PART 3: STRATIGRAPHY, PALEONTOLOGY, AND DEPOSITIONAL ENVIRONMENTS OF THE MIDDLE DEVONIAN OF WESTERN NEW YORK

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Middle Devonian Hamilton Group, upper Ludlowville and Moscow formations at Lake Erie shore near the mouth of Eighteenmile Creek

THE MIDDLE DEVONIAN HAMILTON GROUP OF WESTERN NEW YORK

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INTRODUCTION

The Middle Devonian (Givetian) Hamilton Group of New York State comprises a westwardly-thinning sedimentary wedge ranging from nearly 1200 m-thick of mudstones and coarse siliciclastics at the Catskill Front to approximately 100 m-thick in western New York. Hamilton Group strata have been well known since the time of publication of James Hall's Geology of the Fourth District (1839), as the source of some of the most diverse and best-preserved Devonian fossils on Earth. Over most of the outcrop belt these strata are undeformed and have minimal diagenetic overprinting. Hamilton Group stratigraphy and paleontology have been documented in numerous studies (Vanuxem, 1840, 1842;Hall, 1839, 1843, 1867, 1879, 1884, 1888; Hall and Clarke, 1888, 1892, 1894; Hall and Simpson, 1887; Grabau, 1898, 1899; Cleland, 1903; Goldring, 1923; Cooper, 1929, 1930, 1933, 1934; Cooper and Warthin, 1942; Rickard, 1975, 1984; Rickard and Zenger, 1964; House 1965, 1978, 1981; Oliver and Klapper, 1981; Brett, 1986; Landing and Brett, 1991; Brett and Baird, 1981, 1994, 1995, 1996, 2000, 2003; Brett et al., 1990). Much of the present text is excerpted and modified from a new synthesis of Hamilton stratigraphy and facies (Brett et al. 2023).

The Hamilton Group sediments, derived from Acadian source terranes to the southeast, were deposited in an actively subsiding and migrating foreland basin in the area of present-day New York, Pennsylvanian, Maryland, West Virginia, and Virginia (Fig. 1). Foreland basin development, as well as sedimentary filling, are linked with the third major tectophase of the Acadian Orogeny, the result of oblique collision with one or more terranes, i.e., Avalonia and the Carolina terranes in what is today New England and the mid-Atlantic states (Ettensohn, 1985, 1987, 1998, 2004, 2008; Dennison and Ettensohn, 1994). These sediments were deposited during Ver Straeten's (2010) Acadian Tectophase 3 (modified after Ettensohn's 1985 Acadian Tectophase II). The bulk of the foredeep of the Acadian foreland basin system had migrated into New York and tended to progress westward (cratonward) during much of the deposition of the Hamilton Group with a short-lived reversion to eastward migration of small-scale flexural features during the deposition of the uppermost Moscow and Tully formations (Brett and Baird, 1994; Ver Straeten, 2010).

The New York region was located in the southern subtropical to warm temperate belt about 30 south paleolatitude (Dennison and Textoris, 1987; Scotese, 2001; Blakey, 2019; Ver Straeten et al., 2023; Fig. 1). Sandstones with classic storm depositional indicators, such as hummocky cross stratification, sedimentary grading, and gutter casts are typical of eastern proximal facies. The presence of prograding deltaic sedimentation suggests a relatively wet source area, with rivers draining the Acadian uplands, although equivalent age strata in the Laurentian interior (e.g., Wapsipinicon Formation of Iowa) show some evidence of hypersalinity (Witzke, 1990; Witzke et al., 2010).

Orogenic uplift and thrusting to the east of the present-day New York area led to flexural bending of the cratonic lithosphere in eastern Laurentia (Quinlan and Beaumont, 1984; Beaumont et al., 1988; Ettensohn, 1988, 2008; Dennison and Ettensohn, eds., 1994). Tectonic loading produced the foreland basin, which tended to migrate westward toward the craton through most of the Middle Devonian deposition of Hamilton sediments (Fig. 2). Sedimentation from the orogen led to the development of a series of prograding deltaic

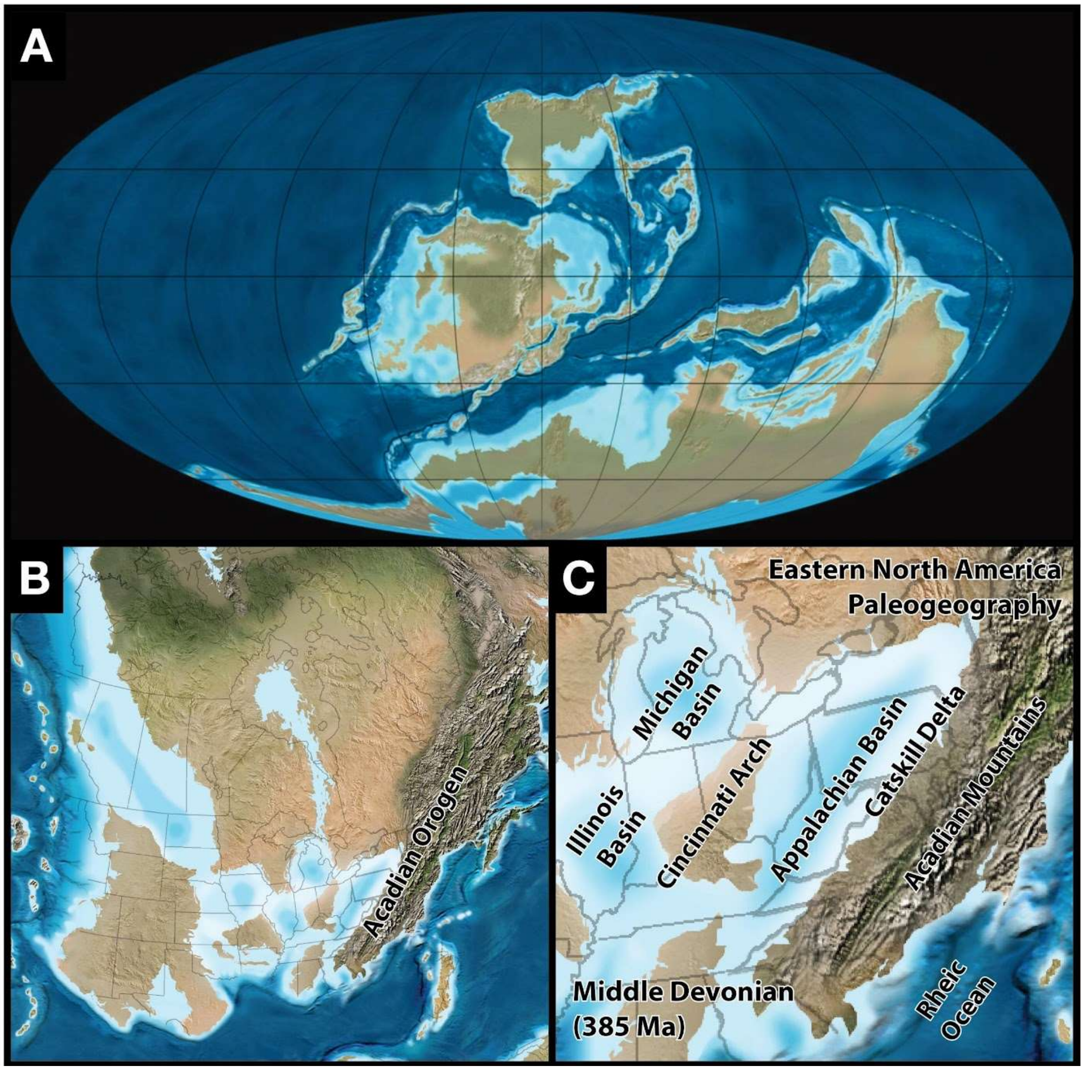

Figure 1. Paleogeographic setting of Laurentia during the Middle Devonian. **A,** Global view showing position of Laurentia relative to Siberia, Baltica, and Gondwanaland. **B,** Enlargement of Laurentia showing the proximity of Avalonia and islands of the Carolina Terranes forming the Acadian Orogen. **C,** Details of eastern Laurentia showing state outlines and positions of New York in the Acadian highlands, foreland basin, proto-Cincinnati Arch, and Michigan and Illinois basins: Adapted from Blakey (2019)

complexes, parts of the so-called Catskill Delta (Barrell, 1913; Woodrow and Sevon, 1985). Prograding sediments filled proximal parts of the basin by early Givetian time such that mid-Givetian upper Hamilton Group sediments in eastern New York State are characterized by marginal marine sandstones and thin conglomerates, as well as terrestrial fluvial dominated facies with red beds. In central and

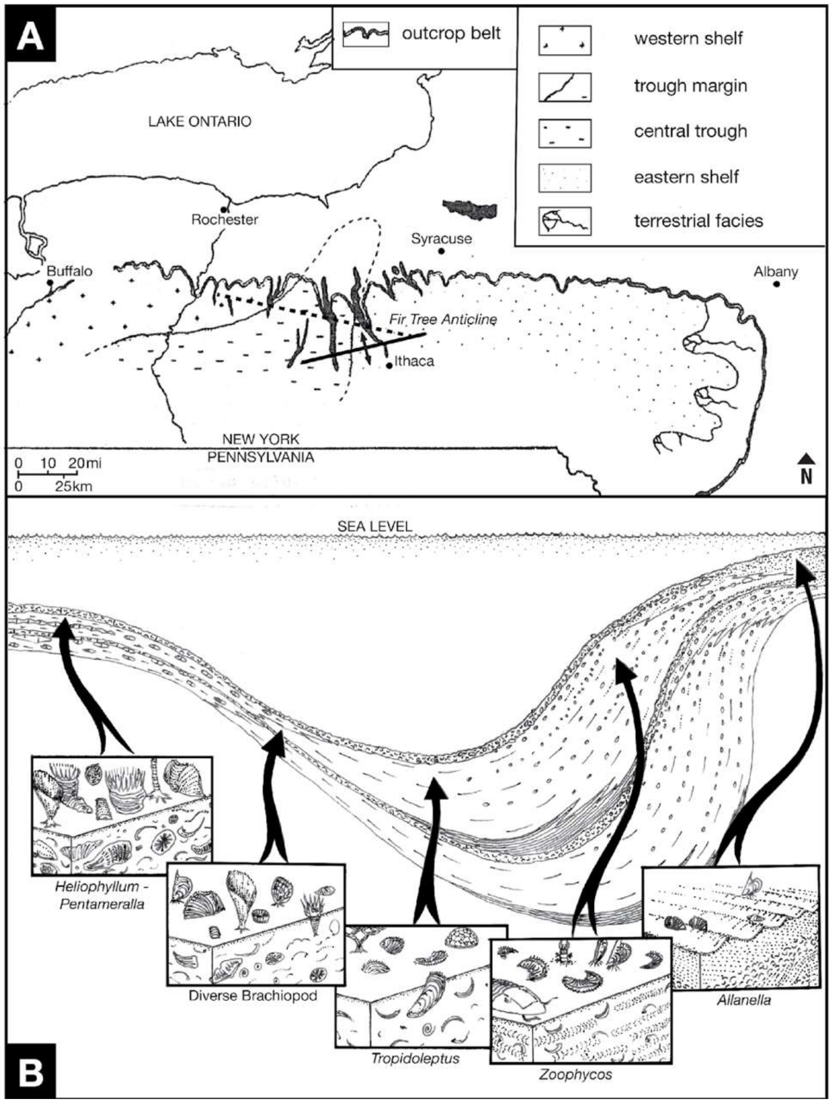

Figure 2. Paleogeographic setting of the Middle Devonian Hamilton Group, showing a portion of the Acadian foreland basin in western and central New York State. **A,** Map of New York State showing the outcrop belt and inferred position of foreland basin axis and deltaic shoreline in late Hamilton Group time. Diagonal solid line shows location of the Alleghanian structural Fir Tree anticline; dotted line gives orientation of cross section shown in B. **B,** Schematic showing hypothetical facies profile across the basin center during times of relative lowstand when the sea floor was oxygenated in the study area; note extreme vertical exaggeration. Inset pictures give vignettes of different biofacies from eastern silty shelf through basin axis and into western calcareous shelf.

western New York, the basin migration is manifest by the successive westward displacement of terrigenous depocenters of thickest areas, which is punctuated by minor interruptions, such as the eastward shift in depocenter of the Butternut Member of the upper Skaneateles Formation. These episodes may indicate successive new pulses of thrust-loading. The uppermost Hamilton Group upper Moscow Formation appears to record a transition to relative tectonic quiescence as the progradational aspect of various units is less pronounced. Individual stratigraphic units and facies persist much farther east than in subjacent units, and migration of the depocenters was reversed. Quiescence culminates in deposition of the carbonate-dominated limestones of the Tully Formation.

GIVETIAN CHRONOSTRATIGRAPHY IN EASTERN NORTH AMERICA

GLOBAL BIOCHRONOSTRATIGRAPHY

The biostratigraphic framework of the Devonian is underpinned by conodonts (Klapper, 1971, 1981; Figs. 3, 4). The uppermost Eifelian and lower to middle Givetian interval that encompasses Hamilton Group strata is divided into six zones: *Polygnathus xylus ensensis*, *Polygnathus hemiansatus*, *Polygnathus timorensis, Pol. rhenanus*/*varcus*, *Pol. ansatus*, and *Pol. semialternans* (Becker 2005; Becker et al., 2020). The boundaries of these zones have been recognized in certain Hamilton units in New York and the Midwest (Fig. 3). Many Hamilton Group units do not yield diagnostic conodonts and therefore remain poorly dated. However, representatives of other faunal groups have proven useful for purposes of correlation. Rare identifiable goniatites are very important in providing biostratigraphic control. In particular, species of *Tornoceras*, have long been recognized as reliable index fossils (House, 1965, 1978, 1981; Becker and House, 2000). In addition, certain brachiopods, bivalves, gastropods, and even crinoids also have some utility in defining and correlating particular Hamilton Group intervals in the Appalachian Basin and marginal areas. Details of biostratigraphy discussed in Bartholomew and Brett (2007) are summarized here.

CONODONT BIOSTRATIGRAPHY

Conodont biostratigraphy has been documented for the Middle Devonian of much of eastern North America (see Klapper, 1981; Figs. 3, 4); however, much work remains to be done. Zonally significant conodonts are sparse in the Hamilton Group and many units have not yielded diagnostic taxa. Certain zonally significant conodonts also appear to have had a delayed appearance in the Appalachian Basin (Becker, pers. comm., 2006), thus necessitating reliance upon other biostratigraphic markers, such as goniatites.

The base of the Givetian Stage, as presently defined, is placed at the base of the *Pol. hemiansatus* Biochronozone (Walliser et al., 1995). The first appearance datum (FAD) of the icriodid conodont *Latericriodus latericrescens latericrescens* (Branson and Mehl 1938) approximately coincides with the base of the *Pol. hemiansatus* Chronozone; this species then extends upward to the basal Frasnian Stage and thus is of no further biostratigraphic importance. The FAD of *L.l. latericrescens* in the Hamilton Group lies within the correlative Mottville-Stafford members at the base of the Skaneateles Formation. However, data from goniatites in the subjacent Oatka Creek Formation strongly suggests that this is a delayed entry and that the *Pol. hemiansatus* Chronozone and base of the Givetian lies considerably lower, near or just below the level of the Halihan Hill Bed (base of Otsego Member; see Ver Straeten, 1994; Ver Straeten et al. 2023).

<table>
<tr><th>Stage</th><th>Conodont Zones</th><th>Goniatite Faunas</th><th>Strat. Unit</th><th>Formation</th></tr>
<tr><td rowspan="14">Givetian</td><td>"O." semialternans</td><td>P. amplexum</td><td>Tully</td><td>Tully</td></tr>
<tr><td rowspan="3">Pol. ansatus</td><td rowspan="2">T. uniangulare</td><td>Garrattsville</td><td rowspan="4">Moscow</td></tr>
<tr><td>Windom</td></tr>
<tr><td rowspan="3"></td><td>Deuel Road</td></tr>
<tr><td rowspan="5">Pol. rhenanus / Pol. varcus</td><td>Portland Pt.</td></tr>
<tr><td>Jaycox</td><td rowspan="4">Ludlowville</td></tr>
<tr><td>M. n. sp. / S. unilobatus</td><td>Wanakah</td></tr>
<tr><td>T. amuletum / T. u. aldenensis</td><td>Ledyard</td></tr>
<tr><td rowspan="2"></td><td>Centerfield</td></tr>
<tr><td rowspan="4">Pol. timorensis</td><td>Butternut</td><td rowspan="4">Skaneateles</td></tr>
<tr><td>T. arkonense</td><td>Pompey</td></tr>
<tr><td rowspan="2"></td><td>Delphi Station</td></tr>
<tr><td>Stafford</td></tr>
<tr><td>Pol. hemiansatus</td><td>Parodiceras / T. mesopleuron</td><td>Chittenango / Morrisville St.</td><td rowspan="4">Oatka Creek</td></tr>
<tr><td rowspan="4">Eifelian</td><td>Pol. ensensis</td><td></td><td>East Berne</td></tr>
<tr><td>Pol. eiflius</td><td>A. expansus</td><td>Cherry Valley</td></tr>
<tr><td>T. kockelianus</td><td>C. plebeiforme</td><td>Hurley</td></tr>
<tr><td>T. australis</td><td></td><td>Bakoven</td><td>Union Springs</td></tr>
</table>

Figure 3. Conodont and goniatite biostratigraphic framework of Middle Devonian (late Eifelian-middle Givetian). Abbreviations for genera: Condonts, "O." = *Ozarkodina*, Pol. = *Polygnathus*, T. = *Tortodus*; Goniatites, A = *Agoniatites*, C = *Cabrieroceras*, M = *Maenioceras*, P = *Pharciceras*, S = *Sellagoniatites*, T = *Tornoceras*. Adapted from Bartholomew et al. (2006, fig. 5).

The FAD of *Polygnathus timorensis* Klapper, Philip, and Jackson, 1970 defines the base of the *Pol. timorensis* Biozone. The entry of *Pol. timorensis* in the upper part of the Centerfield Member, the basal unit of the Ludlowville Formation (Klapper, 1981) also appears to have been delayed in the Appalachian Basin given that other conodonts indicative of the *Pol. timorensis* Chronozone occur lower, in equivalents of the lower Skaneateles Formation. Landing and Brett (1987) reported *Pol. timorensis* from the upper Arkona Formation in southern Ontario, in their basal Hungry Hollow Member, but subsequently shown to be equivalent to the Butternut Member of the Skaneateles in New

York (Bartholomew and Brett, 2007; Brett et al., 2011b), an indication that this interval falls within the *Pol. timorensis* Zone.

The *Pol. rhenanus-Pol. varcus* Zone is designated as beginning with the first occurrence of *Polygnathus rhenanus* Philip and Jackson 1970, but as with *Pol. timorensis*, *Pol. rhenanus* also apparently displays a delayed appearance in the Appalachian Basin, first occurring in the basal Moscow Formation. However, the conodont *Polygnathus varcus* Stauffer 1940, which first appears near the base of the *P. rhenanus* Zone, is found in the Hungry Hollow Member of the Widder Formation in Ontario (Uyeno et al., 1982) suggesting that the entire Ludlowville Formation and perhaps the lower Moscow (Portland Point subformation) may lie in the *Pol. rhenanus-Pol. varcus* Chronozone. As noted below, rare goniatite occurrences also suggest that the Ludlowville Formation lies partly or entirely within the *P. rhenanus* zone (J.T. Becker, personal comm., 2014). The base of the *Pol. ansatus* Zone is defined by the first appearance of the conodont *Polygnathus ansatus* Ziegler and Klapper 1976. At present the lowest occurrence of *Pol. ansatus* is in the Barnes Guly Bed (Klapper, 1981), herein assigned to the Deuel Road Member (new). As such, the upper portion of the Moscow Formation (i.e., Deuel Road, Windom, and Garratsville members) and the overlying lower to middle parts of the Tully Limestone (Shackham Brook to lower Long Hill Members of Baird et al., this volume, Chapter 7) appear to lie within the *Pol. ansatus* Chronozone. However, again, as with *Pol. timorensis* and *Pol. rhenanus*, the first appearance of the diagnostic conodont of this zone could show a delayed appearance in response to facies control.

DEPOSITIONAL SETTING

WESTERN NEW YORK SHELF

The Hamilton Group of New York includes Middle Devonian sediments deposited near the northern margin of the Appalachian Basin; they accumulated in the northern arm of a foreland basin, the deepest part of which was developed southeast of the study area. The northern and western boundaries of the basin bordered low relief, cratonic shelf regions; these areas supplied relatively little detrital sediment to the basin as compared with actively rising Acadian tectonic source terrains to the southeast of the basin. This accounts for the thin deposits in western New York (Dennison and Head, 1975). A broad, gently south-sloping, muddy shelf existed across most of central and western New York during Hamilton deposition (Cooper, 1957; McCave, 1969, 1973; Grasso, 1970, 1973; Heckel, 1973).

The lower to middle Eifelian is represented by the carbonate dominated Onondaga Formation. The basal Edgecliff Member is crinoidal grainstone with reworked clasts, including sandy phosphatic cobbles. The upper part of the Edgecliff Member is pack to wackestone with abundant chert nodules. The overlying Nedrow Member is micritic, shaly limestone with two dark shale bands that are tentatively correlated with the Chotek event level of the standard Prague Basin section (Ver Straeten et al., 2023). Higher beds display a return to shallower crinoidal to cherty facies of the mid Eifelian Moorehouse and Seneca members (Ver Straeten et al., 2023).

The eastward thickening Hamilton clastic wedge is a result of Acadian tectonic events, including uplift to the east and southeast (Cooper, 1957; Heckel, 1973; Oliver, 1977). It is the initial expression of the Catskill Deltaic Complex, which expanded greatly during the Late Devonian. Upper Hamilton formations are composed largely of detrital sediment; in eastern and central New York they record basin filling and general westward migration of the eastern shoreline. In western New York the Hamilton Group is markedly different, consisting of thin shelf/ramp sediments, which do not record simple shallowing upward sequence but show strong cyclicity at several scales.

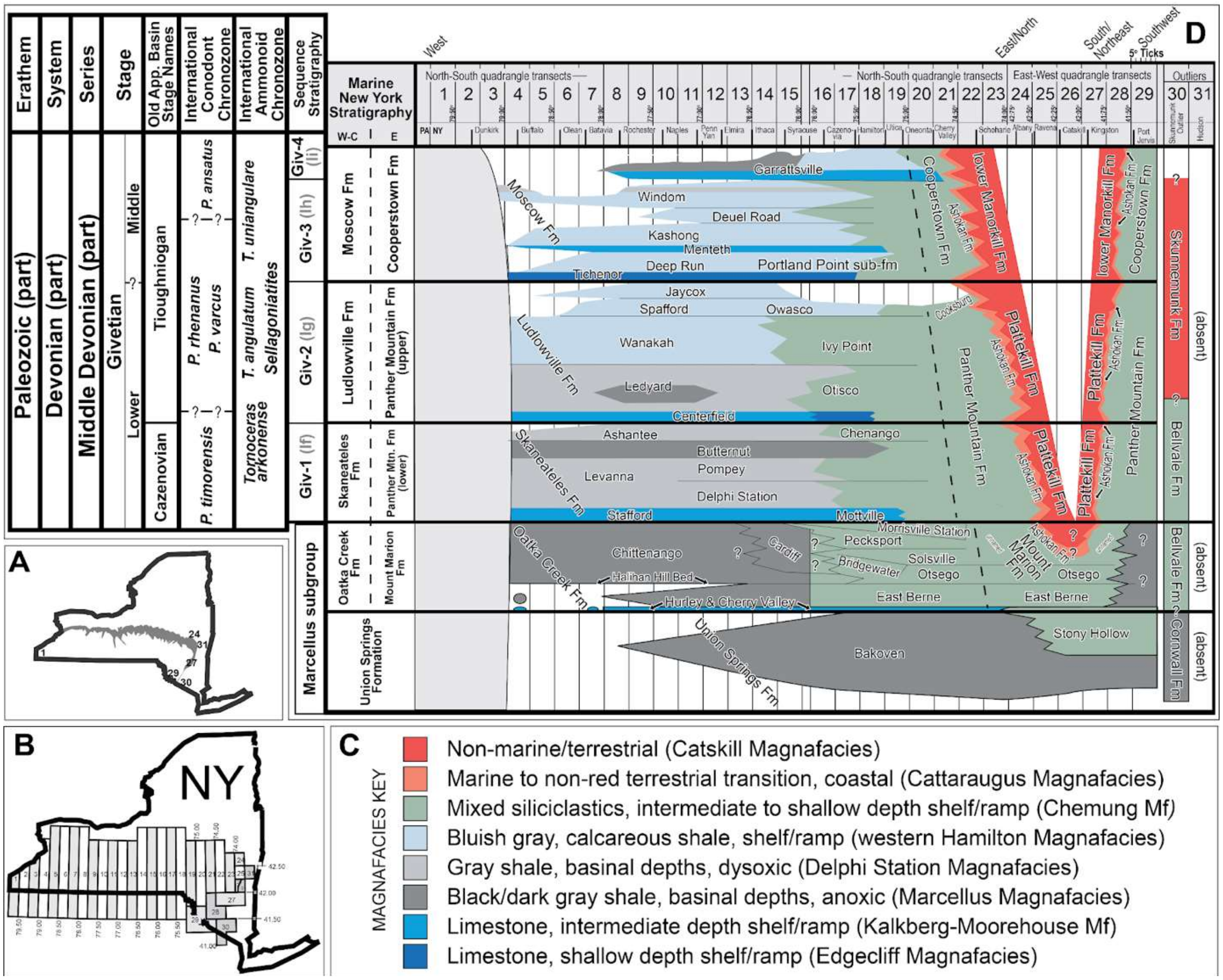

Figure 4. Time-rock chart with color key to facies for the middle to upper part of the Hamilton Group along entire New York State outcrop belt. **A,** Simple outcrop belt map of Hamilton Group across New York showing the location of select numerical meridians. **B,** Map showing the distribution of west to east columns of USGS 15' quadrangles shown in this and all subsequent time-rock charts. **C,** Key to colors used to depict magnafacies shown; same colors used in subsequent detailed time-rock charts for each formation. **D,** Generalized time-rock chart for upper Hamilton formations. All units are member-level unless otherwise stated in the figure. From Brett et al. (2023).

Upper Hamilton sediments are characteristically fossiliferous; the rich biotas of the Ludlowville and Moscow Formations in Erie County have been a source of study for paleontologists for more than a century (Hall, 1843; Grabau, 1898-1899; Cooper,1929, 1930, 1957; Buehler and Tesmer, 1963). The Hamilton sea apparently was relatively shallow as indicated by photoauotrophic endoliths in shells and a near-normal salinity, water temperatures, and circulation as evidenced by the presence of diverse stenotopic benthic organisms. In contrast to the fossiliferous Hamilton beds in Erie County, overlying Genesee shales contain low diversity assemblages, which are dominated by pelagic taxa. Only in the paraconformity-related Leicester and North Evans Members is the fossil diversity greater but many of these fossils may have been reworked from the underlying Moscow Formation.

SLOPE AND BASIN ENVIRONMENTS

The western New York Shelf was bounded to the south by a more actively subsiding central region of the Appalachian Basin during the Middle Devonian. A southward trending regional slope is recognized for Onondaga (Eifelian) carbonates based on extensive study of subsurface drill cores and well log data (Koch, 1978, 1981). Brachiopod/coral associations reflect southward increasing depth within the Onondaga and there is major southward thinning of the whole Onondaga carbonate package across the southern tier of western New York (Koch, 1981).The Onondaga Formation is nearly everywhere overlain by dark gray to black shales of the Marcellus subgroup; the latter are interpreted as relatively deep dysoxic to anoxic facies associated with both eustatic rise and a major pulse of subsidence in the Acadian foreland basin (Ver Straeten et al., 2023). Marcellus deposits have been subdivided into two formations, the lower or Union Springs Formation carries in its upper part an unusual “Stony Hollow” fauna of Old World Realm Cordilleran brachiopods and other benthic fossils suggesting temporary warming associated with transgression (DeSantis et al. 2007; Brett et al., 2009). The upper or Oatka Creek Formation commences with Hurley and Cherry Valley limestones, deeper shelf to pelagic (styliolinid) limestones marking a renew transgression following overall shallowing in upper Union Springs. These units still bear a “Stony Hollow” fauna, but the overlying dark East Berne Shale shows an abrupt influx of temperate water forms of the Hamilton fauna, presumably associated with the global Kačák Event (DeSantis et al., 2007; Ver Straeten et al., 2023).

Fossiliferous, gray mudstones and thin limestones of the upper Hamilton Group are correlated southward with the Millboro Member, a thick sequence of dark gray and black shale developed in western Pennsylvania, southeastern Ohio, and West Virginia (Dennison and Hassan, 1976). Similarly, the Tully Formation, which is a compact, laterally extensive carbonate unit in central New York grades southward and westward across Pennsylvania into a thick sequence of calcareous shale and finally into black shale (Burket Member) near the Pennsylvania-Maryland border (Heckel, 1973).

The Moscow-Genesee unconformity of western New York is coextensive with disconformities of decreasing magnitude in the Tully Formation in central New York, this hiatus disappearing southward as the Tully thickens and grades into black shale. Thus, in the region of greater subsidence, the upper Middle Devonian sequence is characterized by deeper water deposits , as indicated by the dysaerobic-anoxic mudstones, and is apparently more complete. Anoxic bottom conditions inhibited development of benthos. However, as will be shown, significant bottom currents were present to the degree that reworked fossil and diagenetic debris were sorted into lenses within the basal Genesee sequence (Baird and Brett, 1986, 1991).

GENERAL STRATIGRAPHY AND SEQUENCE STRATIGRAPHY

The Middle Devonian (Givetian) Hamilton Group eastward thickening wedges of terrigenous sediment, which are predominantly marine except in east-central and eastern New York (Fig, 4). This aggregate sequence, ranging from 88 m (290 ft) at Lake Erie to more than 1220 m (4000 ft) at the Catskill Front, is composed of detrital sediments, which coarsen to the east and southeast. In western New York, the Genesee beds are highly condensed stratigraphically, thinning westward from over 305 m (1000 ft) in the Seneca Lake region to as little as 3 m (10ft) at the Lake Erie Shore, the Erie County region being characterized by particularly slow sedimentation. Hamilton and Genesee marine shales in western New York are displaced eastward by siltstone and sandstone facies in central New York, these to be succeeded, in turn by red bed floodplain deposits and fluvial sandstones in eastern New York State (Rickard, 1975). Westward thinning of marine Hamilton strata is associated with appearance of widespread discontinuities and condensed sedimentary units.

The general principles of sequence stratigraphy (see Coe, ed., 2005; Catuneanu, 2006, 2018) have been applied to the Devonian of New York. The Middle Devonian succession has recently been subdivided into a series of 3rd-order (~1 million year) depositional sequences which approximately correspond to the formations of the Hamilton Group (Brett et al., 2011). The lower two Hamilton sequences belonging to the upper Eifelian to lower Givetian stages are identified as Eif-2 (in part) upper Onondaga and Union Springs Formation; Eif-Giv: Oatka Creek Formation (latest Eifelian *T. kockelianus* Zone to lower Givetian; *Pol. hemiansatus* Zone). Together, the Union Springs and Oatka Creek intervals were formerly united as Marcellus Formation. However, Ver Straeten and Brett (2000) recognized the members as formations and elevated Marcellus to an informal subgroup (see Ver Straeten et al., 2023 for detailed discussion).

The middle and upper Hamilton Group and succeeding Tully formation are divided into four 3rd-order sequences (Fig. 4): Giv-1: Skaneateles Formation (lower Givetian, *Pol. hemiansatus*? To timorensis zones); Giv-2 Ludlowville Formation (middle Givetian, *Pol. rhenanus-Pol. varcus* Zone); Giv-3 Moscow Formation through Windom Member (middle Givetian, Pol. ansatus Zone in part, and Giv-4: upper Moscow-Garrattsville Member (new) through lower Tully Formation upper *ansatus* Zone). Finally, the middle-upper Tully limestone and overlying Geneseo formations (upper middle to upper Givetian), corresponding to cycle IIa of Johnson et al. (1985) are assigned to Giv-5.

In addition, these 3rd-order (~million-year scale) successions are divisible into a series of 4th order 100-400 yrs sequences and these in turn into a series of meter scale sequences. In general, these sequences follow similar patterns (Fig. 5). Their basal boundaries are erosional disconformities (3rd-order) or simply sharply defined diastems that are overlain by thin limestones, calcareous siltstones, or simply relatively condensed shell-coral beds (4th and 5th order sequences; Figs. 4, 5). In western New York, the upper portions of each cycle are dominated by more sparsely medium to dark gray, fossiliferous mudstones in most locations and may show faunal evidence for upward shallowing. The basal shell-rich limestones and calcareous offshore areas owing to sequestration of siliciclastic sediments in estuaries and other coastal sediment traps in proximal areas. In places, the upper contact of the limestone or shell rich bed is sharp and may show hardgrounds, abundant corroded, reworked skeletal material and black phosphatic pebbles (Baird, 1978, 1981; Fig. 5). These condensed beds are inferred to record periods of stronger sediment starvation associated

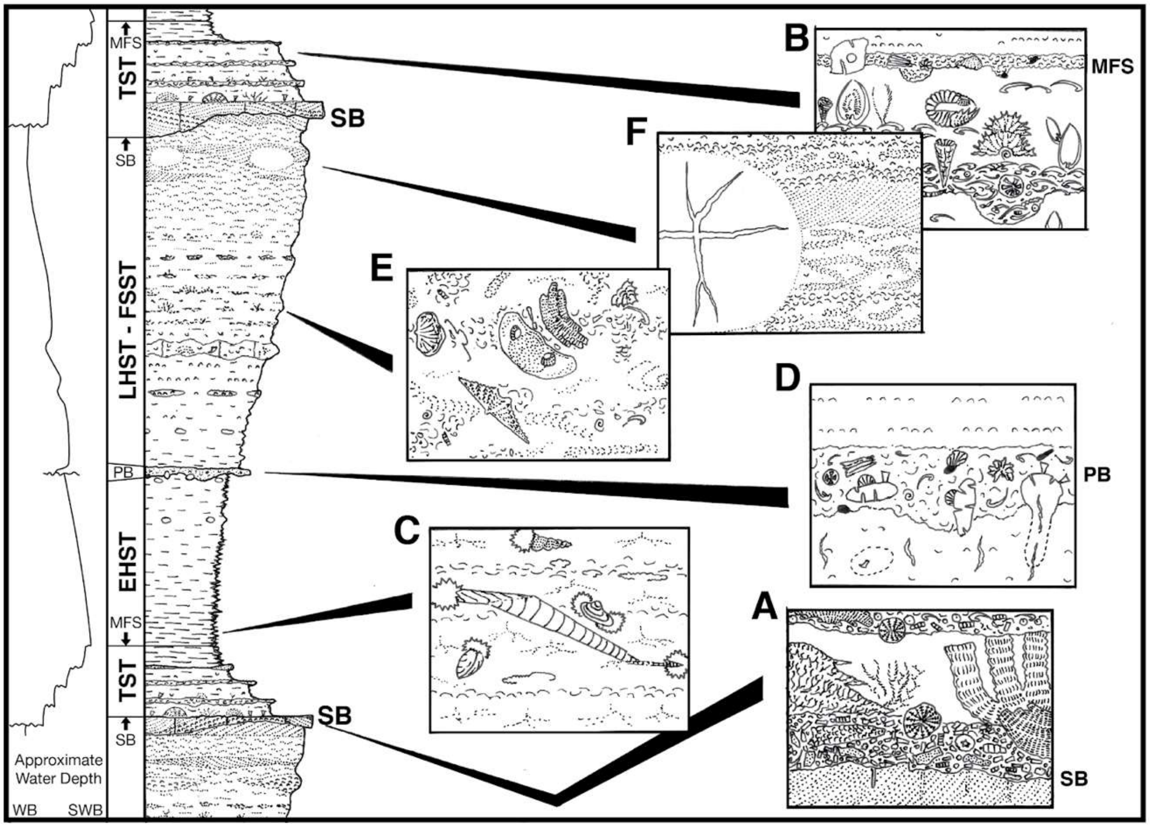

Figure 5. Idealized facies and sequence stratigraphic succession for siliciclastic-dominated shallowing-upward cycle and depositional sequences, based upon Ludlowville Formation, middle Hamilton Group in central New York. Relative sea level curve: WB = fair-weather wave base, ~5–10 m; SWB = storm wave base, <50 m. Systems tracts abbreviations: EHST and LHST = early- and late-highstand systems tracts, respectively; FSST = falling-stage systems tract (regressive); SB = sequence-bounding disconformity; MFS = maximum flooding surface; PB = "precursor bed," i.e., condensed bed overlying basal surface of forced regression; TST = transgressive systems tract. Vignettes of litho- and taphofacies identified by letter are as follows: **A,** Early TST showing skeletal grainstone/rudstone with abundant tabulate and rugose corals; **B,** Later TST showing shell- and small-coral-rich beds separated by thin obrutionary shales; **C,** Early highstand dark shales with small pyritic nodules and molluscan steinkerns; **D,** "Precursor bed" condensed shell lag associated with abrupt shallowing ("precursor bed" may approximate a basal surface of forced regression; note reworked, bored concretions and minor phosphatic shell hash); **E,** Early FSST deposits showing shell hash storm lags in *Zoophycos*-bioturbated silty mudstones; **F,** Late FSST regressive shoreface sands with thin coquinites of storm-reworked shells. Note diagenetic overprint of large carbonate concretions associated with sediment starvation in overlying seafloor during periods of initial base-level rise. Modified and used from Brett (1995).

with more rapid rise of base level and deepening below the zone of strong shell production; we have termed these surfaces of maximum starvation. They do not appear to record maximum flooding surfaces (Fig. 5). Rather there is mudstones are interpreted to record initial transgressions and associated siliciclastic starvation in offshore areas owing to sequestration of siliciclastic sediments in estuaries and other coastal sediment traps in proximal areas. In places, the upper contact of the limestone or shell rich bed is sharp and may show hardgrounds, abundant corroded, reworked skeletal material and black phosphatic pebbles (Baird, 1978, 1981; Fig. 5). These condensed beds are inferred to record periods of stronger sediment starvation associated with more rapid rise of base level and deepening

below the zone of strong shell production; we have termed these surfaces of maximum starvation. They do not appear to record maximum flooding surfaces. Rather there is commonly a deepening upward pattern in the immediately overlying mudstones that suggests a later transgressive phase
in which, with decreasing sediment starvation permits influx of fine-grained sediments. The actual maximum flooding surface is not always strongly marked but rather is zone which may show evidence of increased organic content, darker color and finest grain size.

The increased influx of muddy to silty sediments record highstands to falling stages in which coastal traps were emptied and clastic wedges prograded into the basin.
The patterns are accentuated in central New York. Shell rich mudstones pass eastward into calcareous, bioturbated silty or sandy beds. They retain their thin, widespread geometry and sharply overlie the tops of coarsening upward sparsely fossiliferous silty mudstones, siltstone and sandstones (Fig. 5). The lower shaly divisions of early highstands in western New York pass eastward into gray silty mudstones that persist into east central New York. Later highstands, which are merely mudstone rich intervals to the west pass grade into distinctly coarsening upward mudstone to siltstone to fine-grained sandstone intervals. The uppermost 4th order sequences of Hamilton formations (3rd order sequences) typically show abrupt bases marked by thin, shell-rich beds that show abrupt facies dislocations (abrupt shallower over deeper facies motifs); these so-called “precursor beds” (Brett, 1995; Fig. 5) represent strong forced regressions and they are overlain by distinctly shallowing upward successions in eastern to central New York. This pattern suggests that phases of strong forced regressions induced progradation of coarser sediment wedges. Overall, sharp erosive bases of sequences and evidence of forced regression as well as widespread correlation of both large and smaller cycles (see Brett et al. 2011) suggests an over-riding eustatic control on sedimentation. Moreover, the fractal and nested patterns of large, intermediate, and small-scale cycles suggest that these patterns may reflect Milankovitch cyclicity.

BROADER ISSUES INVOLVING HAMILTON PALEONTOLOGY

The rich and well-preserved fossil assemblages of the Hamilton Group have given rise to numerous concepts related to taphonomy, paleoecology, paleoenvironments, and evolutionary paleobiology, as well as to sequence stratigraphy (Brett, 1995, 1998). These concepts are briefly reviewed here.

TAPHONOMY: TAPHOFACIES

Taphofacies were defined as strata characterized by particular modes of preservation including such quantifiable indices as articulation of bivalves and multi-element skeletons, fragmentation, degree and type of corrosion, and early diagenetic mineralization. The original formulation of the concept of taphofacies was based upon comparative taphonomy of phacopid trilobites in different facies of the Hamilton Group. Using these trilobites as a control organism, Speyer and Brett (1986) noted consistent, facies-specific changes in the degree of articulation, posture, such as enrolled vs outstretched, and type of diagenetic enhancement (see Figure 8). This led to the more general formulation of taphofacies (Brett and Baird, 1986b). The taphofacies concept has been used by many authors and cited several hundred times and is being tested in modern environments (Parsons-Hubbard et al., 2011).

Concepts of shell beds as the product of reduced sedimentation (Kidwell, 1985, 1986a-b, 1989, see R-sediment model) were strongly corroborated by studies of Hamilton Group skeletal accumulations (e.g., Baird, 1978, 1979, 1981; Parsons et al., 1988; Miller et al., 1988). Taphonomic biasing and time-averaging in shell beds was examined in the R-C Bed in the Kashong Member (Brett and Bordeaux, 1991), where they documented the occurrence of a very strongly biased pedicle/brachial ratio in the robust spiriferid *Spinocyrtia granulosa*, in which pedicle valves may outnumber brachial valves by 5 to 1. Also, highly corroded pedicle valves are common, whereas corroded brachial valves are rare. Such marked differences in preservation are not seen among smaller, more fragile shells. This implies that only the more robust skeletal components can withstand prolonged reworking; because the presence of hinge plates and differentially thickened umbonal areas gave pedicle valves much greater resistance to fragmentation than brachials, permitting the shells to accrue substantial damage and yet still be identifiable.

Obrution deposits, or “smothered bottom assemblages” are rather abundant within the Hamilton Group. Notable examples include beds of articulated and enrolled trilobites (Speyer and Brett, 1985; Brett et al., 2012a). Comparative studies of storm-related burial effects or obrution deposits (Brett et al., 1986b; Brett and Seilacher, 1991) has drawn multiple examples of proximal to distal event beds taken from the Hamilton Group of New York.

Concretionary and/or pyritic obrution beds in the Devonian reflect the combination of episodic event burial and possibly periodic fluctuations in overall sedimentation rate as outlined in the concept of “diagenetically enhanced event deposits” (Brett et al., 2012a). This led to establishment of criteria for the identification of optimal conditions for preservation of uncompressed fossils such as enrolled trilobites and aragonitic shells.

PALEOECOLOGY-PALEOBIOLOGY

Building on a variety of case studies from the Hamilton Group and elsewhere, Brett and Baird (1997a) published the edited volume *Paleontological Events: Stratigraphic, Paleoecological, and Evolutionary Implications.* They resurrected the concept of *epiboles* as signifying thin, but widespread occurrences of normally rare or absent taxa that frequently cross-cut facies (Brett and Baird, 1997b). These examples, primarily from the Middle Devonian of New York, permitted further subdivision and genetic classification of epiboles as taphonomic, proliferation and incursion events. These concepts have been successfully applied to many other successions. A mass molt-mate hypothesis for trilobites (Speyer and Brett, 1985), based upon trilobite body and molt clusters from the Hamilton Group obrution deposits, is but one conceptual idea arising from this work.

Community Paleoecology and Paleobathymetry

Not surprisingly, the rich and diverse faunas of the Hamilton Group fostered numerous studies of paleoecology, beginning with the seminal paper on Devonian paleoecology by Cooper (1957). Several researchers studied fossil associations in the Hamilton Group from particular regions or stratigraphic levels. Thus, Brower and Nye (1991) used cluster analysis and ordination techniques, including principal component analysis and non-metric multidimensional scaling of bulk samples from stratigraphic horizons in central New York to define some 13 paleocommunities and provided excellent illustrations of reconstructed benthic assemblages. Additional paleoecological studies include those of Grasso (1986), Gray (1985, 1991), and Miller (1986, 1991). Most of these studies recognized similar associations, although they were given varied names.

A depth-sedimentation model for Devonian biofacies was developed as a more general conceptual and working model to explain patterns of biofacies distribution in communities based upon Hamilton Group fossil assemblages (Brett et al., 1990, 2007a). This model is applicable to, and has been quantified, using gradient analysis techniques, such as detrended correspondence analysis or principal components analysis (Brett et al., 2007a, b; Zaffos, 2014).

The use of distinctive assemblages of encrusting and endolithic organisms on select control substrates, including corals, brachiopods, hardground surfaces, and reworked concretion surfaces, revealed a possible new tool for determining relative slope-related bathymetry and changing depositional environments (Baird, 1981; Baird and Brett, 1981, 1983; Brett et al., 2012b). Bathymetric gradients have been established using a variety of evidence, including microendoliths and facies specific associations of microendoliths. Borings by algae, fungi, bacteria, and sponges provide indicators of light levels and indirectly of paleobathymetry (Vogel et al., 1987). The presence of probable cyanobacterial traces, even in some of the relatively deepest water brachiopods in the Hamilton Group, indicate that the much of the gradient is confined to the photic zone and, therefore, absolute depths are constrained to 150 meters or less. Data on encrusting sclerobionts on shells of widespread Hamilton Group brachiopods led a model of “sclerobiofacies”: using distinct assemblages of encrusters on standardized substrates as a tool for inferring paleoenvironment (Brett et al., 2012b). In particular, if these distinctive assemblages can be calibrated with data on microendoliths, the sclerobiofacies can be used to determine absolute depths as well (Smrecak and Brett, 2014).

Organism-Substrate Interactions

Hamilton Group fossils have been used to examine ancient organism substrate interactions and coaction pairs among Devonian animals. For example, detailed study of attachment scars in the tabulate coral *Pleurodictyum* revealed strong substrate selectivity. Moreover, the corals appear to have selectively colonized hermitized shells rather than living gastropods (Brett and Cottrell, 1983), as do nearly all examples of modern “towed corals”, which encrust secondarily occupied shells carried by hermit sipunculid worms.

Substrate selectivity of sclerobionts was studied in large samples of well-preserved brachiopods from the Hamilton Group. Bordeaux and Brett (1990) demonstrated substantial differences in colonization frequency among different species of brachiopods. These variations are correlated in part with surface textures of the shells and, possibly, the presence of punctae in the shells.

Bryozoans and related organisms encrusting on Devonian cephalopods were discussed by Baird and Brett (1989b). The probable phoronid *Reptaria* was found to be oriented preferentially parallel to the long axes of nautiloid conchs with apertures directed anteriorly. Acrothoracid barnacle borings occur exclusively in Hamilton Group platyceratid gastropods, including those that were preserved *in situ* on crinoid hosts (Baird et al., 1990).

Documentation of some of the most ancient gastropod-like boreholes and evidence of prey selectivity was based upon borings in Hamilton Group brachiopods (Smith et al., 1985). Frequency of durophagous predation within a generally stable interval, the ecological-evolutionary (EE) subunit (Brett and Baird, 1995), has been assessed, based upon bite marks in Hamilton Group bivalve shells. The frequency was found to be statistically the same within two major 3rd-order sequences in the Skaneateles and Ludlowville formations (Nagel-Meyers et al., 2009, 2013). Documentation of correlation between spinosity in Devonian crinoids and their propensity as hosts of platyceratid gastropods is evidenced by indirect targeting of crinoids by predators on platyceratid commensals, meaning collateral damage of crinoids by predators attacking commensal platyceratids, as derived, in part, from data on Hamilton Group crinoids.

EVOLUTIONARY PALEOBIOLOGY

Hamilton Group fossils have provided exemplars for several important concepts in evolution. The punctuated evolution of eye files in Hamilton Group phacopid trilobites was used as a dataset in the original formulation of the concept of punctuated equilibrium (Eldredge and Gould, 1972). This concept, one of the most critical evolutionary ideas derived largely from the fossil record, also emphasized the importance of stasis, based partly on the observations of Niles Eldredge (1972) on Hamilton Group fossils.

The Hamilton Group contributed strongly to the formulation by Brett and Baird (1995) of the concept of ecological-evolutionary subunits, as divisions of Boucot's (1975, 1982, 1990) ecological-evolutionary units. The Hamilton Group provided an exemplar of a stable long-lasting fauna, characterized by a relatively stable suite of species over approximately 3-4 million years duration. More than 80 % of species were found to persist through this interval with little extinction or immigration. However, at the boundaries with older and younger EE-subunits, many species were most heavily impacted by extinction, and a new suite of species was established. Thus, only a handful of species were held over from the previous Stony Hollow Formation fauna, and a fewer than 25 % carried over to the subsequent Geneseo Formation fauna in offshore facies in western and central New York; however, the reader is referred to Zambito et al. (2012b) for a detailed faunal analysis of the nearshore Genesee Group, where almost 40% of the Hamilton Group taxa found refuge during the EE-subunit turnover and returned in the last recurrent Hamilton faunal episode in the upper part of the Tully Limestone for a geologically brief interval prior to major local extinction and the incoming of a more cosmopolitan Genesee fauna (see Baird et al., 2023).

An important aspect of the EE-subunits was the apparent near synchronous turnovers that form their boundaries, coordinated turnovers and immigration events. As noted, the appearance of much of the Hamilton fauna coincides with the later phase (late Eifelian 2 Event or LEE2; see Suttner et al., 2021) of the Kačák Episode (DeSantis et al., 2007; Brett et al., 2009). Recent studies of conodont apatite oxygen isotopes indicate the latest Eifelian and earliest Givetian was a time of strong temperature fluctuation and climatic change that permitted faunal migrations initially of warm water taxa into higher southern latitudes (Suttner et al., 2021). Likewise, the majority of the fauna disappears during the Taghanic Event (Aboussalam, 2003, Aboussalam and Becker, 2011; Baird and Brett, 2003, 2008). Zambito et al. (2012a, b) demonstrated the the Taghanic Event, like the Kačák, was a relative brief time of substantial environmental volatility featuring strong temperature fluctuations, sea level change and carbon isotopic anomalies.

Brett et al. (2009) defined the Hamilton Group fauna as a diverse assemblage of over 250 species, including rare forms, that reflected a mixture of recurrent Onondaga Formation lineages and immigrants from the Old World Realm Rhenish-Bohemian Province. About 80 % of species persisted through the interval.

Building on the hypothesis of punctuated equilibrium, Brett and Baird (1995) proposed that, within EE subunits, most species showed a pattern of "coordinated stasis". This implies that the majority of species concurrently showed morphological, as well as ecological stasis, for intervals of up to several million years and that many lineages changed, or were terminated synchronously, in relatively short intervals of geologic time, coincident with EE subunit boundaries (see also Brett et al., 1996, 2007a, b, 2009). Furthermore, it was argued that, during an EE subunit, most biofacies or groups of communities remained consistent in terms of species list and relative abundance for the duration of the EE subunit. In some cases, even species that persisted across EE boundaries showed new associations and changes with respect to ecological gradients.

The predictions of coordinated stasis were supported by some follow-up studies (e.g., Pandolfi, 1996; Pandolfi and Jackson, 1997), but were challenged by several researchers (see Miller, 1997, for summary). In particular, Bonuso et al. (2002 a, b) argued, on the basis of detailed samples from the Hamilton Group in the Syracuse area, that species did not show long persisting associations and that particular biofacies, previously recognized by Brower and Nye (1991), were confined to particular levels. Moreover, they argued that samples from supposedly similar environments of different ages had quite distinct biofacies. Bonelli et al. (2006) compared coral bed assemblages through the upper Hamilton Group and Tully Formation and showed that, although there were similar species lists, the relative and rank abundance of particular species were not conserved from bed to bed. Similarly, detailed study of the critical Hamilton-Tully transition indicated that certain "invading" taxa appeared asynchronously (Sessa et al., 2002; Sessa, 2003).

However, it was noted that, simply saying these assemblages were obtained from gray mudstone facies, did not prove that they were really derived from the same environments, as there were many environmental factors not recorded in lithology alone and that much of the Hamilton Group could be typified as "gray mudstone". Furthermore, as a result of overall patterns of progradation, sedimentary environments shifted westward through time, so that sampling in one particular region could not really capture the composition of the most analogous biofacies. Rather, for a fair test, assemblages must be sampled in different places at different ages. Consequently, Brett al. (2007b), made a more comprehensive study of fossil depth gradients of a large cross section of samples obtained from a much broader region. Using cluster analysis and detrended correspondence analysis, the researchers showed a persistent pattern of gradients through much of the Hamilton Group and upper Tully Formation assemblages from all parts of New York State. On this basis, they suggested that fossil associations did indeed persist and shifted following favored environments in terms of depth, sedimentation, and other factors, a pattern they termed tracking. Even though particular species tracked individualistically, many species had sufficiently similar environmental preferences, such that entire associations appeared to track. Brett et al. (2007b, c) then presented a general discussion of tracking as a key factor in concurrent stasis and persistent community structure. Further statistical treatment of the original dataset for the Hamilton Group using Monte Carlo methodologies to produce model datasets provided a strong test for the recurrence of similar assemblages through time (Ivany et al., 2009). A subsequent study of a large number of quantitatively analyzed assemblages from multiple stratigraphic horizons provided a test of niche conservatism: most species showed similar ecological preferences modeled along gradients, for intervals of 3 million years or more (Zaffos, 2014; Brett et al., 2016).