Evidence of a tectonically driven sequence succession in the Middle Ordovician Taconic foredeep

Michael P. Joy
Charles E. Mitchell*
Department of Geology, State University of New York, Buffalo, New York 14260, USA
Soumava Adhya
Department of Earth and Atmospheric Sciences, State University of New York, Albany, New York 12222, USA

ABSTRACT

The late Mohawkian through early Cincinnatian (Ordovician) Trenton Group carbonates and coeval siliciclastic succession of the central Mohawk Valley, New York State, were deposited in a foreland basin during the Taconic orogeny. Development of this facies mosaic records changes in stacking patterns that took place during episodic basin deepening and simultaneous carbonate-ramp shallowing along a ramp to basin transect located on the distal slope of the foreland basin. Differential rates of subsidence across the region produced accommodation rates that increased by an order of magnitude from west to east. High rates of siliciclastic sediment supply and even higher subsidence rates resulted in a thick, deep-water succession in the eastern part of the study region. The coeval Trenton Group succession in the west formed under conditions of moderate sediment supply and lower subsidence rate, resulting in a net shallowing-upward succession. These relationships suggest that active margin tectonism was the proximate cause of the Mohawk Valley facies architecture.

Keywords: sequence stratigraphy, tectonics, Ordovician, Appalachian basin.

INTRODUCTION

Sequence stratigraphic analysis in active margin settings substantially improves our understanding of the relationship between plate flexure and basin development. This is particularly true of the upper Mohawkian Series mixed carbonate and siliciclastic succession of the Taconic foreland basin. Holland and Patzkowsky (1996, 1998) and Pope and Read (1997) demonstrated the utility of sequence stratigraphy for recognizing and organizing lithofacies into a series of genetically related depositional packages. In each of these studies, the authors asserted that sequence stratigraphic procedures identify isochronous intervals that are spatially correlative (Vail et al., 1977; Haq et al., 1987). Alternatively, recent work suggests that local tectonism may produce high-frequency stratigraphic cycles within tectonically active basins (e.g., Posamentier and Allen, 1993; Yoshida et al., 1996; Gawthorpe et al., 1997; Ito et al., 1999). These cycles may be restricted to the area of tectonic influence and may be out of phase among different subbasins.

Most of the Taconic foreland succession contains K-bentonites (altered volcanic ash layers; see summary by Kolata et al., 1996) that can be fingerprinted using the techniques of Hanson et al. (1996). We used fingerprinted K-bentonites, graptolite, conodont, and chitinozoan range data, and some regionally extensive event beds to construct a high-resolution chronostratigraphic framework independent of sequence stratigraphy. There are 17 closely spaced stratigraphic sections (Fig. 1) that span this interval, which corresponds, in some measure, to the M4 through C1 interval of Holland and Patzkowsky (1996) in the central Appalachians.

SEQUENCE STRATIGRAPHY

Four third-order sequences spanning the late Turinian through early Edenian stages were deposited during the post-Knox phase of the Taconic transgression in the Mohawk Valley. These sequences closely resemble structural sequences as defined by Howell and van der Pluijm (1999), except that all four sequences recognized in the Mohawk Valley are contained entirely within their larger sequence C in the Michigan basin. Elsewhere in the Appalachian basin, Holland and Patzkowsky (1996, 1998) similarly recognized four sequences of third-order scale in this interval. We use the third- and fourth-order sequence designations to mean sequences developed roughly on the 10 m and 1 m scales, respectively. These designations are intended only to give the reader a sense of sequence scale.

In this paper we present the chronostratigraphic position of four sequences recognized

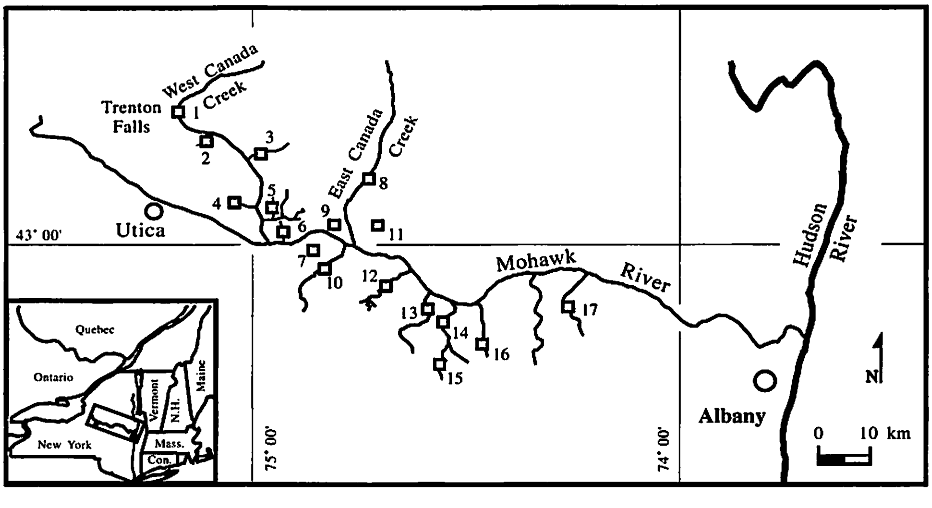

Figure 1. Measured sections in Mohawk Valley, New York. 1—Trenton Falls, 2—Rathbun Creek, 3—Wolf Hollow Creek, 4—Countryman Creek, 5—North Creek tributary at Kelly Road, 6—North Creek tributary at Myers Road, 7—New York State Thruway (I90) at mile 212, 8—Dolgeville Dam at East Canada Creek, 9—West Crum Creek, 10—Nowadaga Creek, 11—outcrop at Allen Road, 12—Otsquago Creek tributary at Potter's Farm, 13—Canajoharie Creek, 14—Flat Creek, 15—southern tributary of Flat Creek, 16—Yatesville Creek, 17—Chuctununda Creek.

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*E-mail: cem@acsu.buffalo.edu.

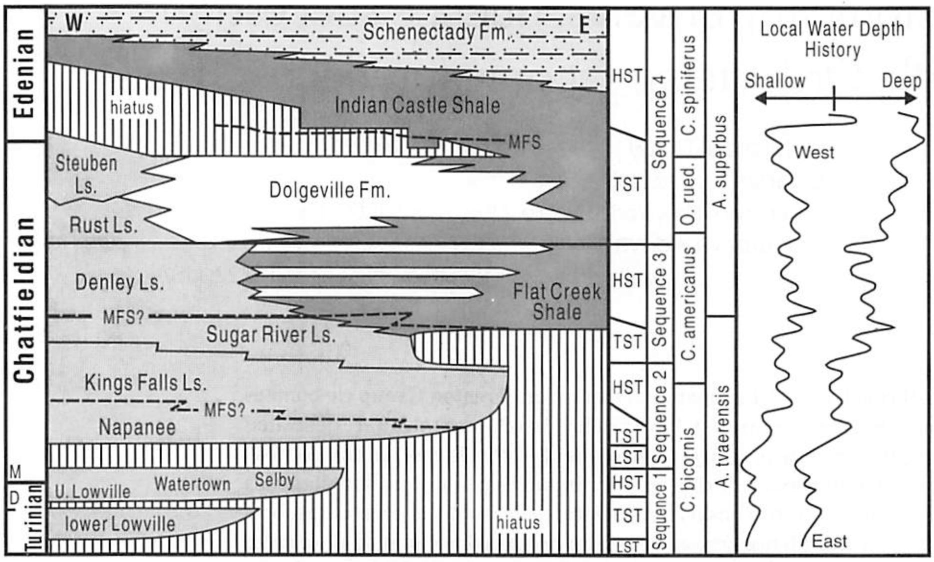


Figure 2. Chronostratigraphic correlation of Mohawk Valley, New York: from left to right, stadial nomenclature (Leslie and Bergström, 1995); sequence stratigraphic boundaries; lowstand, transgressive, and highstand system tracts (LST, TST, and HST); graptolite zones (Riva, 1969; Goldman et al., 1994); conodont zones (Bergström, 1971); and local water depth curves in study area. Dashed maximum flooding surfaces (MFS), shown with respect to facies boundaries, indicate that they are difficult to identify and time transgressive. Basinal shales are shown by dark shading; light shading indicates Trenton Group carbonates; and white indicates Dolgeville Formation and similar facies within parasequences in Flat Creek Shale. Vertical ruling represents hiatus. Letters M and D show approximate position of Deicke and Millbrig K-bentonites.

in the Mohawk Valley and discuss the causal development of sequences 3 and 4 (Fig. 2). Sequences 1 and 2, which were deposited in peritidal settings, are unconformity bounded; lowstand intervals are encompassed by the unconformity. Sequences 3 and 4 also consist only of transgressive and highstand system tracts. Within the siliciclastic-dominated portion of the Taconic foreland basin, sequences 3 and 4 occur as a series of successively deeper water rock units bounded by conformable zones of profound marine flooding: intervals of black shale deposition that cap a progradational parasequence set. Thus, these two cycles appear to be a deep-water manifestation of a Type II sequence. For the sake of objectivity, we place the sequence boundary at the point of reversal in facies stacking but recognize that this is not a conventional usage. We discuss the issue of missing lowstand systems tracts within this conformable succession in the following.

Initially shallow water calcisiltites and thin calcilutites in the base of the Sugar River Limestone in the western Mohawk Valley (Trenton Falls–Herkimer region) deepen upsection into thick-bedded calcilutites interbedded with calcareous shales during development of the transgressive system tract of sequence 3. This transgression culminated in a condensed, sediment-starved zone of maximum flooding at the *Trocholites* bed (Kay, 1953) in the top of the Rathbun Member of the Sugar River Limestone (Goldman et al., 1999). The Sugar River Limestone passes basinward (Amsterdam–Fort Plain region) into a marine unconformity (Mitchell et al., 1994) that appears to have resulted from sediment starvation during transgression.

Carbonate highstand deposits in the Denley and Rust formations shallowed upsection, and comprise at least three regionally persistent parasequences (Fig. 2). The Denley and lower Rust limestones grade basinward into the Flat Creek Shale. The latter is a graptolite-bearing, calcareous, laminated, black shale sparsely interbedded with calcilutites. The Flat Creek Shale also comprises three parasequences (Fig. 2). Each parasequence begins with a recessive black shale that grades upward into ledge-forming calcilutites and distal turbidites (Goldman et al., 1999).

Widespread flooding during the late Chatfieldian resulted in a basinwide return to deposition of sooty black shale (the Valley Brook Member of the Flat Creek Shale). This event, which caps the parasequences in the Flat Creek Shale and their equivalents upslope (Fig. 2), marked the beginning of the transgressive phase of sequence 4. Goldman et al. (1999) noted that a large turnover in the graptolite fauna (corresponding to the *Corynoides americanus–Orthograptus ruedemanni* zonal boundary) took place within the Valley Brook Shale. The shale grades laterally into the Rust Limestone in the region between West Crum Creek (section 9, Fig. 1) and Middleville (section 5, Fig. 1). The overlying Dolgeville Formation consists of two parasequences in the central and eastern basin and grades into and overlies much of the middle and upper Rust Limestone in the west. Graphic correlations by Joy (1997) suggest that the Dolgeville Formation is condensed with respect to the underlying Flat Creek Shale. Dolgeville Formation strata initially appear to be progradational. However, shale content continuously exceeds carbonate content and the upper Dolgeville Formation is strongly retrogradational, backstepping in the direction of the Trenton ramp.

Ramp carbonates representing the upslope equivalents to the transgressive Valley Brook Shale and Dolgeville Formation continued to shallow upsection through a series of small-scale (1–10 m) parasequences, becoming shoal-water carbonate sands within the Stueben Limestone

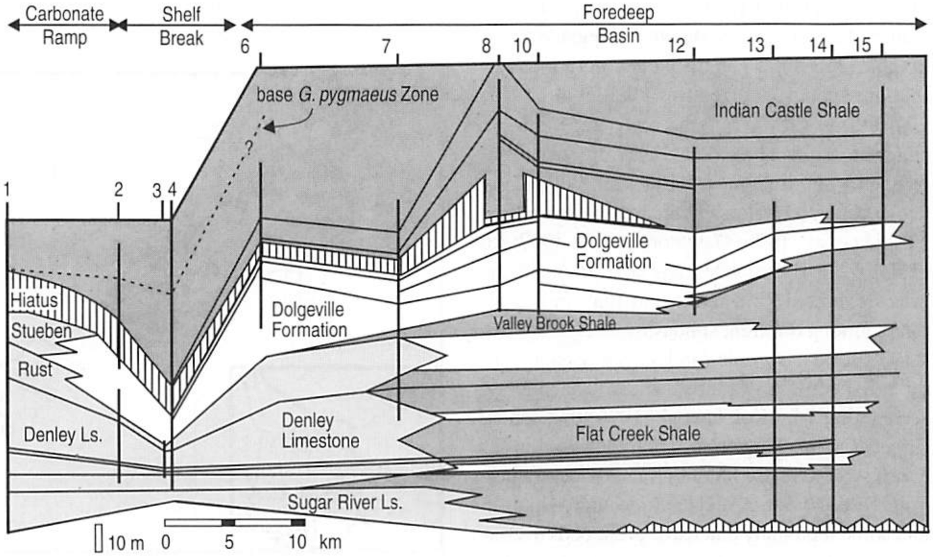
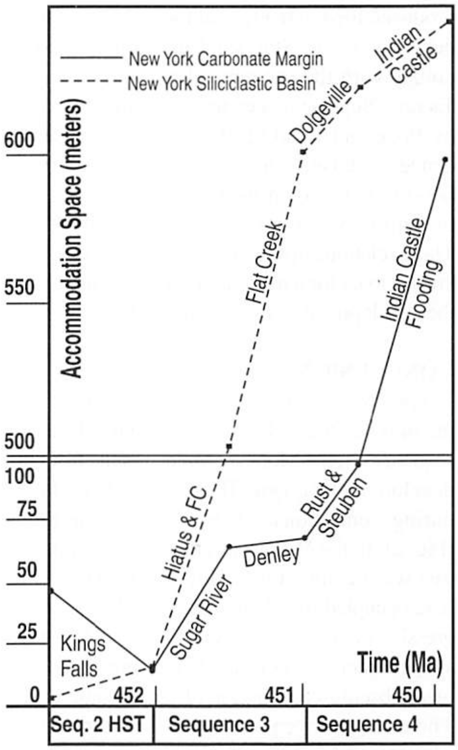


Figure 3. Lithostratigraphic cross section of sequences 3 and 4. Shading as in Figure 2. Sections studied (solid vertical lines) numbered as in Figure 1. Geochemically fingerprinted K-bentonites (black lines; see Mitchell et al., 1994) constrain temporal relationships between disparate facies. In addition to K-bentonites, facies relationships and hiatus duration are determined from graphic correlation based on graptolite, conodont, and chitinozoan range data and regional event beds (Mitchell et al., 1994).

Figure 4. Backstripping curves of representative carbonate succession (distal basin margin) and basinal siliciclastic shale section. Horizontal scale is calibrated to composite standard reference section of Sweet (1984) by graphic correlation. Horizontal lines indicate change in vertical scale (accommodation space). Note divergence of curves during transgressive phase of sequence 3. Accommodation space growth differs between margin and basinal sections by order of magnitude. HST—highstand systems tract.



(Fig. 2). This interval correlates with the late transgressive phase of sequence 4 in the basin. The maximum flooding surface of sequence 4 is located in the marine hiatus separating the Dolgeville and Steuben formations from the Indian Castle Shale (Fig. 2). The Indian Castle Shale progrades from the east, onlapping the unconformity during maximum flooding within the lower *Climacograptus spiniferus* Zone. The remainder of the Indian Castle Shale and overlying coarser grained clastic deposits of the Schenectady Formation prograded into the Taconic basin from the east and overstepped the carbonate ramp during the lower *Geniculograptus pygmaeus* Zone. The upper Indian Castle Shale and Schenectady Formation represent highstand deposits of sequence 4.

BASIN ARCHITECTURE

Explaining the proximate causes of progradational stacking along the carbonate facies belt and simultaneous profound deepening to the east is fundamental to an understanding of Taconic basin history. Differences of this sort can arise in response to relatively greater sediment supply rates in the more onshore setting. Figure 3 is a lithostratigraphic cross section of the Taconic basin. Strata in this interval thicken from the carbonates on the western margin into the siliciclastic-dominated basin. Carbonate-rock accumulation rates were markedly less than those of equivalent siliciclastic sections in the basin. As a result, neither the diachronous maximum flooding surfaces (which become younger from east to west) nor the disparity in facies stacking between the carbonate facies belt and the basin can be explained by local disparities in sediment supply rates.

Figure 4 displays the results of backstripping two representative sections, one from the distal basin margin and the other from deep-water facies within the basin, between synchronous K-bentonites or their correlative position determined by graphic correlation. We used Backstripping 1.1 (obtained from S.M. Holland, University of Georgia, Athens) to construct the backstripping curves and employed the composite standard section of Sweet (1984) as the time axis. Backstripping curves are sensitive to water depth estimates. In addition to field observations, we estimated water depths and sediment thicknesses of Trenton Group rocks from Cameron and Kamal (1977), Cameron and Mangion (1977), Anderson et al. (1978), and Titus (1982, 1986). Water depth estimates for the Flat Creek Shale, Dolgeville Formation, and Indian Castle Shale were fixed at 500 m based on the estimates of Cisne et al. (1982).

Sequence 3 (Fig. 5A) developed in response to basin subsidence as Laurentia collided with, and was overridden by, a prism-arc complex in the late Middle Ordovician (Bradley and Kidd, 1991). The accretionary load flexed the eastern Laurentian margin, resulting in structural deepening in the Taconic foredeep and a rapid increase in the rate of accommodation space growth (Fig. 4). Accommodation space growth in the eastern, more basinal sections, exceeded that of the carbonate facies belt on the western basin slope by an order of magnitude. Allochthonous siliciclastic sediment accumulated preferentially in the eastern basin and spread westward thorough time (Ruedemann, 1912; Kay, 1953). Siliciclastic sediments interfingered with carbonate tempestites during development of the sequence 3 highstand system tract and eventually overstepped in situ Trenton Group carbonates (Steuben Limestone) during sequence 4 transgression.

Sequence 4 (Fig. 5B) continued to develop under conditions of steady siliciclastic sediment supply and tempestite deposition. The basin remained structurally deepest in the east, adjacent to the Taconic thrust stack. However, maximum water depth migrated west as the basin filled. The combination of a carbonate sediment supply rate that slightly exceeded accommodation space growth and slowed subsidence rate

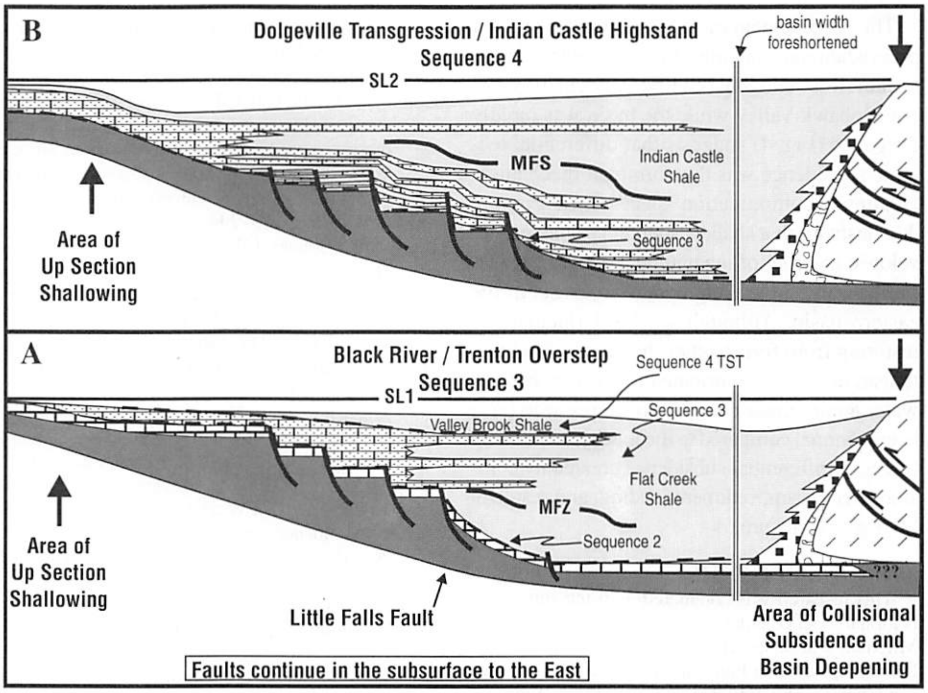


Figure 5. Time step diagram of architecture of Taconic foredeep drawn at tops of sequences 3 and 4. Diagram implies no horizontal scale between Trenton ramp and accretionary prism. A: Deposition of Sugar River through Denley succession and Flat Creek Shale equivalents during sequence 3. B: Deposition of Valley Brook Shale and Dolgeville Formation, shown as retrogradational facies grading upsection into highstand deposits of Indian Castle Shale of sequence 4. Abbreviations as in Figure 2.

produced the relatively shallow-water carbonate deposits in the Stueben Limestone synchronously with the sequence 4 transgression and Taconic Supersequence transgression described by Pope and Read (1997). Differential subsidence produced a disparity between maximum flooding in the basin and synchronous deposition of shallow-water carbonate sands on the shelf. These relationships provide the clearest evidence known to us for a tectonic forcing mechanism in the development of the Taconic sequences.

CONCLUSIONS

The absence of lowstand system tracts from the middle Chatfieldian through early Edenian sequences in the Mohawk Valley results from the development of Type II sequence boundaries during continuously transgressive conditions (Fig. 2). In the Mohawk Valley, the time interval that was occupied by lowstand elsewhere was here occupied by late highstand and early transgressive system tracts. Well-developed lowstand system tracts are not merely unrepresented, but were absent in this region of the Taconic basin. The transgressive phases of the third-order sequences and fourth-order parasequences were accentuated in the rock record and evidence of loss of accommodation space, if it occurred at all, was suppressed. The resultant foreland basin succession was dominated by transgressive and highstand systems tracts accentuated by the transgressive phase of the Taconic Supersequence (Pope and Read, 1997; possibly formed in response to the regional tilting of eastern Laurentia; see Howell and van der Pluijm, 1999).

The development of in situ carbonate and net progradational stacking of parasequences in the Denley, Rust, and Stueben limestones in the western Mohawk Valley while the basin was rapidly deepened (Fig. 4) suggests that differential tectonic subsidence was the dominant mechanism creating accommodation space. Backstripping demonstrates that shallow shelf environments developed an order of magnitude less accommodation space than age-equivalent intervals in the eastern basin. Although sea-level fluctuations resulting from forces other than thrust-load tectonism may have contributed to changes in local water depth, these contributions appear to have been minimal compared to the locally dominating forces of differential subsidence created by collisional tectonism, sediment loading, and resultant lithospheric flexure.

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