

BANGOR LIMESTONE: DEPOSITIONAL ENVIRONMENTS AND CYCLICITY ON A LATE MISSISSIPPIAN CARBONATE SHELF

THOMAS J. ALGEO

*H. N. Fisk Laboratory of Sedimentology
Department of Geology
University of Cincinnati
Cincinnati, OH 45221-0013*

MARK RICH

*Department of Geology
University of Georgia
Athens, GA 30602*

ABSTRACT

The Bangor Limestone accumulated in carbonate shelf and mixed carbonate-clastic basinal settings on the southeastern margin of the North American craton during Late Mississippian time. On the Monteagle Shelf, muddy fossiliferous sediments were deposited in a low-energy, open-marine setting while cross-bedded oolitic grainstones accumulated in high-energy shoals. Muddy, locally dolomitized, fine-grained sediments characterized by tidal channels, flat-pebble breccias, laminae, fenestrae, and evaporite molds were deposited in a facies mosaic of low-energy lagoonal and tidal-flat environments within back-shoal areas.

Shelfal facies-stacking patterns exhibit both small-scale (<1 m) fluctuations within single environmental zones, characterized by interbedding of two or more genetically related facies, and large-scale (3-30 m-thick) shallowing-upward cycles, which exhibit a transition from open-marine to shoal and lagoonal/tidal-flat environments. Facies transitions within a single environmental zone reflect lateral facies shifts and/or short-term variations in energy level due to storms or tides, while shallowing-upward cycles represent long-term shifts in environmental loci owing to seaward progradation of proximal zones over distal ones.

The Bangor Limestone records one major marine transgression, which flooded the interior of the Monteagle Shelf, and several minor ones, which affected only the shelf margin. In the Floyd Synclinorium, a basinal area to the southeast, quiet deep-water sedimentation prevailed throughout the Late Mississippian, broken episodically by thin, grainy oolitic debris flows from the shelf margin and by influx of fine-grained terrigenous clastics from an orogenic collision zone further to the southeast. Correlation of basinal clastics of the middle member of the Bangor Limestone with marine transgressive deposits of the carbonate shelf suggests that clastic influx and shelf flooding shared a common control, probably subsidence of the craton margin owing to tectonic uplift to the southeast and sediment loading of the intervening trough.

INTRODUCTION

The Bangor Limestone is an Upper Mississippian (middle-late Chesterian) formation in the southern part of the Appalachian Valley and Ridge Province and Cumberland Plateau. In the tristate area of northwestern Georgia, northeastern

southeastern margin of the North American craton and, as such, is significant as a record of the tectonic and sedimentologic events which brought about the demise of this pericratonic carbonate shelf during the early phases of the Appalachian Orogeny. Therefore, the goals of this study were: 1) to develop an integrated model for Bangor Limestone paleoenvironments and contrast this with modern carbonate settings, and 2) to summarize the depositional history of the Bangor Limestone with respect to eustatic and tectonic events operating on the Late Mississippian shelf of the tristate area.

The Bangor Limestone was studied in three outcrop sections and three cores between the west side of Monteagle Mountain in southeastern Tennessee and Rock Mountain in northwestern Georgia (Figure 2). Sections were measured and sampled at 0.3 m intervals, where possible. A total of 1450 thin-sections from the six study locales were examined and described using transmitted-light microscopy. Dolomite abundance was determined by etching polished core chips and handsamples in a 5% HCl bath for 15-30 sec and visually estimating percent area of high relief. Acetate peels were made of selected thin-sections and core butts to study sedimentary fabric and microstructures.

BANGOR LITHOFACIES

The Bangor Limestone comprises nine lithofacies which formed the basis for environmental interpretation and facies sequence analysis.

Bryozoan-Echinoderm Wackestone/Packstone/Grainstone

Bryozoan-echinoderm wackestone/packstone units are generally thick-bedded (to 10s m) and structureless owing to pervasive bioturbation. They contain a normal marine fauna of abundant bryozoans and echinoderms and subordinant quantities of other stenohaline organisms such as brachiopods, trilobites, and corals. Disarticulation and fragmentation of fossil debris is limited and sorting is poor, indicating deposition within a low-energy environment.

In contrast, bryozoan-echinoderm grainstone units exhibit good sorting and extensive disarticulation and comminution of fossil debris owing to deposition in a moderate- to high-energy environment. Micrite is restricted to interior voids of fossil grains (e.g., gastropod chambers and bryozoan fenestrules) suggesting a source in a muddy, low-energy environment such as that in which bryozoan-echinoderm wackestone/packstone was deposited.

Oolitic Packstone

Oolitic packstone units are generally thin- to medium-bedded (<3 m) and exhibit poor sorting or, occasionally, weak inverse grading. Oolites range from 0.25 to 2.0 mm in diameter and vary from superficial to mature in cortical development. Matrix micrite comprises from 5 to 50% of rock volume. Fossils are more abundant and show less fragmentation than in oolitic grainstone units.

Oolitic Grainstone

Oolitic grainstone units are medium- to thick-bedded (to 10s m) and exhibit planar cross-bedding (sets mostly 1-5 m thick). Oolites range from 0.5 to 1.0 mm

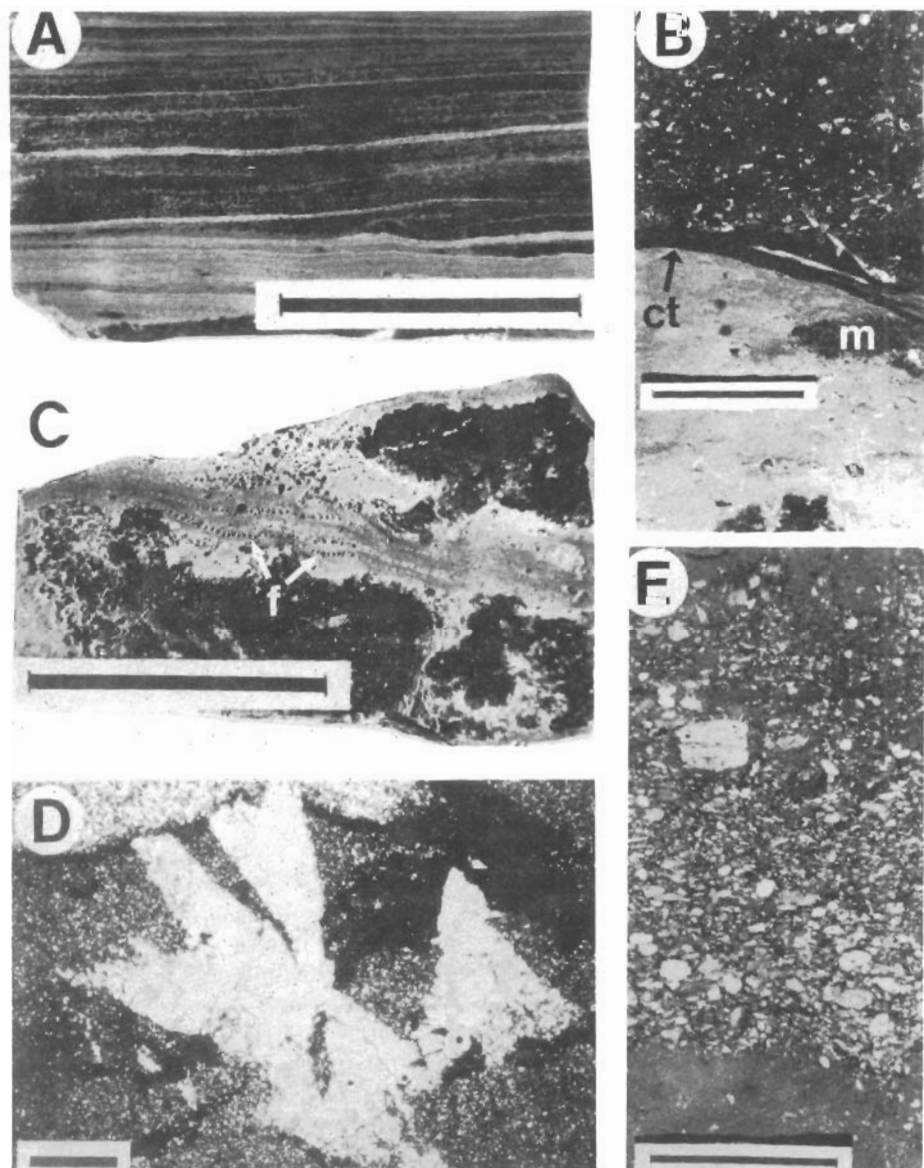


Figure 3. (A) Laminated tidal-flat carbonate/dolomite mudstone from Raccoon Mountain (dolomitic layers are light colored). The scale in this and all subsequent core samples is 1 inch. (B) Contact between two shoaling cycles at Raccoon Mountain. The underlying cycle is capped by a fine-crystalline dolostone containing pods of unreplaced carbonate mudstone (m). Note the absence of dolomite in oolitic packstone basal unit of the overlying cycle. (C) Partially dolomitized bryozoan wackestone from Pigeon Mountain. Note strong dolomitization adjacent to bryozoan fronds; dolomitizing fluids probably moved through open fenestrae (f). (D) Radiating clusters of pseudomorphic dolomite crystals after gypsum from fine-crystalline tidal-flat dolostone at Raccoon Mountain. Blebs of coarse-crystalline anhydrite are also present in this unit. (E) Tidal-flat intraclast breccia from Raccoon Mountain. Note angularity, coarseness, and lithologic heterogeneity of clasts and fining-upward trend within unit.

in diameter and generally display mature cortical development. Oolite nuclei are mostly normal-marine fossil fragments, although small micritic pellets and intraclasts are an important secondary source. Fossil debris is generally restricted to robust fossil fragments such as echinoderm plates and columnals, and sorting is excellent.

Foram-Ostracod Wackestone

Foram-ostracod wackestone units are generally thin- to medium-bedded (<5 m) and structureless. They are characterized by a restricted-marine fauna composed mainly of ostracods and forams, although sponge spicules are locally abundant. Stenohaline fossil types are found in some samples, but their occurrence as comminuted debris suggests derivation from another source. Matrix micrite is commonly finely pelleted, although compaction locally masks pellet identity.

Carbonate Mudstone

Carbonate mudstone units are generally thin-bedded (<1 m) and exhibit mm-scale lamination (Figure 3A). Fenestrae locally comprise up to 25% of rock volume, ranging from 1 to 10 mm in size and exhibiting infill by geopetal micrite or calcite spar. Fenestrae frequently appear to have originated as voids between soft, partially compacted mud clasts, possibly developing through in-situ brecciation resulting from gas generation (e.g., Mazzullo and Birdwell 1989), although some fenestrae may have formed through dissolution of evaporite crystals, gas entrapment, or dessication-induced sediment shrinkage (e.g., Shinn 1968).

Dolomitic Mudstone/Wackestone

All Bangor dolomite originated through the replacement of matrix micrite and allochems. Evidence for replacement includes remnant patches of lime mud and isolated fossils "floating" in many dolostones (Figure 3B), irregular nonstratified distribution of dolomite in partially dolomitized units (Figure 3C), and cross-cutting relations between dolomite rhombs and allochems. In units exhibiting variable degrees of dolomitization, host-rock components are replaced in a fixed order: 1) matrix micrite, 2) micritic clasts, 3) thin-shelled calcitic fossils (e.g., bryozoans and forams) and 4) massive calcitic fossils (e.g., echinoderms, and sparry calcite cement). Dolomitization commonly ceased after replacement of matrix micrite, leaving fossil debris "floating" in a dolomitic matrix.

Samples were classified as dolomitic mudstone/wackestone where replacement obliterated most of the original texture of fine-grained limestones. This microfacies is characterized by 0.01-0.05 mm dolomite rhombs that commonly exhibit a sugary, intergrown texture and a patchy distribution within host units. Dolomitic units are generally interbedded with carbonate mudstones and foram-ostracod wackestones capping shoaling cycles, and dolomitization tends to decrease in intensity downward from cycle tops (Figure 3B). Association with gypsum (Figure 3D) and dolomitic intraclast breccias (Figure 3E) at or near cycle tops indicates development of hypersaline conditions and pene-contemporaneous dolomitization. In contrast, open-marine bryozoan-echinoderm wackestones and

packstones are marked by low concentrations (10-30%) and relatively even distribution of coarse (0.05-0.10 mm) dolomite rhombs within the rock matrix, and near-total obliteration of the original texture of such units is rare.

(Oo-)Intraclastic Packstone/Grainstone

(Oo-)intraclastic packstone/grainstone units are generally thin- to medium-bedded (<5 m) and exhibit bedding-parallel lamination characterized by mm- or cm-scale variation in clast size. Intraclasts are comprised of lime mud, are generally round and fine-grained (0.2-0.5 mm), and may be either structureless or wispy (algally laminated?) internally. Rare interbeds containing large, angular clasts (e.g., flat-pebble breccias) are generally thin (<10 cm) and fine upward. Local oolitization of intraclastic units is marked by oolites with a high percentage of intraclast nuclei, abundance of superficially-coated grains, and considerable admixture of large lime-mud clasts and algal fragments (Rich 1974). Clast development and ooid formation in a predominantly muddy environment suggest the occurrence of episodic high-energy events within a generally low-energy setting.

Terrigenous Clastics

The most common terrigenous clastic lithofacies are gray to gray-green shale and clayey sandstone composed of angular to subangular, coarse-grained silt and fine-grained sand. Clastic units commonly exhibit mm- or cm-scale interlamination of clay, silt, and sand. Fossils, predominantly weathered echinoderm fragments, are common.

DEPOSITIONAL ENVIRONMENTS

The Bangor Limestone was deposited in three broad environmental zones, each of which is characterized by diagnostic microfacies, sedimentary structures, and facies-stacking patterns. The environments reflect differences in water depth, distance from the paleo-shoreline, and energy level (Figure 4). These environments are: 1) a low-energy open-marine shelf, 2) a high-energy ooid shoal, and 3) a low-energy back-shoal lagoon and tidal-flat complex. Many other shallow-marine carbonate sequences record deposition in similar environments, and numerous ancient and modern examples have now been documented (e.g., Wilson 1975; James 1984).

Distal Low-Energy Open-Marine Shelf

Bangor open-marine shelf facies accumulated below wavebase, where low-energy conditions allowed carbonate mud to settle. Normal marine salinities supported a diverse fauna which contributed abundant skeletal debris to form wackestones and packstones. Intense bioturbation commonly gave rise to structureless units, although storm layers of imbricated coarse fossil debris are present locally. The open-marine shelf facies association of the Bangor Limestone is dominated by bryozoan- echinoderm wackestone/packstone, which is petrographically similar to Mississippian Waulsortian mound facies (Wilson 1975) but which lacks characteristic mound morphology or stromatactid textures.

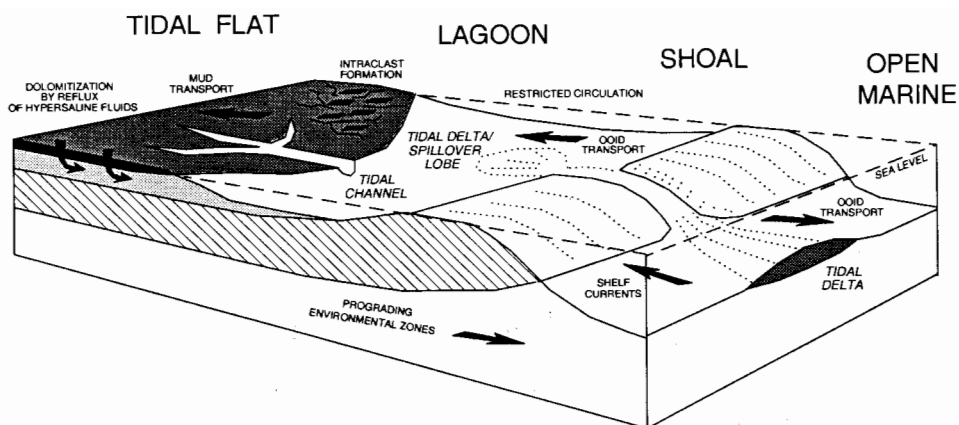


Figure 4. Paleoenvironmental model of Monteagle Shelf facies of the Bangor Limestone. Sedimentation occurred in three distinct energy zones: a low-energy lagoonal/tidal-flat environment, a high-energy oolitic shoal environment, and a low-energy open-marine environment. Environments are distinguished based on characteristic facies associations, facies-stacking patterns, and sedimentary structures. See text for details.

Subtidal lamellibranch mud and muddy sand of the Persian Gulf (e.g., Wagner and van der Togt 1973) are modern examples of such sub-wavebase sediments.

Fossil grainstone, oolitic packstone, sandstone, and shale are also prevalent in Bangor open-marine environments. Grainstones are indicative of episodic higher-energy conditions resulting from storms or strong bottom currents. Thin beds of oolitic packstone are common in foreshoal (<3 m thick) and deep basinal (<1 m thick) environments and probably represent grainy debris flows emanating from the Monteagle Shelf margin. These units may be comparable to debris flow deposits from the lower slope of Little Bahama Bank, which thin (to <1 m) and become grain-supported in distal slope areas (e.g., Mullins and others 1984). Fine-grained sandstone and shale are found in small quantities in shelf areas but accumulated mainly in deep-basinal environments.

Medial High-Energy Shoals

Bangor high-energy shoals developed where wavebase intersected the landward-rising marine shelf, causing wave- and tidal-current energy to dissipate through friction (Figure 4). Such high-energy conditions resulted in shell fragmentation, abrasion, and sorting, and winnowing of carbonate mud. The high-energy shoal facies association is characterized by oolitic and, to a lesser degree, fossil grainstones. Oolitic grainstone represents the highest sustained energy conditions, as ooid formation occurs only through persistent turbulence at shallow depths (Loreau and Purser 1973). Analogy with environments of oolitization in the Persian Gulf (Loreau and Purser 1973), Andros platform in the Bahamas (Purdy 1963b), and Shark Bay, Australia (Hagan and Logan 1974) suggests that maximum depths of formation were no more than 5 m, and commonly less than 2 m.

Bangor oolitic sands form 1-20 m-thick, planar cross-bedded units extending laterally for at least several hundreds of meters. They are generally similar in

thickness and internal structure to Bahamian oolitic tidal bars (e.g., Ball 1967). Oolitic grainstone isolith data from Vail (1959) and Handford (1978) suggest that Mississippian ooid shoals formed northeast-southwest-oriented chains of tidal bars parallel to the paleo-shoreline in northeastern Alabama and eastern Tennessee. Bangor high-energy shoal environments migrated freely across the Monteagle Shelf in response to sea-level fluctuations as evidenced by lateral correlatability of oolitic units over a distance of at least 60 km perpendicular to paleo-depositional strike.

Other facies found in association with oolitic grainstones are not diagnostic of shoal environments. Oolitic packstone occurs not only interbedded with oolitic grainstone, but also in more proximal and distal sequences, indicating that landward and seaward transport of ooids as spillover lobes and tidal deltas was common (Figure 4; e.g., Ettensohn and Chesnut 1985). Similar muddy oolite is forming in modern environments at Joulter's Cay in the Bahamas, where backshoal sandflats are several times wider than the active shoal (Harris 1977), and along the Trucial Coast of the Persian Gulf, where seaward transport of ooids occurs in tidal-bar channels (Loreau and Purser 1973).

Bryozoan-echinoderm grainstone is found most commonly underlying oolitic grainstone units, indicating deposition in foreshoal areas just seaward of prograding shoal environments. Foreshoal energy conditions were thus intermediate: sufficient to winnow fines but insufficient to initiate oolitization. Foreshoal skeletal sand beds may have served as the major source of ooid nuclei as shelf currents swept sand into the shoal environment. Similar skeletal grainstone facies are found in modern foreshoal environments of the Persian Gulf (Wagner and van der Togt 1973) and in the Bahamas (Purdy 1963b; Multer 1977).

Proximal Low-Energy Lagoons and Tidal Flats

The most proximal environments in which the Bangor Limestone accumulated were lagoons and tidal flats located shoreward of the high-energy shoal zone. Bangor backshoal sequences are characterized by a diversity of lithologies deposited in thinly-bedded units, suggesting a complex and rapidly shifting facies mosaic and/or variable energy conditions. This is typical of backshoal environments, which are broad, shallow low-energy zones subject to episodic high-energy events such as storms and tides (e.g., Ginsburg and Hardie 1975), and in which slight changes in depth result in large changes in sediment type (e.g., Hagan and Logan 1974).

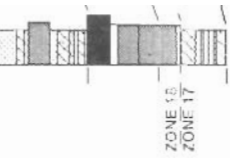
Lagoonal Association: Bangor lagoonal units accumulated in shallow subtidal areas bounded basinward by high-energy shoals and shoreward by tidal flats (Figure 4). The lagoonal facies association includes carbonate mudstone, bryozoan-echinoderm wackestone/packstone, and oolitic packstone, but the most diagnostic facies is ostracod-foram wackestone. While a stenohaline fauna of this type indicates restricted-marine conditions, burrows, mottled fabrics, and absence of primary laminae are evidence of bioturbation and oxygenated bottom-waters, suggesting elevated and/or fluctuating salinity or temperature rather than anoxia as the cause of restriction. Similar restricted-marine sediments are found in modern lagoonal settings such as the shallow subtidal platform west of Andros Island (Purdy 1963b; Shinn and others 1969).

Hydrographic and bathymetric conditions within the Bangor lagoon were

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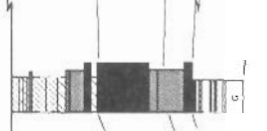
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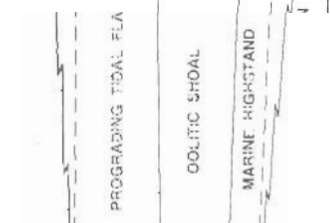


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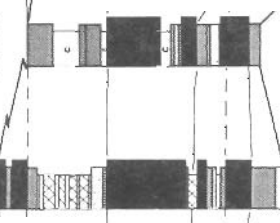
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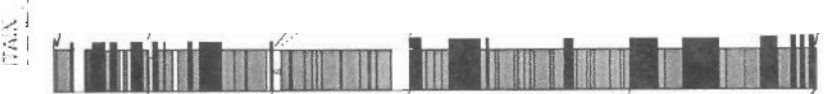
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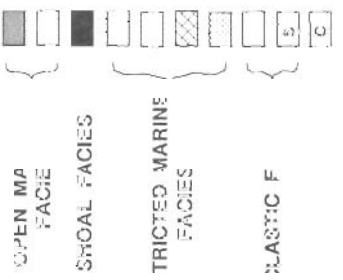
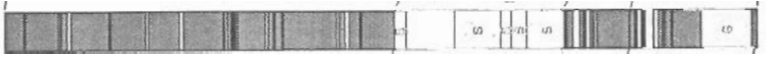
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probably similar to those of modern tropical lagoons. Water depths in analogous settings on the Andros Island platform and in the Persian Gulf are generally less than 5 m and only rarely exceed 10 m. In addition, restricted circulation and increased evaporation tend to elevate salinity. In the Bahamas, salinities increase from normal marine (35 o/oo) at the platform edge to 38-46 o/oo just west of Andros Island (Purdy 1963a), while salinities in restricted lagoons of the Persian Gulf commonly range between 50 and 70 o/oo (Loreau and Purser 1973; Wagner and van der Togt 1973). Similar conditions probably existed in the Bangor lagoon, in which variations in faunal abundance and diversity reflect variations in water circulation, temperature, or salinity.

Tidal Flat Association: Tidal flats are the most proximal environments preserved in the Bangor Limestone (Figure 4). The tidal-flat facies association comprises carbonate and dolomitic mudstone and (oo-)intraclastic packstone/grainstone. Dolomitic mudstone of the Bangor Limestone is similar petrographically and stratigraphically to fine-grained, tan to medium-gray tidal-flat dolomites of the Persian Gulf, which form thin, laterally continuous beds extending from the supratidal zone into adjacent subtidal lagoonal units (Illing and others 1965).

Bangor tidal-flat sedimentary structures include mm-scale laminae, fenestrae, intraclast breccias, dolomite pseudomorphs after gypsum, and tidal channels (Figure 3). Laminae and fenestrae are ubiquitous on modern tidal flats such as on Andros Island, where they are found in beach ridge, levee, and marsh sediments, but are absent in nearby lagoonal and intertidal units (Shinn and others 1969). Bangor intraclast breccias occur as thin, fining-upward layers of angular to subangular dolomitic clasts in a carbonate mud matrix (Figure 3E). In modern tidal flats, they develop when semilithified supratidal crusts are broken by plants, dessication, or storms (Ginsburg and Hardie 1975; Logan 1974; Woods and Brown 1975). While anhydrite blebs and dolomitic pseudomorphs after gypsum crystals

Figure 5. Stratigraphic cross-section of the Bangor Limestone in southeastern Tennessee and northwestern Georgia. Sections at Monteagle West and Monteagle East are dominated by tidal-flat sedimentation punctuated by a single marine transgression. Sections at Raccoon Mountain and Johnson Crook are characterized by oolitic-shoal sedimentation and exhibit one major and several minor marine transgressions. The Pigeon Mountain section was located in an upper slope fore-shoal environment marked by thinly interbedded open-marine fossiliferous and oolitic units. The Rock Mountain section records quiet deep-basinal fine-grained carbonate sedimentation interrupted episodically by thin, grainy oolitic debris flows and influx of terrigenous clastics. Cross-section datum: zone 18/19 contact of Mamet's global foram zonation. Although the lower Bangor Limestone correlates with the upper part of Mamet's zone 17, most of the Bangor is coeval with zone 18 (Rich 1980, 1986). The upper contact of the Bangor Limestone is approximately coincident with the zone 18/zone 19 contact across the Monteagle Shelf but is found within the upper part of zone 18 at Rock Mountain, reflecting a time-transgressive relationship between the Bangor Limestone and the overlying Pennington Shale (Rich 1986). The section at Raccoon Mountain has not been biostratigraphically zoned, and stratigraphic relations presented here are based on lithologic correlation.

occur sporadically in the Bangor Limestone, the relative paucity of evaporites suggests that Bangor tidal flats may have been of the humid-zone variety, such as those found in the Bahamas (Hardie and Garrett 1977), rather than of the strongly evaporitic Persian Gulf type. Small tidal channels (<2 m deep and 2-20 m wide) are common in Bangor tidal-flat sequences as on modern tidal flats.

Energy conditions were variable on Bangor tidal flats as evidenced by cm-scale interbedding of low-energy mudstone with higher-energy (oo-)intraclastic packstone/grainstone. Similar facies associations are found in modern carbonate tidal flats such as Shark Bay, Australia, where intraclasts form in high intertidal/low supratidal areas through storm-induced fragmentation of indurated micritic crusts and are distributed across the intertidal and supratidal zones (Hagan and Logan 1975; Woods and Brown 1975). Oolitic coating of intraclastic sediments required frequent moderate turbulence, possibly through wave and tidal action within the intertidal zone (Figure 4). Similar oolitic tidal-flat sands have been described from the Persian Gulf (Loreau and Purser 1973).

SEQUENCE ANALYSIS AND TECTONIC CONTROLS ON SEDIMENTATION

Paleogeography

Late Mississippian paleogeography of the tristate area was controlled by structural elements that had persisted since the early Paleozoic (Thomas 1977; DeWitt and McGrew 1979). Inherited tectonic elements included: 1) the Nashville Dome, a low-lying landmass which was part of the structurally-high Cincinnati Arch, 2) the Monteagle Shelf, a shallow-marine area on the southeastern flank of the Nashville Dome, and 3) the Floyd Synclinorium, a deep-water trough to the southeast of the Monteagle Shelf (Figure 2). The Monteagle Shelf was bounded by a sharply-defined shelf margin approximately coincident with the northern side of Pigeon Mountain in northwestern Georgia.

The regional distribution of Bangor facies and environmental zones reflects this paleogeography (Figure 5). Sections from Monteagle West in the northwest to the northern side of Pigeon Mountain in the southeast were located on the Monteagle Shelf, while Pigeon Mountain and Rock Mountain, the southeastermost sections, were located on the northwestern margin of the Floyd Synclinorium. Low-energy lagoonal and tidal-flat units are most abundant in the Monteagle West and Monteagle East sections, which represent inner-shelf areas flanking the Nashville Dome (Figure 6). High-energy shoal sediments occur most frequently in the Raccoon Mountain and Johnson Crook sections on the midshelf, while low-energy open-marine sediments dominate the Pigeon Mountain section on the outer shelf. Basinal sediments, comprised of open-marine carbonate and terrigenous clastic units, make up the entire section at Rock Mountain.

Facies-Stacking Patterns

Variability in facies-stacking patterns in the Bangor Limestone reflects differences in proximity to paleo-shorelines and shelf margins. While alternation between two or more facies within the same environmental zone is common at all locales, shallowing-upward cyclicity is restricted to shelf areas (Figure 5).

Inner Shelf: In inner-shelf areas at Monteagle West and Monteagle East,

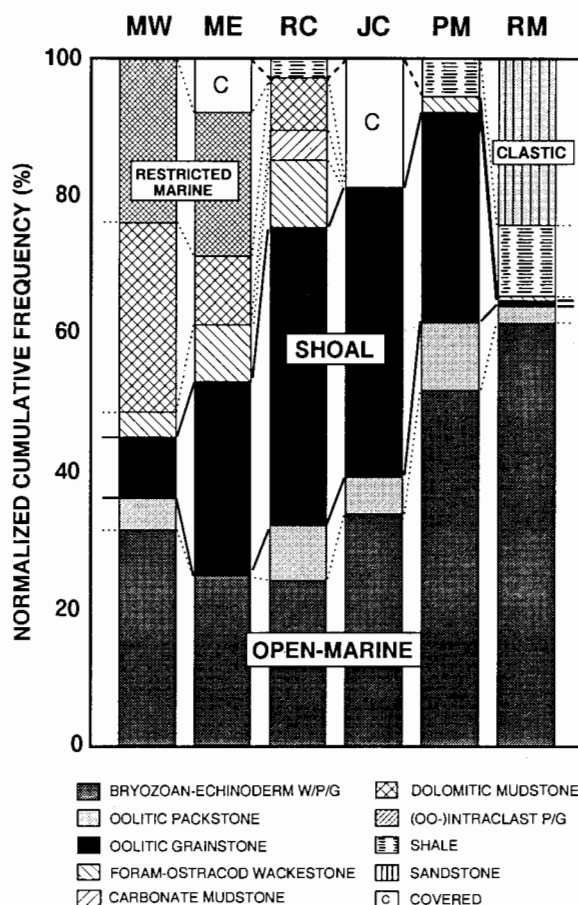


Figure 6. Facies distribution by study locale (MW = Monteagle West; ME = Monteagle East; RC = Raccoon Mountain; JC = Johnson Crook; PM = Pigeon Mountain; and RM = Rock Mountain). Frequencies are based on sampling at 0.3-m intervals and are normalized to total sample count. Facies are grouped according to dominant environment of occurrence: bryozoan-echinoderm wackestone/packstone/grainstones and oolitic packstones are predominantly open-marine facies; oolitic grainstone is predominantly a shoal facies; and foram-ostracod wackestone, carbonate and dolomitic mudstone, and (oo-)intraclastic packstone/grainstone are predominantly restricted-marine facies.

intrazonal transitions between dolomitic mudstone, (oo-)intraclastic packstone/grainstone, and foram-ostracod wackestone of the lagoonal/tidal-flat association are dominant (Figure 7). The high frequency of occurrence of dolomitic mudstone/intraclastic packstone transitions at Monteagle West may reflect its proximal location and abundance of tidal-flat facies (Figure 4). In contrast, at Monteagle East, foram-ostracod wackestone/intraclast packstone transitions predominate, reflecting dominance of lagoonal depositional environments.

Middle-Outer Shelf: Sedimentation at Raccoon Mountain, a mid-shelf locale, was dominated by shallowing-upward cyclicity, although intrazonal facies shifts

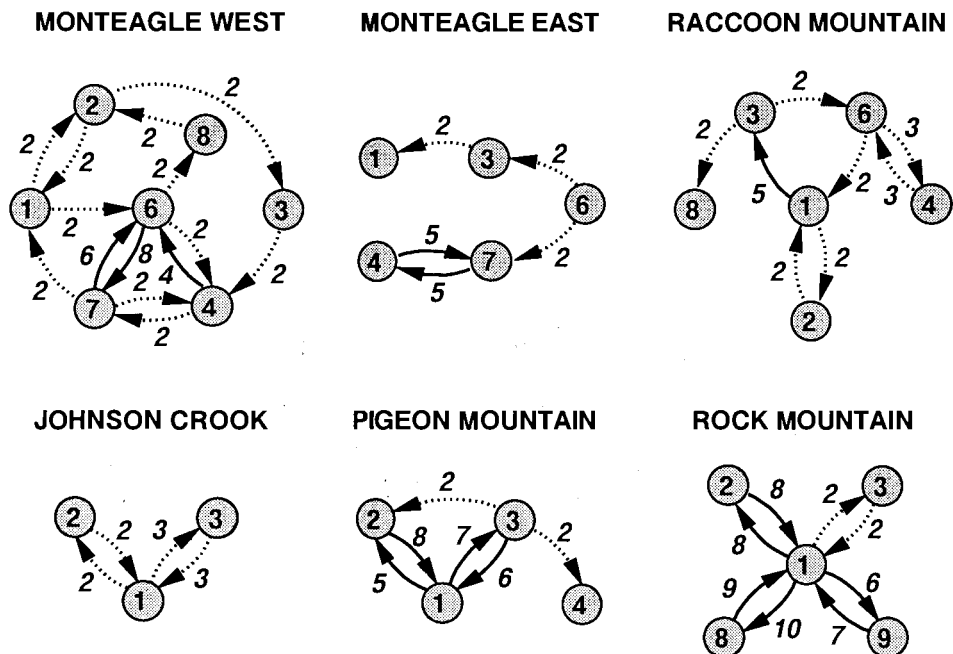


Figure 7. Facies flow diagram. Frequency of upsection transition between a given facies pair is indicated by italicized numbers and by arrow style (solid = >4 occurrences, dotted = 2-3 occurrences, single occurrences not shown). Facies types are represented by circled numbers: 1 = bryozoan-echinoderm wackestone/packstone/ grainstone, 2 = oolitic packstone, 3 = oolitic grainstone, 4 = foram-ostracod wackestone, 5 = carbonate mudstone, 6 = dolomitic mudstone, 7 = (oo-)intraclastic packstone/grainstone, 8 = shale, 9 = sandstone.

(e.g., between open-marine fossiliferous oolitic packstones and between lagoonal wackestones and tidal-flat dolomites) were common (Figure 7). Similar patterns are probably present at Johnson Crook, although covered intervals in the measured section there preclude firm conclusions. At Pigeon Mountain, an outer-shelf to upper slope locale, shifts between open-marine fossil wackestone/packstone and oolitic packstone are dominant, reflecting a combination of incomplete shoaling cycles (e.g., where capped by oolitic units up to 5 m-thick) and shoal-sourced grainy oolitic debris flows (e.g., <1 m-thick oolitic packstone interbeds; Figure 5). Such facies-stacking patterns suggest deposition in a foreshoal environment on the basinward margin of an oolitic shoal or tidal bar.

Clastic Basin: The upper and lower members of the Bangor Limestone at Rock Mountain are characterized by alternation of thick (10s m) open-marine bryozoan-echinoderm wackestone/packstone units with thin (mostly <1 m) oolitic packstone and sandstone interbeds (Figure 7). Such facies-stacking patterns record episodic influx of carbonate and terrigenous detrital material into a deep-basinal environment from extrabasinal source areas.

Shallowing-Upward Cyclicity

Shallowing-upward cycles (e.g., transitions from open-marine through shoal

to lagoonal/tidal-flat units) are found in all shelf sequences of the Bangor Limestone (Figure 8). In inner-shelf areas, one major shoaling cycle (25-30 m thick) is present, while in mid- to outer-shelf areas several additional minor cycles (3-10 m thick) are recorded (Figure 5). Cycle boundaries are marked by sharp, disconformable lithologic contacts, separating proximal restricted-marine sediments of the underlying cycle from distal open-marine sediments of the overlying cycle (Figure 3B). Cycle tops commonly exhibit strong dolomitization decreasing rapidly downward over a few tens of centimeters, while the bases of overlying cycles show no alteration.

Each cycle commenced with a marine transgression marked by a 0.3 to 2.0

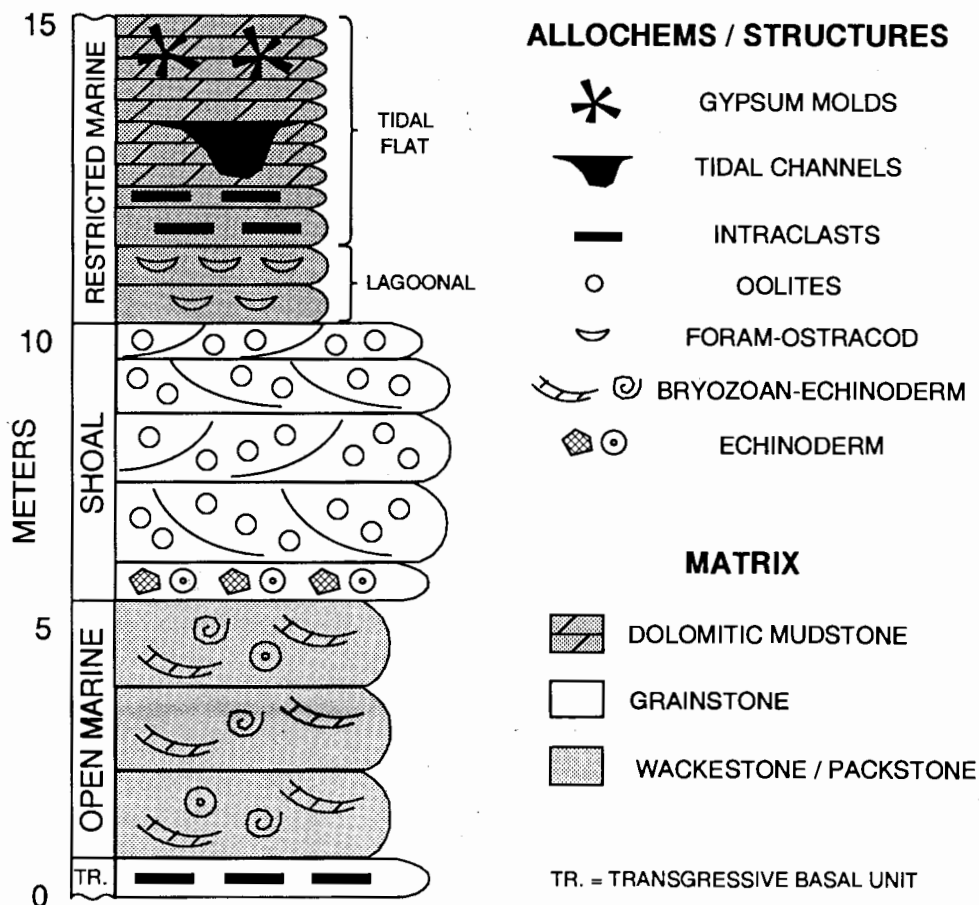


Figure 8. Bangor Limestone shallowing-upward cycle. This model emphasizes the vertical relations of energy zones, variations in bedding thickness, and facies-specificity of allochems and sedimentary structures.

m-thick basal unit composed of intraclastic-oolitic packstone/grainstone exhibiting poor to moderate sorting and considerable admixture of quartz sand and glauconite (Figure 8). Basal-unit intraclasts are of diverse lithologies, indicating penecontemporaneous erosion and mixing of semi-lithified sediment from several facies within the lagoonal/tidal-flat association. Sparry matrices, ooid and

intraclast formation, and coarse-grained allochems are evidence of high-energy conditions. These observations are consistent with deposition of basal units during transgression of partially consolidated and dolomitized shelf sediments. The thinness of the transgressive deposits may reflect either rapidity of the transgressive events or their inherently erosional nature.

Intrazonal facies shifts and interzonal shoaling patterns probably had fundamentally different origins. Frequent alternation between two or more facies within an environmental zone suggests that such sequences developed through short-term fluctuations in energy conditions and/or lateral facies shifts which may have been unrelated to larger-scale cyclic processes. The latter are marked by an orderly shoaling pattern reflecting seaward progradation of energy zones during episodes of stable or falling relative sea level. Subsequent marine transgressions re-established open-marine conditions and reinitiated the shoaling process.

Tectonic Control of Shelf-Basin Subsidence

A single major transgression affected the entire Monteagle Shelf, flooding areas at least as far landward as the Monteagle West section (Figure 5). While this flooding event could have resulted from either eustatic or regional tectonic movements, correlation of the clastic middle member of the Bangor Limestone at Rock Mountain with highstand units on the Monteagle Shelf suggests that the latter is more probable. Progradation of a coarse clastic wedge derived from an active orogen to the southeast into the Floyd Synclinorium flysch basin may have resulted in subsidence of both the basin and the adjoining shelf, and transgression of the latter (Rich 1986). If the transgressive event had been due to eustatic rise without tectonic movement, then coarse-grained clastics should have been trapped closer to the receding shoreline on the southeastern margin of the Floyd Synclinorium, rather than flooding into the basin.

While the Bangor thickens into the Floyd Synclinorium by a factor of 2.5-3.0 in relation to Monteagle Shelf sections (Figure 5), the locus of thickening, i.e., whether distributed uniformly through the section or concentrated at a particular horizon, is unknown. If the middle member of the Bangor Limestone is equivalent to the Upper Floyd Shale/"Hartselle interval," then thinning of the shelf section is concentrated in units correlative to the thick clastic middle member of the basinal sequence (Rich 1982, 1986). This would be consistent with drowning-induced low sedimentation rates on the shelf, a widely-observed phenomenon in carbonate environments (e.g., Read 1985). In this event, the carbonate-rich lower and upper members of the Bangor Limestone at Rock Mountain correlate with the thick, regressive, predominantly tidal-flat sequences of inner-shelf locales.

CONCLUSIONS

- 1) The Bangor Limestone was deposited in shallow carbonate shelf and basinal mixed carbonate-clastic settings on the southeastern margin of the North American craton during Late Mississippian (middle and late Chesterian) time.
- 2) Deposition occurred in three broad environmental zones: a distal low-energy open-marine shelf, medial high-energy shoals, and a proximal low-energy lagoonal and tidal-flat complex.
- 3) Each environmental zone is characterized by diagnostic microfacies, sedimentary structures, and facies-stacking patterns which reflect differences in

water depth, distance from the paleo-shoreline, and energy level.

4) Fluctuations within an environmental zone, marked by cm-scale interbedding of two or more genetically-related facies, are the most common form of facies transition. Such transitions reflect lateral facies shifts and/or short-term variations in energy level due to storms or tides.

5) Shelf sequences are characterized by 3-30 m-thick cycles that shallow upward from open-marine through shoal to lagoonal/tidal-flat sediments, reflecting long-term shifts in environmental loci owing to seaward progradation of proximal environmental zones over distal ones.

6) Inner areas of the Monteagle Shelf are dominated by tidal-flat sedimentation, punctuated by a single major marine transgression, while outer-shelf areas are dominated by ooid-shoal and foreshoal sedimentation and record several minor flooding events in addition to the major one.

7) In the Floyd Synclinorium, a basinal area to the southeast of the Monteagle Shelf, quiet deep-water sedimentation prevailed throughout the Late Mississippian, broken episodically by thin, grainy oolitic debris flows from the shelf margin and by influx of fine-grained terrigenous clastics from an active orogen to the southeast.

8) Correlation of the clastic middle member of the Bangor Limestone with marine-highstand units of the Monteagle Shelf suggests that clastic influx and shelf flooding share a common control, probably subsidence of the craton margin owing to uplift of tectonic highlands to the southeast and sediment loading of the intervening flysch trough.

9) Bangor Limestone deposition terminated when the Monteagle Shelf was overwhelmed by southwestward- (Pennington Formation) and northeastward-prograding (Parkwood Formation) clastic wedges in late Chesterian time.

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