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CONTINUITY OF STRATA IN THE NEWARK AND HARTFORD BASINS

Paul E. Olsen[1]

Abstract

Trangressive-regressive lacustrine sedimentary sequences, called Van Houten cycles, can be traced over large areas of the Newark and Hartford basins by use of six independent means: (1) walking out the trace of the beds; (2) detailed matching of unique sequences of beds between isolated outcrops; (3) detailed ecostratigraphic correlation; (4) identification of key marker beds; (5) magnetostratigraphy; and (6) matching of microlaminae. By use of these methods, Van Houten cycles of the Lockatong and Passaic Formations in the Newark basin and the East Berlin Formation in the Hartford basin have been traced over most of the areas of their respective basins. Demonstration of the lateral continuity of Van Houten cycles is necessary for their use in stratigraphy, geochronology, paleoclimatology, and paleoecology in the Newark Supergroup.

INTRODUCTION

The title of this paper is tribute to the classic work of Dean B. McLaughlin, an astronomer at University of Michigan and later of Harvard University. In his spare time, McLaughlin doubled as one of the finest physical stratigraphers to work in the Newark Supergroup (Froelich and Olsen, 1984) of eastern North America. In McLaughlin's paper (1948) entitled "Continuity of Strata in the Newark Series," he showed how individual red and black members of the Lockatong and Passaic (lower Brunswick of Kummel (1897); Olsen, 1980a,b) Formations could be traced over much of the Newark basin (figs. 1 and 2). It is vital that the lateral continuity of small-scale lithologic units be understood, because only then can local effects be differentiated from regional ones. Further, it is these laterally continuous units that have the potential to provide very fine-scaled stratigraphic and geochronologic tools (Olsen, 1986). In this paper, I follow up on McLaughlin's work by describing (1) how individual components of his informal members can be traced over most of the Newark basin, (2) how this lateral continuity holds for the other parts of the Newark basin section, and (3) how the same pattern pertains to parts of the Hartford basin.

VAN HOUTEN CYCLES—MODAL SEDIMENTARY SEQUENCES OF THE NEWARK SUPERGROUP

The Lockatong and Passaic Formations of the Newark basin make up a natural facies package united by a common theme of repetitive transgressive-regressive lake-level sequences called Van Houten cycles (fig. 3, table 1) after their discoverer (Van Houten, 1964, 1969, 1980; Olsen, 1980a,b,c, 1984a,b, 1986). Van Houten cycles make up at least two orders of compound cycles, which as described by Olsen (1986), can be viewed either

Table 1. Divisions of the Van Houten cycle

[See figure 3 for illustration of cycle]

Division	Description
1.	A calcareous claystone to siltstone with pinch and swell lamination with thin bedding, occasional desiccation cracks, burrowed or rooted horizons, stromatolites, and oolites. This represents a lacustrine transgressive sequence including shoreline deposits.
2.	A laminated to microlaminated calcareous claystone and siltstone, or limestone, with desiccation cracks rare to absent. This division has the highest organic content of the cycle, and fish and other animal fossils are sometimes abundant; it represents the lake's high-stand deposit.
3.	A calcareous claystone and siltstone, with abundant desiccation cracks, burrowed and rooted horizons, vesicular and crumb fabrics, and reptile footprints. Division 3 represents the sequence of the lake's regressive through low-stand deposit; the lake was at least occasionally dry, with incipient soil development.

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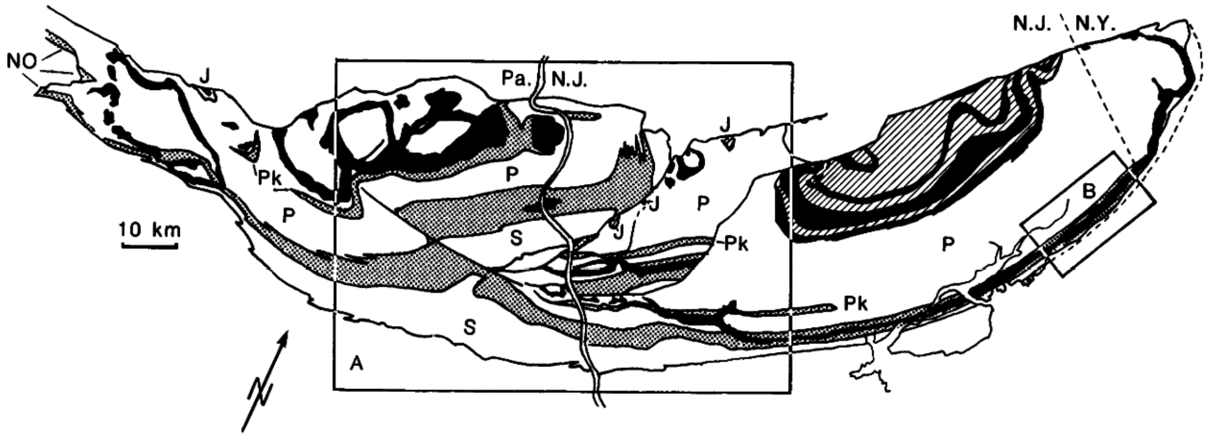


Figure 1. Simplified geologic map of the Newark basin showing the major areas discussed in text: A, Delaware Valley area; B, Weehawken area. Abbreviations and symbols for units are P, Passaic Formation; S, Stockton Formation; J, Jurassic extrusive basalts and interbedded sedimentary rocks; NO, New Oxford Formation; Pk, Perkasie Member of Passaic Formation; stippled areas, Lockatong Formation, except where designated as Pk; diagonally ruled areas, Jurassic sedimentary rocks; black areas, diabase and basalt, extrusive where adjacent to Jurassic sedimentary rocks.

typologically or by numerical means through Fourier analysis. These second- and third-order cycles (fig. 4) show up as modulation of the expression of Van Houten cycles. Van Houten cycles and the compound cycles similar to those in the Lockatong and Passaic Formations occur through the Jurassic portions of the Newark basin and through most of the rest of the Newark Supergroup (Olsen, 1984a, 1986) and span a total interval of more than 40 million years.

McLaughlin (1943, 1944, 1945, 1946, 1948, 1959) concentrated on tracing out the second- and third-order cycles across the largely continuous sequences comprising the northwestern fault block in the Newark basin (fig. 2). He did this during the 1930's and 1940's when central New Jersey and southeastern Pennsylvania were largely farmland and the gray and red members of the Lockatong and Passaic Formations could be walked out easily over plowed fields. Tracing individual Van Houten cycles and their compound cycles laterally in faulted, overgrown, or densely populated areas is now more difficult and inferential.

Where cycles cannot be walked out, lateral correlation of individual Van Houten cycles and the second- and third-order cycles is afforded by five independent means: (1) detailed matching of unique sequences of beds between isolated outcrops; (2) detailed ecostratigraphic correlation of fossils in stratigraphic sequences (Cisne and Rabe, 1978; Hoffman, 1981); (3) identification of key marker beds such as radioactive units or fluidized beds; (4) correlation of stratigraphic units and magnetozones (McIntosh and others, 1985); and (5) matching of microlaminae within division 2 of single, distinctive Van Houten cycles. Because the rocks are not continuously exposed, these correlations are hypotheses that are only as good as the rigor of the tests they survive.

LOCKATONG FORMATION, NEWARK BASIN

Middle Lockatong Formation, Hunterdon Plateau Fault Block

The longest single outcrop of the Lockatong occurs in the northern fault block in Byram, New Jersey, along the west side of Route 29 and along a small brook (fig. 2, locality 1). More than 400 m of middle Lockatong Formation (fig. 5) crop out; this outcrop forms the main basis of Van Houten's original interpretations. The upper part of the section contains the important marker units called the "First Thin Red" (fig. 5) and "First Thick Red" units of McLaughlin (1946), which he mapped throughout the northwestern fault block. The surrounding 100 m of section contain a distinctive sequence of Van Houten cycles that include two Van Houten cycles in which division 2 is a microlaminated fish-bearing unit (SH1 and SH2, fig. 5). These two cycles contain the only two such units in this section.

About 25 km to the southwest of these outcrops, the Haines and Kibblehouse quarry exposes about 120 m of middle Lockatong Formation (fig. 5). McLaughlin (1946) mapped his "First Thin Red" unit through this area prior to the opening of the quarry in 1965. The quarry now exposes all of the First Thin Red initially mapped by McLaughlin (fig. 2) and apparently replicates the entire pattern of Van Houten cycles and higher order

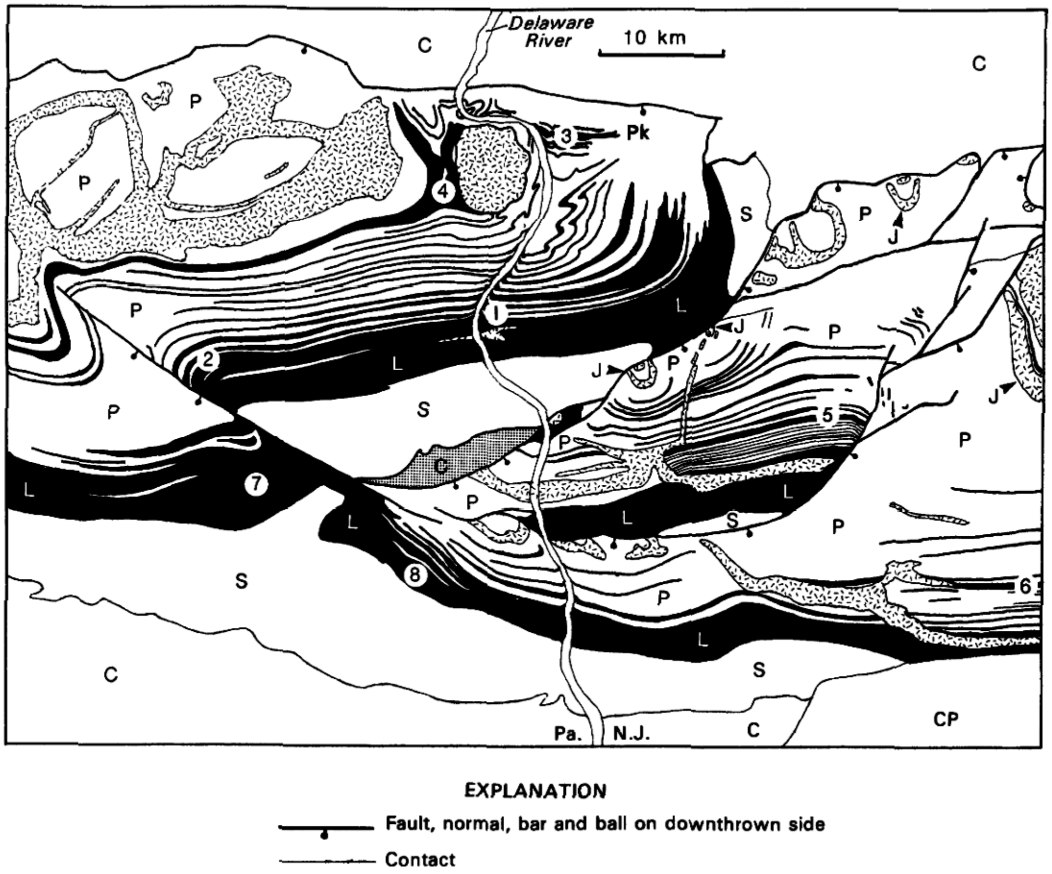


Figure 2. Simplified geologic map of the Delaware Valley area of the Newark basin showing positions of major localities: 1, middle Lockatong Formation, Route 29 exposures, Byram, New Jersey; 2, middle Lockatong Formation, Haines and Kibblehouse quarry, Chalfont, Pennsylvania; 3, Perkasie Member of Passaic Formation, Milford, New Jersey; 4, Perkasie Member of Passaic Formation, Harrow, Pennsylvania; 5, Perkasie Member of Passaic Formation, Furmans Corner, New Jersey; 6, Perkasie Member of Passaic Formation, New Brunswick, New Jersey; 7, lower Lockatong Formation, Eureka, Pennsylvania; 8, lower Lockatong Formation, Rushland, Pennsylvania. Abbreviations and symbols for units are C, crystalline and Paleozoic basement, stippled within basin; J, Jurassic extrusive basalts and sedimentary rocks; L, Lockatong Formation; P, Passaic Formation; Pk, Perkasie Member of Passaic Formation; S, Stockton Formation; irregular dashed pattern, tholeiitic igneous rocks, intrusive unless designated by J; CP, coastal plain sediments.

cycles present along Route 29. This includes the relative positions of the microlaminated fish-bearing units relative to the First Thin Red, thereby providing additional support to McLaughlin's original hypothesis.

The quarry section differs from that along Route 29, however, in having much more sandstone and in lacking the common analcime- and carbonate-rich massive mudstones with breccia and crumb fabrics (Smoot and Katz, 1982). These mudstones are replaced by red massive mudstones with less dense breccia fabric, rooted and burrowed fabrics, beds of red ripple cross-laminated siltstone and sandstone (often with soft-sediment deformation and desiccation cracks), and rare tufa gravels. Some of these red units contain rare to abundant bones of the little reptile *Tanytrachelos*, larger bones of phytosaurs, and reptile footprints (fig. 5) (Olsen and Flynn, in press). The massive gray mudstones of cycles above the First Thin Red are replaced by flaggy, oscillatory- and climbing-ripple bedded sandstones with reptile footprints. The features that Van Houten used to distinguish his chemical cycles from detrital cycles are absent in the quarry section, even though correlative cycles are present.

Lower Lockatong Formation, Weehawken area

The lower Lockatong and upper Stockton Formations are exposed in the northeastern Newark basin along

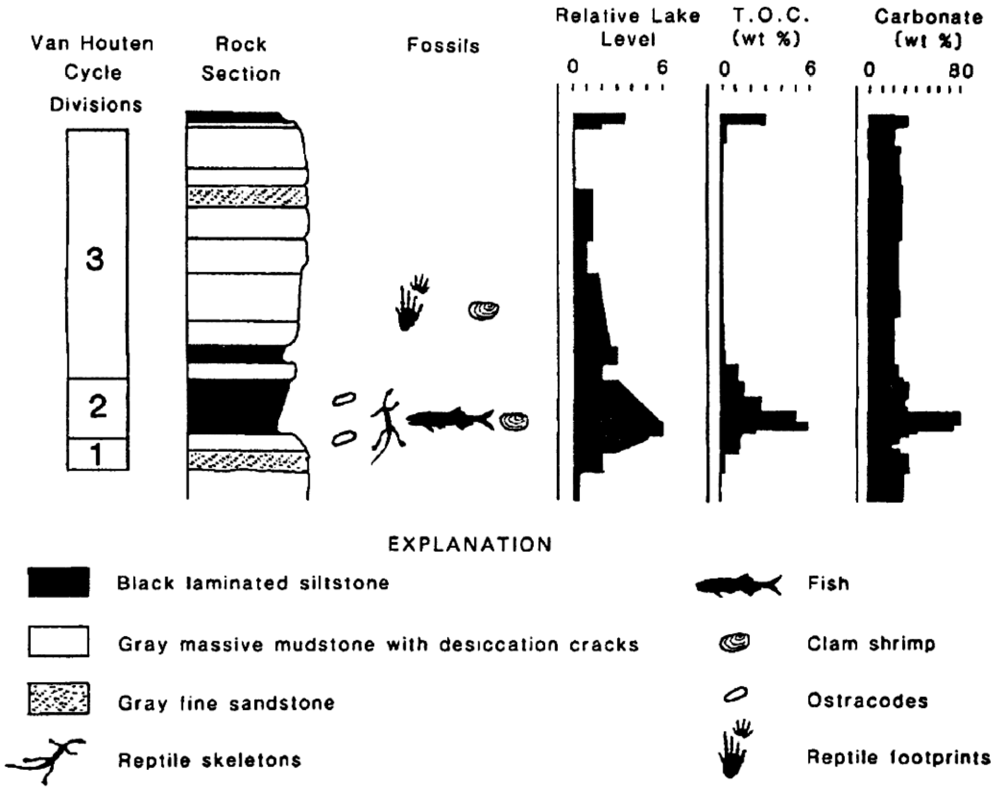


Figure 3. Sketch showing single Van Houten cycle (SH2 in fig. 5). Relative lake level increases from 0 to 6 (depth ranks of Olsen, 1984b, 1986). T.O.C., total organic carbon. See table 1 for explanation of cycle divisions.

the base of the Palisade sill in the Weehawken, New Jersey, area (Hoboken north to Alpine, fig. 1). Exposures are small, the area is densely populated, and there are no mappable units of different color. Fortunately, the Van Houten cycles of the lower Lockatong are richly fossiliferous and much thinner—an average of 1.5 m in this area (Olsen, 1980c) compared to 5.9 m in the Hunterdon Plateau Fault Block (Olsen, 1986). Small exposures therefore provide a disproportionally large amount of information.

Olsen (1980c, 1984a) used ecostratigraphic methods (Cisne and Rabe, 1978) to correlate a long series of cycles at five main exposures from Hoboken to Fort Lee, New Jersey. Ecostratigraphic correlation uses the partial vertical ranges of fossils as sensitive indicators of relatively subtle regional changes in environments rather than using the total vertical ranges of taxa as indicators of origination and extinction as in standard biostratigraphy. The taxa used by Olsen (1980c) have total ranges that span most of the Lockatong Formation, and these would be useless in using standard biostratigraphic methods to correlate within the formation. There seems to be a correlation between pyrite sulfur content and the fish taxa that can be interpreted as a correlation with salinity (Olsen, 1984a; 1987, unpub. data). The vertical distribution of taxa may thus reflect salinity changes in the Lockatong lakes.

By this approach in the Weehawken area, individual cycles and the compound cycles are correlated over a distance of about 12 km. Additional outcrops near Alpine, New Jersey (still under study), extend this correlation another 4 km.

Correlation of Lower Lockatong Across Newark Basin

The same ecostratigraphic method used in the Weehawken area allows the development of a reasonable hypothesis of correlation (fig. 6) from Weehawken southwest 140 km to the Eureka quarry (fig. 2), despite the large distances involved and the dramatic increase in the thickness of Van Houten cycles. This correlation involves much more significant lateral facies change and some lateral change in the distribution of fossils as well; hence, it is not as secure as that within the Weehawken area or within the middle Lockatong in the Hunterdon Plateau. However, it may be possible to test the correlation by

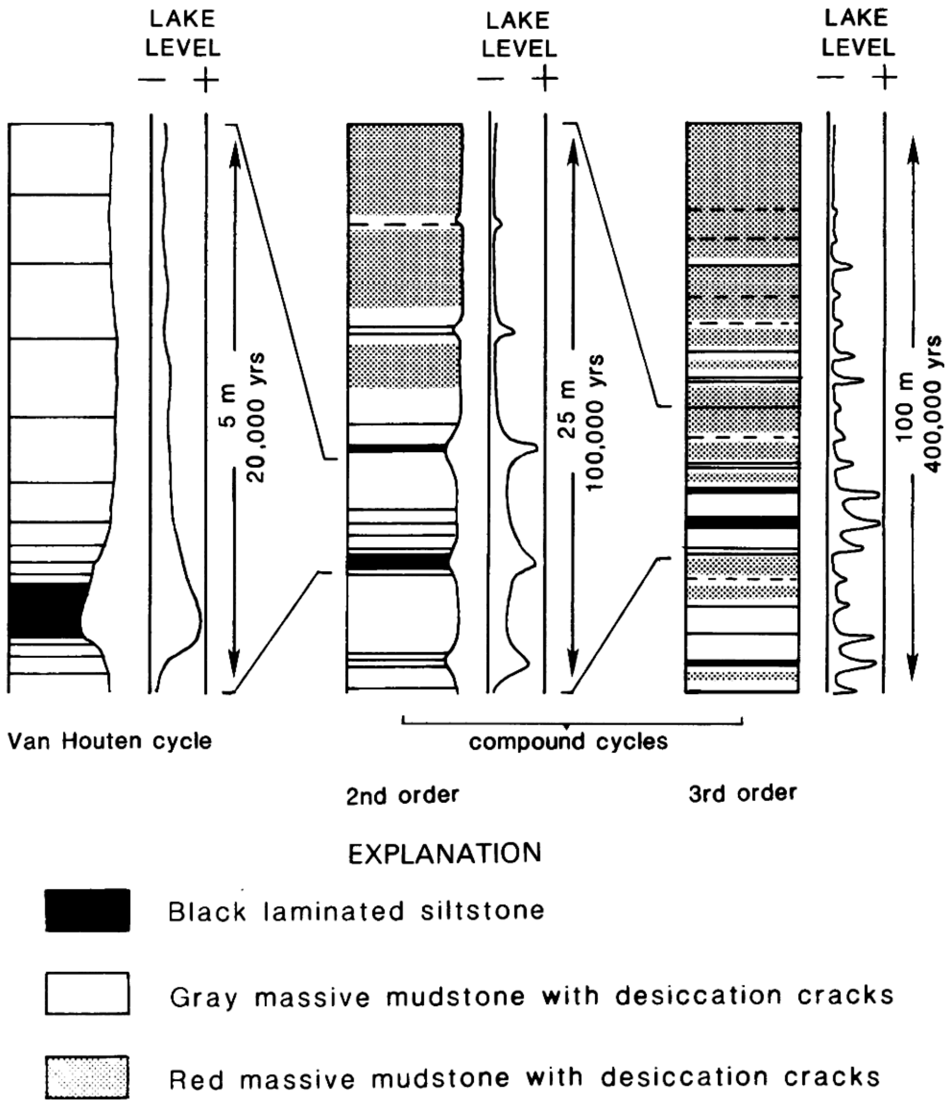


Figure 4. Idealized Van Houten and compound cycles showing thickness for Lockatong Formation and general interpreted durations and relative lake levels.

magnetostratigraphy, because the lower Lockatong contains at least one reversed interval (W. Witte, personal commun.).

PASSAIC FORMATION, NEWARK BASIN

One of the most distinctive units mapped by McLaughlin (1948, 1959) in the lower Passaic Formation is the Perkasie Member (Johnson and McLaughlin, 1957). The Perkasie crops out extensively across the Hunterdon Plateau from a coarse-grained marginal facies at Milford, New Jersey, to a much finer grained facies exposed in Pennsylvania. In the Hunterdon Fault Block, the Perkasie Member consists of two second-order cycles, each containing two Van Houten cycles that have laminated black calcareous siltstones in division 2. Exposures along strike of the mapped distribution of the Perkasie (figs. 1, 2, and 7) show the same pattern of Van Houten cycles and compound cycles. One of the Van Houten cycles (shown in fig. 7) is unusually radioactive at all but the Milford outcrops.

A lithologically very similar sequence to the Perkasie Member occurs in the lower Passaic Formation at New Brunswick, New Jersey (fig. 7). The pattern of Van Houten cycles and compound cycles is the same as in the northwestern fault block. In addition, units lithologically similar to McLaughlin's members K, L, and M crop out within this New Brunswick section in the homotaxially

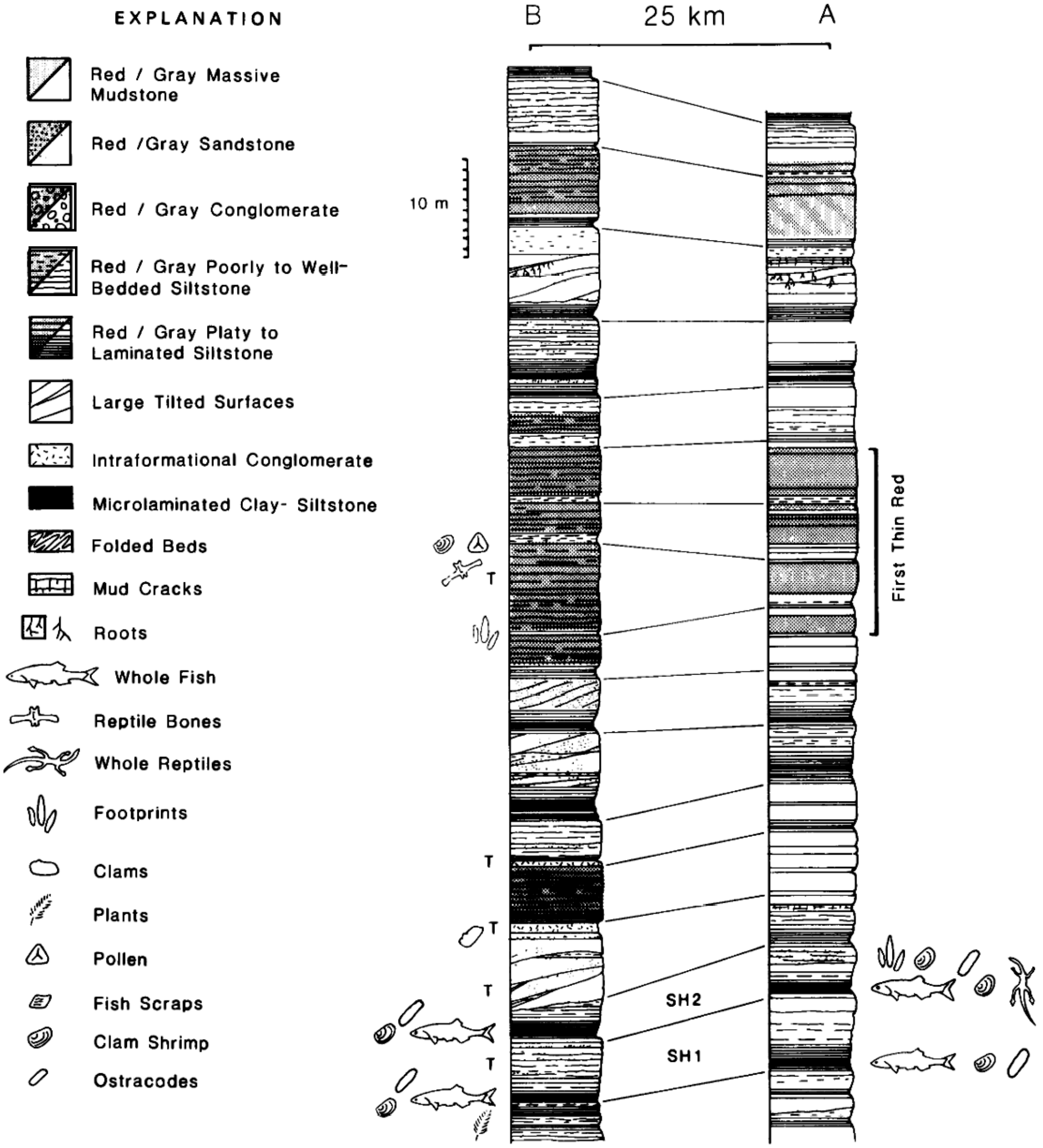


Figure 5. Comparison of sections of middle Lockatong Formation at Route 29 (A) and the Haines and Kibblehouse quarry (B) exposures. SH1 and SH2, two Van Houten cycles in which division 2 is a microlaminated fish-bearing unit; T, *Turseodus*.

appropriate section. McIntosh and others (1985) show the presence of a polarity boundary in the same relative position in both the New Brunswick outcrops and in the Perkasie Member. One black shale is strongly radioactive, and it occurs in the same relative position as well. In their 1985 paper, however, McIntosh and others do not correlate this New Brunswick unit with the Perkasie, as suggested by West (1980). Rather than accept their own magnetic data, they correlated this New Brunswick unit with McLaughlin's Graters Member of the northwestern fault block. This produced a mismatched magnetic stratigraphy. Correlated as in figure 7, both the magnetostratigraphy and the cycle stratigraphy match precisely over 60 km and provide a test of the match of cycles between three fault blocks that was first suggested by the lithologic pattern and stratigraphic position alone (Olsen, 1984a). This correlation is also consistent with all paleontologic data.

An outcrop near Furmans Corner in the central fault block lies geographically between the New Bruns-

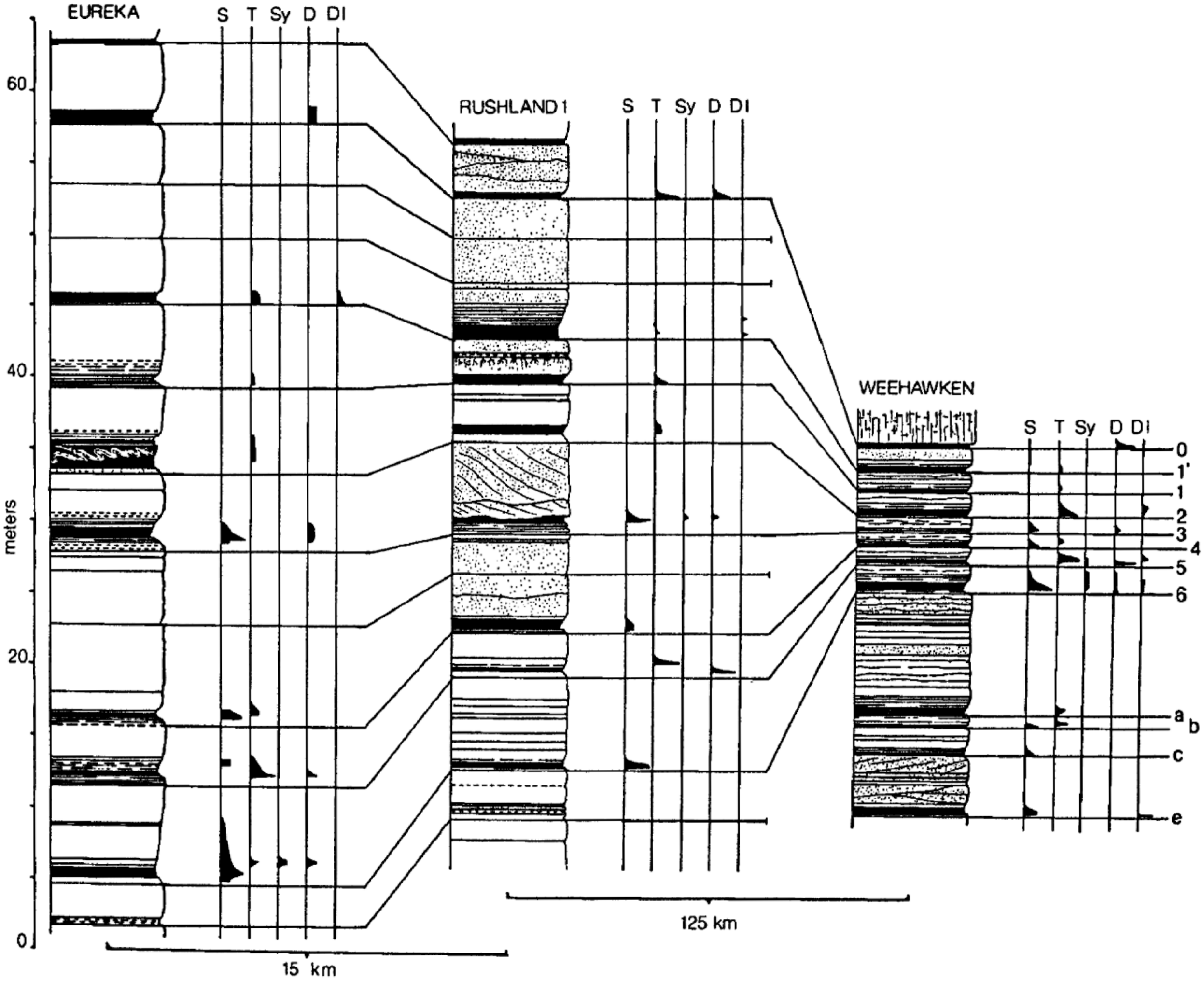


Figure 6. Correlation of Van Houten cycles, lower Lockatong Formation from Weehawken area across Newark basin. Cycle designations shown on right. Key to lithologic symbols in figure 5, and key to localities in figures 1 and 2. Abbreviations of vertebrate taxa are D, *Osteopleurus* (*Diplurus*) *newarki*; DI, large coelacanth; S, *Semionotus braunii*; T, *Turseodus*; Sy, *Synorichthys*.

wick, New Jersey, area and the northwestern fault block (fig. 7). This outcrop shows the same pattern of Van Houten cycles and higher order cycles as seen in outcrops of the Perkasie Member and its hypothesized correlative in the New Brunswick area. Correlation of this unit with the Perkasie can now be tested by looking for the magnetostratigraphic boundary present in the other areas.

EAST BERLIN FORMATION, HARTFORD BASIN

The pattern of Van Houten cycles and higher order cycles in the Jurassic strata interbedded and overlying the extrusive basalt in the Newark basin (Olsen, 1986; 1987, unpub. data) corresponds with a nearly identical homotaxial pattern of cycles in the Jurassic syn- and post-extrusive strata of the Hartford basin (Olsen and Fedosh, 1987, unpub. data). The East Berlin Formation (fig. 8) is the thicker and better exposed of the two syn-extrusive units in the Hartford basin.

Good outcrops of the East Berlin Formation occur in three areas in the Hartford basin (fig. 8). While no outcrops expose the entire formation, some do expose more than half the thickness, and it is possible to piece together adjacent outcrops and to build a local composite section by walking out single beds or matching beds over short, covered intervals. Analysis of the lateral continuity of cycles in the East Berlin Formation is aided by measuring down from the base of the Hampden Basalt and up from the top of the Holyoke Basalt (fig. 9).

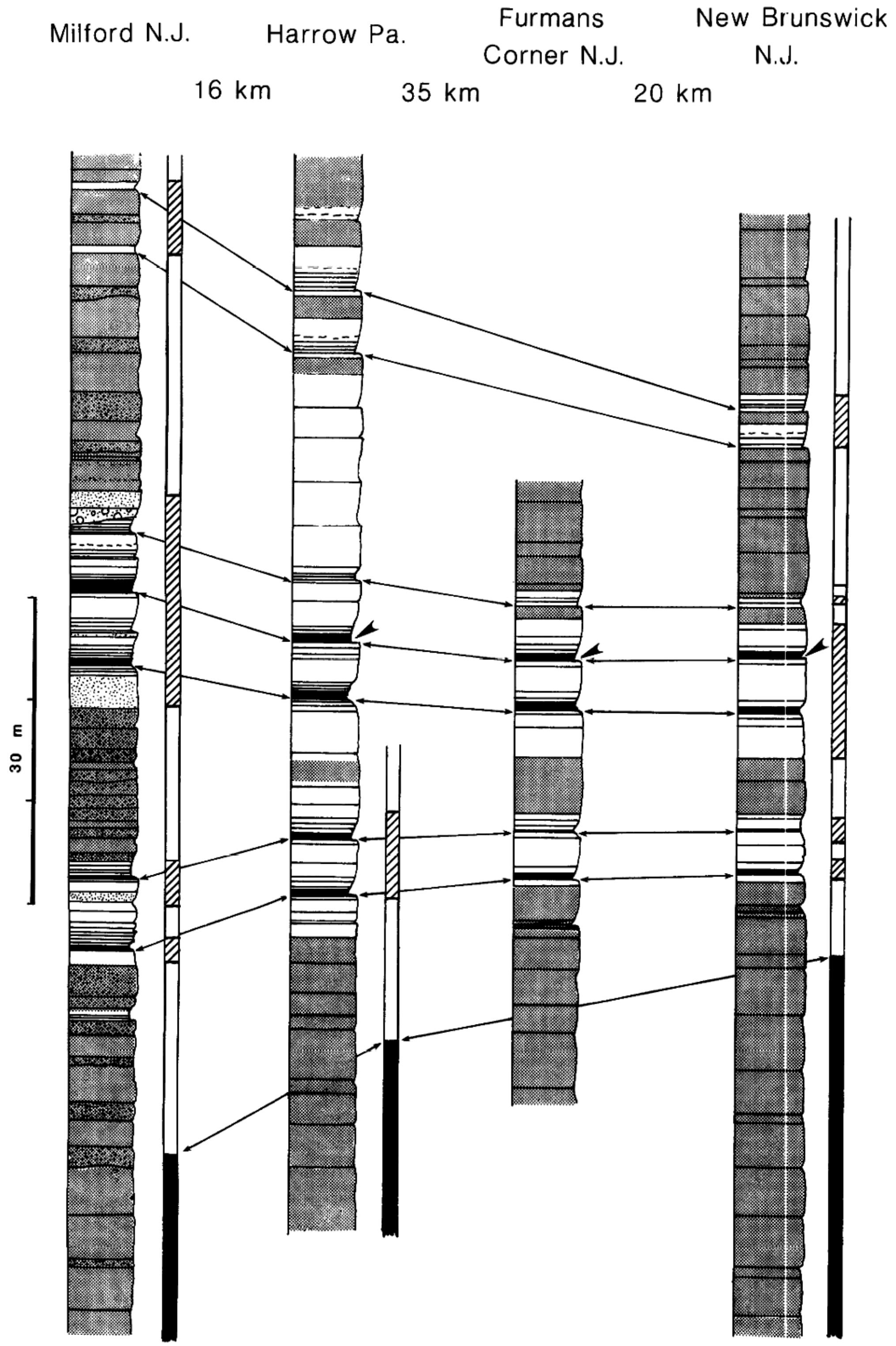


Figure 7. Lateral correlation of Perkasie Member of Passaic Formation across Newark basin and correlative magnetostratigraphy (magnetic polarity data from McIntosh and others, 1985; Hargraves, personal commun.). Vertical black, white, and diagonally ruled bars represent normal, reversed, and uncertain polarity zones, respectively. Large chevrons denote unusually radioactive zones. Key to lithologic symbols in figure 5.

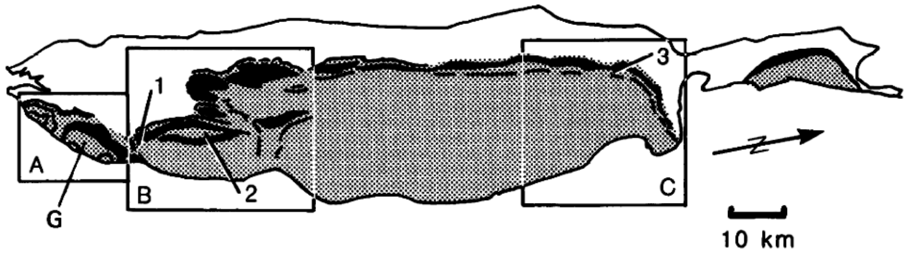
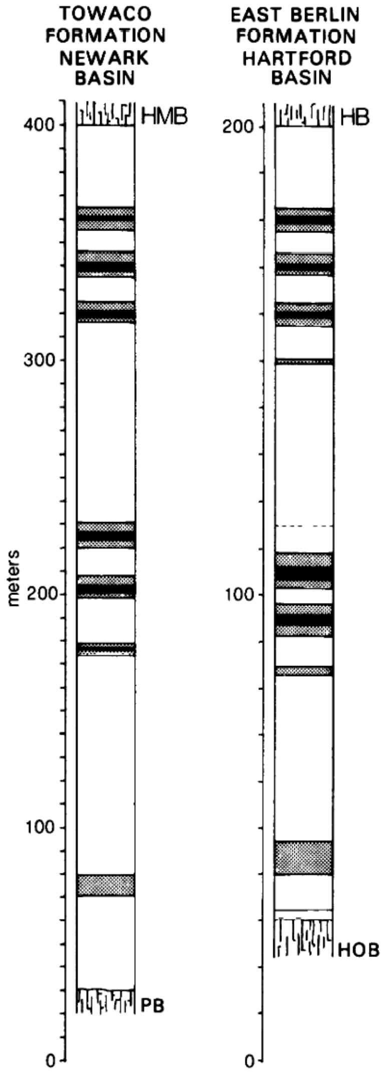


Figure 8. Map of the Hartford basin showing the main areas of exposure of the East Berlin Formation: A, southern area (Gaillard Syncline, labeled G); B, central area; C, northern area; 1, Parmele Brook exposures of Westfield Fish Bed, Durham, Connecticut; 2, Miner Brook exposures of Westfield Fish Bed, Westfield Connecticut (Route 72 exposures are about 3.5 km northeast of this locality); 3, Mount Tom Area, Northampton, Massachusetts. Gray and black areas are Jurassic sedimentary rocks and extrusive basalts, respectively.



◀**Figure 9.** Composite sections of Towaco Formation of Newark basin and East Berlin Formation of Hartford basin showing homotaxial sequences of Van Houten cycles. Compare to figure 4. Key to lithologic symbols in figure 10 caption. Abbreviations: HMB, Hook Mountain Basalt; HB, Hampden Basalt; PB, Preakness Basalt; and HOB, Holyoke Basalt.

Klein (1968) was first to recognize the cyclic nature of the East Berlin. Transgressive-regressive cycles in the upper part of the East Berlin Formation were described by Hubert and others (1976), who proposed that the cycles could be traced basinwide. Additional descriptions have been supplied by Demicco and Kordesch (1986). The East Berlin cycles are Van Houten cycles. As is typical of the Newark Jurassic, the East Berlin cycles are generally 2 to 5 times thicker than the Triassic cycles in the Newark basin.

A cluster of three Van Houten cycles, each bearing a black microlaminated division 2, occurs in good continuous outcrops at several localities in the central area of the Hartford basin and at one excellent exposure in the northern area (fig. 10) (Hubert and others, 1976). At the type section of the East Berlin Formation in the central area (Hubert and others, 1976), this cluster of cycles is underlain by about 45 m of red clastic strata (which in other areas show a vague cyclic pattern), which are in turn underlain by two Van Houten cycles, each having a microlaminated division 2 (fig. 11). These two cycles mark the middle of the East Berlin. Nearby, stream exposures show that the upper of these two Van Houten cycles is unique in the East Berlin by containing abundant whole fish (*Semionotus*, *Redfieldius*, and *Diplurus*) and abundant *Cornia*-type clam shrimp. This unit is traditionally termed the Westfield Fish Bed (Davis and Loper, 1898). Division 2 of the Westfield Fish Bed (figs. 11 and 12) has a distinctive graded bed interpreted as a lacustrine turbidite that, together with the microlaminae surrounding it, can be matched closely in outcrop over a distance of 18 km (fig. 12). The lower East Berlin

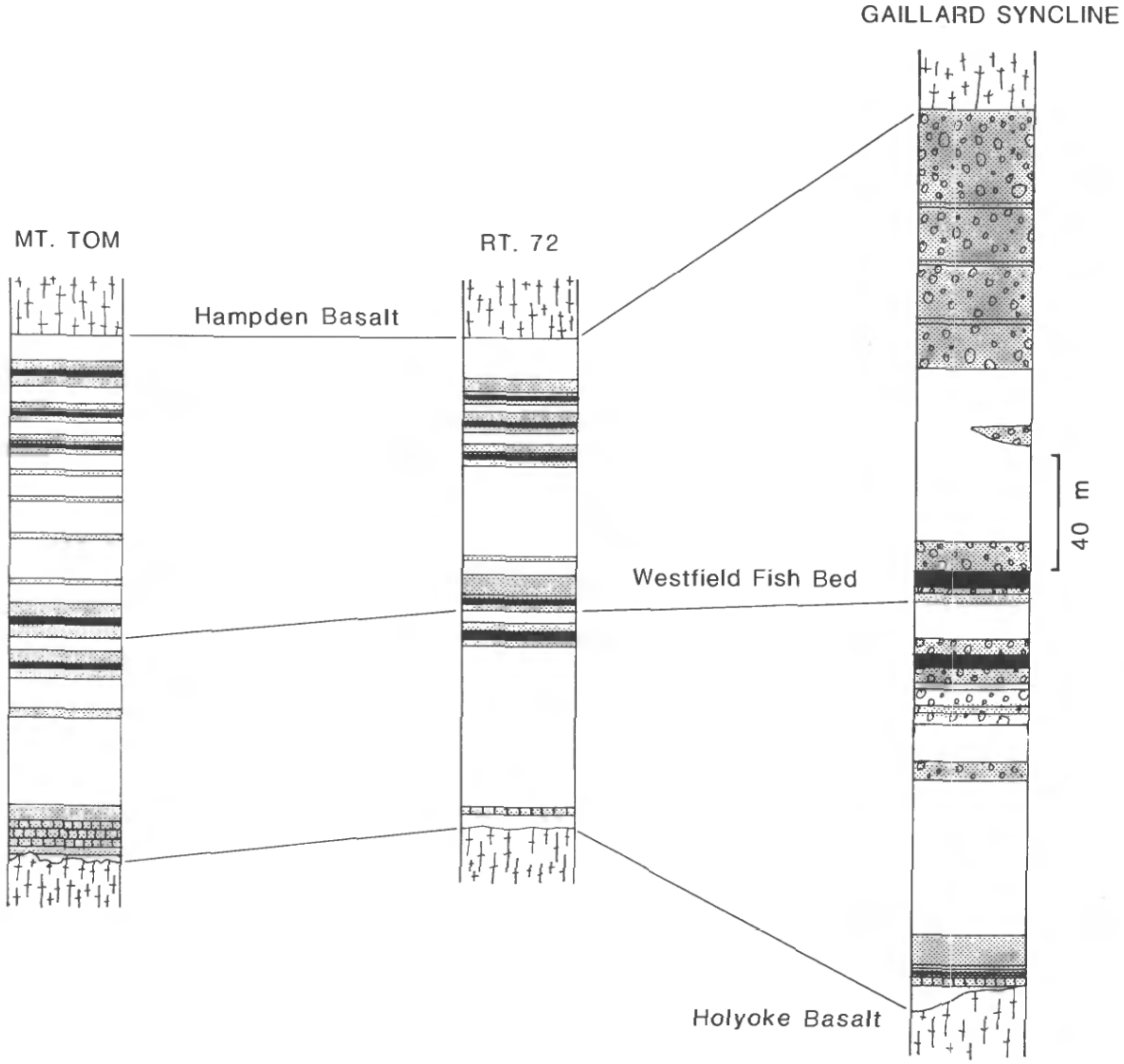
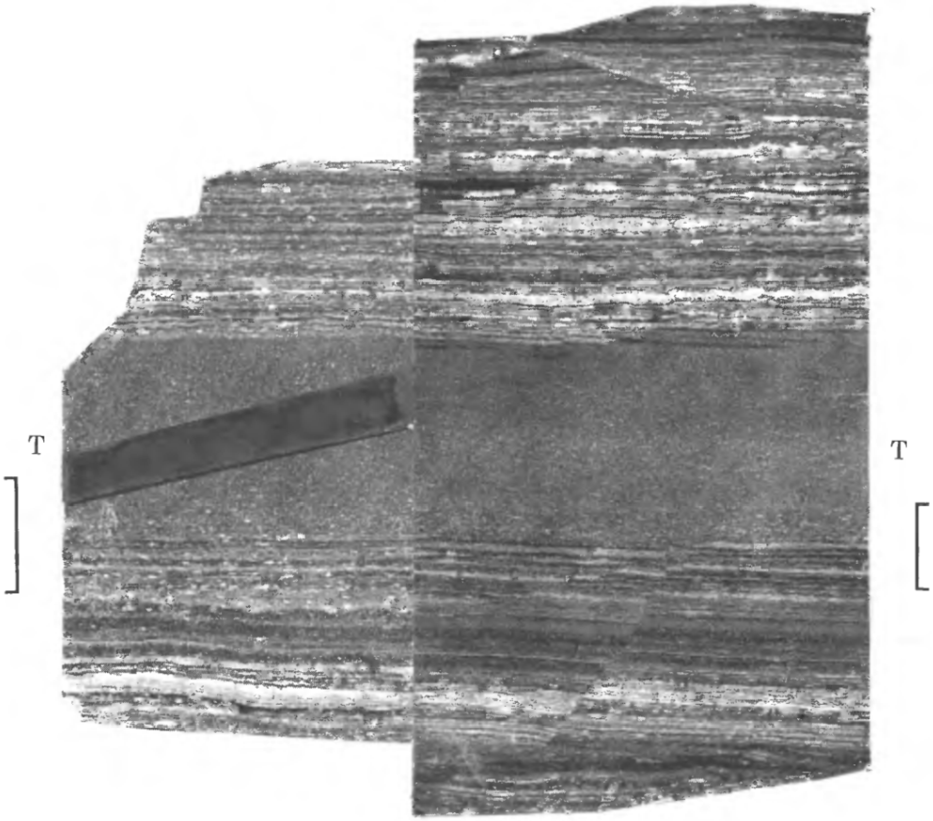


Figure 10. Correlation of Van Houten cycles of the East Berlin Formation from north (left) to south (right) across the Hartford basin. Lithologic symbols are: white, red clastics; black, microlaminated calcareous siltstone or limestone; gray, gray clastics; small circles, conglomerate; bricklike pattern, nonmicrolaminated limestone. Note that only Van Houten cycles having a black division 2 can be traced laterally with confidence.

Formation, in the central area, consists of a 60-m red clastic sequence underlain by a limestone-rich Van Houten cycle that lacks a black, microlaminated division 2. This limestone-rich cycle overlies a thin and variable sequence of red clastics overlying the Holyoke Basalt. These three clusters of Van Houten cycles define three second-order cycles, themselves demarcating three-quarters of a third-order cycle (fig. 10).

In the northern area (fig. 8), the uppermost three Van Houten cycles and their match to the cycles in the central area have already been described by Hubert and others (1976). The two middle Van Houten cycles also have counterparts in the northern region with the upper cycle matching the Westfield Fish Bed in faunal content and details of lithology (figs. 10 and 12). Likewise, the basal limestone-bearing cycle is very well developed, locally serving as a source of cement during the last century (Hitchcock, 1858).

In the southern area, the thickness of the East Berlin Formation is about double that in the central area, and the constituent Van Houten cycles are roughly twice as thick. The units that are believed to be correlated to the upper three cycles consist of gray shales surrounded by coarse conglomerate. The middle two cycles are exposed in a number of areas, and the upper of these contains a fauna characteristic of the Westfield Fish Bed.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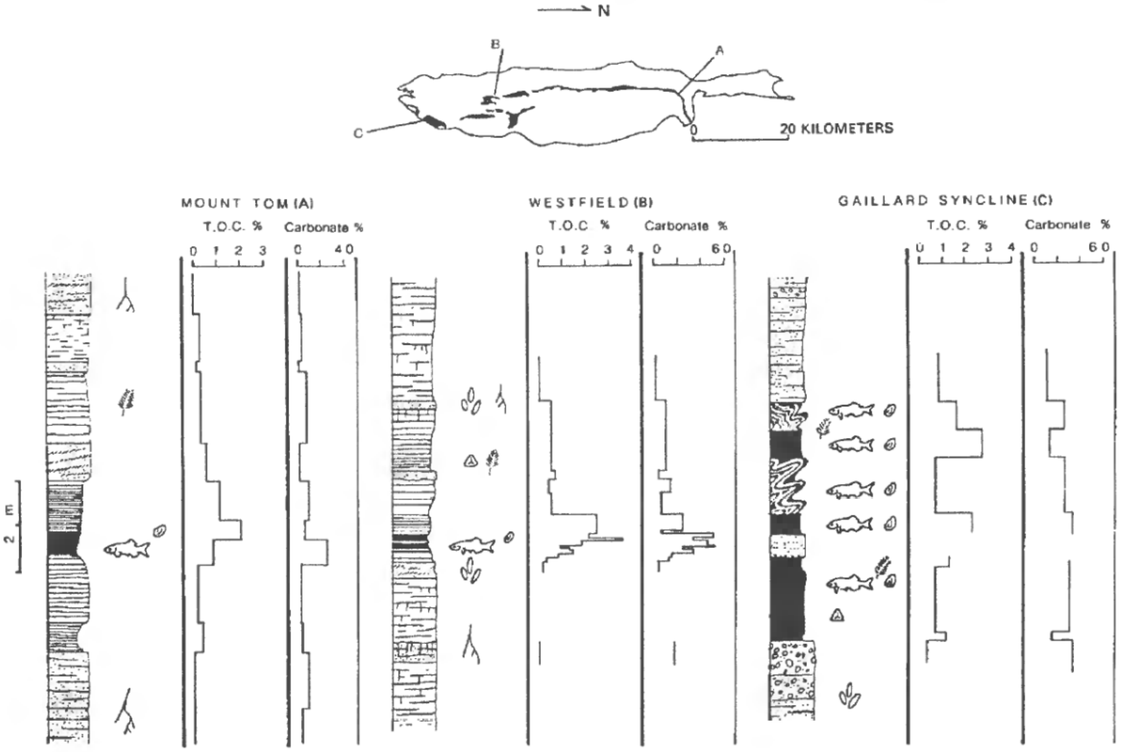
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◀**Figure 11.** Comparison of portion of microlaminated units from the Westfield Fish Bed from Stevens locality on Parmele Brook, Durham, Connecticut (right), and Westfield locality on Miner Brook, Westfield, Connecticut (left). T marks lacustrine turbidite. Scale bar is 1 cm; note difference in magnification. Black diagonal bar in turbidite on left reflects amount turbidite must be expanded in order for the microlaminae to match. This reflects a greater amount of thinning of the turbidite relative to the microlaminae over the same distance. Localities shown in figure 8.

The microlaminated unit is, however, over eight times as thick as in the more northern exposures (fig. 12). This local expression of the Westfield Fish Bed is the unit described by Thorpe (1929). The lowest limestone-dominated cycle is especially well exposed.

LATERAL CONTINUITY BETWEEN THE NEWARK AND HARTFORD BASINS

The remarkable match between the Van Houten cycles of the strata interbedded with the basalt flows of the Hartford and Newark basins does not necessarily imply former lateral continuity between the two basins as in the Broad Terrane Hypothesis of Russell (1880) and Sanders (1963). This is because the fish assemblages in homotaxial cycles are very different in the two basins (Olsen, 1983, 1984a). The lakes within the two basins were thus not connected, and the homotaxial Van Houten cycles could not have been physically continuous between the basins. This suggests a regional control of the cyclicity, such as periodic climate change, which has already been invoked as the cause of Van Houten cycles and the compound cycles (Van Houten, 1969; Olsen, 1984a,b; unpub. data, 1987), in accord with the orbital theory of climate change.

IMPLICATIONS

Understanding the lateral continuity of Van Houten cycles is vital to a number of major concepts including (1) the use of Van Houten cycles and compound cycles as time-stratigraphic markers for stratigraphic and structural studies (Olsen, 1985a), (2) the interpretation that these cycles represent basinwide lake-level cycles controlled by climatic cycles imposed by variations in the Earth's orbit, (3) the interpretations of the size and metabolism of Newark Supergroup lakes (Olsen, 1982, 1985b,c), and (4) the use of the Newark Supergroup as a standard for calibrating early Mesozoic time. Knowledge of the physical stratigraphy of the Newark sequences permits the development of higher order interpretations. No doubt, McLaughlin would have been pleased to see the developing connection between his two seemingly disparate areas of inquiry: physical stratigraphy and astronomy.

◀**Figure 12.** Comparison of sections of the Westfield Fish Bed from the three major exposures (fig. 10) (from Olsen, 1984a). Key to lithologic and paleontologic symbols in figure 5. Scale bar in map inset is 20 km; T.O.C., total organic carbon.

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