Facies Analysis and Depositional Environments of the Upper Cambrian Eau Claire Formation in Central and Northern Illinois

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Summary

The Cambrian Eau Claire Formation is a confining unit for geologic carbon dioxide (CO_2) storage, and potentially a confining unit for hydrogen storage, within the underlying Mount Simon Sandstone in the Central and Northern Illinois Basin. However, extensive regional studies on lateral continuity, environment of deposition, and depositional fabric of the Eau Claire Formation in the Illinois Basin are minimal compared to studies of the underlying Mount Simon Sandstone. This study presents an integrated facies analysis using sedimentological, stratigraphic, ichnological, and mineralogical data to interpret the depositional environments of the Eau Claire Formation, emphasizing the dynamic nature of sedimentary systems. By combining core analyses, thin-section analysis, facies interpretation from geophysical logs, and regional stratigraphic framework interpretation, this work provides insights into the integrated depositional framework across diverse depositional environments. These findings suggest that the Eau Claire Formation in the Central and Northern Illinois Basin was deposited in a shallow marine environment, ranging from tidal flats to offshore settings. Its mixed siliciclastic-carbonate succession was primarily controlled by relative sea-level change.

Method

The research analyzed data from 62 wells (Fig. 1), including geophysical logs, cores, and cuttings. A core from the UPH3 well in Stephenson County was used as a reference for the northern Illinois Basin. Core from the FutureGen well and three wells from the Illinois Basin Decatur Project, along with the Covert well, were studied in the central basin (Fig. 1). These cores and logs contributed to the interpretation of sedimentology, stratigraphy, and depositional processes, focusing on attributes like grain size, sorting, sedimentary structures, and trace fossil development. A lithofacies model was developed using core observations, thin-section analysis, and geophysical logs, allowing for interpretations in wells without core data. Mud log notes and core descriptions refined these interpretations.

Results

Depositional Environments

Seven distinct lithofacies, representing several depositional environments ranging from tidal flat to offshore marine, were identified in the core and geophysical logs from the central and northern Illinois Basin. These seven lithofacies, grouped into a broader depositional framework, are organized from bottom to top as follows: Siliciclastic, mixed siliciclastic-carbonates, fully carbonate, and mixed siliciclastic-carbonate (Fig. 2). The siliciclastic facies association comprises mud flat/mixed-flat facies of tidal flat environment, tidal-channel facies, foreshore to upper shoreface facies, lower shoreface facies, and offshore marine facies. The term “mixed” here refers to both textural mixtures of carbonate and siliciclastic material, and interstratified sequences of “pure” carbonate and siliciclastic sediments. Core samples, thin-sections, and geophysical logs suggest that carbonate deposition in the northern part of Illinois (outside the Illinois Basin) occurred under higher-energy conditions compared to the central part. This is evidenced by the association of sandstones with carbonates in the northern region, as observed in both cores, thin-sections, and geophysical logs, and the association of shales with carbonates in the central region, as shown in thin-sections and geophysical logs. These findings highlight lateral heterogeneity in the mixed carbonates, with sandy carbonates dominating the northern region and shalier deposits prevailing in the central region. The upper mixed-siliciclastic facies, which lies above the fully carbonate facies, appears to have been deposited in a deeper or more sediment-starved environment. This is suggested by the higher abundance of glauconite compared to the lower mixed-siliciclastic facies. It should be noted that deposition of all lithofacies occurred in a shallow marine platform environment where small oscillations of sea level could produce depositional environments which ranged from tidally influenced, protected coastal carbonate systems, and upper to lower shoreface depositional fabrics. These oscillations in sea level combined with other factors resulted in a complex, depositional structure of carbonate, shale, and coarser-grained siliciclastics.

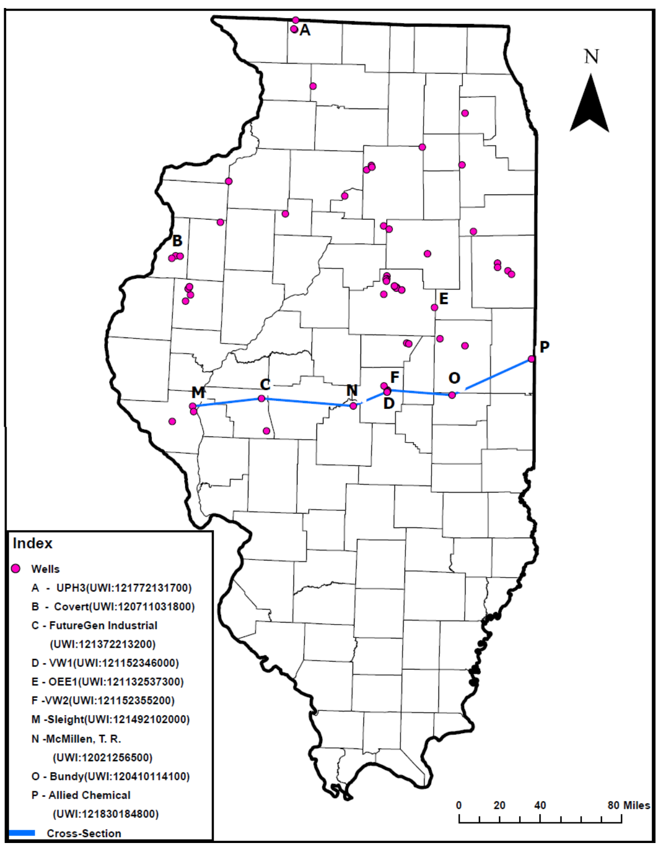

Figure 1: Map of Illinois showing the location of wells. A, B, C, D, and E are the wells used for core analysis.

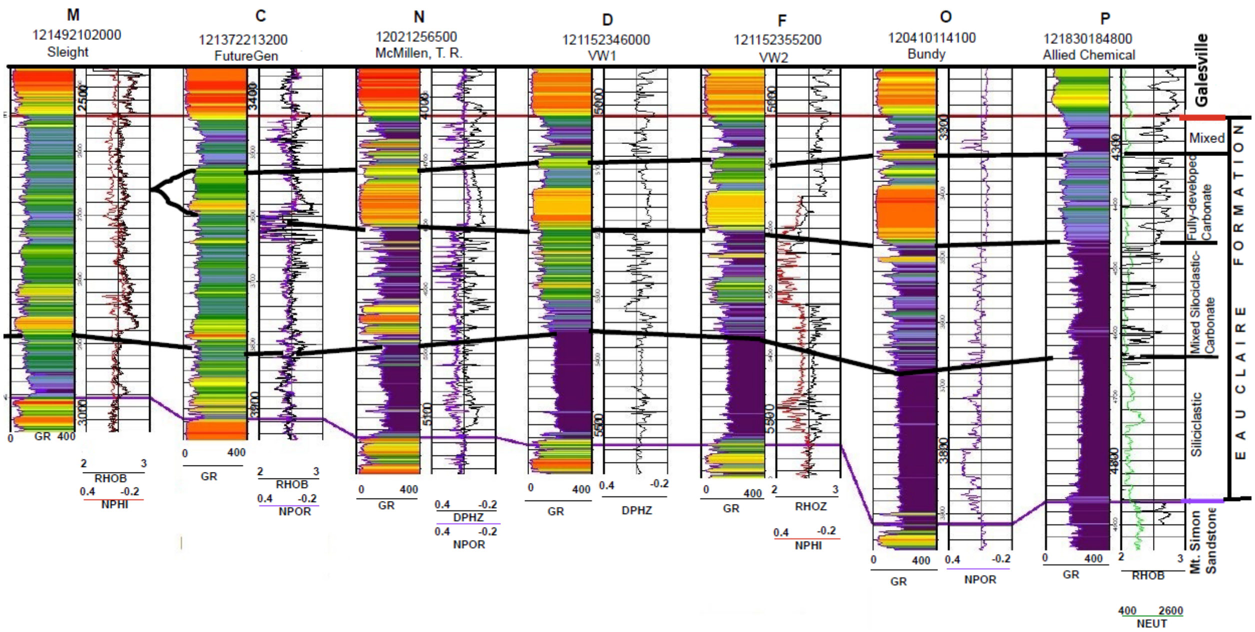

Figure 2: Geological cross section in the central part of the basin. See fig. 1 for well locations.

Thin-section analysis shows that the carbonate layers are primarily ooid/skeletal grainstones, suggesting deposition in high-energy environments. Mixed carbonate-siliciclastic sequences in the Eau Claire Formation typically follow deepening events, as suggested by the presence of black shale beneath these layers. In the northern area, however, these carbonates appear to have been deposited following relatively shallow siliciclastic environments than in the central area, as suggested by the presence of underlying sandstone beds and the absence of shales. While water chemistry and other environmental factors may have played a role, sea-level fluctuations appear to be the primary control on carbonate deposition. Following shale deposition, a regressive phase likely promoted carbonate production. These patterns indicate a transgressive system tract up to the top of the siliciclastic-rich interval, a highstand system tracts throughout the “mixed” interval, and a transition to a falling stage system tract in the upper “pure” carbonate zone. Notably, the Eau Claire Formation’s mixed siliciclastic-carbonate sequence does not conform to the classical “reciprocal sedimentation model” (Wilson, 1967; Catuneanu et al., 2011).

Implications for Geologic Storage

An offshore marine facies (Fig. 3), consisting of dark grey shale interbedded with maroon/pink siltstone, is observed in the lower part of the Eau Claire Formation within the siliciclastic component of a broader depositional framework (Fig. 2). This facies is likely the most suitable facies within the Eau Claire Formation to be the primary confining layer for CO_2 storage relative to the underlying Mount Simon Sandstone due to its high proportion of shale and the low proportion of sand. Additionally, an upper shoreface facies, primarily composed of interlaminated maroon/pink to grey/dark grey shale, is also observed in the lower part of the Eau Claire Formation within the siliciclastic component of a broader depositional framework. This facies is interpreted to have been deposited near the fair-weather wave base. Although potentially less effective than offshore marine facies due to its lower overall shale content, this facies may serve as a secondary confining layer for CO_2 storage. Its sealing capacity may be significant, particularly in areas where offshore marine facies is absent or discontinuous, ensuring containment of CO_2 within the storage formation. A comprehensive understanding of the spatial distribution, thickness, and properties of both facies is crucial for the successful implementation of CO_2 storage in the Mount Simon Sandstone.

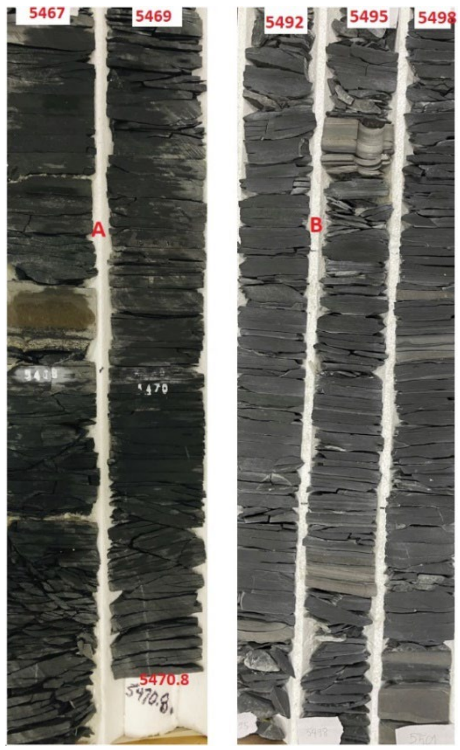

Figure 3: Offshore marine facies observed in VW1 well between 5467 to 5470.8 feet (picture-A), and in CCS1 well between 5492 to 5501 (picture-B). See Fig. 1 for well locations and Fig. 2 for geophysical logs.

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