

Transgressing barrier islands and lagoons: Application to mixed carbonate-siliciclastic successions in the Chazy Group (Ordovician), eastern North America

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Summary

This presentation describes a repeated stratigraphic motif consisting of mixed siliciclastic and carbonate sedimentary rocks in the Middle to Late Ordovician Chazy Group in Ontario, Quebec, New York State and Vermont, eastern North America. Each instance of the succession of facies described here is interpreted to record the landward migration of a carbonate barrier island and its associated landward lagoon and seaward open-marine, shelf carbonates. The succession from the bottom up is: restricted, fine-grained carbonate and siliciclastic lagoonal deposits; an erosion surface formed by wave ravinement during passage of the barrier island; cross-bedded quartz-carbonate grainstones formed by tidal currents on the shelf; and storm-bedded and bioturbated grainstones and packstones that accumulated just above and below storm-wave base. The barrier-island model presented here explains the occurrences of cross-bedded grainstones better than the classic subaqueous “shoal” model.

Theory / Method / Workflow

A recent global review of modern carbonate coastal systems (Dalrymple and Rivers, 2023) has demonstrated that many of the classic ideas of carbonate coastal sedimentation are not supported by the observations. Carbonate barrier islands are not rare, and they do migrate landward (i.e., they transgress) as sea-level rises. Instead, prograding carbonate tidal flats are rare, whereas transgressive successions are thick and abundant! Furthermore, subaqueous shoals that occur in coastal areas (C-type shoals), as opposed to platform-margin (reef-related) shoals (R-type shoals), are not common and are interpreted to represent either incipient or disintegrating barrier islands. This study represents a test of these ideas.

Outcrops in four localities spanning the Chazy carbonate ramp, from near Ottawa in the west to the Lake Champlain area in the east, were chosen because each of them contained quartz-rich cross-bedded grainstones of the type that have previously been interpreted as a carbonate shoal complex. The outcrops represent a repeated stratigraphic succession of facies and are found at various stratigraphic heights in the Chazy Group across its geographic extent. At each locality, the cross-bedded grainstone and both the under- and overlying facies were logged in detail and

placed in the context of larger-scale, published stratigraphic logs from the studied sections. Thin sections were examined to determine textural details and the composition of the bioclasts.

Results, Observations, Conclusions

Three facies, each representing a distinct depositional environment, occur in a predictable order in the outcrops examined (Figure 1).

Facies 1 consists of fine-grained, low-energy deposits composed of siliciclastic siltstones and lime mudstones with uncommon occurrences of wackestone. Fauna is mostly absent, except for ostracods and rare occurrences of a less restricted assemblage near the uppermost exposures of this facies. Landward occurrences of this facies locally contain evidence of evaporite minerals. This facies averages ~ 1.5 m thick, but it is locally absent.

Facies 2 is composed predominantly of medium to coarse-grained bioclastic grainstones that contain a significant fraction (5-50%) of similarly sized quartz grains. The bioclasts are dominated by echinoderm fragments, with lesser amounts of articulate and inarticulate brachiopods, fenestrate bryozoans, trilobites and ostracods. Ooids are present locally. These sediments are ubiquitously cross-bedded in 10-50 cm-thick sets, with both simple and compound cross bedding present. The dominant paleocurrent direction is to the west-northwest (landward), with a subordinate mode to the east-southeast. Tidal bundling is observed in some outcrops, along with scattered occurrences of wave and current ripples. No exposure of this facies exceeds 2.5 m in thickness, and most are < 1.5 m thick.

Facies 3 is relatively pure limestone; quartz sand is a minor constituent and can be absent. The grains consist mainly of fragments of echinoderms, bryozoans and brachiopods. Ooids are rare. This facies is horizontally bedded, with evidence of storm event beds in the lower part of exposures, with more homogeneous grainstones and packstones higher in each succession as a result of bioturbation. Facies thicknesses are on the scale of metres.

The environmental interpretations of Facies 1 and 3 are relatively straightforward. Facies 1 is interpreted to be a lagoonal deposit that accumulated in a low-energy, restricted setting with elevated salinities that locally exceeded gypsum saturation, an interpretation that is consistent with its subtropical paleolatitude. This implies the lagoon had limited water exchange with normal marine waters. The siliciclastic siltstones are believed to represent wind-blown dust derived from the exposed Canadian Shield to the west and north. Facies 3, by contrast, accumulated in an open-marine environment that allowed for the proliferation of an unrestricted faunal assemblage. Physical energy in the form of storm waves acted on the seafloor in the lower parts of this facies, but energy apparently became less upward allowing the degree of bioturbation to increase.

Interpretation of Facies 2 is the key to understanding the origin of the succession. The cross-bedding was obviously formed by currents. The bipolar paleocurrent pattern and the local presence of tidal bundling strongly suggest that this current was tidal. The abundance of echinoderm debris indicates the existence of normal-marine salinity. Classically, these cross-beds would be interpreted as having formed in a subaqueous shoal that separates open-marine conditions from a more sheltered lagoon (cf. Jones, 2010, figures 18A and 21A). However, several aspects of the Chazy cross-bedded deposits are inconsistent with this interpretation. First, the

occurrences are all thin, only a single bedform thick in some instances, and appear laterally extensive and tabular in outcrop, characteristics that are inconsistent with aggradation of an area that was elevated significantly above the surrounding seafloor. Second, the sharp and erosive contact between this facies and the underlying lagoonal deposits (Facies 1) is, we believe, inconsistent with formation in a shoal, as is the lack of any significant salinity gradient between the lagoon and the area where the cross-bedding formed. Subaqueous coastal (C-type) shoals in the modern allow enough water exchange that there is typically not a significant salinity difference across the shoal and conditions in the lagoon are rarely sufficiently elevated to cause the development of evaporites. Instead, the cross-bedded units are interpreted as recording unimposing open-marine dune fields rather than a notable shoal. We suggest, therefore, that the preserved succession and the character of the surfaces between facies records the former presence and transgressive landward migration of a barrier island and its associated lagoon, generating a transgressive facies succession with seaward deposits mantling the barrier island's ravinement surface (Figure 2).

The former presence of a subaerial coastal barrier is indicated by the abrupt and dramatic change in facies and faunal characteristics between Facies 1 and 2. The erosion surface that separates these facies is interpreted to represent the wave ravinement surface that forms on the seaward face of the barrier as it migrates landward. Facies 2 with its significant quartz-sand content represents the transgressive lag, with the quartz believed to be derived from siliciclastic deposits that were carried onto the exposed ramp during the preceding lowstand. Those deposits were cannibalized by the ravinement processes, with the quartz sand mixing with the newly produced bioclasts and carried back landward during the transgression and reworked into tidal dune fields on the seafloor.

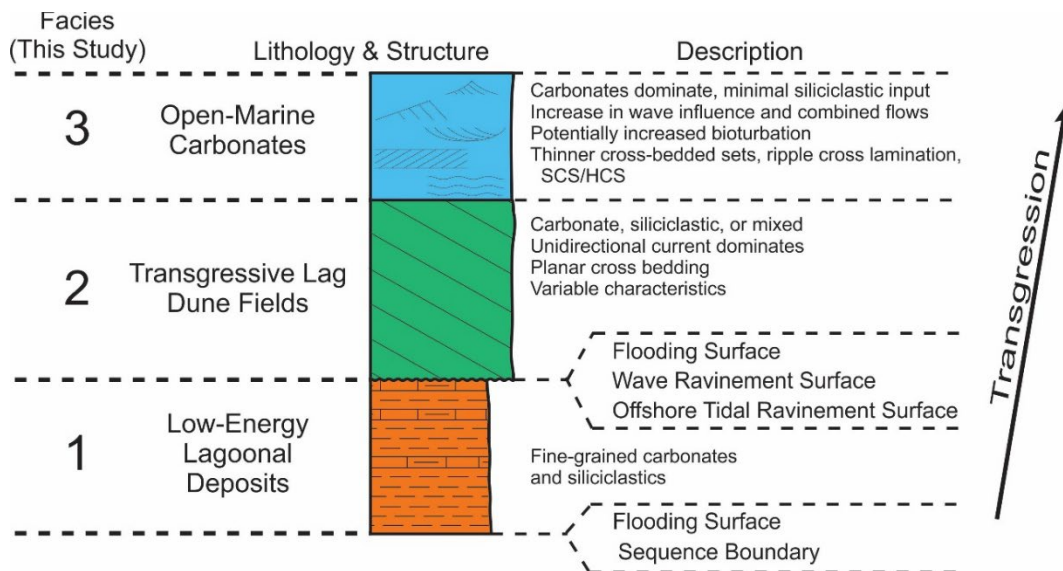


Figure 1: Simplified, complete depositional succession for Chazyan transgressive deposits based on the four examples examined. The cross bedding in Facies 2 is shown schematically only; several sets are typically present in each occurrence of this facies.

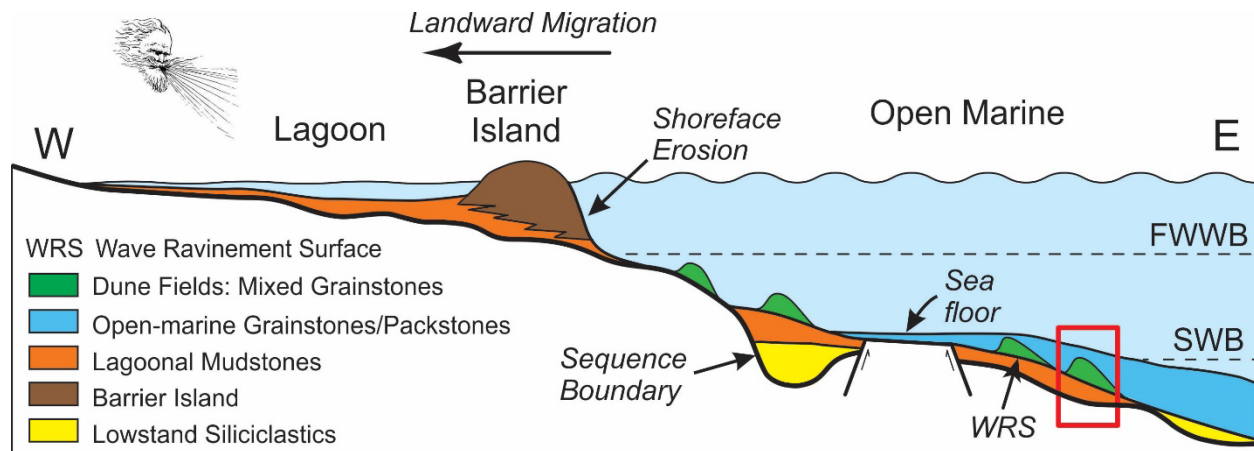


Figure 2: Interpreted depositional model for transgressive Chazy successions. The recorded succession of facies (red box; see also Figure 1) is transgressive in its organization, with lagoonal deposits at the base, overlain by cross-bedded, quartz-rich grainstones that mark the transgressive lag that was sculpted into tidal dunes seaward of fair-weather wave base (FWWB), and capped by open-marine limestones that accumulated around storm-wave base (SWB). The erosive contact between the lagoonal and transgressive-lag deposits marks the wave ravinement surface (WRS) that records the landward passage of the barrier island.

Novel/Additive Information

The succession of deposits, as interpreted here, is transgressive in character and utilizes a model (a landward-migrating barrier island-lagoon complex) that is almost never applied to carbonate successions, although we believe it should be. The utility of this model supports the observations made from modern carbonate coasts by Dalrymple and Rivers (2023). Early cementation appears to have minimal affect on barrier formation and morphodynamics, and they behave similarly to their siliciclastic counterparts. Thus, ideas and concepts developed in siliciclastic settings (modern and ancient) can potentially be applied directly to carbonate successions. The idea that carbonate successions are dominated by progradation (i.e., the upward-shallowing facies model; e.g., Pratt, 2010) requires re-evaluation.

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