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Lithology-Based, Sequence Stratigraphic Framework of the Mixed Siliciclastic-Carbonate Lower Cretaceous Sediments, Atlantic Coastal Plain, Eastern United States

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Summary

A lithology-based sequence stratigraphic framework for the Lower Cretaceous mixed carbonate-siliciclastic sediments of the subsurface Albemarle Basin of eastern North Carolina was developed using thin sectioned well cuttings, wireline logs, and 2D seismic. Thin sections were analyzed to characterise lithology, fossil components, depositional facies, and diagenetic events, because the study interval is confined to the deep subsurface in a basin lacking core control. Integration of lithologic data with 2D seismic data and biostratigraphic control allowed regional correlation of major transgressive-regressive events between wells, resulting in the generation of a sequence stratigraphic framework for the onshore basin. Dominant lithofacies include: (shallow to deep): sandstone, skeletal sandstone, variably sandy mollusk packstone/grainstone, siltstone to shale, skeletal wackestone, variably sandy (quartz and glaucony) lime mudstone, and marl.

Comparison of observed facies with cores and wireline logs from the Baltimore Canyon Trough and Southeast Georgia Embayment confirms that many updip sequences consist of upward-shoaling siliciclastic shoreface successions, with basal open shelf mollusk-rich carbonates often marking transgressive events. Basin-scale depositional trends indicate greater accumulation of the carbonate facies in the southern portion of the basin, with increased fine siliciclastic material to the north. This trend may reflect a major siliciclastic point-source in the vicinity of the ancestral Chesapeake region. The depositional and diagenetic models generated provide insight into the facies and reservoir properties in coeval offshore units comprising frontier exploration targets along the Western Atlantic margin of the U.S. and Canada.

Introduction

This project presents a lithology-based depositional model (Figure 1) and sequence stratigraphic framework for the subsurface Early Cretaceous sediments of the Albemarle Embayment. This framework provides an analogue for coeval strata along the North Atlantic margin. It also provides an updip stratigraphic reference section for offshore exploration targets within the basin (Manteo prospect; Vigil, 1998).

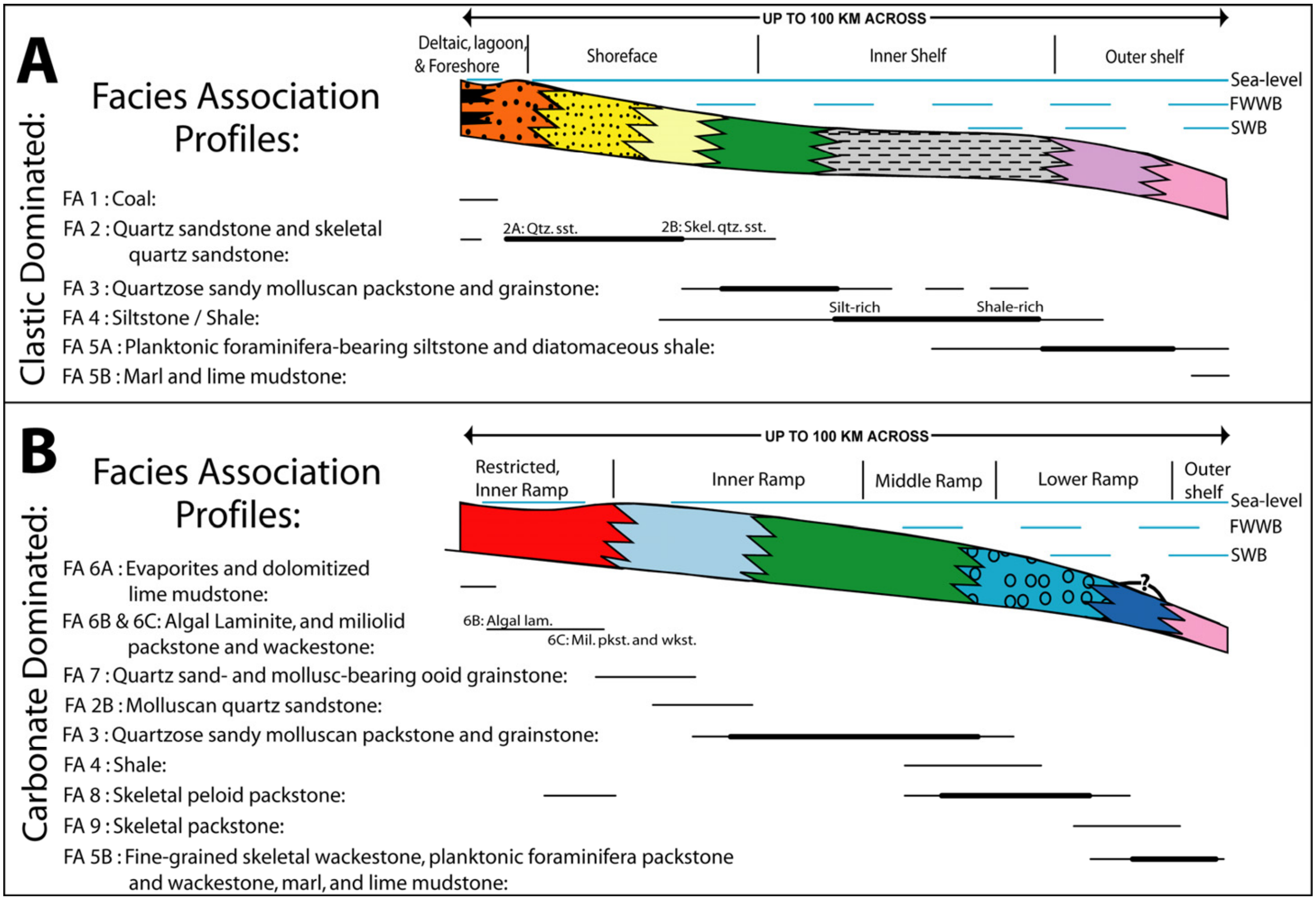

Figure 1: Generalised facies association profiles of the Early Cretaceous sediments in the Albemarle Embayment of North Carolina. Siliciclastic-dominated sedimentation (profile A) is most common. Carbonates (profile B) accumulated primarily during periods of low siliciclastic input to the shelf, largely during the relative sea-level lowstand transitioning from Sequence 1 to Sequence 2. Shelf setting indicated at top. Heavy lines represent region of maximum accumulation of facies types; light lines represent zone of likely accumulation.

The datasets employed in this project were vintage well and 2D seismic data. As discontinuous core was recovered from only one well within the basin, cuttings samples provided invaluable lithologic control. The observed lithologies were compared to core from more recently drilled offshore wells in adjacent basins (Baltimore Canyon Trough and Southeast Georgia Embayment) to confirm stacking patterns and discern environments of deposition.

Depositional Model

The observed mixed carbonate-siliciclastic lithologies were grouped into ten facies associations that were deposited in environments ranging from marginal marine to deep, open shelf. Sediments were deposited on a low angle, high-wave energy shelf or ramp (Figure 1). The tropical paleolatitude of the basin during the Early Cretaceous (Scotese, 1995) favoured carbonate sedimentation during periods of reduced siliciclastic transport to the basin from the proximal Appalachian Mountains.

The more common, siliciclastic-dominated system (Figure 1A) consisted of marginal marine environments (lagoons, coastal and delta plains), which graded seaward to open shelf settings. Biostromes consisting dominantly of molluscs (likely rudist bivalves) existed locally on the shallow shelf in areas downdip of the quartzose, sand-dominated shoreface. Proximal to terrigenous point sources, abundant siliciclastic material limited carbonate productivity, resulting in thicker accumulations of siliciclastics. The deep, open shelf setting was dominated by pelagic and hemipelagic sedimentation, typified by shale, diatomaceous shale, planktonic foraminifera-bearing siltstone, and marl in more distal settings.

The carbonate-dominated system (Figure 1B) was prominent only during the late highstand systems tract of Sequence 1. It consisted of restricted tidal flats and lagoons, which graded seaward to high-energy quartzose sand-bearing, shallow subtidal, ooid shoals and barriers. The system graded basinward to open-marine, mollusc-rich biostrome accumulations of the middle ramp. Mollusc-rich carbonates were periodically reworked by storm and swell waves. As water depth increased, more carbonate mud accumulated, which was reworked with benthic biota to form sediment dominated by molluscs and peloids. In nutrient-rich, deep waters of the outer ramp, bryozoans and brachiopods flourished, resulting in the local deposition of skeletal packstone showing little evidence of reworking. The deep shelf was characterised by marls with abundant planktonic foraminifera. Minor amounts of siliciclastic material were deposited within the carbonate succession; storm mixing processes or longshore drift probably transported this material downdip onto the shelf from sand-rich coastal regions.

During short-term transgressions, much of the siliciclastic material was trapped in updip estuaries (cf. Galloway and Hobday, 1996), favouring biogenic carbonate production on the open shelf (Milliman et al., 1968; Ginsburg and James, 1974). Molluscan carbonate production likely was widespread during these periods, with pelagic sedimentation occurring in deep shelf settings. Localised hardground surfaces developed in regions characterised by minor sedimentation and/or bottom scouring by nutrient-rich currents.

This study documents a very heavily admixed carbonate-siliciclastic depositional system (Figure 1). It also corroborates the contention that climate plays a major role in controlling carbonate- versus siliciclastic-dominated sedimentation patterns in times of global greenhouse climate. Arid climate cycles favour carbonate sedimentation, whereas humid climate cycles favour siliciclastic sedimentation (Wilson, 1975;Riggs, 1984; Read, 1995). Sea-level also plays a major role in controlling carbonate versus siliciclastic abundance (Wilson, 1975; Martindale and Boreen, 1997). However, the late highstand, carbonate-rich sediments of the upper sequence studied demonstrate that relative sea-level falls do not always favour siliciclastic sedimentation.

Sequence Stratigraphic Summary

Sequence stratigraphic surfaces were identified in a manner similar to that employed by Coffey and Read (2004). Regionally correlatable, upward-shoaling packages 15 to 20 m (50 to 70 ft) thick were identified in all of the studied wells. These packages were interpreted as parasequences; and record high frequency changes in relative sea-level. Parasequences were grouped into parasequence sets characterised by either progressive progradational or retrogradational stacking patterns. Sequence boundaries were assigned to the tops of progradational highstand parasequence sets (HST) that sometimes corresponded with downlapping reflectors on seismic data. Maximum flooding surfaces were placed below facies interpreted to record the deepest-water facies association capping transgressive, retrogradational parasequence sets (TST). These surfaces typically coincide with regional seismic reflectors upon which downlaps occur. Lowstand sediments were not identified in the study area (criteria used were shallow-water facies associations occupying a basinal position and wedge-like, onlapping geometries expressed on seismic profiles). If developed, they are believed to be present downdip of the study area. On this basis, transgressive flooding surfaces are considered to closely coincide with the underlying sequence boundaries.

Three third-order sequences were identified, each with a maximum duration of approximately four million years. The oldest (Sequence 0) is dominated by siliciclastics, with regionally extensive marls and shales marking the maximum flooding surface. The middle sequence (Sequence 1) is siliciclastic-dominated at the base, but grades into carbonate-dominated facies associations during late highstand conditions. The maximum flooding surface in this interval is seismically traceable in updip regions, but due to either thickness changes or facies transitions, it is not seismically resolvable in basinal areas. The youngest identified sequence (Sequence 2) contains a carbonate-dominated transgressive package that grades abruptly to siliciclastic-dominated associations during the following relative sea-level highstand. The maximum flooding surface is marked by a marl/shale unit in southern regions, and by a thick, diatomaceous marl/shale in the northern regions.

The sequence boundaries identified in this project generally correspond to the positions of the sequence boundaries identified by Zarra (1989). However, important differences exist between this and previously published studies. This study provides a more comprehensive sequence stratigraphic framework that includes major flooding surfaces in addition to the sequence boundaries. This study also identifies a previously unrecognised sequence within the study interval. Most importantly, this study provides valuable depositional and stratigraphic models that incorporate lithologic, biostratigraphic and geophysical datasets from a mixed carbonate-siliciclastic system that developed on an open shelf during a time of global greenhouse climate.

Conclusions

This study contributes to the understanding of mixed carbonate-siliciclastic systems. It has resulted in a regional depositional and sequence stratigraphic model that incorporates lithologic, seismic, and biostratigraphic data. It provides a framework which can be used to guide future exploration of coeval units along the western Atlantic Margin.

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References

Coffey, B. P., and J. F. Read, 2004, Mixed carbonate-siliciclastic sequence stratigraphy of a Palaeogene transition zone continental shelf, southeastern USA: Sedimentary Geology, v. 166, p. 21-57.

Galloway, W. E., and D. K. Hobday, 1996, Terrigenous Clastic Depositional Systems, Applications to Fossil Fuel and Groundwater Resources, New York, N.Y., USA, Springer, second edition, 489 p.

Ginsburg, R. N., and N. P. James, 1974, Holocene carbonate sediments of continental shelves. In C. A. Burk, and C. L. Drake, eds., The Geology of Continental Margins, New York, Springer-Verlag, p. 137-155.

Martindale, W., and T. D. Boreen, 1997, Temperature-stratified Mississippian carbonates as hydrocarbon reservoirs – examples from the foothills of the Canadian Rockies. In N. P. James, and J. A. D. Clarke, eds., Cool-Water Carbonates, Tulsa, Oklahoma, Society for Sedimentary Geology, SEPM special publication no. 56, p.391-409.

Milliman, J. D., O. H. Pilkey, and B. W. Blackwelder, 1968, Carbonate sediments on the continental shelf, Cape Hatteras to Cape Romain, Southeastern Geology, v. 9, p. 245-267.

Read, J. F., 1995, Overview of carbonate platform sequences, cycle stratigraphy and reservoirs in greenhouse and ice-house worlds. In: J. F. Read, C. Kerans, L. J. Weber, J. F. Sarg, and F. M. Wright, eds., Milankovitch Sea-Level Changes, Cycles, and Reservoirs on Carbonate Platforms in Greenhouse and Ice-House Worlds, SEPM Short Course no. 35., p. 1-102.

Riggs, S. R., 1984, Paleoceanographic model of Neogene phosphorite deposition, U.S. Atlantic Continental Margin, Science, v. 223, n. 4632, p. 123-131.

Scotese, C.R., 1995, Phanerozoic Plate Tectonic Reconstructions, PALEOMAP Progress Report #36, Department of Geology, University of Texas at Arlington, 82 pp. (copyrighted in 1997)

Vigil, D. L., 1998, North Carolina/Minerals Management Service Technical Workshop on Manteo Unit Exploration: February 4-5, 1998, OCS Study MMS 98-0024, U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, 168 p.

Wilson, J. L., 1975, Carbonate Facies in Geologic History, New York, Springer-Verlag, 471 pages.

Zarra, L., 1989, Sequence Stratigraphy and Foraminiferal Biostratigraphy for Selected Wells in the Albemarle Embayment, North Carolina: North Carolina Geological Survey, Open-File Report 89-5, 48 p.