of the study area (>90km). The reservoir sandstones in Marten Hills thin to the NE towards Nipisi however in Nipisi, reservoir-quality sandstones also exist in an underlying unit. In dip section, towards the basin, the thickest sandstones abruptly terminate over less than 2km whereas thinner sandstones extend further basinwards. Feldspathic and moderate clay content within the sandstones can cause Gamma-ray curves to present an elevated radiation response and thus appear "dirtier" than those seen in the underlying Wabiskaw Member/Bluesky Formation. As a result, these sandstones were overlooked as potential reservoir targets. By establishing a stratigraphic framework based upon sound facies- and wireline-analyses, reservoir-quality sandstones can be correlated with greater confidence and thickness trends can be mapped, aiding in the prediction of reservoir quality and distribution.

Study Area and Methods

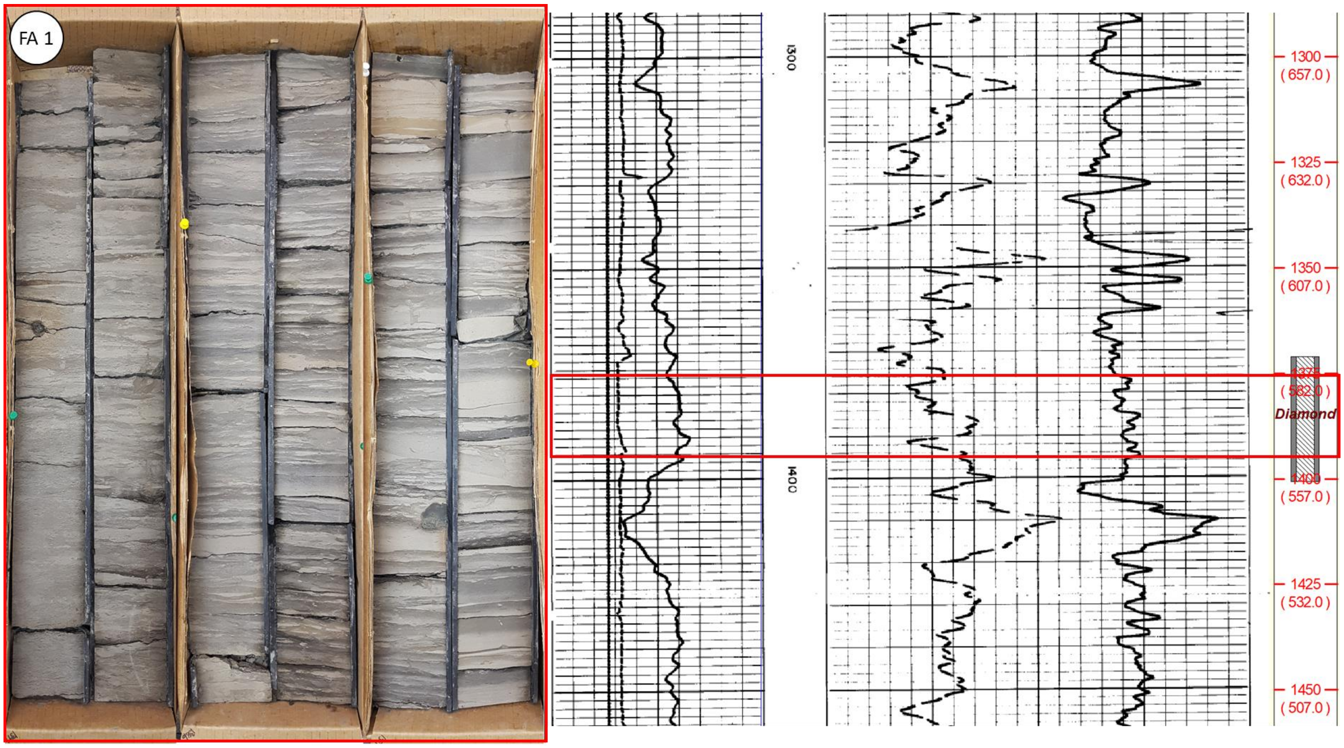
The study area includes Townships 71-78, Ranges 21W4-8W5. This includes both the Marten Hills and Nipisi regions of north-central Alberta. Wireline data included over 5500 vertical or deviated wells within the study area providing sufficient well data to correlate with core observations. 50 cored intervals totaling over 1040m in thickness were analyzed using a detailed sedimentological and ichnological approach. From these 50 cores, lithology logs were constructed using AppleCore software to note sedimentological characteristics such as grain size, sorting, bed thickness, bedding contact, primary sedimentary structures as well as penecontemporaneous deformation structures. Lithological accessories were also noted including features such as the presence of siderite, glauconite, rip-up clasts, and pyrite nodules. Ichnological observations were also included within the analysis including trace identification, abundance, diversity, and bioturbation intensity. By combining petrophysical data obtained from well logs with observations from core, a strong facies model was constructed aiding in the interpretation of facies associations within the study area.

Results

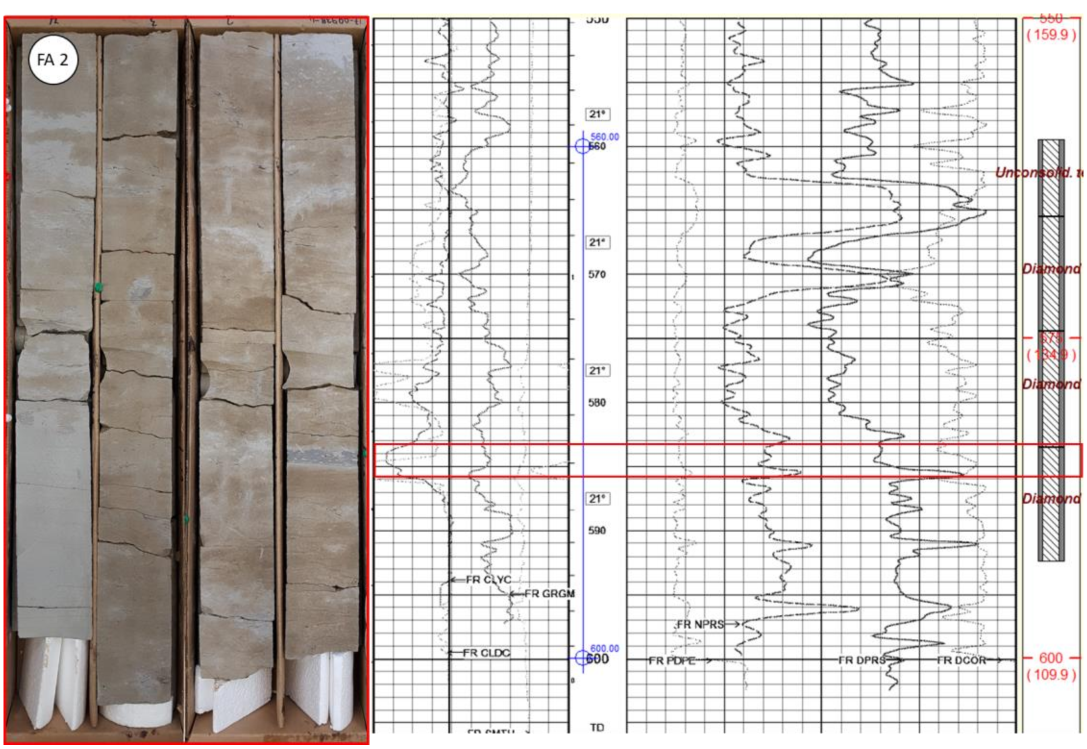
FA1 offshore transition/distal pro-delta: This FA comprises interbedded siltstone, mudstone, and very fine-grained sandstones. The coarser (very fine sandstone) material typically presents itself in thin, normally graded beds with occasional sideratization and sporadic pyrite nodules. Thicker (30-50cm) sandstone intervals contain phytodetrital grains with oscillatory ripples and hummocky cross-stratification and are attributed to tempestite deposition. Larger wood clasts are observed within several cores. Trace fossils observed include *Chondrites, Phycosiphon, Asterosoma, Scolicia, Teichichnus, Schaubcylindrichnus freyi, Rhizocorallium, Thalassinoides, Cosmorhaphe*, diminutive *Zoophycus* and occasional fugichnia within sandstone beds (i.e. *Cruziana* Ichnofacies). Bioturbation within this facies association is variable (BI 2-4) although the mudstone beds are characteristically more heavily burrowed (BI 3-4). Some sandstone beds are pervasively bioturbated (BI 5), which likely represent episodes of lowered overall energy / sedimentation and aggradation rates. Based on the interbedded lithologies, tempestites, and moderate bioturbation, the interpreted depositional environment was classified as an offshore transition or distal pro-delta.

FA2 wave-dominated shoreface: FA2 occurs beneath the main reservoir sandstones in Marten Hills, above the interpreted offshore transition of FA1. FA2 contains very fine- to fine-grained sandstone beds with minor siltstone and mudstone beds. Low-angle planar and oscillatory bedding as well as hummocky and swaley cross-stratification can be identified in several cores. An overall increase in grain size is observed upwards. Small (1 cm) rip-up clasts and organic laminae are also prevalent throughout much of FA2. Trace fossil occurrence throughout this facies is sporadic with higher degrees of bioturbation occurring in the lower sandstones and mudstones. Mudstones commonly contain *Phycosiphon* and *Chondrites*. Within the lowermost sandstones, heavy bioturbation has overprinted the original sedimentary fabric. Robust *Rosselia*, *Cylindrichnus,* and *Ophiomorpha nodosa* are sporadically distributed throughout the lower to mid portions of FA2 within lower fine-grained sandstones. Towards the upper portion of FA2 massive-appearing sandstones are interpreted as cryptically bioturbated intervals (BI 6): this interpretation is supported by the observation of biogenic sedimentary structures in some thin sections. *Macaronichnus* and *Harenaparietis* are also interpreted in small intervals (few cm) within the mid to upper portions of this facies association. This facies association is interpreted as being related to a wave dominated shoreface system.

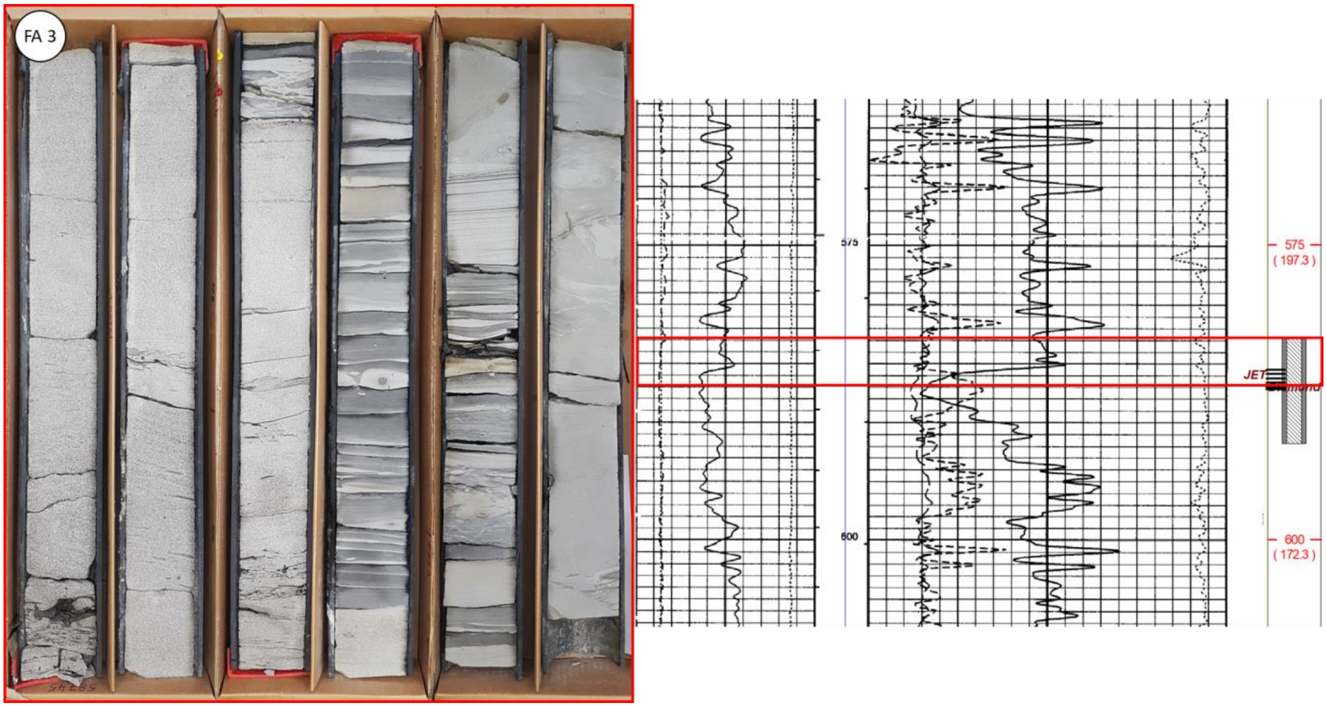
FA3 wave-dominated delta: FA3 commonly occurs above FA2. Sandstones are the dominant lithology within this facies association but cm scale sharp-based mudstones and mud drapes are also present. Grain sizes are predominantly fine- to upper fine-grained with occasional scattered pebble sized clasts and lower-medium -grained sandstones. Massive sandstones are abundant throughout much of FA3 within the study area, in addition to an increase in organic rip-up clasts. Cross-beds and climbing ripples are interpreted within FA3 above rounded to sub-angular mud rip-up clasts. Desiccation cracks are present within core indicating that subaerial exposure occurred within FA3. Prodeltaic hyperpycnites are also present near the uppermost regions of the facies association. Traces are relatively rare within the sandstones of FA3 (BI 0-1), although rare fugichnia were observed. *Skolithos* and *Diplocraterion* are also present in the uppermost region of FA3 but in low abundance. Based on the presence of sharp-based muds, high organic content, convolute bedding, massive sands, and low BI of FA3, the interpreted depositional environment was that of a wave-dominated delta.



Facies Association 1: Well UWI (10-19-78-24W4) Depth 424.1-419.6.



Facies Association 2: Well UWI (102-16-11-75-25W4) Depth 583.5-586.2.



Facies Association 3: Well UWI (7-5-76-25W4) Depth 583-587m.

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