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ORIGIN OF LATE PALEOZOIC CYCLOTHEMS

Cyclic sedimentary sequences of similar origin but diverse manifestations are widespread in later Mississippian, Pennsylvanian, and early Permian successions of the northern hemisphere. They are best developed in cratonic areas, and vary from wholly marine through marine-non-marine alternations, to wholly non-marine. They are associated with widespread coals in many areas, but are equally evident in successions lacking coal.

Their origin has been assigned to (1) intermittent downwarping of sedimentary basins; (2) continuous downwarping; (3) periodic elevation and depression of both source areas and basins; (4) eustatic changes of sea-level associated with (a) alternate growth and wastage of late Paleozoic glaciers in the southern hemisphere and in India, or (b) controlled by diastrophism in the ocean basins; (5) climatic oscillations, and (6) the superposition of subdeltas such as those of the Quaternary in Louisiana.

The present paper attempts to resolve their origin by (1) study of the varied tectonic conditions in areas displaying cyclic successions; (2) environmental mapping of the separate beds of cyclothems through several states; (3) determination of the time and frequency of late Paleozoic glaciers; and (4) critical appraisal of the various mechanisms proposed.

The kinds and quantities of sediment composing a cyclothem at any place are held to be controlled by (1) rate of downwarping; (2) type and quantity of clastic sediment available; (3) distance between sediment source and basin. The varied number of cyclothems in basins and adjacent shelves suggests that many nondepositional periods occurred both between and within cycles.

Eustatic shifts in sea-level through 100 feet or less, controlled by glacial episodes or submarine diastrophism, and climatic oscillations, are judged to be the most probable causes of these cycles.

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TRACE ELEMENT COMPOSITION OF DOLOSTONES AND DOLOMITES AND ITS BEARING ON THE DOLOMITE PROBLEM

Three hundred specimens of "primary" and "secondary" dolostones and 150 specimens of dolomite quantitatively analyzed in triplicate for 20 trace and minor elements statistically yield separate populations of the two major lithologic varieties of dolomitic carbonate rocks for certain trace elements. Histograms, probability plots and measure of the coefficient of variation suggest a lognormal distribution for the trace-element data, which when tested statistically at the 1 per cent level of significance, indicate higher concentrations of Al, Ba, Fe, K, Li, Zn, and Na in the "primary" dolostones. Sr is significantly concentrated in the secondary dolomites separated from the dolostones. On the basis of carbon-oxygen isotope ratios and crystallo-chemical considerations, the dolomite is considered to be a replacement mineral after calcite or aragonite, and the abundance of Sr in "secondary" dolomite is interpreted as a minor impurity originally derived from metastable aragonite and entrapped in the dolomite structure. For the samples studied, trace element patterns appear to suggest that "primary" dolostones (characterized by very fine and uniform grain size; complete absence of fauna, relict textures and phantom structures; lack of appreciable porosity; relatively light color; frequent fine lamination; conchoidal fracture; and association with evaporitic sequences) may represent the early replacement of predominantly calcitic limestones under conditions of somewhat above normal salinity; "secondary" dolostones (characterized by relatively coarse and non-uniform grain size; euhedral dolomite rhombs; frequent oölith, pellet, and fossil relict textures; or organic fossil remains) may represent the early replacement of predominantly aragonitic limestones under normal marine conditions. A specific example of Ordovician Nittany dolostone comprising alternating zones of "primary" and "secondary" dolostones confirms the relationship evident in samples differing widely in age and geographic location.

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PETROLOGY AND LITHOSTRATIGRAPHY OF THE CYNTHIANA AND EDEN FORMATIONS OF THE OHIO VALLEY

Two hundred to three hundred feet of highly fossiliferous limestone, interbedded with abundant shale, are exposed in the Ohio Valley. The monotonous apparent uniformity of these Ordovician rocks (Cynthiana and Eden) has long discouraged lithostratigraphic work. Studies of the past several years have demonstrated that lithostratigraphic analysis is possible and useful.

Petrographic conclusions are based on standard methods. Lithostratigraphic methods of greatest effect are the computation of curves of clastic ratio, bedding index, and frequency of limestone types from detailed measured sections.

The "shales" include beds of shale, siltstone, and some mudstone. They consist largely of clay and fine and medium silt of illite, chlorite, quartz and pyrite, and about 15 per cent calcite. The fineness of these evenly layered muddy rocks and the variety of thicknesses of the beds indicate that the persistent sedimentary accumulation in the region was fine terrigenous detritus that was locally and intermittently interrupted by accumulation of biogenic carbonate debris.

Biogenic limestones in a limited variety of textures and structures occur in beds ranging from thin laminae to ledges about a foot thick. The silty limestones are laminated and cross-laminated. Pararipples are common in the coarse shell-fragment ledges and are thought to have been formed by surf and tidal currents augmented by waves. Submarine slump structures are conspicuous at several levels in the Cynthiana limestone, and occur typically in the fine-grained silty limestones. The principal diluent of calcite in the limestones is quartz silt, much of which is authigenic.

Several limestone texture-structure systems are repeated many times. These form the basis of a practical classification of the limestones which aids environmental interpretations. Limestone beds were formed of debris originating in local colonies of benthos on the sea floor, which appear to have been concentrated on low swells along the shoal forming the incipient Cincinnati arch. Such colonies were intermittently destroyed and the debris sorted into lenses of different texture. Continual alteration of the topography of the sea floor and the sites of colonies of benthos led to the interbedded limestones and shales preserved today.

For the future, attention to the pararipples and possible facies relationships between the several types of limestone may contribute to a better understanding of the sedimentary environment.

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CARBONATE CYCLES: LOWER PENNSYLVANIAN MARBLE FALLS FORMATION, MASON AND KIMBLE COUNTIES, TEXAS

Samples from detailed measured sections were successfully classified by using Folk's descriptive limestone classification. Later in the investigation genetic rock categories (facies) that reflect ecologic environments were recognized and classified separately. The nine facies are shown in the following table.

Facies Name	*Characteristics*	*Inferred Environment*
1. Mottled facies	Pale yellowish brown fragmental biosparite and burrowed biomicrite containing fusulinids, paleotextulariids, *Calcitornella*, *Millerella*, and *Bradyina*	Nearshore and tidal flat of transgressive and regressive facies tracts
2. Churned dark fragmental facies	Dark gray fragmental biomicrite with disoriented grains	Middle shelf; transgressive facies tract
3. Laminated dark fragmental facies	Laminated, locally graded, dark fragmental spiculitic biomicrite; evenly bedded with shale interbeds	Seaward slope beyond shelf edge; mostly transgressive facies tract
4. Light fragmental facies	Light gray fragmental biomicrite and pelmicrite	Middle shelf, seaward of *Ivanovia* facies; transgressive facies tract
5. *Ivanovia* facies	Light olive-gray *Ivanovia* biolithite	Middle shelf with dark fragmental facies to landward, and light fragmental facies to seaward; transgressive facies tract
6. Tubular alga facies	Medium to light gray, delicately branching red alga biolithite; probably a growth form of *Komia*	Shelf edge in deep or protected areas; transgressive facies tract
7. *Komia* facies	Coarse-grained, light gray biosparite, containing *Komia*, fusulinids, and crinoid fragments; or fine-grained biosparite and biomicrite containing *Calcitornella*, *Millerella*, and calcite spicules	Shelf edge in shallow or turbulent areas; transgressive facies tract, or seaward slope beyond shelf edge; regressive facies tracts
8. *Chaetetes* facies	*Chaetetes* biostromes in pale yellowish brown biomicrite containing mat algae, fusulinids, *Calcitornella*, *Komia* fragments, paleotextulariids, *Bradyina*, *Ozawainella*, laminated shell fragments and gastropods.	Shelf, on surfaces of bypassing; regressive facies tract
9. Shale facies	Very dark gray shale	Shelf and seaward slope beyond shelf; mostly transgressive facies tract

A transgressive facies tract can be identified, comprising four depositional areas: (1) nearshore and tidal flat, bearing the mottled facies; (2) middle shelf composed either totally of the churned dark fragmental facies or of *Ivanovia* banks with the churned dark fragmental facies to landward and the light fragmental facies to seaward; (3) shelf edge with algal banks or knolls, the tubular alga facies in deeper or protected areas, the *Komia* facies in turbulent or shallow areas; (4) seaward slope bearing the laminated dark fragmental facies grading seaward to the shale facies.

The regressive facies tract begins with the seaward migration of the mottled facies and the lateral expansion of the *Komia* facies. It culminates on the shelf with the mottled facies and *Chaetetes* facies which developed on a surface of bypassing, and on the slope by deposition of debris transported from the *Komia* facies.

Cycles have four phases: (1) minor transgression with shale at the base overlain by a poorly developed regressive facies tract; (2) slight regression with a poorly developed regressive facies tract; (3) major transgression with well developed transgressive facies tract; (4) major regression with well developed regressive facies tract.

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APPALACHIAN TECTONIC DEFORMATION AND THE DEEP BASIN

Much of the central Appalachian region fits a single geometric pattern that is bilaterally symmetrical to an axis or radius passing N. 40°W. from the Baltimore dome through the high point of the Nittany arch. Many elements are likewise concentric to a focus situated on that axis near Baltimore and (or) are symmetrically tangential to a baseline that crosses the above axis at right angles in the vicinity of Baltimore. It is suggested that all of these symmetrical features result from (a) primary uplift of the Baltimore dome with outward gravitational sliding in the overlying skin of sediments; (b) a secondary forward movement along the axis of a crustal block containing the Baltimore dome; or (c) some combination of these two factors.

There is possible distortion of this symmetry along a conjectured slip- or wrench-fault at about Lat. 40° N., which may involve a dextral offset amounting to 80 or more miles along a trace now concealed by younger sediments or the Atlantic Ocean, from the Susquehanna River eastward to the Kelvin Seamount Group, 400 miles offshore at Lat. 40° N.

The nature of the deep part of the central Appalachian basin is reviewed in the light of a general theory of