1-1-1985

The sedimentology, stratigraphy, and paleontology of the Lower Jurassic Portland Formation, Hartford Basin, central Connecticut

LeTourneau, Peter M.

McDonald, G. Nicholas

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Peter M. LeTourneau and Nicholas G. McDonald
Dept. of Earth and Environmental Sciences
Wesleyan University, Middletown, CT.

> "It is too generally a habit to think that while extraordinary examples of geological structure may be found in remote parts of the world they are not to be looked for at home, where familiarity with the hills and valleys brings them to be regarded as commonplace."
> - W.M. Davis, 1898, p. 25.

PART I.

Geologic Setting

In the Middle and Late Triassic, regional extensional stress associated with the incipient rifting of the North American and African plates created a series of half-graben and graben (the Newark Supergroup) along the eastern margin of the Appalachian orogen from Nova Scotia to South Carolina (Froelich and Olsen, 1984). The Hartford Basin, in central Connecticut and south-central Massachusetts, is approximately 140 km long and up to 30 km wide (Fig. 1). Basin subsidence began in mid-Norian and was primarily controlled by large, west-dipping, north-south-trending listric normal faults developed on the flanks of mantled gneiss domes of Devonian age (Olsen and others, 1982; Wise and Robinson, 1982). The greatest subsidence occurred on master faults located along the eastern edge of the basin. The western margin of the basin is delineated by minor normal faults, monoclinal flexures, and angular unconformities. Deposition in the resulting asymmetric trough was penecontemporaneous with subsidence, and for at least 25 million years the basin was filled with sediment derived primarily from the metamorphic and igneous terranes of the highlands to the east. Due to post-Jurassic uplift and erosion, the original extent and volume of the deposits in the Hartford Basin cannot be determined. As much as 7.5 km of Newark strata may remain in the north-central part of the basin (Burger and Ataman, 1984).

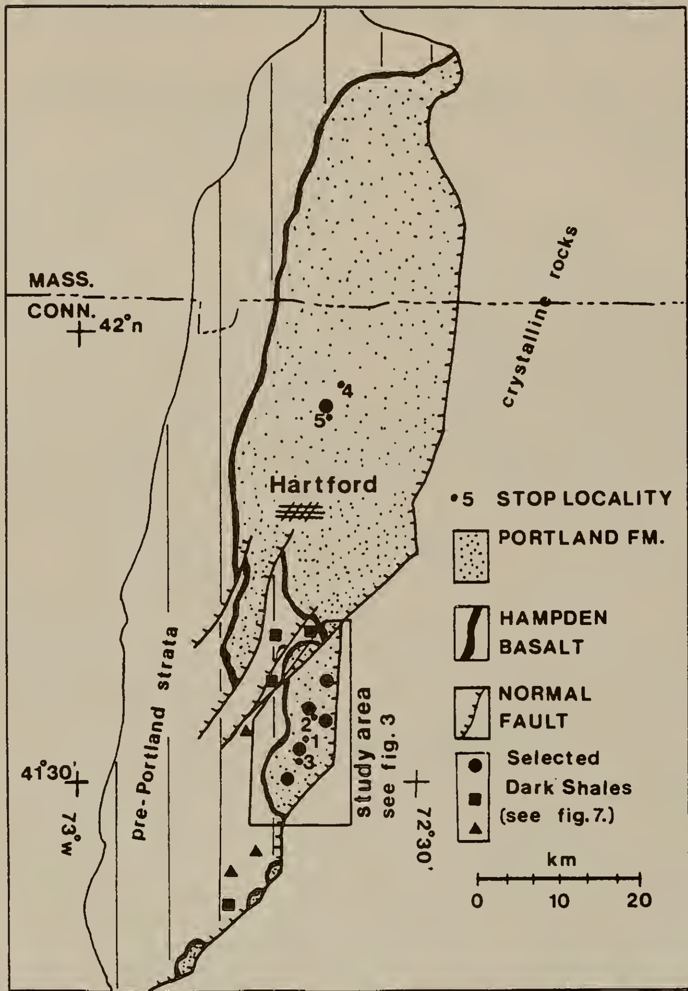

Figure 1. A simplified geologic map of the Hartford Basin.

Underlying magma sources were tapped intermittently during the infilling of the basin. Recently identified feeder dikes may have been the conduits through which tholeiitic lavas were extruded on to the basin floor during three separate intervals in the earliest Jurassic (Martello and others, 1984; Philpotts, 1985). The stratigraphy of the Hartford Basin consists of four sedimentary formations delineated by three interbedded, laterally-continuous basalt flow units (Table 1). This relatively simple stratigraphy is locally complicated by block faults, folds, and a lack of distinctive marker beds in the sedimentary rocks. All units in the Hartford Basin dip generally to the east and progressively younger rocks are exposed in a traverse from west to east across the basin.

	Stratigraphic Divisions	Estimated Thickness
	Portland Formation	450 - >2000m
	Hampden Basalt	60 - 100m
	East Berlin Formation	170m
	Holyoke Basalt	100 - 150m
	Shuttle Meadow Formation	100m
J	Talcott Basalt	65m
Tr	New Haven Formation	>2200m

Table 1.
Data from Cornet (1977), Hubert and others (1978), Olsen and others (1982).

The sedimentary rocks of the basin have been dated and correlated with the standard European stages by palynofloral comparisons supplemented by megafossil plant and vertebrate evidence (Cornet and others, 1973; Cornet and Traverse, 1975; Cornet, 1977; Olsen and others, 1982). Deposition of Portland sediments began in the late Hettangian and continued through the Toarcian, a span of at least 15 million years (Cornet and Traverse, 1975; Palmer, 1983). The Portland Formation contains the youngest rocks in the Hartford Basin and the uppermost Portland strata are the youngest of all Newark Supergroup deposits (Olsen and others, 1982).

The Portland Formation is exposed in a belt that widens from 1/3 to fully 2/3 of the width of the basin from central Connecticut north to the Holyoke Range in Massachusetts; the Formation is largely faulted out in southern Connecticut. The Portland varies in thickness and ranges from as little as 450 m in southern Connecticut to perhaps as much as 4000 m in southern Massachusetts (Cornet, 1977).

The Portland Formation was named by Krynine (1950) for the spectacular exposures of medium to coarse sandstone in the old quarries at Portland, Connecticut, but these red-brown, planar- and cross-stratified sandstones comprise no more than half of the Formation as a whole. Extreme lateral and vertical variations are characteristic of the Portland and the rocks become progressively finer-grained from east to west across the basin. The coarsest rocks, including polymictic boulder and cobble conglomerate and pebbly sandstone, are found along the eastern margin of the basin. As much as 30% of the Formation consists of red, red-brown, grey, and black siltstone and shale (Krynine, 1950), primarily in the central and western portions of the outcrop area. Asymmetrical and symmetrical dark shale cycles, similar to those described from the East Berlin Formation (Hubert and others, 1976) are common in the lower half of the Portland. These dark shale units are of paleontological importance and may prove to be of economic value as hydrocarbon source beds.

During the long interval of Portland sedimentation, southern New England was situated in the sub-tropics, 15°- 20° north of the paleoequator (Olsen, 1984). The lateral and vertical distribution and variable character of the rocks and fossils of the Portland Formation suggest that the Early Jurassic climate was seasonal and characterized by varied-length oscillations between humid and semi-arid conditions (Hubert and others, 1982; Thomson, 1983). Perennial and ephemeral streams flowed generally westward across the eastern and central parts of the basin. Along the eastern margin, alluvial fan complexes were deposited against active fault escarpments. The basin floor contained braided and meandering stream channels and broad, fine-grained floodplains. During dry intervals, the basin floor was occupied by ephemeral lakes and playas. However, at times of increased rainfall, large, perennial, stratified lakes became established in the basin and encroached on the eastern margin to form transgressive depositional sequences over the distal portions of alluvial fans. Several lacustrine shoreline deposits have been recognized within 0.75 km of the basin margin in central Connecticut.

Facies and Facies Distribution

The sedimentary rocks can be divided into four general facies and eight numbered sub-facies that define distinct depositional sequences. The facies divisions are based primarily on grain size, e.g., maximum clast size in the conglomerate units, or sandstone/siltstone ratios in the fine-grained units. Diagnostic fossils also assist in the recognition of facies, particularly in the fine-grained units. Facies are mappable units at a 1:24,000 scale. Sub-facies divisions are based on sedimentary structures, grain size, sorting, color, nature of bedding and stratification, and other characteristics. A summary table of facies and sub-facies defined within the Portland Formation follows. The colors of the rocks are various shades of red, red-brown, or brown unless otherwise specified.

FACIES	SUB-FACIES	DESCRIPTION	DIAGNOSTIC FOSSILS	DEPOSITIONAL ENVIRONMENT		
Conglomerate	1	matrix-supported, poorly-sorted boulder and cobble conglomerate	N/A	debris flow	Alluvial Fan	upper to mid fan
	2	poorly-stratified, clast-supported conglomerate and pebbly sandstone	N/A	shallow braided stream (ephemeral)		
	3	cross-stratified conglomerate and pebbly sandstone	scarce reptile bones	braided stream (possibly perennial)		mid to lower fan
Sandstone	4	planar-laminated and ripple cross-laminated silty fine sandstone	scarce invertebrate burrows	sheetflow		distal fan
	5	planar- and cross-stratified medium to coarse sandstone with thin, interbedded siltstone	invertebrate burrows, plants, reptile tracks, scarce reptile bones	braided and meandering stream and floodplain	Basin Floor	along the eastern half of the basin
Siltstone	6	thin-bedded siltstone with mudcracks and medium to coarse sandstone lenses and layers	reptile tracks, invertebrate trace fossils, ostracodes, conchostracans, plants	floodplain with shallow stream and crevasse-splay sandstone		primarily in the central portions of the basin
Dark Shale	7	grey, well-sorted, ripple cross-laminated sandstone and siltstone	abundant plants, unionid mollusks, reptile tracks, conchostracans, ostracodes, pollen /spores, invertebrate burrows	shallow water at or near wave base and shoreline	Perennial Lake	lake margin and shoreline
	8	dark grey to black siltstone and finely-laminated shale	abundant fishes, coprolites, conchostracans, abundant plants	below wave base in quiet, oxygen-poor water		deep lake water and lake bottom

Table 2. Summary of Portland Formation facies and inferred depositional environments.

The distribution of facies in the Portland Formation is shown in Figure 2. All units dip to the east and consequently both the lateral and vertical distribution of the facies is illustrated. The Conglomerate Facies of the Portland Formation is limited to the eastern margin of the basin. The Sandstone Facies of the Portland is generally restricted to the eastern half of the outcrop area, but also occurs in a narrow, north-south-oriented belt overlying the Hampden Basalt, particularly in northern Connecticut. The Siltstone Facies occupies a broad belt along the central axis of the basin and limited areas along the eastern margin. The Dark Shale Facies is intercalated with the coarser Sandstone and Conglomerate Facies in central Connecticut, but in northern Connecticut and Massachusetts, the dark shale units are almost exclusively associated with the finer Sandstone and Siltstone Facies.

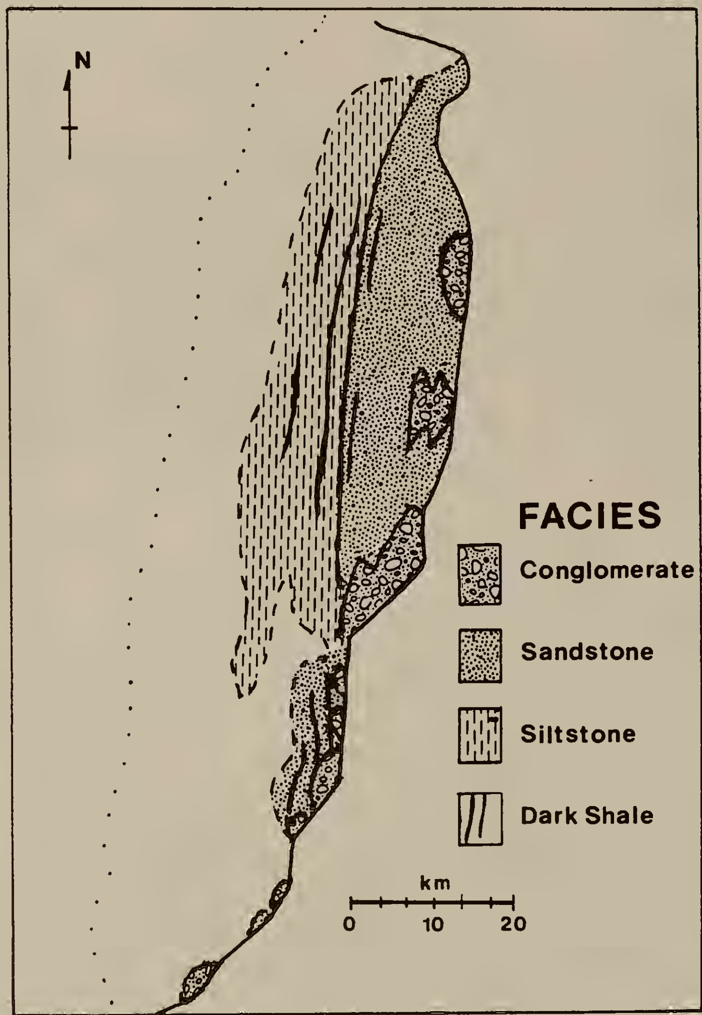

Figure 2. Distribution of Portland facies in the Hartford Basin. (Dark Shale not to scale and locations approximate).

Alluvial Fan Deposits: The Basin Margin

> "...on the very margin of the valley, we find a coarse conglomerate in a few places, of quite peculiar character... The fragments are sometimes several feet in diameter, and the stratification of the rock is very obscure."
>
> – E. Hitchcock, 1858, p. 11.

The best exposures of the coarse strata of the Conglomerate Facies are located along the basin margin in Durham, Middletown, and Portland, Connecticut. Over 700 m of measured section was compiled at Round Hill (Middletown) and Crow Hill (Portland) to understand the stratigraphic succession and depositional history of the coarse-grained units (Fig. 3). Preliminary results of investigations in this detailed study area have been previously discussed in LeTourneau and Horne (1984), LeTourneau and Smoot (1985), and LeTourneau (1985a, 1985b, 1985c).

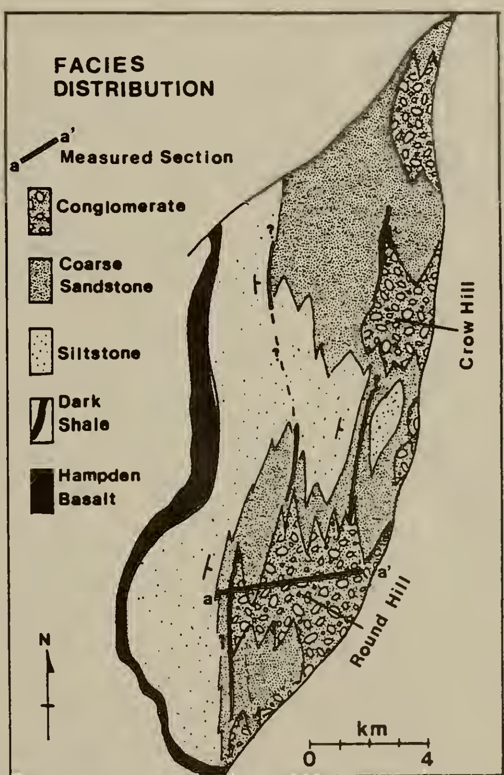

Figure 3. Facies distribution in the detailed study area, central Connecticut (see Fig. 1).

The texture, fabric, sedimentary structures, clast-size distribution, bedding geometry, and sediment dispersal patterns of the rocks of sub-facies 1 - 4 are characteristic of alluvial fan deposits. These coarse-grained sedimentary rocks form wedge- or prism-shaped bodies that thin and fine away from the basin margin (Fig. 3).

A map of the maximum clast-size distribution (Fig. 4a) demonstrates that the conglomerate grain size decreases rapidly over a distance of 2 - 3 km from the basin edge and that the coarsest units outline discrete lobate areas. The paleocurrent patterns at Round Hill and Crow Hill (Fig. 4b) radiate out from the central parts of the conglomerate lobes. The sediment dispersal patterns and the composition of the conglomerate clasts indicate that the source area for the alluvial fan sediments was in the Paleozoic crystallines east of the present basin margin.

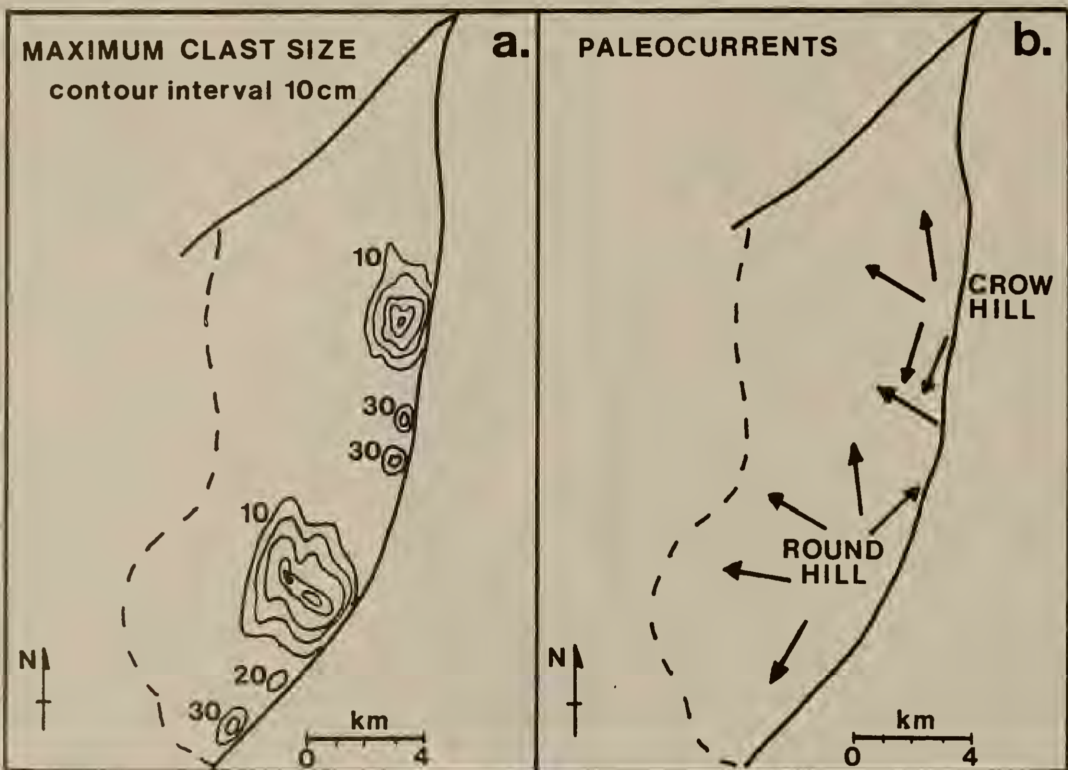

Figure 4. (a.) Maximum clast size distribution and (b.) paleocurrent patterns in the detailed study area.

Deposition on alluvial fans is by stream flow or debris flow processes which represent end members of a continuum of increasing flow viscosities beginning with clear water. Fluvial discharge across an alluvial fan forms shallow, temporary, braided streams that become more disperse in a down-fan direction. These braided streams shift back and forth on the fan surface as sediment accumulates in the stream bed. Very broad, shallow, essentially unconfined stream flows in the lower reaches of an alluvial fan are termed sheetflows.

Debris flows are highly viscous slurries of unsorted coarse sediment supported in a fine-grained matrix. Because of the high matrix strength and the non-turbulent internal flow, very large boulders and cobbles are commonly rafted on the surface or carried within the debris flow. Debris flows are the major process which transports large clasts to the mid-fan and lower-fan areas.

The poorly-sorted boulder and cobble beds of Sub-facies 1 compare most favorably with descriptions of modern and ancient debris flow deposits (Nilsen, 1982; Wasson, 1977). Diagnostic features include: random or chaotic orientation of clasts in a mud-rich matrix, concentration of the largest clasts near the upper and outer contacts of the deposit, hummocky and irregular upper contacts, planar and distinct lower contacts, and an absence of cross-bedding or stratification within the deposit. These debris flow units form distinct layers or lenses surrounded by pebbly sandstone and conglomerate of Sub-facies 2.

Sub-facies 2 consists of thin bedded, poorly-stratified conglomerate and pebbly sandstone in normal-graded and laterally-discontinuous lenses. These beds are interpreted as ephemeral braided stream deposits from the mid-fan area. The predominately fining-up depositional units suggest decelerating flow events terminating with the deposition of fine sand and silt during the waning stages of flow. Most of the fine drapes forming the upper contacts of individual units have dessication features (mudcracks and mudcurls), which strongly implies that flow events were punctuated by periods of non-deposition and subaerial exposure. Cross-bedding is generally rare in this sub-facies. Horizontal- and inclined-planar stratification is the most common internal structure in these units. The fine-grained upper contacts are planar-laminated to ripple cross-laminated.

Sub-facies 3 is characterized by trough and planar cross-stratified conglomerate and pebbly sandstone. Cross-bed sets average 0.2 - 0.3 m thick and reach a maximum of 1.5 m. Imbricate pebbles define the lower contacts and the foresets of the conglomerate and pebbly sandstone units. Typically, the upper and lower contacts are discontinuous and the lens-like, cross-stratified units interfinger within larger meter-scale beds. Pebbles and cobbles are dispersed in the coarse sand and granule matrix or rarely occur in discrete lenses or layers.

The conglomerate and sandstone units of Sub-facies 3 are interpreted as deposits of moderately deep, possibly perennial, braided streams. This interpretation is based on the occurrence of sedimentary features indicative of persistent stream flow: abundant, well-developed, large-scale cross-stratification, moderate sorting, the absence of dessication features, and a fairly uniform style of stratification and bedding. The lack of large boulders (such as those found in Sub-facies 1 and 2) suggests that the streams were not competent enough to transport very large clasts or that debris flows were not associated with this sub-facies. When traced in a basinward direction, this sub-facies is laterally adjacent to, and in part correlative with, the Dark Shale Facies.

Sub-facies 4 is composed of thin, planar-laminated and ripple cross-laminated, poorly-sorted, micaceous, silty fine sandstone. This lithology characteristically contains a high percentage of carbonate cement and pore fillings. Granule interbeds are common.

Sub-facies 4 includes the finest-grained alluvial fan sediments which are, in part, transitional between the lower fan and basin floor depositional environments. These units can be traced for hundreds of meters or more and provide easily-identified, laterally-correlative horizons within the coarse sandstone and conglomerate units. Laterally, this sub-facies thins and pinches out against coarser units. In a basinward direction, it thickens and becomes gradational with thin-bedded siltstone.

The rocks of Sub-facies 4 are sheetflow deposits formed by shallow, unconfined flow on sandflats at the distal portions of alluvial fans. This unit is typically found downsection from the rocks of Sub-facies 1 and 2. This relationship is repeated through the vertical section at Round Hill; the predominately coarsening-up depositional sequences delineate successive progradational alluvial fan cycles. The fine-grained rocks of Sub-facies 4 provide convenient marker units that define the base of individual cycles.

Figure 5 is a paleoenvironmental reconstruction of the detailed study area in central Connecticut showing the location of alluvial fans and a perennial lake (see discussion below) in the Early Jurassic. Alluvial fan locations are based on the geometry and distribution of the coarse-grained units (Fig. 3), particularly Sub-facies 1 - 4, discussed above. The maximum clast-size distribution (Fig. 4a) and the radial paleocurrent patterns at Crow Hill and Round Hill (Fig. 4b) define discrete alluvial fans along the eastern margin of the basin. The location of the hypothesized lake is based on several well-exposed lacustrine cycles that are interbedded with the alluvial fan deposits, for example, at Laurel Brook in Middletown (Stop 3).

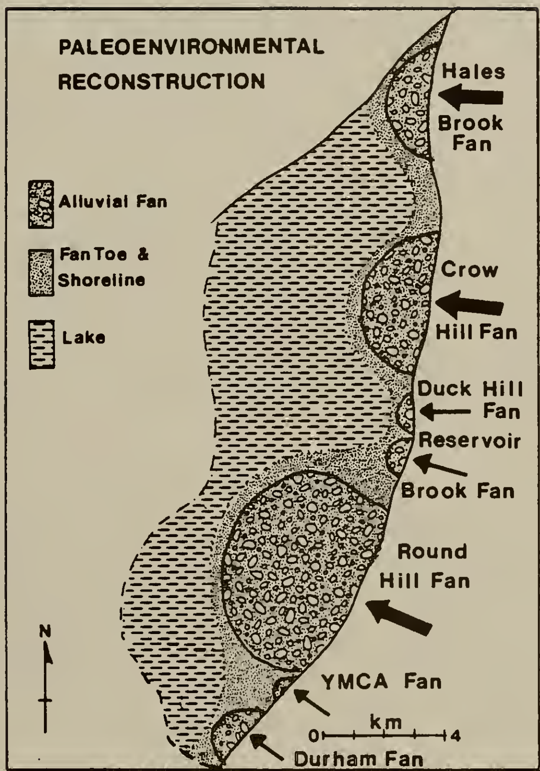

Figure 5. Paleoenvironmental reconstruction of the detailed study area during a period of maximum lake expansion.

Braided and Meandering Streams and Floodplains: The Basin Floor

The medium to coarse sandstone, siltstone, and minor shale of Sub-facies 5 and 6 dominate the sedimentary section along the central axis of the Hartford Basin and comprise well over half of the Portland Formation as a whole. Sub-facies 5 is primarily found east of the central axis of the basin. Sub-facies 6 is generally confined to the western side of the basin in central and northern Connecticut and southern Massachusetts (see Figure 2).

Sub-facies 5 consists of cross-stratified, coarse and pebbly sandstone with intercalated, laminated and thin-bedded, burrowed and mudcracked siltstone. The coarse sandstone forms the thickest units, ranging from 0.2 to 1.0 m thick. Bedding consists of horizontal- and inclined-planar stratification and tabular and trough cross-stratification. Pebbles comprise less than 10% of the coarse fraction and rarely exceed 6 cm in diameter. The lower contacts are scoured into the underlying siltstone or sandstone and contain abundant mud rip-up clasts. The upper contacts are planar to undulatory and are delineated by sharp changes in grain size.

In Sub-facies 5, the coarse sandstone layers or lenticular beds are separated by micaceous, planar-laminated and ripple cross-laminated maroon, red, or red-brown siltstone. The siltstone beds range from 0.1 to 0.5 m thick and may be laterally continuous or pinch out over several meters. Distinctive characteristics of the siltstone units are the ubiquitous dessication cracks and abundant trace fossils, including invertebrate burrows and reptile tracks.

Sub-facies 6 is closely related to Sub-facies 5; these two divisions represent end members of varied sandstone/siltstone ratios for the fluvial basin floor deposits. Sub-facies 6 is composed largely of massive to thin-bedded red and brown siltstone with interbedded thin lenses and layers of medium to coarse sandstone. Internal structures in the siltstone include horizontal and wavy lamination, ripple and climbing-ripple cross-lamination, and minor oscillatory ripple cross-lamination. Mudcracks and soft sediment deformation features, including load casts and pseudonodules, are abundant. The suite of trace fossils found in the siltstone is similar to that described from the fine-grained units of Sub-facies 5. Orange-brown dolomitic concretions up to 15 cm in diameter are very common in some of the laminated siltstone units, particularly in exposures along the central axis of the basin. Evaporite mineral casts (halite and gypsum) have also been identified in this sub-facies.

The thin sandstone lenses and layers average 0.2 m thick and typically have scoured and irregular lower contacts and planar to undulatory upper contacts. Planar and trough cross-stratification is well developed and mud rip-up clasts are very abundant along the lower contacts and cross-bed foresets.

Sub-facies 5 and 6 formed in braided and meandering stream and floodplain depositional environments in the central portions of the Hartford Basin. The location of the sand-dominated units of Sub-facies 5 may indicate the relative positions of the stream channel networks at various stratigraphic levels. Channels became incised into the finer-grained deposits and as the streams scoured the substrate and migrated laterally across the surrounding broad floodplains, the cohesive silt and clay was incorporated into the cross-stratified stream channel sands as mud rip-up clasts. At the K-F Quarry (Stop 4), an illustration of the meandering nature of the broad, shallow stream channels in the central part of the basin is provided by abundant, well-exposed lateral accretion barforms or point bars that define the edges of the 0.5 to 1.5 m thick sandstone lenses. Along the eastern side of the basin, trough cross-bedded, coarse and pebbly sandstone units are the typical braided stream deposits.

The siltstone units of Sub-facies 5 and 6 are fine-grained floodplain deposits. Sedimentary features in the siltstone are indicative of periods of rapid sedimentation alternating with prolonged episodes of subaerial exposure and dessication. When streams overtopped the shallow channels, sand and silt were deposited on the broad floodplains in climbing ripples and as planar-stratified sheets, and bioturbating organisms worked through the fine-grained, water-saturated substrate. Some of the thin sandstone lenses and sheets may be crevasse-splay deposits formed adjacent to the main stream channel networks during high discharge conditions. Shallow floodplain lakes and oxbow lakes formed as a result of channel meandering, by periodic inundation of the floodplains, and because of the shallow water table in the low-gradient basin floor.

During drier conditions, stream-flow was confined to the sand-filled channels and the floodplains developed extensive dessication surfaces. Standing water in shallow pools and ponds formed playas, as evidenced by the extensively mudcracked and mechanically-disrupted mudstone and siltstone fabrics. The evaporative concentration of surface and ground waters produced carbonate (including ferroan dolomite) nodules and irregular layers and, less frequently, evaporite minerals, including halite (Parnell, 1983) and gypsum (Krynine, 1950).

Lacustrine Deposits

> "Now it is in the shales and sandstones...that we find organic remains - the fishes, the tracks, and the plants."
>
> \- E. Hitchcock, 1858, p. 11.

The sedimentary structures, sorting, bedding thickness and geometry, and fossils of the grey sandstone, grey siltstone, and black shale of the Dark Shale Facies are analogous to features of both modern and ancient lacustrine deposits (Link and Osborne, 1978; Hardie and others, 1978).

The grain size of the siltstone, sandstone, and minor conglomerate of Sub-facies 7 correlates with the offshore - onshore relationships in an inferred lake margin depositional environment. Grey, ripple-laminated and wavy-bedded siltstone units were deposited at or below wave base in the sub-littoral zone. The intercalation of laminated silt and clay and thin, fine sand layers is indicative of the variable energy conditions that existed between the nearshore and deeper water environments.

The grey sandstone units contain a wide variety of wave-generated sedimentary structures. Oscillatory ripples are the most common sedimentary structure observed in this unit; some of the ripples have sheared crests suggesting that they were planed by turbulence from shoaling waves. Planar-stratified and tabular cross-stratified low-angle accretionary sandstone lenses were deposited as nearshore bars in the littoral zone and as linear beach ridges in the swash zone. These sandstone units are very well sorted, indicating a high degree of reworking and winnowing by waves. Fragmental plant material is very abundant and reflects the proximity of heavily-vegetated areas to the lake margin. Beds containing plant fossil layers suggest that detrital plant material may have formed floating and/or submerged masses near shore.

The sandstone beds become coarser and more conglomeratic onshore. Often, large boulders or cobbles are found as isolated clasts in the wave-rippled, well-sorted sandstone units. Large-scale, tabular cross-stratification in the coarse sandstone and minor conglomerate was formed in beach ridges built by wave reworking of alluvial fan sediment (LeTourneau and Smoot, 1985).

Sub-facies 8 is composed of thin-bedded, laminated and microlaminated black shale deposited under reducing conditions in periodically or permanently stratified lake waters (Sanders, 1968; McDonald, 1982). The fine laminations in the black shale indicate that bioturbating organisms were excluded from the substrate. Anoxic bottom conditions probably resulted from the thermal or chemical stratification of the lake waters. Many of the black shale units of the Portland Formation can be classified as oil shales because of the high percentage of kerogenous organic matter (Robbins and others, 1979). Abundant fossil fishes (semionotids and redfieldiids) characterize several of the black shale deposits; the excellent preservation of these fossils confirms the absence of scavenging benthos.

The finely-laminated nature of the black shale indicates deposition below wave base, but the size and depth of the lakes is uncertain. Anoxic or reducing conditions may form in shallow, eutrophic ponds or lakes, as well as in deep, stratified bodies of water. The thickness of the black shale units does not provide a measure of the depth of the ancient lakes of the Portland Formation, but only an indication of the temporal persistence of a particular depositional environment. In all probability, Portland lakes varied widely in size and depth, from ephemeral pools and playas to deep, stratified lakes hundreds of square kilometers in area.

Along the eastern edge of the basin, the lake and lake-margin deposits (Sub-facies 7 and 8) are intercalated with coarse-grained, stream-flow-dominated alluvial fan deposits (Sub-facies 3). Here, the thickest and best exposed transgressive and regressive shoreline sequences are located (Stop 3). The distribution of the Dark Shale Facies rocks (as shown in Figures 2 and 3) suggests that, at times, the ancient lakes drowned the distal margins of the alluvial fans (Fig. 5).

In contrast, the lake and lake-margin deposits identified in north-central Connecticut (Stop 5) are interbedded with finer-grained, carbonate-rich clastic rocks and form fluvial-deltaic sequences in the central and western portions of the basin.

A Depositional Model for the Portland Formation

The combined influence of climate and tectonics on sedimentation in the Portland Formation can be interpreted from the lateral and vertical distribution of the sub-facies described above, the geometry of the various depositional units, and the sedimentary features of the different rock types.

The Climate Hypothesis

Two sub-facies assemblages have been recognized in central Connecticut. One sub-facies assemblage (Fig. 6a) is composed of Sub-facies 1, 2, 4, 5, and 6, which formed in alluvial fan and basin floor environments. Sedimentary features in this assemblage are evidence of ephemeral fluvial activity. The presence of debris flow deposits, abundant mudcracks and other dessication features may indicate that this assemblage was deposited during a "dry" phase of sedimentation, probably under arid to semi-arid climatic conditions.

The optimum conditions for the formation of debris flows are arid and semi-arid climates with less than 500 mm/yr of strongly seasonal rainfall (Blissenbach, 1954; Lustig, 1965). The preservation potential of debris flows on alluvial fans is highest in drier climates because low volume, low frequency stream flows often cannot rework the coarse-grained debris flow lobes on the fan surface. Because of these relationships, debris flows in ancient alluvial fans may be reliable paleoclimatic indicators.

Further evidence of "dry" depositional conditions in the Portland Formation is found in the fine-grained rocks of the central and western portions of the basin. Emerson (1917) and Parnell (1983) describe halite hopper-crystal casts in the Portland strata along the Connecticut and Chicopee Rivers in Massachusetts. Saline brines capable of precipitating halite and gypsum are easily formed by the evaporation of standing bodies of water in an arid or semi-arid environment. Gilchrist (1979) identified caliche paleosol horizons in the Portland Formation in north-central Connecticut. Caliche formation is dependent on evaporative concentration of alkaline ground water in the vadose zone; its occurrence implies semi-aridity and seasonal precipitation (Leeder, 1975; Hubert and others, 1978).

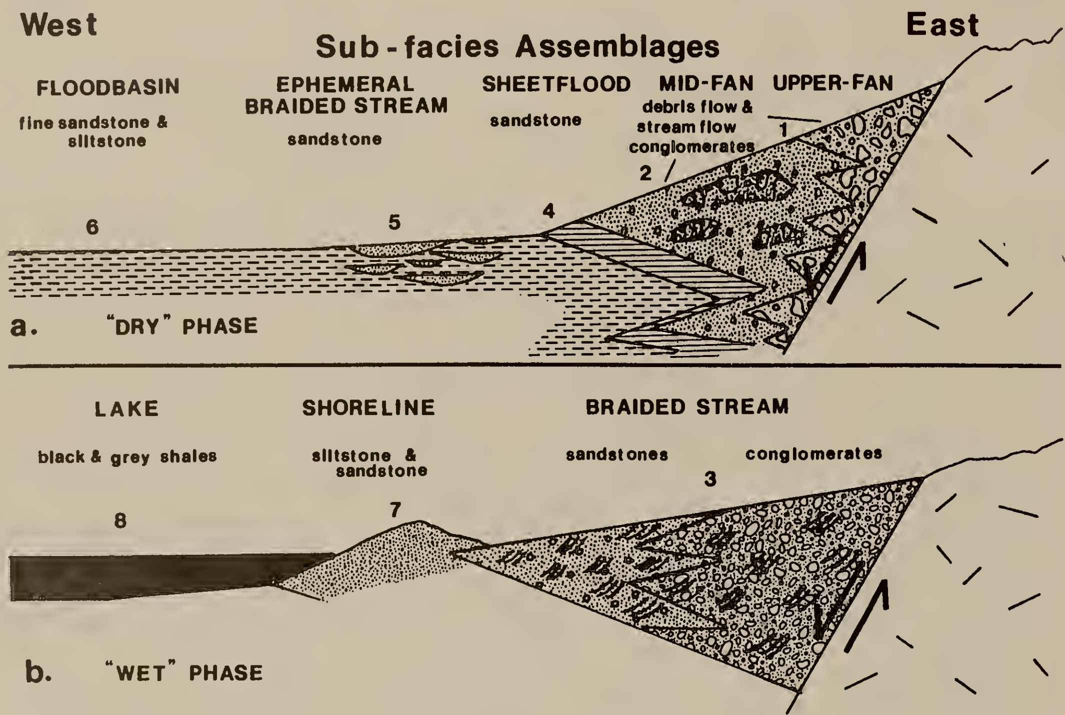

Figure 6. Sub-facies assemblages indicative of (a.) "dry" and (b.) "wet" phases of deposition.

The second assemblage (Fig. 6b) is composed of Sub-facies 3, 7 and 8, which represent: 3) proximal and distal braided stream deposits near the basin margin, 7) lake shoreline and littoral sediments, and 8) the profundal muds of a perennial lake. The laminated black shale (8) and grey sandstone (7) correlate laterally with the cross-bedded sandstone and conglomerate of Sub-facies 3. This assemblage is also found in vertical succession (for example, at Laurel Brook - Stop 3) in the following ascending sequence: 3-7-8-7-3, which represents a single transgressive - regressive lake cycle. This sub-facies assemblage may indicate a "wet" phase of sedimentation, the result of high fluvial discharge under humid climatic conditions. In the central and western portions of the basin, more humid climatic conditions are represented by an assemblage containing Sub-facies 5, 7, and 8.

Along the eastern border of the basin, alternating wet-dry-wet-dry-wet depositional cycles are documented through 700 m of measured section, beginning at Laurel Brook - "wet"

(Stop 3), and continuing through Coleman Road - "dry" (Stop 1) toward the eastern border fault.

The alternation of lacustrine strata with fluvial strata containing caliche, evaporite mineral casts, carbonate nodules, and dessication features provides convincing evidence for wet and dry depositional cycles during much of Portland time. Van Houten (1964) and Olsen (1984) described similar climatic cycles from the Triassic Lockatong Formation in the Newark Basin. Hubert and others (1982) and Gierlowski-Kordesch (1985) recognized cyclic depositional sequences in the Jurassic East Berlin Formation in central Connecticut.

The Tectonic Hypothesis

Several lines of evidence support the conclusion that syndepositional tectonic subsidence also controlled the style of sedimentation and the distribution of facies in the Portland Formation.

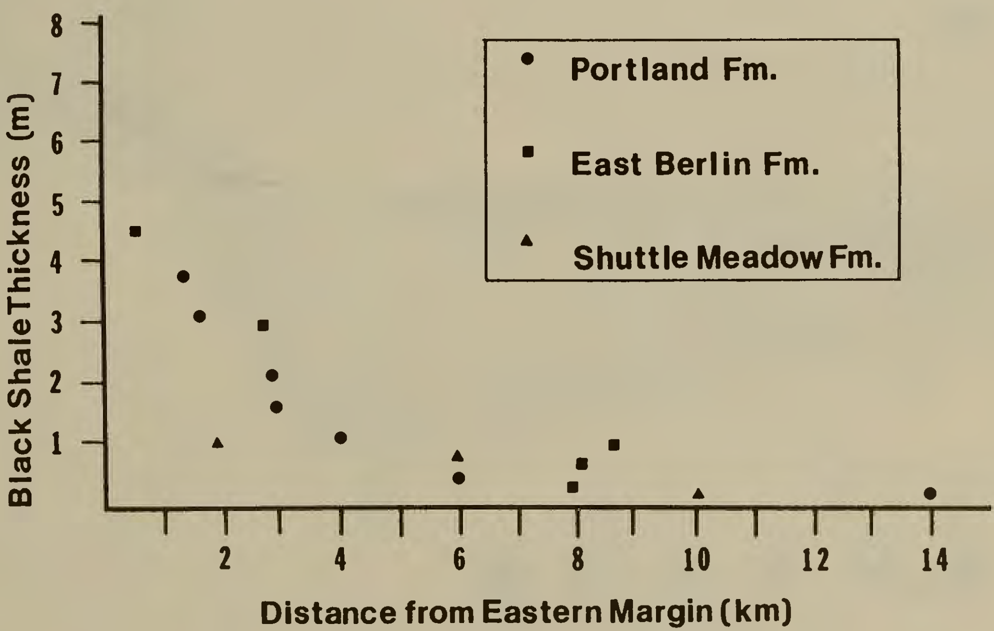

Figure 7. Thickness of black shale beds vs. distance from the eastern fault margin.

The grain-size distribution and the paleocurrent patterns of the eastern margin conglomerate and sandstone delineate discrete alluvial fans with radii of 1 to 3 km. Small, radial alluvial fans are typically associated with rapidly subsiding basin margins, for example, as along the east side of Death Valley, California. In contrast, the western side of Death Valley functions as a "hinge zone" for the asymmetric basin subsidence and the alluvial fans form deeply embayed, coalescing complexes (Hooke, 1972; Steel, 1976; Heward, 1978).

The syndepositional eastward tilting of the floor of the Hartford Basin is also suggested by the geometry of the lacustrine strata. Figure 7 graphs the thickness of the finely-laminated black shale units versus their distance from the present eastern border fault. In each of the formations containing lacustrine strata, the black shale units are thickest nearest to the eastern margin and thin towards the center of the basin. In addition, several lacustrine sequences located within 1 km of the basin margin contain features indicative of syndepositional seismic activity, including slump folds, ductile faults, and thin turbidites (Sanders, 1968; McDonald, 1975).

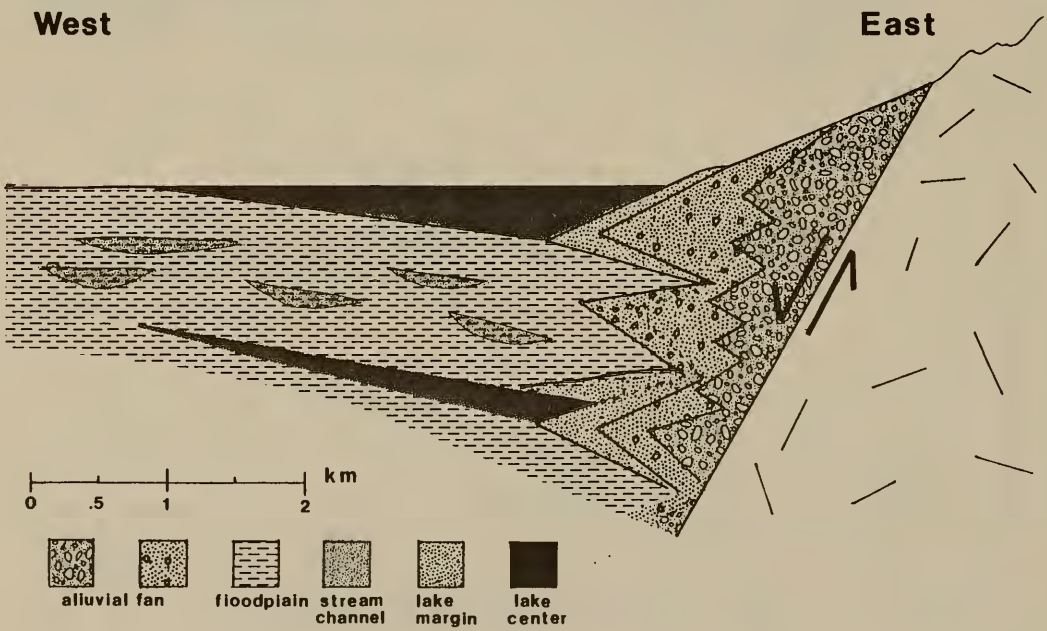

Figure 8. Inferred geometry of an Early Jurassic lake basin and deposits based on facies distribution and the data shown in Figure 7.

Figure 8 diagrams the geometry of a hypothesized Early Jurassic lake basin and its deposits. As a result of asymmetric basin subsidence, the perennial lakes of the Portland, East Berlin, and Shuttle Meadow Formations were deepest and persisted longest along the eastern margin. Shoreline features are well developed in the coarse alluvial fan deposits of the Portland Formation (Stop 3) (LeTourneau and Smoot, 1985).

Further evidence of the active tectonic subsidence of the Hartford Basin is provided by the provenance of basalt clasts in the conglomerate units at Round Hill (Fig. 3 and 5). The geochemical signature of the basalt clasts is comparable to that of the Hampden Basalt (Puffer and others, 1981) which underlies the Portland Formation (Table 1). One or more of the basalt flows in the basin may have crossed the fault margin and continued some distance into the eastern highlands. Subsequent uplift and erosion could then transport the basalt fragments on to the surface of the alluvial fans. At Round Hill, the basalt clasts are restricted to the lowest 250 m of the measured section (Fig. 3). This suggests that only a thin tongue of the Hampden Basalt encroached into the eastern highlands and a limited volume of material was available for transport into the basin.

Coarsening-up sequences of conglomerate and sandstone, 10 to 30 m thick, are the dominant depositional trend in the measured section through the Round Hill Fan (Fig. 3). These repetitive sequences reflect the progradation of alluvial fan lobes due to tectonic rejuvenation of the basin margin and the relative uplift of the source area (Heward, 1978; Gloppen and Steel, 1981).

Summary

The depositional model proposed for the Portland Formation is useful for predicting the distribution of lithofacies in the Lower Jurassic sedimentary rocks of the Hartford Basin. This model provides a framework for understanding a rift basin depositional system based on tectonic and climatic controls on sedimentation. Tectonic tilting of the basin floor is the primary control on sedimentation and influences the distribution of the depositional sub-environments in the basin. The vertical distribution of the lacustrine deposits provides a record of cyclic climatic change during the infilling of the basin.

Figure 9 summarizes the depositional system proposed for the Lower Jurassic rocks of the Portland Formation during a hypothetical period of maximum lake expansion.

The eastern parts were dominated by coarse clastic deposition and the greatest sedimentation rates. The easternmost black shales are the thickest and have the best preserved fossil fishes - a result of the well-developed stratification of the lake waters. Episodic influxes of sediment, due to the proximity of alluvial fans, may have contributed to the rapid burial and good preservation of the organisms.

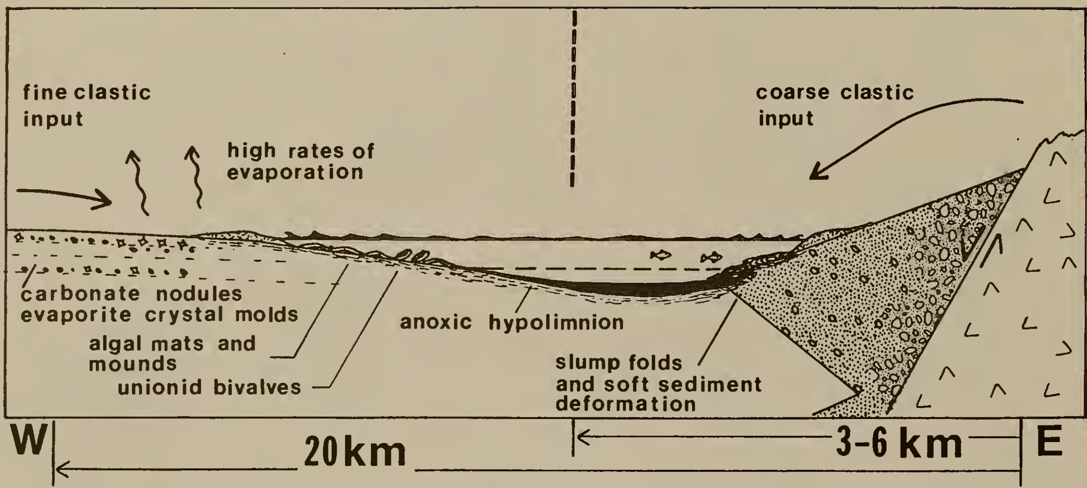

Figure 9. Summary of the depositional system of the Portland Formation during a period of maximum lake expansion.

In the western portions, deposition took place on a broad, low-gradient basin floor. The lake gradually shallowed to the west and fine-grained sedimentation was dominant. Carbonate nodules, limestone beds, algal stromatolites, and evaporite crystal casts were abundant along western shorelines, but rarely formed on the opposite shore. At Stony Brook (Stop 5), western shoreline sandstones of a perennial lake contain abundant micritic intraformational conglomerate, unionid mollusks, and plant debris. Low sedimentation rates encouraged carbonate production by algae, forming stromatolitic mats and mounds in the photic zone. The abundant carbonate nodules and less common evaporite mineral casts in the surrounding floodplain siltstone and shale formed from elevated rates of evaporation on the basin floor. Figure 10 is a reconstruction of Early Jurassic paleogeography based on the sedimentology and paleontology of the Portland Formation.

Figure 10. Paleogeographic reconstruction of the Hartford Basin during Portland time. View from west to east across the center of the basin. For descriptions of the organisms illustrated, see text (Stops 4 and 5) or McDonald (1982).

PART II.

Stop Descriptions

AUTHORS' NOTE: Do not enter any of the localities listed below without obtaining the permission of the landowner(s). Please respect their property rights or access may be denied to future investigators.

Stop 1. Coleman Road, Middletown.

Exceptional exposures of alluvial fan conglomerate and sandstone are found throughout the Round Hill area in Middletown (Middletown 7.5 min. quadrangle). Several linear ridges are located 250 m east of Coleman Road, 1.5 km south of its intersection with Rt. 17. The vertical section at this stop incorporates coarsening-up, progradational alluvial fan cycles - from sheetflow sandflats of the fan toe (Sub-facies 4), to shallow stream deposits (Sub-facies 2) and debris flows (Sub-facies 1) of the mid-fan. These deposits accumulated during arid to semi-arid climatic conditions. The following discussion focuses on the lower or westernmost ridge in the outcrop area. This ridge extends in an essentially unbroken line over a distance of at least 2.5 km, from Round Hill Road in the south, to just west of Mapleshade Road in the north (Stop 2).

A complete range of wholly to partially preserved debris flow deposits occurs at this location. A "boulder bed" horizon is the most prominent feature in the 10 m high linear cliff. At the north end of the boulder bed, a number of diagnostic debris flow features can be observed, including: inverse grading, matrix-supported clasts in chaotic or random orientations, planar lower contacts, hummocky upper contacts, and abrupt grain-size contrasts with adjacent units. Grey-green, weathered basalt clasts are abundant and are possibly derived from the Hampden Basalt. The high percentage of mud in the debris flow matrix causes these layers to be eroded deeply into the cliff face.

Along the outcrop, approximately 50 m north of the boulder bed, several large boulders over 1 m in diameter are found. Some of these boulders shelter remnant debris flow fabrics beneath them; other large boulders occur as isolated clasts in a pebbly sand matrix. These boulders were originally freighted on to the alluvial fan by debris flows. Subsequent stream flow removed most or all of the finer matrix and smaller clasts and left the largest clasts behind.

The debris flows are surrounded by normal-graded, poorly-sorted, poorly-stratified conglomerate and pebbly sandstone (Sub-facies 2) deposited by braided streams.

Cross-bedding consists of small-scale trough cross-stratification representing "scour-and-fill" surfaces in the active channels. Horizontal-planar and inclined-planar stratification indicates that much of the sediment was deposited by shallow, high-velocity streams. Fine-grained, ripple- and wavy-laminated rocks of Sub-facies 4 are typically found at the base of each coarsening-up sequence.

The next ridge to the east (upsection) is similar; 10 - 30 m coarsening-up cycles repeat through the 700 m sequence at Round Hill. Covered intervals are underlain by fine-grained distal fan deposits that thicken in a basinward direction (toward Stop 2). Paleocurrent indicators at Stop 1 trend north - northwest revealing that this locality is on the northwest flank of the Round Hill Fan complex. The central area of the alluvial fan complex is located near Sunshine Farms and Round Hill Road, approximately 1 km south of Stop 1.

Stop 2. Mapleshade Road, Middletown.

Two well-exposed, parallel ridges of alluvial fan conglomerate and sandstone (Sub-facies 2 and 4) are located just northeast of Stop 1 (Coleman Road) at the sharp bend in Mapleshade Road (Middletown 7.5 min. quadrangle). These ridges are laterally correlative with the two ridges at Stop 1.

The ridges at this stop contain two coarsening-up, progradational alluvial fan cycles. At this site, the maximum clast size is smaller and the fining-up beds comprising the fan cycles are thinner than at Stop 1. Debris flow deposits have not been recognized here. Cobbles and boulders occur as clast-supported, imbricated lenses and layers at the base of the normal-graded beds.

A survey of the lower ridge shows that all of the cross-stratification is very small scale. Most of the outcrop is comprised of thin, fining-up depositional units, representing decelerating flow events (Sub-facies 2). In this ridge, a broad, shallow alluvial fan channel can be observed. This channel is less than 1 m thick and is approximately 5 m wide. Its lower contact is concave-upward and scoured into the underlying unit; the upper contact is planar and distinct. The base of the channel is defined by a clast-supported cobble or pebble lag. The channel fill is finer grained and better sorted than the surrounding beds. Large cobbles and boulders are absent in the channel. The channel is composed entirely of well-developed, small-scale trough cross-stratification. A comparision of the sorting and stratification within the channel lens and the surrrounding units indicates the subtle contrast between more frequent, longer-duration stream flow in the shallow channel and short-duration, high velocity flow over broader areas of the fan during high discharge events.

The upper (eastern) ridge at this stop shows features similar to those in the lower ridge. A small channel is exposed at the base of this outcrop. At the north end of the outcrop, the sheetflood sandstones of Sub-facies 4 are well exposed.

It is interesting to note that the covered interval between the two ridges at Stop 2 is thicker than that between the correlative ridges at Stop 1. This indicates that the distal fan deposits pinch out southward toward the central part of the fan complex. The upper ridge is approximately 5 m thick at Stop 2, but 200 m to the north it thins to less than 1 m - a clear illustration of the wedge-like geometry of the alluvial fan lobes. Both Stop 1 and 2 represent "dry" alluvial fan cycles.

Stop 3. Laurel Brook, Middlefield.

Laurel Brook contains up to 30 m of well-exposed alluvial fan conglomerate, lake margin sandstone, and lacustrine dark shale (Sub-facies 3, 7, 8). The outcrops are 0.5 km south of Laurel Brook reservoir and 0.75 km west of the weigh station/parking area along Rt. 17, south of Middletown (Middletown 7.5 min. quadrangle). This locality illustrates the typical intercalation of Portland alluvial fan and lacustrine strata. Similar sequences can be seen at Prout Brook and Long Hill Brook, Middletown, and along the south bank of the Connecticut River in north Portland.

The complete transgressive - regressive lacustrine cycle at Laurel Brook is composed of the following sub-facies, from base to top: 3 - 7 - 8 - 7 - 3. The strata surrounding the central microlaminated black shale have a marked asymmetry. The shallow lacustrine/shoreline strata (Sub-facies 7) below the shale are thinner than the equivalent rocks above. Evidently, the initial lake transgression occurred over a relatively short interval. In contrast, the regressive phase was of substantially longer duration.

The finely-laminated and microlaminated black shale produces abundant well-preserved fishes (redfieldiids and semionotids). Other fossils at this locality include plants, coprolites, and scarce reptile tracks (McDonald, 1975; 1982).

Red mudstones, poorly-sorted conglomerate, and pebbly sandstone overlie the lacustrine cycle. These sediments were deposited on floodplains/mudflats and alluvial fans surrounding the perennial lake. Shoreline features, such as well-sorted bars and wave-generated beach ridges have been recognized in the basal 1.5 m of the upper conglomerate beds.

The stratigraphic sequence at Laurel Brook illustrates the evolution of a perennial lake system and the migration of its onshore - offshore facies as a function of varying depth. This sub-facies assemblage documents a "wet" phase of deposition during early Portland time.

Stop 4. K-F Quarry, Suffield.

A typical sequence of lower-middle Portland "mid-basin" strata is exposed in the quarry of the K-F Brick Company, on the west bank of the Connecticut River, 3.6 km east of Suffield center (Broad Brook 7.5 min. quadrangle). At present, some 20 m of vertical section are visible along the west wall at the southern end of the quarry. These strata are of particular interest because of their lithologic and paleontologic diversity, for the variety of sedimentary structures they exhibit, and for their copper mineralization.

Laterally-extensive, lenticular or tabular units of red-brown, buff-white, or grey, very fine- to medium-grained stream channel sandstone (Sub-facies 5) make up most of the quarry section. The sandstones are seldom greater than one meter in thickness, and are usually well-sorted, well-indurated, calcareous and micaceous. They display planar and distinct upper contacts; the lower contacts of the units are undulatory and scoured into the underlying beds. Laterally, the sandstone bodies terminate abruptly or interfinger with finer-grained deposits. At a few horizons, the sandstones contain angular to rounded clasts of red or grey mudstone; the clasts vary from sand-sized particles to flattened, polygonal plates up to 50 cm in diameter. Interbedded with the sandstones and locally dominant are millimeter- to meter-scale lenses of red-brown, micaceous floodplain siltstone and silty mudstone. Conspicuous among the quarry redbeds are two 20 cm units of fissile, thinly-bedded, partly microlaminated, fossiliferous, "lacustrine" grey-black shale which occur near the base and top of the section.

The exposed rock faces, the extensive rubble piles, and huge quarried slabs at this locality permit both cross-section and bedding-plane examination of numerous primary and secondary sedimentary structures. Large-scale cross-stratification with meter-scale, planar cross-bed sets can be seen on the south wall of the quarry. Megaripples with wavelengths of 1.5 - 2 m are found on the upper surface of a buff-white sandstone along the west wall. Most of the sandstone and siltstone beds are planar-laminated or ripple cross-laminated, some display climbing-ripple lamination. Oscillatory ripples, current ripples, and parting lineations are abundant on certain bedding surfaces, as are polygonal dessication cracks, flute casts, raindrop imprints, foam impressions, swash and wrinkle marks, and a variety of tool marks. Syndepositional soft-sediment deformation structures include load casts, ball-and-pillow structure, and convoluted bedding. Later deformation produced small faults with well-developed slickensides, gentle folds, and small, orthogonal joint sets. Manganese oxide dendrites and calcite druse coat fracture and bedding surfaces in some units; dolomitic nodules and mottling occur in some of the red mudstone-siltstone beds.

The quarry exposures contain a variety of fossils. Trace fossils are conspicuous in the red-brown siltstone and mudstone;

most abundant are horizontal and vertical burrows of the Scoyenia type, probably made by non-insect arthropods, possibly crayfish (Olsen, 1980; Gierlowski-Kordesch, 1985). These linear burrows are from 0.1 to 1.0 cm in diameter and up to 30 cm long, are often branched, and possess irregular, knobby, longitudinal ridges on the external surface. Faint meniscate infillings are visible in a few specimens. An unusual, sinuous crawling trace 21 cm long and 1 cm wide was collected at the site. It has lobate furrows made by appendages, and may have been produced by the arthropod responsible for the Scoyenia burrows. Smooth, usually horizontal, cylindrical burrows, 1-2 mm in diameter are also present. Indistinct reptile footprints occur sparingly on bedding surfaces; types represented include the tracks of small and large dinosaurs (Grallator, Anchisauripus, Eubrontes) and possibly those of small, crocodile-like reptiles (Batrachopus).

Most of the non-red rocks at the quarry contain copper-rich, coalified plant remains, mainly woody stem and branch fragments up to 0.5 m long. A few stem fragments display the longitudinal striations and constricted nodes characteristic of the horsetail Equisetites. Well-preserved, carbonized leafy shoots of the conifers Brachyphyllum and/or Pagiophyllum are found at several horizons, sometimes accompanied by ovuliferous cones and cone scales referable to Hirmerella.

In addition to plant fossils, the two thin, grey-black shale units preserve dissociated scales and bones of the holostean fish Semionotus, large coprolites, and rare conchostracans and ostracodes. A 1.5 cm zone of chocolate-brown silty claystone immediately above the upper grey-black shale is particulary rich in invertebrate remains, and has produced conchostracans (Cyzicus and ?Cornia), darwinulid ostracodes, and possible beetle elytra.

The existence of copper minerals in the Suffield - Enfield area is mentioned in colonial land transactions (Gray, 1982). Subsequent discoveries of copper-rich, coalified plant remains in the region led to explorations for productive coal beds and copper deposits (Silliman, 1818; Shepard, 1837), most of which were soon abandoned when the limited extent of the "coal" and copper mineralization was realized. At the K-F quarry, chalcocite and bornite and their oxidation products coat bedding planes and surround and replace carbonized wood fragments in the grey, buff, and white sandstones and organic-rich grey-black shale units (Gray, 1982). Malachite is most conspicuous in mineralized samples; azurite, chrysocolla, covellite, and cuprite occur in small amounts. The concentration of copper minerals in the non-red units suggests hydrothermal emplacement. Local reducing conditions in the sediments were created by decaying organic matter and as a result of hydrogen sulfide production by anaerobic bacteria. This facilited the precipitaion of insoluble sulfides from copper-rich groundwaters. Gray (1982) proposes that the copper mineralization took place prior to significant compaction of the sediments.

The lithic character, sedimentary structures, and fossils of the K-F quarry strata collectively suggest deposition in braided river - floodplain environments. The geometry of the sandstone bodies and the dune-scale bedforms present in some units characterize broad, meandering, usually shallow, sand-bed rivers with braided channels delineated by bars. During frequent periods of flooding, rivers undercut the fine-grained margins of the main channels and incised smaller, secondary, crevasse-splay channels in the floodplains. Mud clasts of various sizes and abundant plant debris were incorporated into the channel sands. During the waning stages of flood events, fine sand, silt, and clay formed climbing-ripples and planar beds on the adjacent floodplains. The abundant dessication features, mud-draped surfaces, and burrowed zones found on the upper contacts of many sandstone/siltstone units indicate that the episodes of fluvial activity were punctuated by short-duration (probably seasonal) dry intervals. The density of well-preserved, little-transported conifer remains in some beds suggests that at least parts of the floodplain and possibly stream channel bars and islands were heavily vegetated. The thin beds of red and grey-black "lacustrine" shale may have formed in oxbow lakes or small floodplain ponds rich in organic debris.

Stop 5. Stony Brook, Suffield.

One of the largest and most informative exposures of the lower-middle Portland Formation in north-central Connecticut is revealed along the north and south banks of the Stony Brook ravine, 3.4 km southeast of the town of Suffield and 0.8 km west of the intersection of Stony Brook with the Connecticut River (Windsor Locks and Broad Brook 7.5 min. quadrangles). More than 60 meters of section outcrop on the near-vertical walls of the gorge.

The bulk of the Stony Brook section is composed of thinly-bedded to massive, irregular- to wavy-laminated, pale red to brick red, calcareous stream channel sandstone, floodplain siltstone, and minor red shale. Typically, these redbeds are highly micaceous and intensely burrowed; ripple marks, dessication cracks, and reptile footprints are locally abundant on bedding surfaces. The succession of oxidized fluvial deposits is interrupted by at least two large, asymmetrical cycles of grey-black lacustrine strata and a number of smaller non-red units.

The best-exposed lacustrine cycle is found along the south bank of the stream 0.2 km west of the Rt. 159 bridge, and is noteworthy because of its unusual lithologies and abundance of fossils. The 6 m thick lacustrine sequence is characterized by an alternation of well-indurated lenses of well-sorted, ripple cross-laminated, fine- to medium-grained, calcareous grey sandstone and interbedded units of friable, thinly-bedded, red-grey, grey-green, and black calcareous siltstone, shale, and limestone. Though the sandstone beds form prominent ledges in outcrop (up to 0.6 m thick in the western portions of the exposure), they thin markedly east or downdip. Paleocurrent directions derived from current or climbing ripples and linear scour marks in the sandstone units trend N 30°E to N 50°E. The siltstone and claystone units usually thicken in an easterly direction. Near the base of the section are two thin lenses of grey-black, algal-laminated silty limestone with well-defined "loop structures" and/or planar laminations. The limestone beds pinch and swell, but do not exceed 5 cm in thickness. Normally, they have distinct mudcracked, burrowed, or loaded upper and lower contacts. Three meters from the base of the cycle, a 0.4 m disrupted bed of grey, sandy siltstone contains nodular carbonate septaria and massive, elongate nodules of silty limestone up to 30 cm in length. These carbonate nodules or lenses may be stromatolitic mounds.

Three thin lenses of calcareous intraformational conglomerate are the most distinctive units in the lower lacustrine cycle at Stony Brook. These conglomerate lenses vary in thickness along the length of the outcrop and range from 0.5 cm to 25 cm. The three lenses are similar in structure and overall composition, but differ slightly in clast size and lithology and matrix composition. Typically, the intraformational conglomerate is composed of a diverse assortment of the following: 1) very angular to well-rounded, sand- to pebble-sized limestone or dolomitic limestone peloids; 2) concentrically-zoned ooids, pisoids, and probable oncolites; 3) well-rounded grey siltstone or black shale clasts up to 9 cm in diameter; 4) micrite clasts enclosing fish scales, bones, and coprolites; 5) cylindrical, tufa-coated, micrite-filled or hollow structures (probable plant stem or branch casts); and 6) large, complex intraclasts and fragments of the foregoing. These sediments are contained in a matrix of grey or red-grey, micaceous, highly calcareous, fine-grained sandstone or siltstone. The middle and upper conglomerate lenses display poorly-defined graded bedding. The lower lens is reverse graded. The upper and lower contacts of the intraformational conglomerate lenses and the enclosing sandstones and siltstones are undulatory and sharp. Because of the abundance of carbonate cement, the lenses of conglomerate are very well indurated; the fresh rock is very hard and splits along irregular fractures parallel to bedding or along vertical, planar joint surfaces. When weathered, the carbonate clasts are readily dissolved and the rock assumes a characteristic vesicular appearance.

A large portion of the lacustrine strata at Stony Brook is fossiliferous. Networks of branching, smooth-walled, mm-scale, horizontal and vertical burrows are common on many bedding surfaces; larger burrows of the Scoyenia type are less common. Carbonized plant stem, branch, and leaf fragments are found throughout the cycle and are particularly abundant in some of the grey sandstone and intraformational conglomerate units. Much of the plant material consists of finely-macerated, taxonomically-indeterminate debris, but Brachyphyllum-like (conifer) leafy shoots and Equisetites (horsetail) remains can sometimes be recognized. The lenses of intraformational conglomerate enclose masses of very large, diamond-shaped or square fish scales and isolated skull, shoulder girdle, and fin bones referable to some of the more robust species of Semionotus. Black, oval, scale-filled coprolites up to 5 cm in length occur in some conglomerate beds; these may indicate the presence of the coelacanth Diplurus longicaudatus (McDonald, 1982) or fish-eating reptiles. Thin, highly calcareous, ooid-filled zones in the middle lens of intraformational conglomerate contain scarce, well-preserved darwinulid ostracodes and ovate conchostracan (clam shrimp) valves. The conchostracans, referable to Cyzicus sp., range up to 4 mm in length and possess calcite-replaced shells with distinct concentric costae.

The most notable fossils in the Stony Brook rocks are the bivalved mollusks contained in the conglomerate lenses and associated grey sandstones. These pelecypods are the only known in-situ mollusks from the Portland Formation and the locality is one of only three sites in the Connecticut Valley Newark where mollusks have been found (McDonald, 1982; 1985). The bivalves occur as detailed internal and external molds and casts and compare favorably with the previously described species of Unio (freshwater clams or mussels) found in a glacially-transported boulder near Wilbraham, Massachusetts (Emerson, 1900; Troxell, 1914). The Stony Brook specimens are narrowly elliptical in outline, with a gently convex beak and long, well-defined lateral teeth; typical individuals are about 5 cm long and 2 cm high. The concentric growth lines of the shell are preserved in several specimens. Nearly all the unionids are fully articulated with closed and unbroken valves. Individuals preserved in cross-section display minute dissolved shell voids about 0.2 mm in thickness. The articulated, undamaged condition of the bivalved remains and their abundance in certain layers strongly implies that these fossils are autochthonous. This conclusion is futher supported by the discovery of presumed mollusk dwelling/escape burrows in the uppermost intraformational conglomerate and the immediately overlying grey sandstone. The larger burrows are straight, roughly cylindrical, unbranched, vertical to sub-vertical structures up to 10 cm long and 2.5 cm in diameter. Along the edge of the burrows, the sediment laminae are bent downward, a diagnostic feature of escape traces (Reineck and Singh, 1980). The deepest portions of many burrows are excavated into the upper few centimeters of the intraformational conglomerate; most burrows terminate upward in ripple cross-laminated, calcareous silty sandstone. Mollusks have not yet been found within the burrows, but they are common at the appropriate horizons. The present-day Unio is a filter-feeding bivalve with an incompletely fused mantle; it lives exposed on lake and stream channel floors, or it can burrow a short distance into the sediment (McKerrow, 1978). Evidence suggests that the

Stony Brook bivalves were semi-infaunal, in-situ residents in the limy conglomeratic and sandy substrate.

The strata exposed in the basal lacustrine cycle at Stony Brook are interpreted as shoreline and nearshore deposits which formed at the western margin of a large, perennial, Portland lake. Periodic fluctuations of lake level account for the interfingering of coarse and fine, clastic and chemical, oxidized and reduced sediments. During deposition, the fluvial-deltaic, mudflat-sandflat, and shoreline environments of the Stony Brook lake were alternately subjected to varied-length episodes of shoaling and subaerial exposure followed by periods of lake expansion.

The lenses of westward-thickening, well-sorted grey sandstone which dominate the section may represent prograding delta lobes which built into the lake from the southwest. The load structures that often mark the sandstone-shale contacts were developed from the accumulation of coarse sediment on top of water-saturated and non-compacted mud. The siltstone-shale units are usually bioturbated and probably formed on broad, partially-oxidized nearshore mudflats or perhaps in shallow lagoons along the shoreline.

Wave agitation and local reworking of the carbonate sediments produced the peloids, ooids, pisoids, oncolites, and intraclasts which were later incorporated into intraformational conglomerate lenses. The presence of large clastic and carbonate rip-up clasts in the intraformational conglomerate suggests that the conglomerate may have formed during a transgressive lacustrine phase when low-standing lake waters re-advanced over previously deposited sediments. Another possibility is that the conglomerate beds are storm deposits or "tempestites". The variety of clast types, the combination of very angular and very well-rounded clasts, the lack of imbrication, the occurrence of massive plant fragments and dissociated fish remains, and the presence of localized, small-scale hummocky cross-stratification supports this conclusion. The character of these deposits closely conforms to the criteria established by Kreisa (1981) for the recognition of storm deposits.

Poorly represented in the Stony Brook section are the reduced, sulfide-organic-rich, rhythmically-laminated, fossiliferous, "deep water" black shale strata that characterize many other Connecticut Valley Newark lakes. However, rounded, pyrite-rich clasts of black shale occur in some of the intraformational conglomerate layers, so this facies no doubt existed offshore, presumably to the east.

The diverse invertebrate community and the very large, abundant semionotid fishes imply that the Stony Brook lake was ecologically hospitable and of substantial size. The sediments, sedimentary structures, and fossils are closely analogous to those described by Link and Osborne (1978) for the marginal lacustrine units of the Pliocene Ridge Basin Group of southern California.

PART III.

Road Log

Miles

00.0 Assemble at WESLEYAN UNIVERSITY, Middletown, at the loading dock behind the SCIENCE TOWER, on Pine St. Proceed left (south) on Pine St. to the intersection of Pine St. and Randolph Rd.

1.5 Turn left (east) on Randolph Rd.

1.6 Turn right (south) on Rt. 17.

2.0 Bear left on Coleman Rd. Ascend the north flank of the Round Hill Fan complex. Note outcrop of conglomerate and sandstone along the left (east) side of the road.

3.0 Park just before the intersection of Kelsey St. and Coleman Rd. Walk northeast along a dirt trail through woods to encounter several linear ridges of alluvial fan conglomerate.

STOP #1: Coleman Road. Alluvial fan deposits and debris flows.

Return to cars and proceed to intersection of Coleman Rd. and Kelsey St. Turn left (east) on Kelsey St.

3.3 Turn left (north) on Mapleshade Rd. Note bedding plane - dip slope exposures of conglomerate along the left (west) side of the road.

4.0 Park on Mapleshade Rd.

STOP #2: Mapleshade Road. Alluvial fan deposits.

Proceed into fields on left (west) side of road and continue northwest into lower field. Follow outcrop until the south end of the lower ridge is encountered. The stop description begins here. After examining the lower outcrop, walk back to upper field and continue east to the prominent cliff in the northeast corner of the field.

Return to cars. Continue along Mapleshade Rd. (north).

4.5 Turn left (west) on Randolph Rd. Proceed to traffic light at intersection of Randolph Rd. and Rt. 17.

Turn left (south) on Rt. 17. Note excellent exposure of coarse sandstone (Sub-facies 5) behind Monte Green Inn along the left (east) side of road. Round Hill (elevation 582 ft.) can be seen along the east side of the road, just past Dooley Pond.

6.6 Bear right into the abandoned weigh station/parking area opposite the Pizza King restaurant. Park and walk due west (right) across fields approximately 1/2 mile to encounter north-south-trending Laurel Brook. Follow brook north (downstream) to prominent chasm or gorge.

STOP #3: Laurel Brook. Alluvial fan and lacustrine strata.

Return north on Rt. 17 from parking area.

8.9 Turn right (east) on Randolph Road (Rt. 155). (10.0 mi.) This slope parallels the east-dipping bedding of the conglomerates on the northeast flank of the Round Hill Fan complex. (10.9 mi.) This steep, west-facing hillslope marks the approximate location of the eastern fault margin of the Hartford Basin. To the southwest the Round Hill Fan complex can be seen.

11.1 Turn right into the entrance ramp for Rt. 9 North (Hartford). Exposures of the Paleozoic basement rocks are visible on both sides of the ramp. Note the panoramic view of the valley (11.4 mi.). The prominent ridge on the western horizon is formed by the Holyoke Basalt, the thickest of the three basalt units in the basin.

18.9 Bear right on to I-91 North (Hartford).

Exit 23: Optional side trip to Dinosaur State Park (20.6 mi.) for excellent exposures of dinosaur trackways in lake margin sandstone and siltstone of the Lower Jurassic East Berlin Formation.

(20.8 mi.) The contact of the Hampden Basalt with the underlying East Berlin Formation can be seen along the right (east) side of I-91. (21.0 mi.) Exposures of the East Berlin Formation are located along the right side of the highway.

28.3 Keep to the right and follow I-91 North past Hartford.

46.4 Take Exit 17 West (Rt. 190) to Suffield. Note outcrops of the Portland Formation (Sub-facies 6) along the highway just before the bridge over the Connecticut River.

48.0 Turn left (south) on Rt. 159.

48.6 Turn left into unmarked dirt road and entrance to K-F Quarry.

STOP #4: K-F Quarry. Braided stream and floodplain strata.

NOTE: This is an active quarry and access to this stop is restricted. Permission must be obtained in advance.

Continue south on Rt. 159.

50.3 Park along the road just before bridge over Stony Brook. Descend to brook along left (east) side of bridge and walk west (upstream) approximately 1/4 mile to large exposures on south bank of stream.

STOP #5: Stony Brook. Fluvial/lacustrine deposits.

-END TRIP-

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