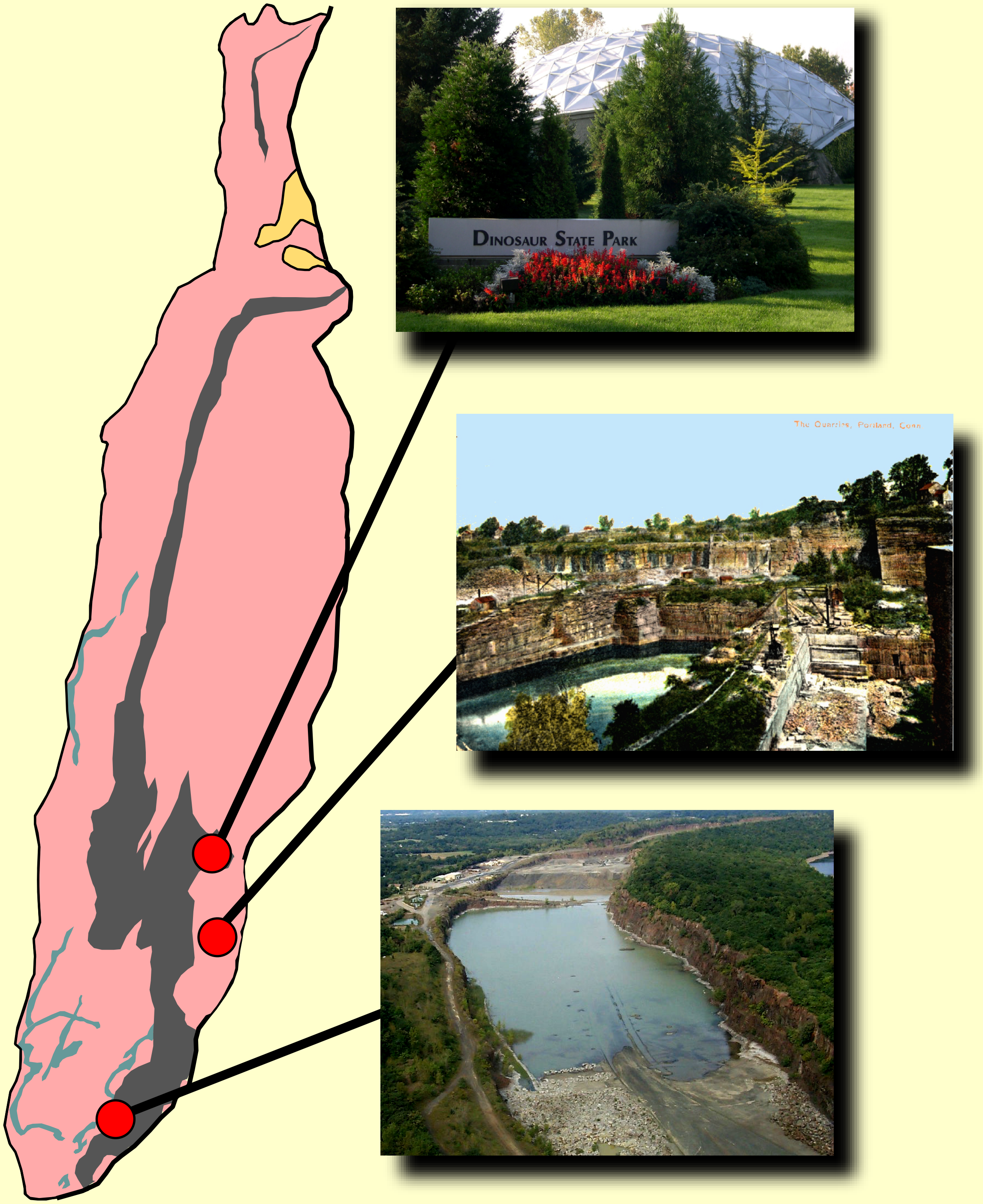
Traprock, Tracks and Brownstone:
The Geology, Paleontology, and History of World-Class Sites in the Connecticut Valley.

Peter M. LeTourneau and Margaret A. Thomas, Editors



The Geological Society of Connecticut
Field Trip Guidebook No. 1

Traprock, Tracks and Brownstone:
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The Geological Society of Connecticut
First Field Trip Meeting
Saturday May 1, 2010

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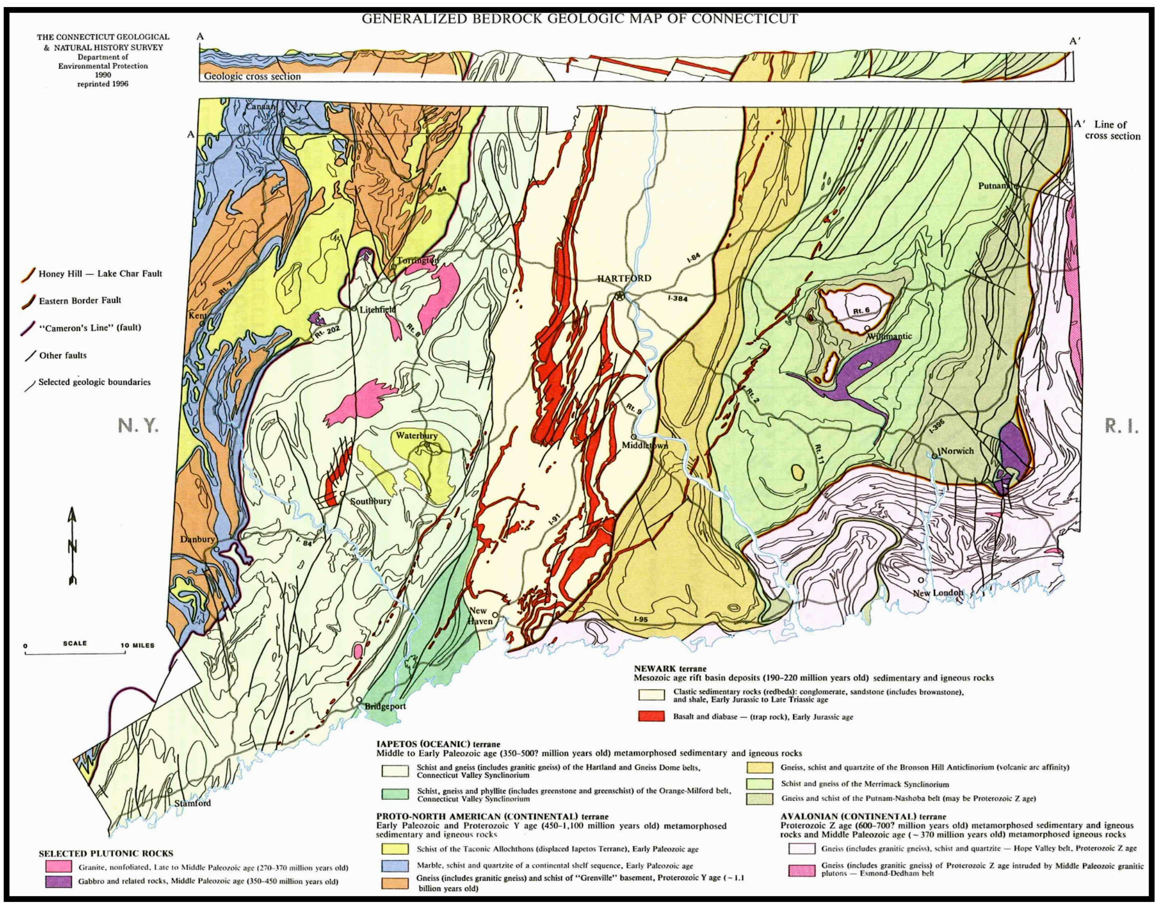

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Geological Society of Connecticut
Field Trip Guidebook 1

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The Geology of the Connecticut Valley

excerpt from **The Connecticut Valley in the Age of Dinosaurs: A Guide to the Geologic Literature, 1681-1995**
by Nicholas G. McDonald, Bulletin 116, State Geological and Natural History Survey of Connecticut, 1996.

One of the more prominent large-scale geologic features of southern New England is the early Mesozoic (Triassic-Jurassic) sequence of non-marine sedimentary rocks, basalt flows, and diabase intrusions that compose the lowland of central Connecticut and west-central Massachusetts. This broad, elongate lowland extends from the Massachusetts-Vermont border southward to Long Island Sound, encompassing an area of some 1,300 square miles (figure 1). Because of its extent and development in Connecticut, and because the Connecticut River drains much of the region, this central lowland was appropriately named the "Connecticut Valley Lowland" by the eminent physiographer W.M. Davis (1898, p. 13). This name is adopted herein and is applicable when referring to the Lowland either as a geologic or topographic feature. Bordering this Lowland are moderately rugged hills known as the Eastern and Western Uplands (Davis, 1898) or Highlands (Barrell, 1915). These uplands are underlain by Proterozoic and Paleozoic metamorphic and igneous rocks which are markedly different in age, lithology, and structure than the rocks of the Connecticut Valley.

An uplifted block of basement in the Amherst, Massachusetts area subdivides the Connecticut Valley region into two primary basins: the short, narrow Deerfield Basin to the north and the expansive Hartford Basin to the south (Fig 1). Four smaller, isolated basins containing early Mesozoic strata have been identified in the crystalline uplands to the east and west of the Hartford and Deerfield Basins. The Cherry Brook Basin (Platt, 1957) and Pomperaug Basin (Hobbs, 1901; Burton et al, 2005) lie in western Connecticut, the Northfield Basin (Zen, 1983) is found immediately northeast of the Deerfield Basin, and the Middleton Basin (Kaye, 1983) is located north of Boston, in Essex County, Massachusetts. Three parallel, northeast-trending dikes of Early Jurassic age also transect the crystallines of the Eastern and Western Uplands; these have been petrographically and chemically correlated with the three basalt flows exposed in the southern half of the Hartford Basin (Philpotts and Martello, 1986). The nomenclature and stratigraphy of the sedimentary and volcanic rocks of the Hartford and Deerfield Basins is shown in Fig 2.

The Connecticut Valley Lowland is a member of a series of similar early Mesozoic rift basins that extends for about 1,200 miles along the eastern margin of North America from Nova Scotia to South Carolina and that largely parallels the structural trend of the Appalachian orogen (Fig 3). These

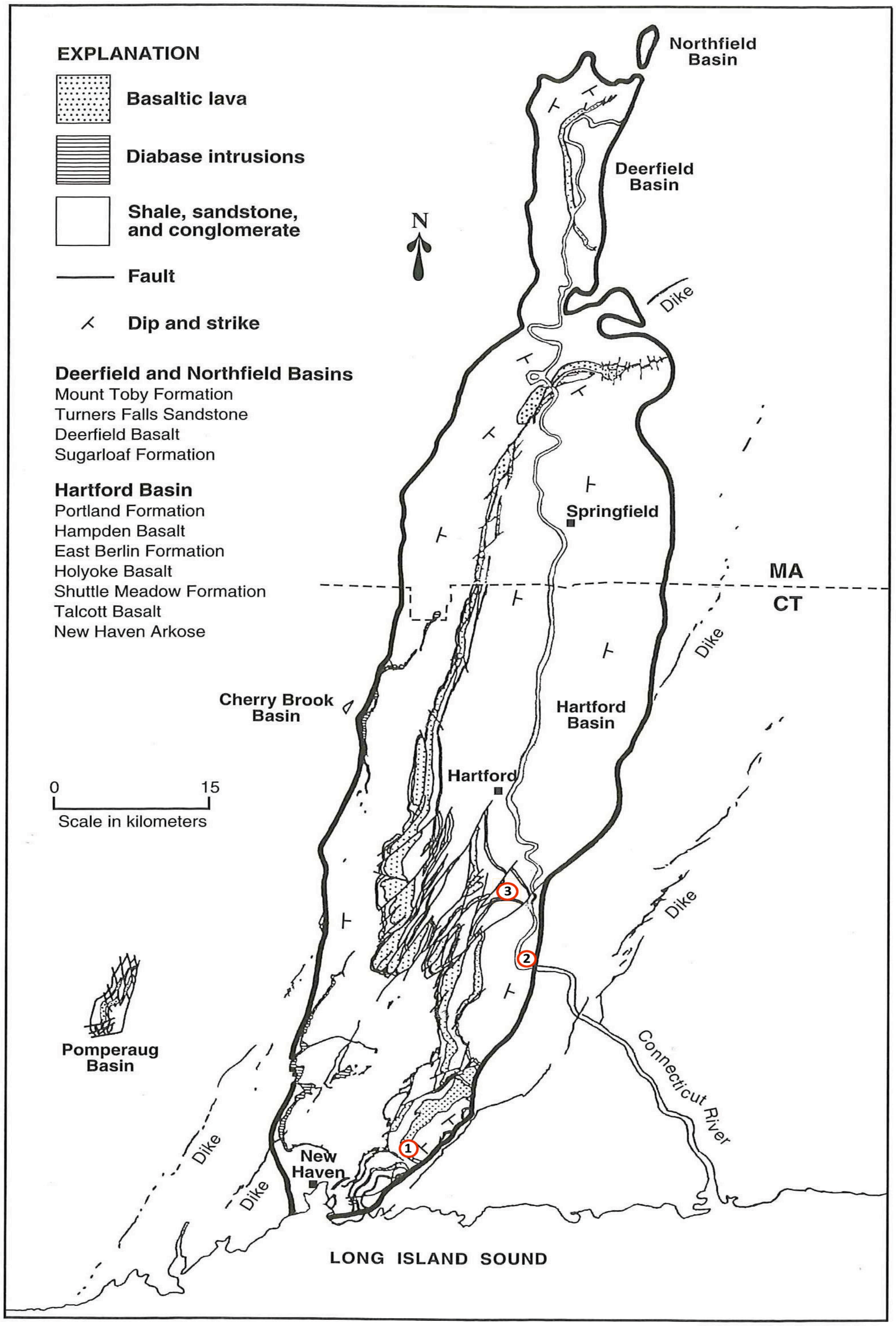


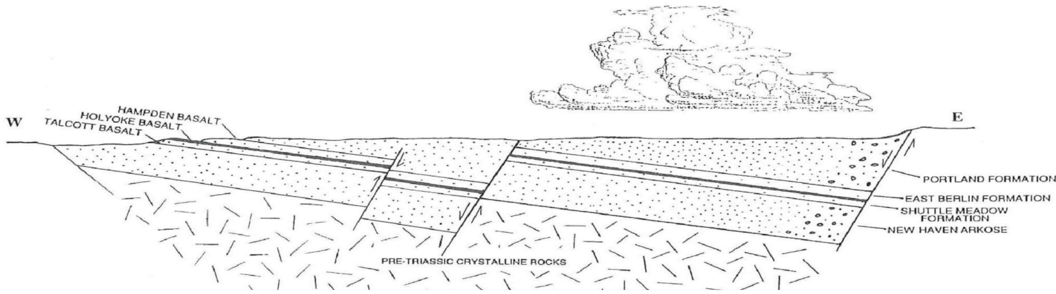
Figure 1.1 Generalized geologic map of the Connecticut Valley Lowland region of southern New England showing the location of the major early Mesozoic depositional basins and the Stratigraphy of Triassic and Jurassic sedimentary and igneous rocks. The Middleton Basin is shown on Fig 3.

The Geological Society of Connecticut Field Trip progresses through the southern and central portions of the Hartford Basin. Field stop locations indicated with red circles in Figure 1.

Stop 1: The vast Holyoke Basalt at the Tilcon Traprock Quarry in North Branford, Connecticut. The Holyoke Basalt geology, petrology, and history are described in Chapter I.

Stop 2: The historic Portland Brownstone quarry, Portland, Connecticut.
The geology and history of the Portland Brownstone quarries are described in Chapter II.

Stop 3: The magnificent dinosaur trackway at Dinosaur State Park, Rocky Hill, Connecticut. The paleontology and geology of the park are described in Chapter III.



UNITS	THICKNESS (m)	AGE		DESCRIPTION
Portland Formation	2000	Pliensbachian-Hettangian	Lower Jurassic	Mostly red, cyclical, shallow water lacustrine clastics; some gray and black lacustrine (some deep water) clastics with minor limestone; red fluvial and alluvial clastics
Hampden Basalt	60	Hettangian		Tholeiitic basalt flows
East Berlin Fm.	150			Mostly red, cyclical shallow water lacustrine clastics; some gray and black lacustrine (often deep water) clastics with minor limestone; minor red fluvial and alluvial clastics
Holyoke Basalt	100			Tholeiitic basalt flows
Shuttle Meadow Fm.	100			Mostly red, cyclical shallow water lacustrine clastics; some gray and black lacustrine (often deep water) clastics with minor limestone; minor red fluvial and alluvial clastics
Talcott Basalt	65			Tholeiitic basalt flows
New Haven Arkose	2250	Hettangian-Late Carnian	Upper Triassic-Lower Jurassic	Red and brown, coarse, soil-modified fluvial clastics

UNITS	THICKNESS (m)	AGE		DESCRIPTION
Mt. Toby Fm. Turners Falls Sandstone	2000	Hettangian	Lower Jurassic	Mostly red, coarse alluvial clastics; lateral equivalent of Turners Falls Ss. Mostly red, cyclical, shallow-water lacustrine clastics; some gray to black, cyclical, deeper-water lacustrine deposits
Deerfield Basalt	50			Tholeiitic basalt flows
Sugarloaf Fm.	1700	Norian?	Upper Triassic	Red, buff, and minor gray, coarse to fine fluvial and alluvial clastics

Figure 1.2
Stratigraphic nomenclature in the Connecticut Valley.
Top: Idealized east-west cross-section through the Hartford Basin.
Table: Currently recognized formations in the Hartford and Deerfield Basins (Modified from Olsen, et al., 1989).

basins formed through lithospheric extension in-the Late Triassic and Early Jurassic, during the early phases of the continental rifting episode that ultimately created the Atlantic Ocean. There is a great deal of lithologic and structural resemblance among the different basins, and they contain similar fossils. Because they share a common chronology and structural history, the rocks in the Connecticut Valley and the other basins are assigned to an all-inclusive lithostratigraphic unit, known as the "Newark Supergroup" (Olsen, 1978; Froelich and Olsen, 1984). The use of the term "Newark" was first suggested by W.C. Redfield (1856, p. 357), who considered the sedimentary strata of the various basins to be extensions or temporal equivalents of the red sandstone rocks occurring near Newark, New Jersey.

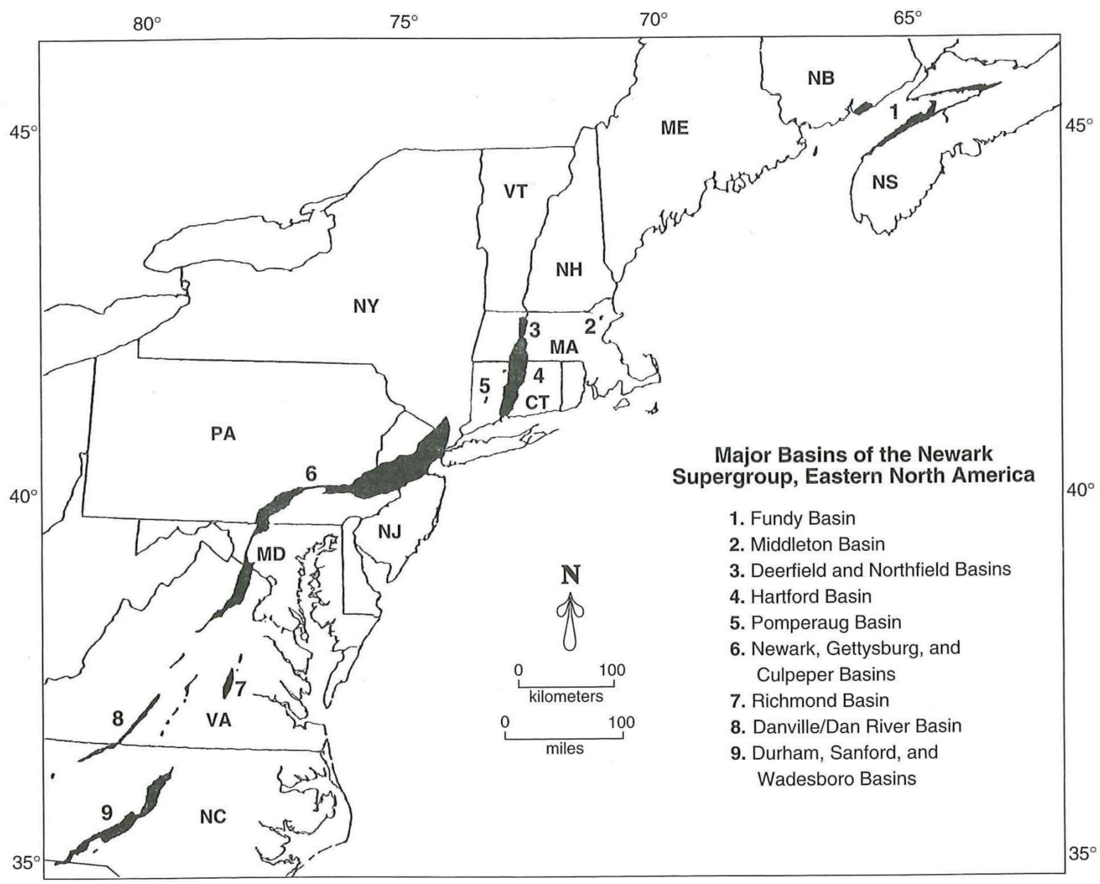


Figure 1.3 Exposed early Mesozoic (Newark Supergroup) basins of eastern North America. These basins formed as a result of lithospheric extension during the early phases of the continental rifting episode that ultimately created the Atlantic Ocean (after Unger, 1988).

Traprock

The most valuable mineral or rock commodity in the Connecticut Valley today is not copper, lead, barite, sandstone, or limestone, but rather crushed basalt and diabase commonly called trap or traprock. The term trap comes from the Swedish word "trappa" meaning stair or step; due to numerous right-angle joints and fractures, large exposures of basalt frequently take on a stair-step appearance. In the earliest Jurassic, extensional forces associated with the rifting of Africa and North America tapped underlying magma sources, repeatedly flooding much of the Valley with basaltic lava. Most of the molten rock emerged from narrow, elongate fissures; actual volcanic cones may have been rare. Some of the igneous material never reached the surface, and cooled more slowly, forming diabase dikes and sills. As a result of tilting, faulting and erosion, the basalt and diabase layers are now exposed as resistant ridges, extending like a backbone along the length of the Valley, except where displaced by faulting. Prominent topographic features in the Valley, such as East and West Rocks, the Hanging Hills of Meriden, Talcott Mountain, and the Holyoke Range are composed of basalt or diabase. Basalt and diabase are durable rocks, resistant to both physical and chemical weathering. They are ideal for use in rail and automotive roadbeds, for concrete aggregates, and for other building purposes (Skinner, 1980). Skerrett (1932) records that in his day, the Totoket Mountain quarry in North Branford (figure 5) was one of the world's largest traprock quarries, with an exposed rock face more than a mile in length. Presently, basalt products are derived from more than 20 large, open-pit operations.

Brownstone

In the 19th century, Portland brownstone became a highly fashionable building stone because of its uniform color (a rich, permanent, muted brown), its fine, even lamination, its easy working qualities adapted to the finest carving, and its ability to take on a smooth, even surface by rubbing or dressing down (Rothwell, 1895). An 1876 report boasts that the Portland quarries were at the time the largest quarries in the world, covering an area of 175 acres, and employing 1,500 laborers and 100 horses and mules (Asher and Adams, 1876). The stone was transported by a fleet of sailing vessels owned by the quarries to markets in all the large cities of the nation, including San Francisco, by way of Cape Horn. The use of brownstone in New York City, in particular, was fostered by fire regulations requiring buildings taller than two stories to be constructed of stone or brick (Guinness, 1987), and because it was the de rigueur stone of choice for the mansions of the wealthier classes. However, the immense popularity of brownstone also precipitated its demise. As Rice and Foye (1927) relate, the great demand for brownstone led to the use of stone of inferior quality, the use of "unseasoned" freshly-quarried stone from which the intergranular moisture had not had time to evaporate, and the employment of brownstone veneers placed with the bedding planes vertical. The inevitable consequence of such improper use was fracturing, crumbling, or spalling of the rock. In time, styles and tastes also changed, and brownstone came to be viewed as drab and excessively somber. For many years the Portland quarries stood as flooded, abandoned monuments to a once glorious and profitable past.

Limited quarrying was resumed in 1993 by Portland Brownstone Quarries, a division of Twin Oaks Enterprises, Inc. Artisans engaged in specialty restoration or reproduction projects produce raw quarry rock, slabs, and custom fabricated work to order. Through grass roots and municipal preservation efforts, the quarries were registered by the Department of the Interior as a National Historic Landmark in May 2000.

In 2007, through a lease agreement with the Town of Portland, a unique recreation area opened, featuring swimming, scuba, rock climbing, and kayaking centered about the quarry lakes.

Dinosaur State Park

Interest in Connecticut Valley footprints has been greatly stimulated by the 1966 discovery of extensive trackways in ancient lake shoreline deposits at Rocky Hill, Connecticut. Exposures at the site, now known as Dinosaur State Park, have revealed nearly 2,000 reptile tracks, one of the largest such accumulations of fossil footprints in the world (figure 4). The size of the tracks and the distance between successive imprints suggests that the adult trackmakers were about 5 feet tall at the hip and nearly 20 feet long. The Park attracts upwards of 80,000 visitors annually and is a focal point for paleontologic research in the Valley.

Figure 1.4 An early exposure of the spectacular reptile trackways at Dinosaur State Park, in Rocky Hill, Connecticut, uncovered in 1966. This is one of the largest accumulations of fossil footprints in the world. Photograph by John Howard, Yale Peabody Museum of Natural History, from the files of Dinosaur State Park.

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Chapter II.

The Holyoke Basalt at the Tilcon Traprock Quarry, North Branford: The geology, petrology, and history of one of the world's largest flood-basalt eruptions.

Anthony R. Philpotts
Emeritus Professor of Geology and Geophysics
University of Connecticut

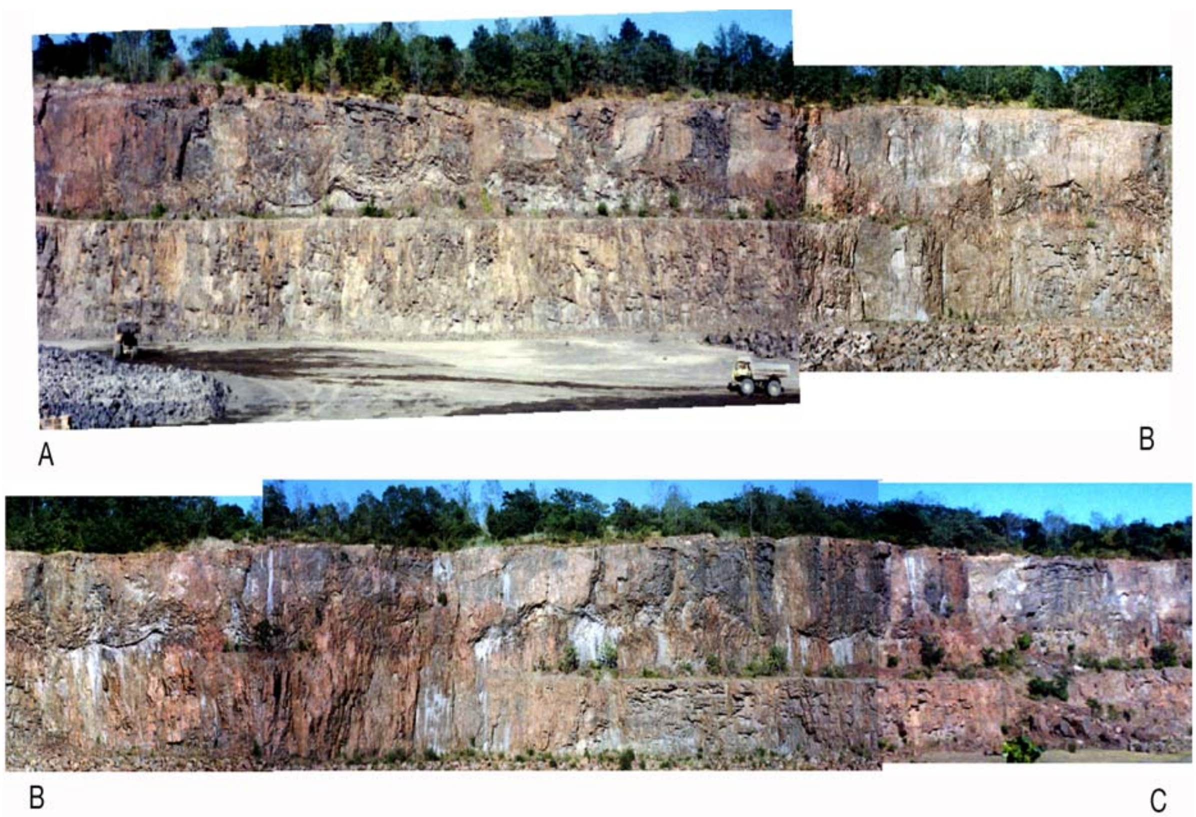

Figure 2.1 Two photographs A/B and B/C fit together to provide a panoramic view of part of the 8-km-long east wall of the North Branford quarry. Horizontal plane shown mid-way through the photographs is a quarried surface 20 m above the quarry floor, at approximately 120 m above the base of the 200-m-thick flow. The cuspate boundary seen in the quarry face marks the division between cooling joints that propagated down from the surface and up from the base of the flow. In the quarry wall beneath this boundary are meter-thick horizontal sheets of ferrodiorite that are slightly darker than the buff colored basalt. These sheets formed from liquid expelled from the lower part of the flow by crystal-mush compaction during solidification of the lava.

The North Branford quarry, operated by Tilcon of Connecticut Inc., is one of the largest trap-rock quarries in the world. It supplies crushed stone for roadbeds, asphalt, and concrete aggregate for use in Connecticut and New York States. The eastern face of the quarry, which purports to be the longest face of any trap-rock quarry in the world, provides a spectacular 8-km long vertical exposure through the central part of the Holyoke flood-basalt flow, the middle and thickest of the three Mesozoic basalt units in the Hartford Basin. Because of its great thickness, the Holyoke flow cooled slowly and differentiated to produce horizontal sheets of ferrodiorite and granophyre (granite) in its central part. This exposure provides an ideal site to witness the products of igneous differentiation where we have a clear understanding of the differentiation mechanisms with none of the complications normally associated with deep-seated plutonic bodies.

The North Branford Quarry was opened by the New Haven Trap Rock Company in 1914 and has remained in continuous operation ever since, despite several changes in ownership. On opening, it produced 2000 tons of crushed stone per day; this has now risen to ten times that. The stone is crushed with a manganese steel gyratory crusher which is a descendent of the "jaw crusher" invented by Eli Whitney Blake, the nephew of Eli Whitney who invented the cotton gin and mass production of muskets. Today, 65-ton-quarry trucks bring the freshly blasted rock from the quarry face to the crusher where it begins a 2-mile-long trip on conveyor belts to other crushers and sorters. The major products are crushed stone for road and rail beds, and aggregate for asphalt and concrete. Basalt is, without doubt, the most desirable stone for all of these purposes, because of its durability and density. Its durability is a direct consequence of its texture, which is determined by the way in which the basaltic magma crystallized.

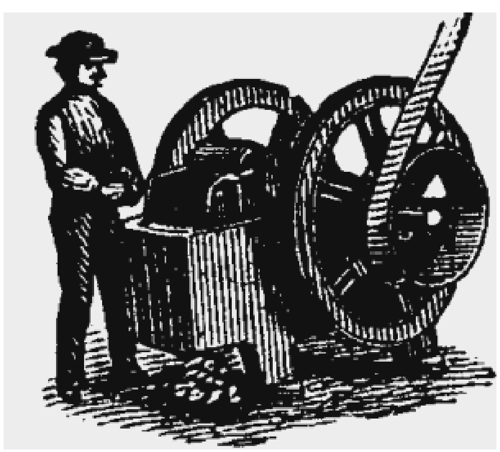

Figure 2.2 Eli Whitney Blake's stone crusher and advertisement from 1879.
Source: www.gutenberg.org.

THIS NEW
BLAKE'S STONE AND ORE BREAKER AND CRUSHER.

For breaking hard and brittle substances to any size. Endorsed by the leading Mining, Manufacturing, and Railroad corporations in the United States and Foreign Countries. First Premium wherever exhibited, and hundreds of testimonials of the highest character.

A NEW SIZE FOR PROSPECTING AND LABORATORY USE.

☞ All Stone Crushers not made or licensed by us, containing vibratory convergent jaws actuated by a revolving shaft and fly-wheel, are infringements on our patent, and makers and users of such will be held accountable.

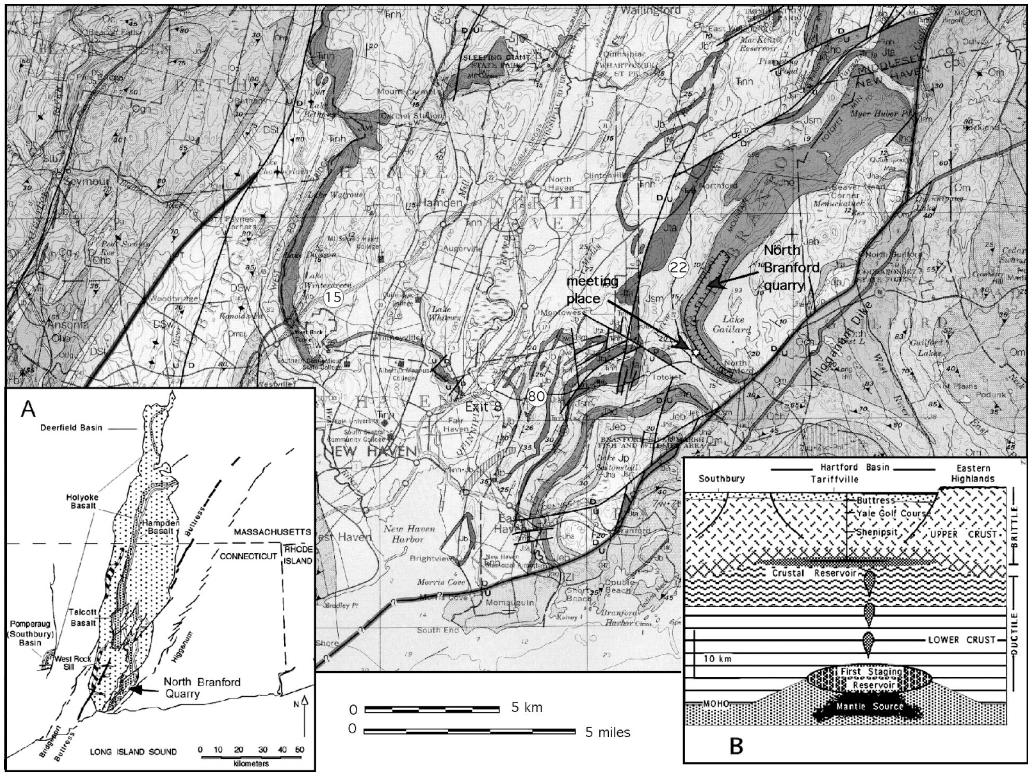

Figure 2.3 Geological map of the southeastern part of the Hartford Basin (Rodgers, 1985) and location of the North Branford quarry. *Inset A*: Distribution of the three volcanic units in the Hartford Basin –Talcott, Holyoke, and Hampden—and their associated dikes (Higganum, Buttress, and Bridgeport) and sills. *Inset B*: Hypothetical cross section through the basin at the time of the Holyoke eruption.

The North Branford quarry is located in the extreme southeastern part of the Mesozoic Hartford Basin, the southern end of the quarry actually terminating against the basin's eastern border fault (Fig. 1). The quarry is in the Holyoke basalt, the middle of the three volcanic units in the basin. The lava erupted from the Buttress dike (Fig. 2.3A), which like the earlier Higganum and later Bridgeport dikes trend obliquely across the basin. These dikes formed perpendicular to the extension that eventually rifted apart Pangea to form the Atlantic Ocean.

The Holyoke basalt is the thickest of the three volcanic units in the basin, forming a single 200-m-thick flow in the North Branford area. This flow can be traced northward to the Vermont border and westward to the Pomperaug Basin. The volume of the flow is estimated to have been in excess of 1000 km^3. This gigantic sea of lava would have taken over 100 years just to solidify and much longer to cool to a temperature where steam was longer gushing from fractures in its surface.

The entire 200-m-thickness of the flow is exposed at North Branford, with the base of the flow being exposed on the road leading from the quarry weighing station into the quarry itself, and the top of the flow being exposed along the shore of Lake Gaillard immediately to the east of the quarry. The flow erupted and cooled as a single unit. This is evidenced by the fact that only one generation of bubbles rose toward the top of the flow. If multiple magma pulses had inflated the flow, multiple layers of bubble accumulation would be found, and they are not. Fluvial sediments rapidly covered the flow, so there was no time for the friable scoriaceous and ropy surface features seen along the shore of Lake Gaillard to be eroded. Water from these sediments would have percolated down through fractures in the crust of the flow and promoted cooling.

When flood basalts solidify they generate characteristic fractures that propagate down from the surface and up from the base of the flow, as seen in the example from Iceland in Figure 2.4. Fractures propagating up from the base form extremely regular polygonal joints, which are referred to as the colonnade and the less regular ones extending down from the surface are referred to as the entablature. Because cooling is more rapid from above, the colonnade and entablature meet at a level, which is usually one-third the height of the flow.

Figure 2.4 *Left*: Colonnade and entablature joints in the 15-m-thick basalt flow at Aldeyjarfoss, Iceland. The colonnade/entablature boundary is one-third the height of the flow. *Right*: The colonnade/entablature boundary in the Holyoke basalt flow in the North Branford quarry, Connecticut. This cuspate boundary is at 60% of the height of this 200-m-thick flow.

The Holyoke also has a well-developed colonnade and entablature, but it is a little more difficult to see because of many addition tectonic joints. The colonnade/entablature boundary, however, is always evident and forms a prominent line along the entire east face of the North Branford quarry. This boundary, however, is at a height of 60% of the flow. This is one of the most important facts about the Holyoke flow, because it indicates that as it solidified, material was transferred from the roof to the floor of the solidifying sheet and hence displacing the final solidification level (colonnade/entablature boundary) upward.

Despite the fine-grain size of the basalt throughout the Holyoke flow at North Branford, this body of magma did not simply freeze *in situ*. It was an actively convecting body of magma that underwent extreme differentiation to eventually produce coarse-grained ferrodiorite and fine-grained granite (granophyre). As you stand on the floor of the quarry, picture yourself in the middle of a huge sheet of magma in which you can look up and see the roof slowly solidifying downward to form the cuspate colonnade/entablature boundary. The question is what was going on in this magma sheet at the time? Photomicrographs (Fig. 2.5) of samples through the flow provide answers.

Water percolating down through prominent fractures in the crust of the Holyoke flow produced "cold fingers" that promoted crystallization in the roof zone. These "cold fingers" distorted the isotherms into the cuspate shape now seen on the colonnade/entablature boundary.
Dripping instabilities developed from the base of the cusps, with dense crystal mush sinking to the floor. This also dispersed crystals throughout the entire thickness of the flow, which is why the basalt is fine-grained throughout, despite the great thickness of the flow.

Although the fine-grained basalt in the quarry appears to be homogeneous, chemical analyses reveal a significant variation with height (Fig. 2.6). In rising from the floor, the basalt steadily becomes enriched in elements that enter early crystallizing minerals (e.g. MgO) and depleted in elements that enter the melt (TiO_2).

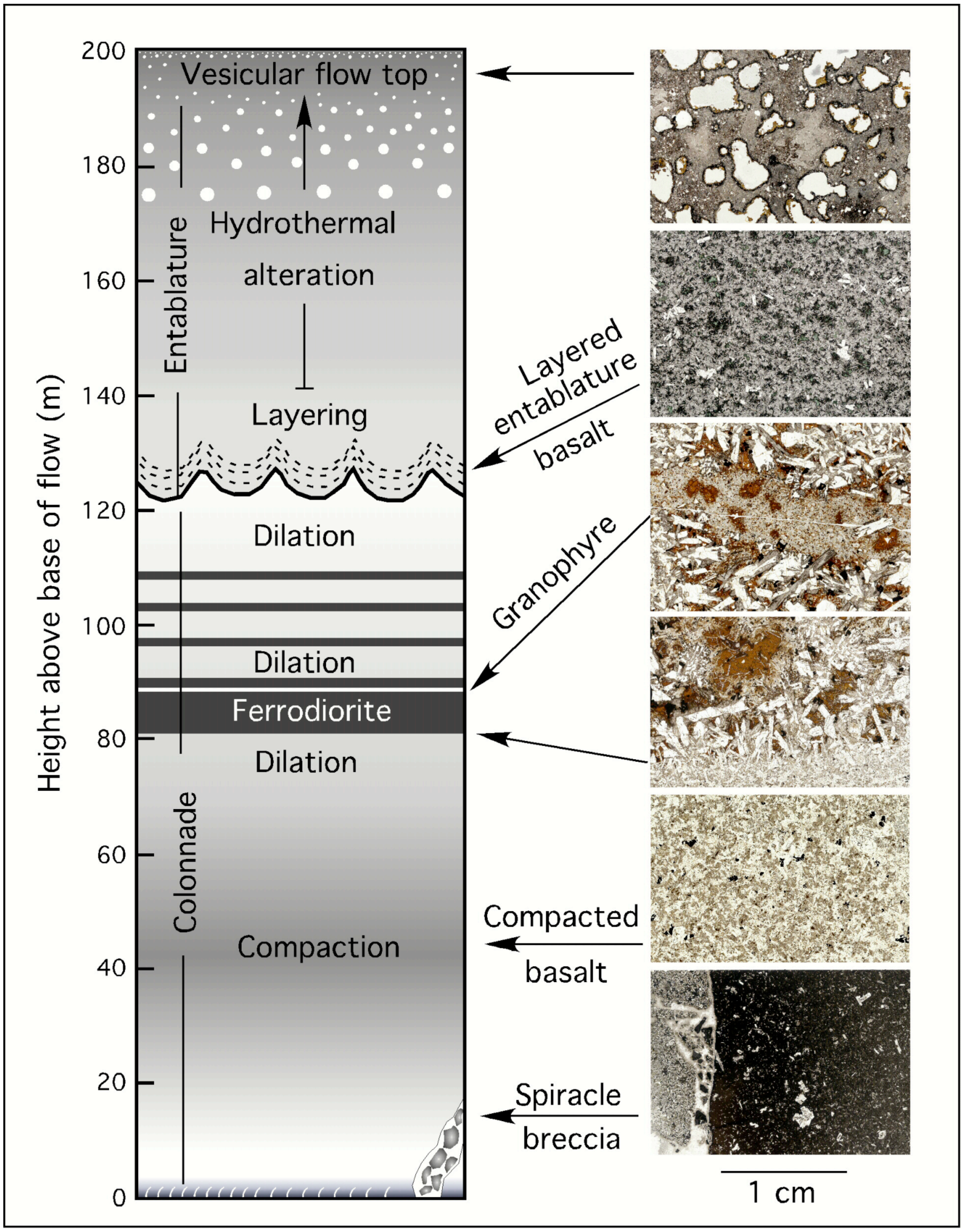

Figure 2.5

Photomicrographs of the different rock types in the Holyoke flow at the North Branford quarry under plane-polarized light and at a magnification given by the 1-cm scale bar.

From top to bottom:

a. Vesicular flow top with altered plagioclase phenocrysts in a devitrified matrix.

b. Basalt of the entablature with small ophitic clusters of pyroxene and plagioclase crystals separated by dark patches of mesostasis. The ophitic clusters and patches of mesostasis form a horizontal layering.

c. Sheet of fine-grained granophyre in the upper part of a ferrodiorite sheet.

d. Lower contact of coarse-grained ferrodiorite sheet with fine-grained basalt.

e. Basalt of the colonnade, showing clusters of small plagioclase crystals surrounding patches of granular pyroxene and equant magnetite grains.

f. Spiracle breccia (*left*) with fragments of crystallized basalt and fragments (*right*) with quenched glassy margins .

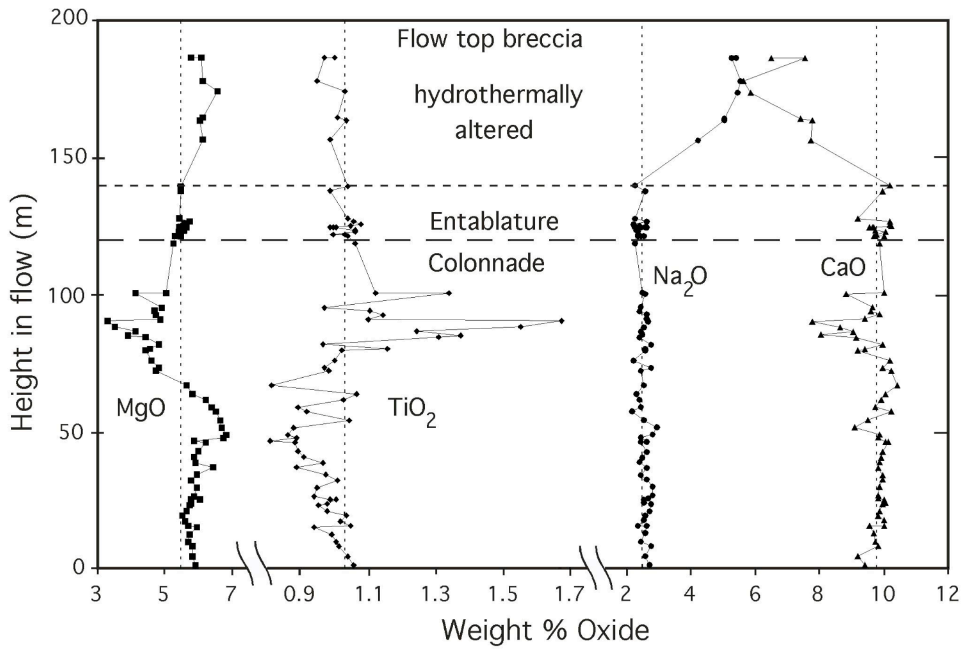

Figure 2.6 Chemical profiles through the Holyoke flow in the North Branford quarry.

About 75 m above the base of the flow, this trend reverses, and the basalt passes rapidly into a 10-m-thick sheet of coarse-grained ferrodiorite, which is depleted in MgO and enriched in TiO_2. Numerous decimeter-thick sheets of ferrodiorite occur at a regular 1-m spacing above this, continuing up almost to the colonnade/entablature boundary. Toward the top of most ferrodiorite sheets, thin centimeter-thick sheets of granophyre occur. At the colonnade/entablature boundary, the composition of the basalt is the same as at the chilled base of the flow. Above this, however, the basalt becomes severely altered and is depleted in CaO and enriched in Na_2O, presumably as a result of hydrothermal alteration brought about by water circulating through the crust of the flow as it cooled.

Calculations show that there is a mass balance through the enrichment and depletion profiles in the colonnade, and that the variation can be explained by the upward expulsion of residual liquid from a compacting pile of crystal mush. The degree of compaction in this crystal mush has actually been determined by quantitatively measuring textural anisotropy in oriented thin sections of the basalt. The maximum compaction measured in this manner is 12%, which occurs in samples with the lowest TiO_2. The liquid that was expelled from the mush dilated and eventually ruptured the basalt in the center of the flow to form the ferrodiorite sheets. Because these sheets were formed from liquid that contained few crystal nuclei, the resulting rock is coarse-grained, in contrast to the juxtaposed basalt which is fine-grained (Figs. 2.4, 2.5). There are no rocks with compositions intermediate between the basalt and the ferrodiorite. The reason for this is that for compaction to take place, an interconnected network of crystals must exist. Melting experiments show that this occurs in the Holyoke basalt when it is one-third crystallized. The melt that is expelled at this degree of crystallization has the composition of the ferrodiorite.

The origin of the granophyre poses a problem. Small amounts of interstitial granophyre can be found in any sample of Holyoke basalt, and it is even more abundant in the ferrodiorite. The granophyre sheets typically occur near the top of ferrodiorite sheets and are composed of a fine-grained intergrowth of alkali feldspar and tridymite with minor fayalite and hedenbergite-rich pyroxene. Their association with the ferrodiorite suggests that they are derived from it. However, both of these rocks were formed from liquids, but there are no rocks with compositions intermediate between the ferrodiorite and the granophyre. How, then, could the ferrodiorite liquid change into the granophyre liquid without leaving a trace of intermediate compositions?

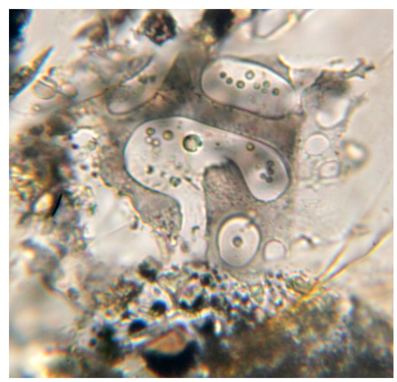

Figure 2.7 Photomicrograph under plane polarized light of glassy immiscible Si-rich (clear) and Fe-rich (brown) droplets in the mesostasis of the basalt in the entablature of the Holyoke flow. The composition of the Si-rich glass is identical to that of the granophyre sheets in the Holyoke basalt. The Fe-rich glass has the composition of an Fe-rich pyroxene with additional ilmenite and apatite. On crystallizing, this liquid could go undetected on the margins of crystals and in interstitial patches. Any resemblance of the large Si-rich droplet to Snoopy is purely coincidental. Width of field 66 mm.

A possible solution can be found in the entablature of the Holyoke flow, where rapid quenching preserved glasses with evidence of liquid immiscibility (Fig. 2.7). When the basalt in the entablature was approximately 75% crystallized, the residual liquid entered a 2-liquid field and split into immiscible fractions, one having an iron-rich pyroxene composition and the other a granophyre composition. In the center of the flow, where cooling was slower, this same immiscibility could have allowed a granophyric liquid to separate and accumulate toward the top of the ferrodiorite sheets. The conjugate iron-rich liquid would have sunk and accumulated amongst the crystals in the ferrodiorite where it would have crystallized to iron-rich pyroxene, magnetite, ilmenite, and apatite, which are abundant in the base of the ferrodiorite sheets (Fig. 2.5).

The following references may be useful if you want to read more about the information presented above.

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Chapter III.

The stone that shaped America in the 19th century: The geology and history of the Portland brownstone quarries.

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Geology of Portland Brownstone.

Located less than 3 kilometers from the eastern border fault of the Hartford basin, the Portland brownstone quarries and nearby exposures illustrate the diversity of sedimentary environments at the rift margin (Figs. 3.1, 3.2). Within 1 kilometer of the quarries, boulder conglomerate, organic-rich laminated black shale, and fluvial sandstone and siltstone all may be observed. The Portland quarries occupy a position on the western edge of the Crow Hill Fan complex that has its depocenter near the high school on the top of Crow Hill, in Portland (Fig 3.3). The eastern edge of the fan complex is observed along Route 17 in Portland, near the golf course, where boulder conglomerate is exposed in road cuts and natural outcrops. The southern margin of the fan complex is observed along the north side of Route 66 in the vicinity of the miniature golf course where thinning and fining wedges of the fan conglomerate lithosomes are observed. The Connecticut River laps against the northern flank of the fan complex in the vicinity of Petzold's Marina where a long stratigraphic section of interbedded alluvial fan and deep water lacustrine deposits, reminiscent of the Hales Brook Fan-Delta (Fig. 3.1) located south of Old Maids Lane in Portland.

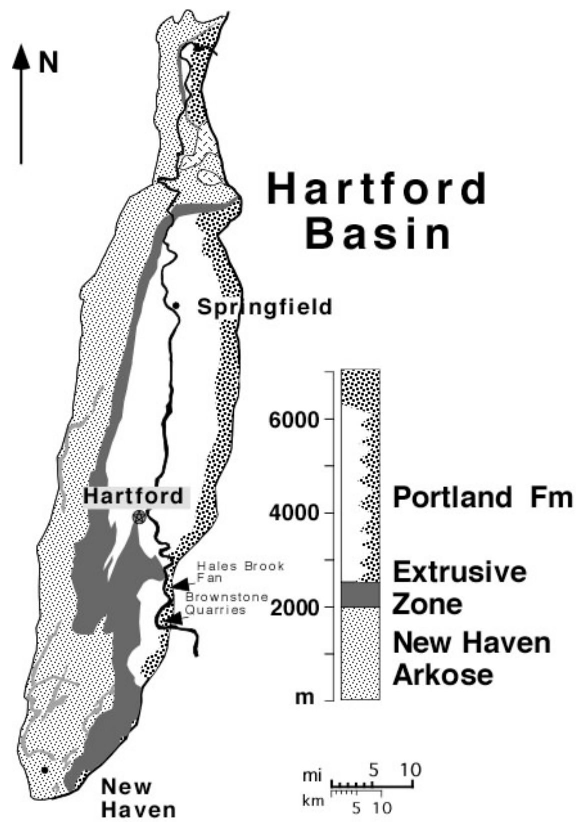
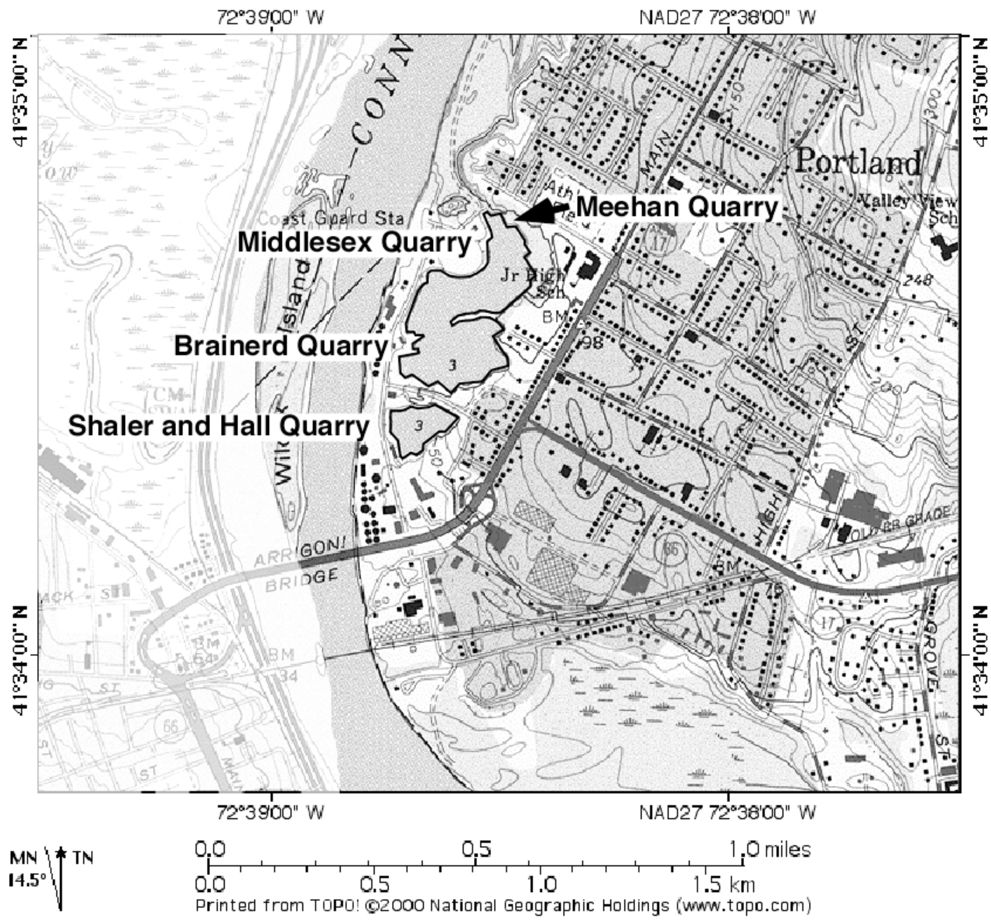


Figure 3.1 Summary of Hartford basin stratigraphy and location of the Portland brownstone quarries.

The Portland brownstone quarries (Fig. 3.2) consist of two large, water-filled pits. The main (northern) pit, where we will focus, consists of the Middlesex quarry on the north side of the promontory and the Brainerd quarry on the south side. South of Silver Street, which bisects the quarries, are the Shaler and Hall workings.



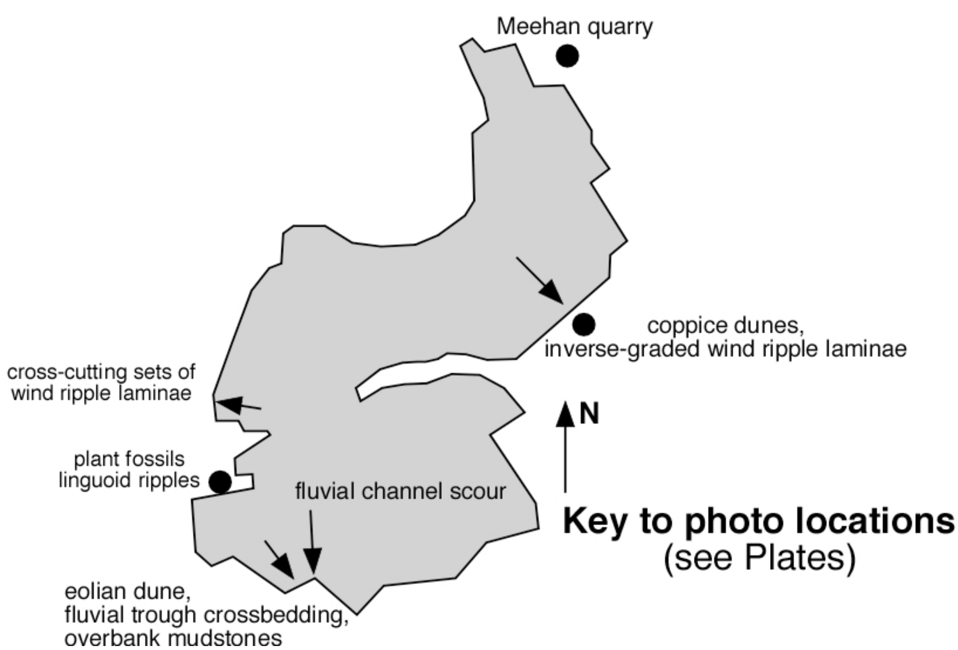


Figure 3.2 Location of the Portland brownstone quarries.

It is surprising that, given their obvious appeal to geologists, very little work has been done on the sedimentology and structure of the rocks, perhaps due to difficulties in approaching the towering quarry walls in the water-filled pits. Nevertheless, several studies including Krynine (1950), Lehmann (1959), Gilchrist (1979) and Hubert, Gilchrist and Reed (1982) provided partial descriptions of the Portland Formation rocks exposed in the quarries. The type section for the Portland Formation (Arkose), atypical though it is for the formation as a whole, was described by Kyrnine (1950). A definitive and captivating account of the history of the brownstone quarries is found in Guiness (2003). LeTourneau (1985) discusses the rocks of the vicinity in context of the paleogeographic distribution of alluvial fan complexes located along the rift margin in central Connecticut.

Brownstone is the trade name for the Portland Formation arkosic sandstone ("Portland arkose"), which is made of quartz and feldspar sand with calcite and hematite cement. Long-regarded as mainly a fluvial deposit, the quarry exhibits many features indicative of stream or river environments, including sand and gravel channels, gravel bars, and overbank sand and silt. Evidence of episodes of desiccation include mudcracks and dinosaur tracks.

Re-examination of sedimentary features reveal that eolian deposits are a significant component of this sequence (LeTourneau, 2002; LeTourneau and Huber, 2006). These rocks contain sedimentary features attributable to sand sheets, low angle dunes, and linear "coppice" dunes. The eolian beds were apparently preferred for building stone because of their grain size and texture. Fluvial beds in intervals about 15m thick alternate with the eolian beds, indicating possible cyclic climatic control on deposition.

A view to the north and east shows the dramatically different character of the downsection rocks in the Middlesex pit, in particular the massive sandstone forming the large wall on the eastern side. Notably, the intercalated fine-grained rocks are nearly absent in this part of the quarry.

A close view of the large east wall of the Middlesex pit reveals an abundance of inverse-graded low-angle inclined planar stratification indicative of migrating wind ripples (pin-stripe lamination). In additional several enigmatic large-scale convex-up dune forms may be observed. LeTourneau (2002) and LeTourneau and Huber (2006) ascribed these unique sedimentary structures as "coppice dunes" formed around clumps of plants. Evidence for the coppice dune origin of these features includes, complex internal stratification with root traces, inverse-graded wind ripple lamination. A modern model for the Portland brownstone eolian deposits is the Stovepipe Wells dune field in Death Valley, California. There a relatively thin sheet of dune sand overlaps alluvial fan and fluvial deposits on the edge of the extensional basin. Small coppice dunes anchored by plants are found in the interdune areas (Fig. 3.8).

Eolian sedimentation in the upper part of the Portland Formation at Portland was promoted by both favorable paleolatitudinal position, deposition within the dry climatic interval of a 405 ky cycle, and proximity to fan-related sources of sand. These deposits formed at about 20° paleolatitude, on the arid side of the estimated 10° latitude arid-humid climate

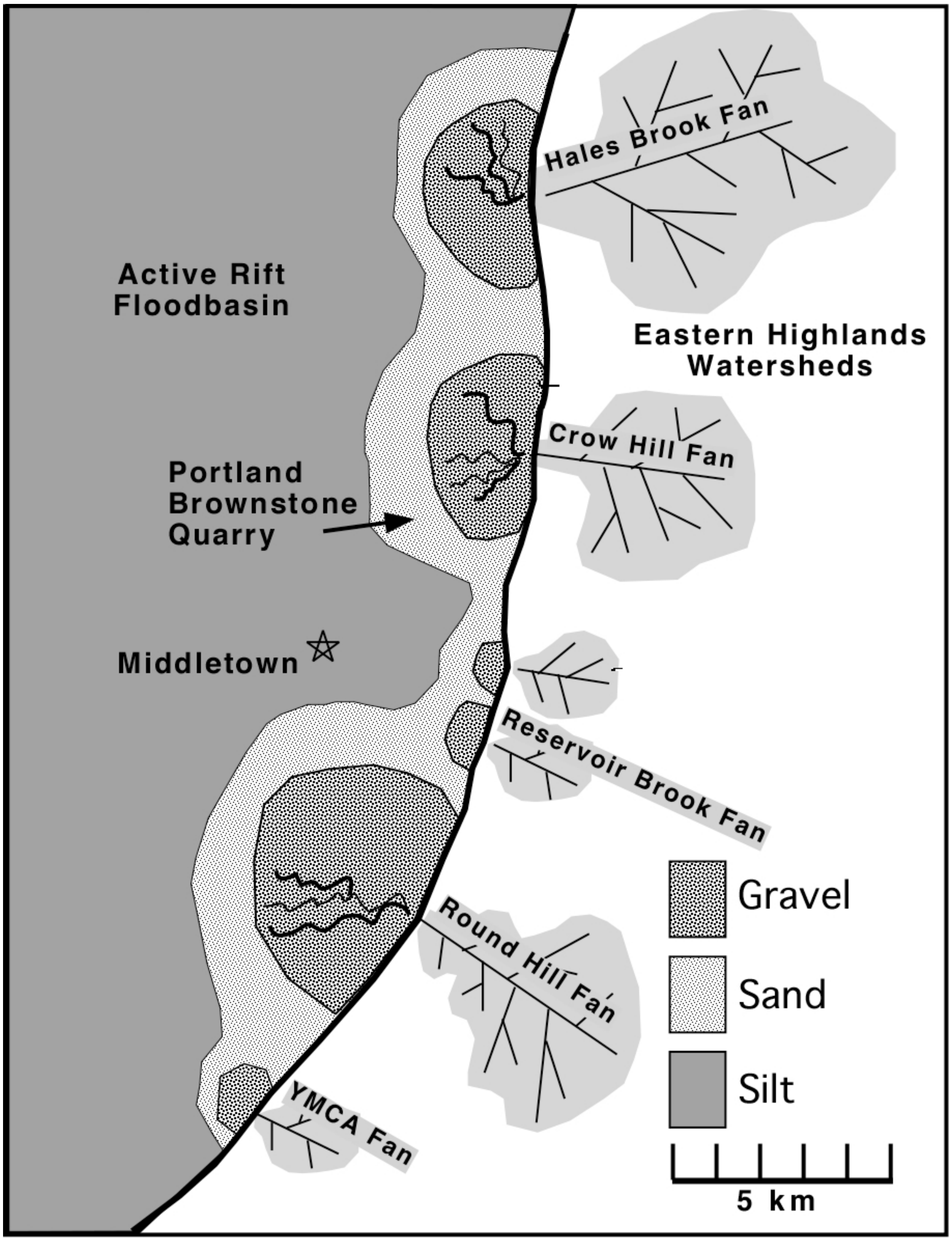


Figure 3.3 Paleoenvironmental reconstruction.

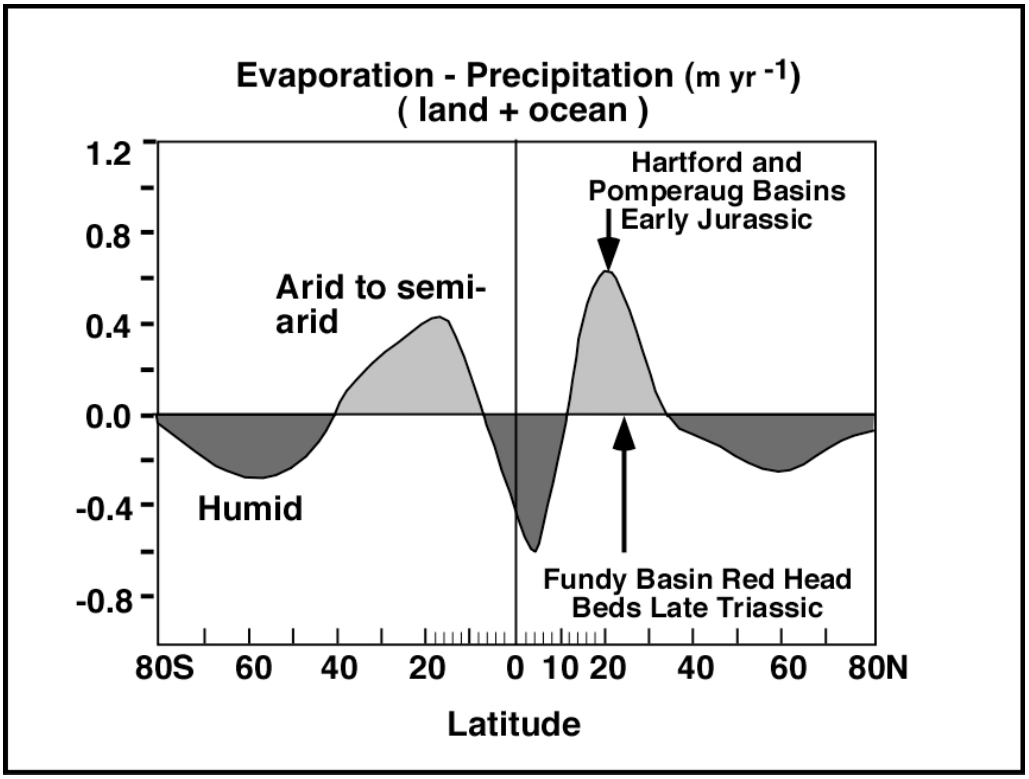
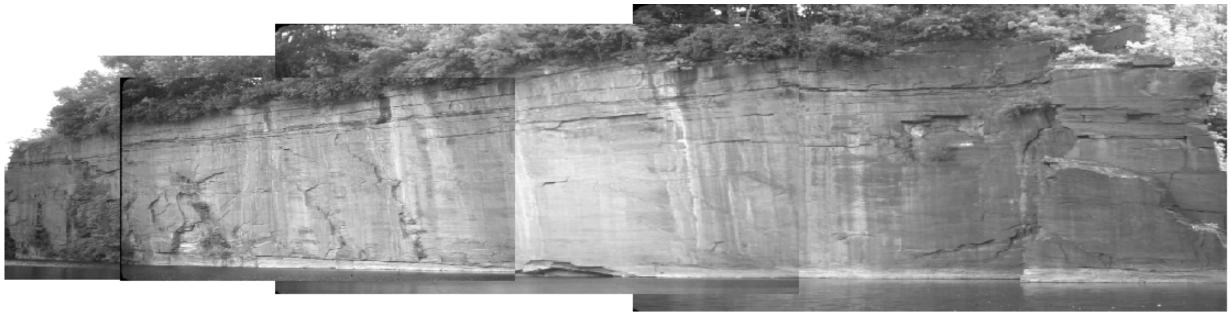


Figure 3.4 Paleolatitude of rift basins and comparison to modern climate zones.

boundary based on the evaporation-minus-precipitation models of Crowley and North (1991). The presence of eolian sand suggests that the Early Jurassic humid equatorial climatic zone may have been constrained to a narrow zone less than 10 degrees north and south of the paleoequator.

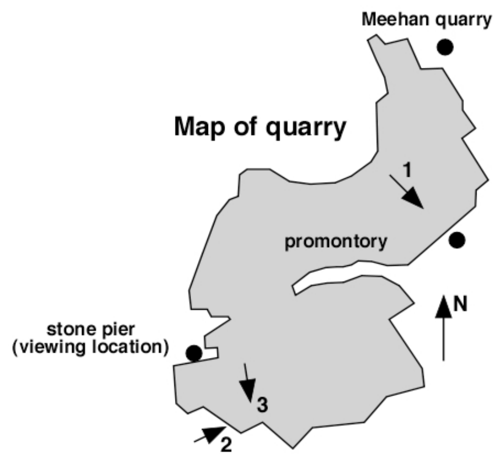
High-resolution correlations with arid to semi-arid intervals in the nearby Newark basin support the hypothesis that the eolian sandstones are indicators of regional paleoclimate conditions, rather than just local depositional environments.

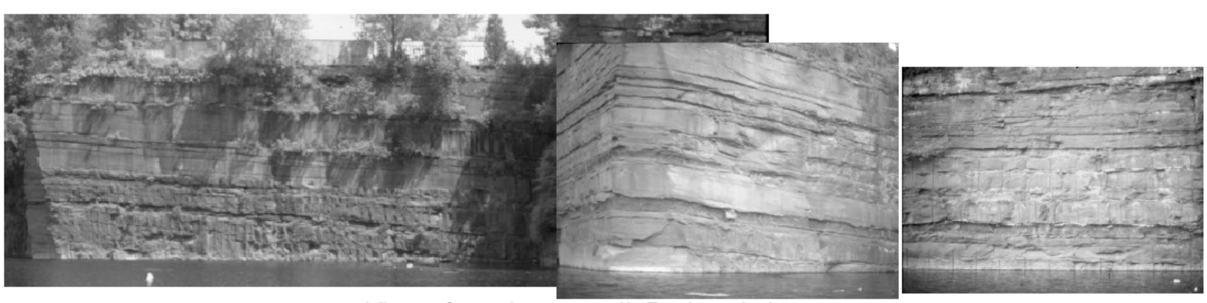
Arid intervals, indicated by eolian sand beds occur throughout the Hartford basin section (Fig. 3.x). It is interesting to note that the two most productive and important sandstone quarries contain substantial, or mainly, eolian sediments. Eolian beds used for building stones were also quarried at and near the New Gate prison copper mine. The high permeability and high porosity beds host hydrothermal malachite that was mined for copper ore during Colonial times.



1. View of southeast wall, Middlesex pit
(see map for direction of view)

2. View of northeast wall, Brainerd pit
(see map for direction of view)



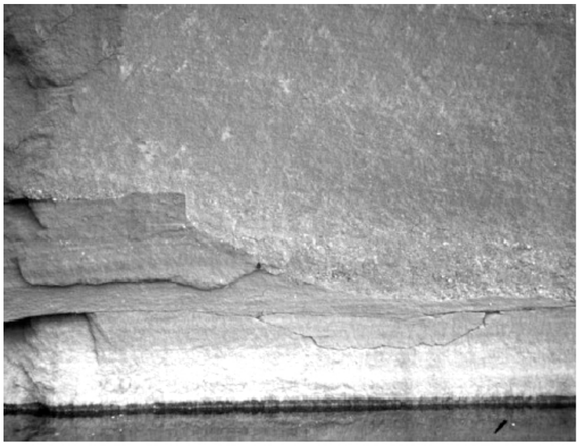


3. View of southwest wall, Brainerd pit
(see map for direction of view)

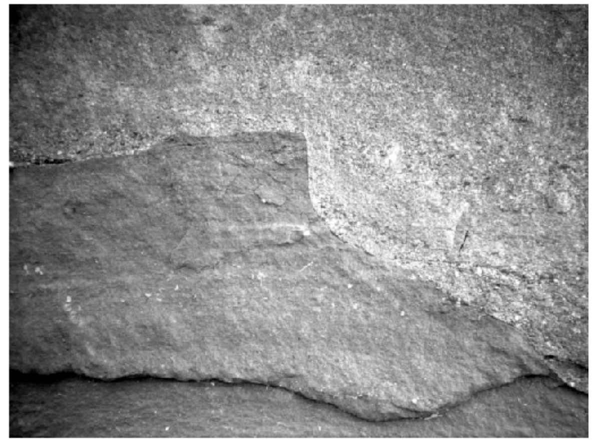
Figure 3.5 Portland brownstone quarry details

Fossils are relatively common in the Portland quarry, but they occur as traces, molds, and casts rather than mineralized remains. Dinosaur tracks including the three-toed prints of the carnivorous therapods *Eubrontes* and *Grallator*, and the large prints of the prosauropod *Otozooum*. Excellent examples of these types from the Portland quarry are on display at Wesleyan University and Dinosaur State Park. .Small, terrestrial crocodiles created quadrupedal tracks known as *Batrachopus*. Burrowing invertebrates also left their marks in the wet sediment. Backfilled burrows called *Scoyenia* are attributed to crayfish or other decapod crustaceans. Plant fossils include layers of macerated debris and putative branch and trunk casts.

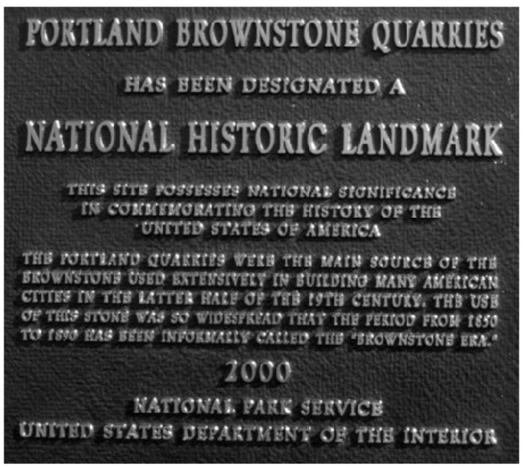
Figure 3.6 Paleoenvironmental reconstruction of the central Connecticut Valley during a wet phase of Portland time. Prosauropods, makers of the *Otozooum* tracks, graze on ferns and cycads near littoral-deltaic strand. Auracarian conifers form the fringe of the montane forest. The Portland quarry will be located near the edge of the large alluvial fan shown in the center-rear background. *Drawing:* P.M. LeTourneau.



a. Channel scour. Base contains channel-lag gravel.



b. Detail of channel scour showing gravel lag



c . National Historic Landmark sign
Portland Brownstone Quarries

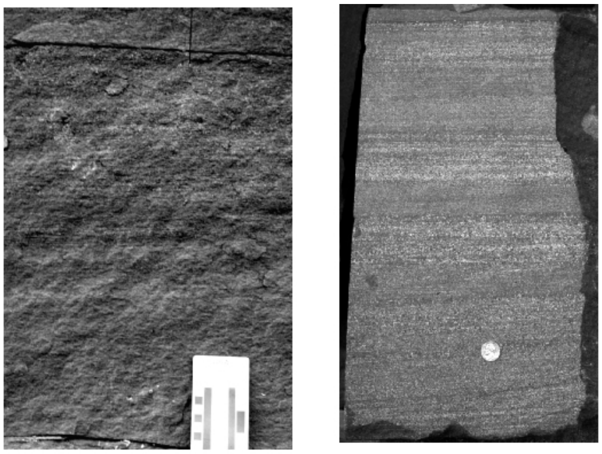
d. Postcard view of the Portland brownstone quarry, early 20th century

e. Active Meehan quarry located at northwest corner of Middlesex (main) pit

f. Quarryman Michael Meehan (left) discusses the finer points of brownstone with paleontologist Nick McDonald

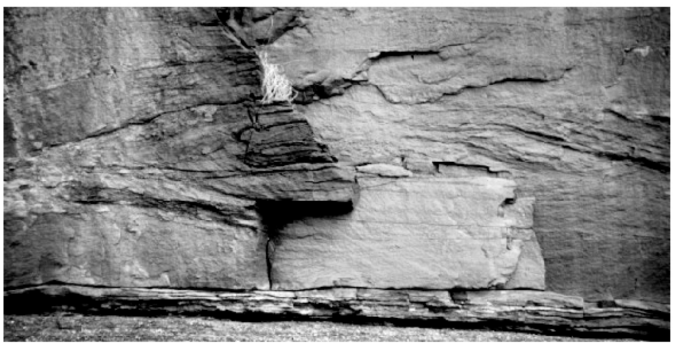
Portland brownstone quarry, Portland, Connecticut.

Figure 3.7



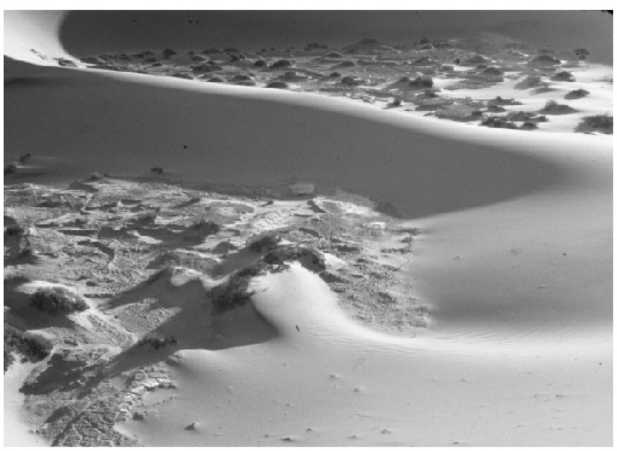
a. Inverse-graded wind ripple laminae
left: outcrop. right: cut slab

b. Grainfall and grainflow toesets on
eolian dune, Portland quarry

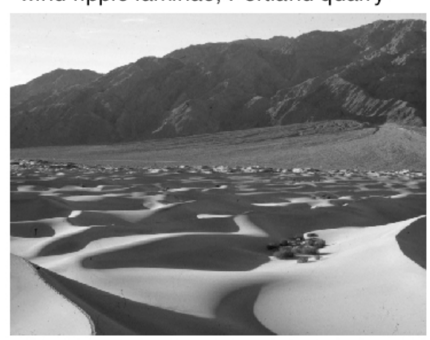


c. Eolian coppice dune, Portland quarry

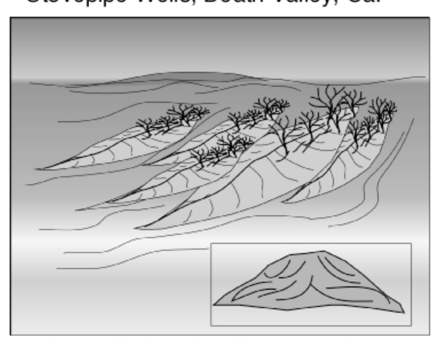
d. Cross-cutting sets of inverse-graded
wind ripple laminae, Portland quarry



e. Eolian coppice dune, Stovepipe Wells
dune field, Death Valley, California

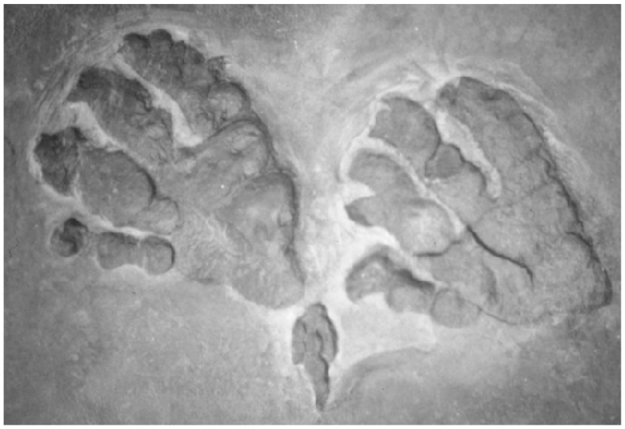


f. Thin dune field lapping on alluvial fan,
Stovepipe Wells, Death Valley, Ca.



g. Schematic drawing of coppice dunes and
internal structures (inset)

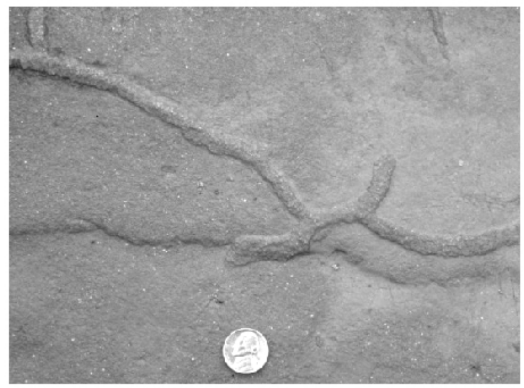
Eolian Features of the Portland Brownstone Quarry
Figure 3.8



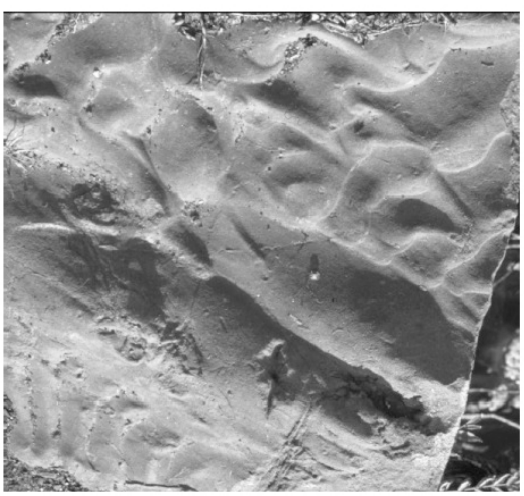
a. Otozooum and Grallator tracks
Wesleyan University Collection

b. Batrachopus manus and pes
impressions

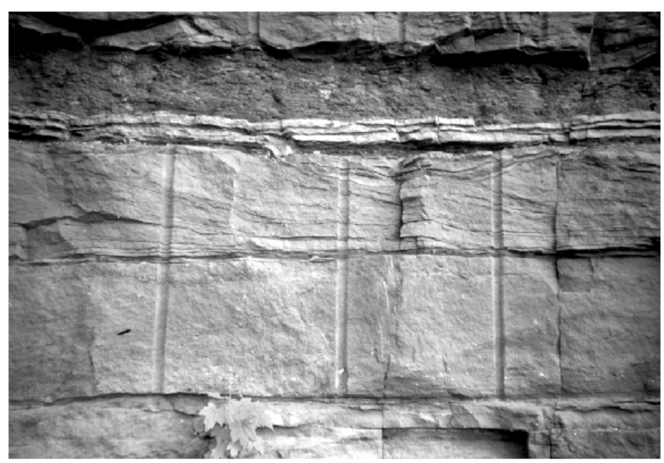
c. Plant stem impressions



d. Meniscate backfilled “Scoyenia” burrows



e. Linguoid ripples in fluvial sandstone



f. Trough cross-bedded fluvial sandstone
and overbank mudstone

Fossils and fluvial features of the Portland brownstone quarry
Figure 3.9

The stone that shaped America.

No building material is more closely associated with American cities than brownstone. The word conjures up images of row houses, elegant town-homes, ornate decorative carvings and monuments. Brownstone was a highly fashionable and desired building material during the late 1800's and early 1900's. The golden age of urban development coincided with the peak desire for the warm brown stone, as a result brownstone buildings are common in cities along the eastern seaboard.

The story of Portland Brownstone began over 185 million years ago when North America, South America, Europe, and Africa were joined together into a "super-continent" called Pangea ("all-land"). During the Early Jurassic the Connecticut Valley rift was marked by alternating wet and dry climatic intervals. with warm and dry climates favoring the formation of sand dunes and seasonal rivers. The Portland brownstone was deposited near the eastern margin of the rift where alluvial fans, sand dunes and seasonal rivers occurred. The vagaries of erosion and sedimentation produced beds of medium-coarse relatively well-sorted sandstone that had good potential for dimension stone.

The Connecticut River flows through a central valley that contains thick deposits of red beds, and in places along the river, cliffs of red and brown sandstone may be observed. The Portland Brownstone quarry is located on the banks of the Connecticut River in Portland, Connecticut where early settlers noticed that the fine-grained sandstone was good for making mill stones (grinding stones) or for structural use in buildings (so-called "jamb-stones"). In Portland, the chance occurrence of fine eolian ("wind-blown") sandstone deposits was responsible for the growth of a regional industry and a national trend in architectural fashion. Other red bed quarries are found in the rift valleys of eastern Virginia, north-eastern Pennsylvania, New Jersey, and Connecticut, but none rival the fine quality and color than the stone found in Portland, Connecticut.

Stone was produced from the quarry beginning in the 1700s and by the late 1800s the brownstone industry was employing hundreds of workers from Wales and Germany, thriving in three quarries. Stone was cut in the quarry and then placed in storage areas for "seasoning", or allowing the natural groundwater in the stone to seep out, slowly firming the stone in the process. Unseasoned stone was subject to peeling or cracking as the water in the rock froze in the winter months.

The cut and seasoned stone was hauled by horse cart and later by steam-powered cable winches to barges docked on the riverbank. The sail-powered barges, called "brownstone schooners" hauled the stone to cities all over the east coast, with most of the stone destined for New York City. Almost every city on the east coast of the United States has fine examples of buildings made of Portland Brownstone, including San Francisco and Denver.

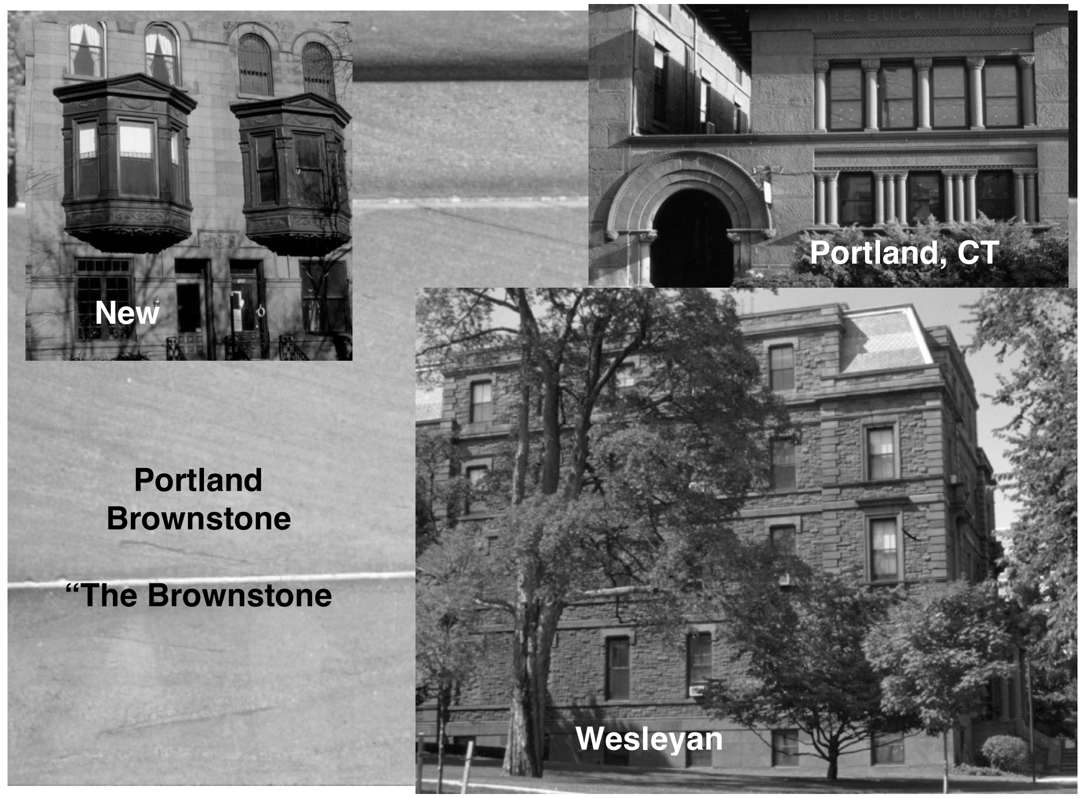
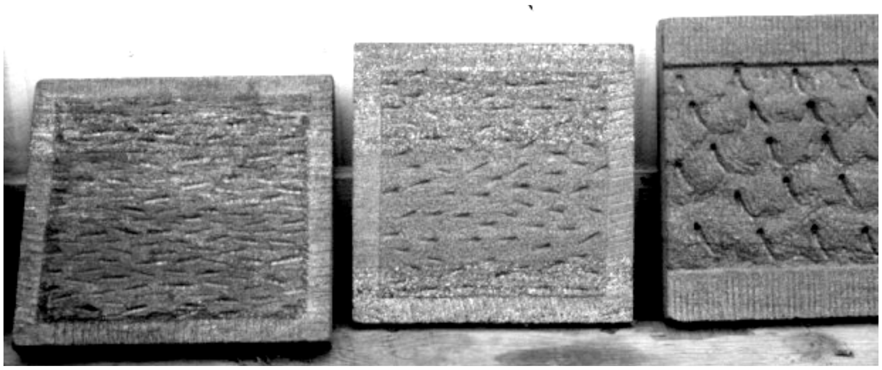


Figure 3.10
***Above*:** Mosaic of brownstone buildings.

Center: Quarryman Mike Meehan works a raw block of brownstone.

***Below*:** Hand-milled surfaces showing a variety of chiseled textures.



The popularity of Portland Brownstone would, however, lead to its demise because Portland, Connecticut was the only place on earth which was able to produce the high quality, fine, chocolate-color, stone desired by builders and architects. During the years of its peak use as a building stone, demand forced the main quarry in Portland to ship rock of less than the highest quality, including "unseasoned" stone. As the price of Portland Brownstone continued to increase, it was used as a "facing" stone, or thin veneer, an orientation that allowed water to seep into the bedding planes causing the stone to rapidly peel or break apart. Portland brownstone quickly gained a new, but undeserved, reputation as an unstable building material. Buildings made of high quality Portland Brownstone that was properly seasoned and placed are sound and beautiful even after more than 100 years. A notable example of a building constructed entirely of Portland Brownstone is the former Villard house, now the front of the Helmsley Palace hotel on Madison Avenue in Manhattan.

The Portland Brownstone quarries closed when a catastrophic flood of the Connecticut River in 1938 inundated the quarries and equipment, but the end was already in sight at that time because the popularity of the stone was in decline. The story of Portland Brownstone has opened an exciting new chapter. In 1994, a small quarry was re-opened on the banks of the main quarry to produce stone for architectural restoration and new building projects. Stone from this quarry is being used to restore the beautiful brownstone buildings of Wesleyan University in Middletown, Connecticut, and to build a library for Gaudellet University in Washington, D.C., among other notable projects. The old quarries were designated a National Historic Landmark in 2000, and the Portland Brownstone quarries are now under development as an historical park and recreational area.

North of the Middlesex pit, Michael Meehan (Figs. 3.7, 3.10) has brought the quarries full circle from early development, to abandonment, to renewed extraction of the historic brownstone. The Meehan quarry uses modern, non-explosive methods of extraction, and rather than the horse- and steam-powered equipment of the past, uses electric and diesel power to cut, shape, and transport brownstone. Standing on the promontory at the Meehan quarry we can peer into the geologic and historic past in the old quarries and see the modern re-emergence of layers than have not basked in the sun for over 190 million years.

Now the quarries enter yet another phase as well. In the 1990’s the Town of Portland purchased the brownstone quarries and in 2000 the quarries were designated a National Historic Landmark (3.7). Recently, a scuba center and water park opened in the main quarry. Preservation thus walks hand-in-hand with recreation. Offering managed recreation al access actually assuaged a main concern of the Town in aquiring the land -- safety. The abandoned pits long attracted vandalism, surreptitious dumping of debris, and teen-age cliff diving. Where steam whistles once signaled the start of the day for immigrant stone workers climbing steep ladders into the shadowed pits, shouts of "on-belay!" may soon reverberate from sun-drenched climbers clinging to thin holds on the sheer rock faces. From small crocodilomorphs scampering across sand flats in the Early Jurassic, to wind-blown dunes, to the clanging sound of hammers during the peak of brownstone production, to the now placid waters of the abandoned pits, the geologic and historic story of the Portland brownstone quarries is truly remarkable.

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Chapter IV.

Window into the Jurassic World: Reconstructing ancient environments with fossils, tracks, and traces at Dinosaur State Park.

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Introduction

Dinosaur State Park provides visitors a unique window into a world undergoing dramatic change. The Early Jurassic dinosaur footprints found here represent some of the very first dinosaurs to emerge from the catastrophic end-Triassic extinction (ETE). These dinosaurs were dramatically bigger than those that came before, and set the stage for 135 million years of evolutionary success. In addition to dinosaur fossils, the rocks of central Connecticut contain evidence of climate cycles, volcanism, and a changing flora and fauna across the Triassic-Jurassic transition. This history is encapsulated in rocks, fossils and dioramas found at the Park.

Dinosaur State Park is located within the Hartford Basin, one of at least 13 exposed rift basins along the eastern margin of North America (Fig. 4.1). The basins formed as Pangaea began rifting apart in the late Triassic. The developing valley filled with a succession of sediments and lava flows, the remains of which span more than 40 million years and up to 7 km thickness (Burger and Ataman, 1984; Olsen, 1986; Wenk, 1983). Of all the exposed Mesozoic rift basins, the Hartford Basin includes the thickest and most detailed section of early Jurassic deposits (Kent and Olsen, 2008), overlying 3000 meters of Late Triassic strata that contain clear evidence of the ETE.

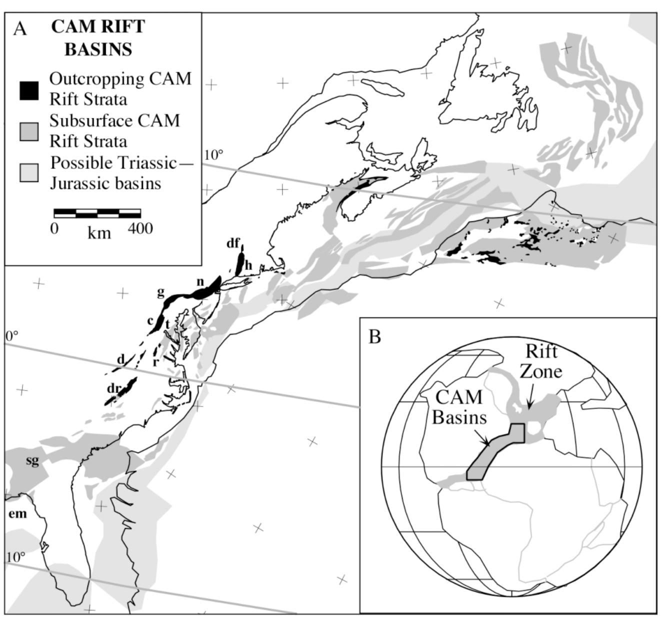

Figure. 4.1 Central Atlantic Margin (CAM) rift basins in their paleogeographic position for the Carnian (~225 Ma).

A. Major components of Newark Supergroup strata in outcropping basins labeled o (Orpheus), f (Fundy), df (Deerfield), h (Hartford), p (Pomperaug), n (Newark), g (Gettysburg), c (Culpeper), t (Taylorsville), r (Richmond), fm (Farmville), d (Dan River-Danville), and dr (Deep River).

B. Reconstruction of Pangea for the Carnian, showing the rifting zone (*gray*) and the CAM basins detailed in *A.* Figure from (Olsen, 1997)

The Late Triassic in Connecticut

During the Late Triassic, Connecticut was located within the humid-arid transition of central Pangaea at ~20 degrees paleolatitude (Kent and Tauxe, 2005). The incipient rift basin was bordered to the east and west by tall mountains, ensuring a steady supply of sediments into the basin. The fluvial environments of the basin at that time can be seen in the arkosic New Haven Formation that makes up the lowest unit of basin fill.

The New Haven Formation is composed mainly of reddish sandstone, siltstone and conglomerate deposited in river and stream channels and on river floodplains. Only a few fossils have been found within this formation, mostly skeletal parts of reptiles; no tracks or fish fossils are known from these rocks. The fluvial conditions were not ideal for preservation of fossils, but fossils from Late Triassic strata in other localities can help us reconstruct a detailed picture of life in Connecticut at that time.

The Sillin Mural and Diorama at Dinosaur State Park depict the Late Triassic environment in central Connecticut. A wide, shallow floodplain with braided channels covers the floor of the rift basin. The base of the mountains to the east marks the location of the Eastern Border Fault, a normal fault accommodating extension during the rifting of Pangaea. The Late Triassic reptiles and amphibians depicted in the mural include dinosaurs such as *Coelophysis*, but dinosaurs were not yet dominant. Crocodile-like phytosaurs were among the top predators during this time. Remains of a Late Triassic reptile similar to the phytosaur *Rutiodon* have been found in the New Haven Formation in Simsbury, Connecticut. The huge amphibian *Metoposaurus*, a distant relative of modern salamanders and newts, grew up to ten feet long. Specimens of *Metoposaurus* are known from Late Triassic rocks in New Jersey, Pennsylvania, and Nova Scotia. Other fossil evidence from this time period indicates the presence of the reptiles *Erpetosuchus*, *Stegomus*, and *Hypsognathus* in the Hartford Basin (McDonald, 2010).

The End-Triassic Extinction

Tetrapod diversity was rising to a peak in the Late Triassic when the dominant vertebrates disappeared abruptly, over a period of less than 850,000 years. The extinction also included many marine invertebrates, including all conodonts, most brachiopods, almost all nautiloid and ammonite families, and most bivalves (Hallam, 1981; Olsen et al., 1987), making this one of the largest of the Phanerozoic extinctions. In the basins of eastern North America, the ETE is clearly indicated by the disappearance of typical Triassic pollen and spores and subsequent appearance of typical Early Jurassic (Hettangian) assemblages (Fowell et al., 1994).

A transient but marked increase in fern spore abundance occurred about 1 ky above the last occurrence of Triassic pollen and spores, and about 5 ky below Hettangian assemblages (Olsen et al., 2002). Such fern spikes commonly occur in the aftermath of catastrophic extinctions, when the rapid dispersal of spores allows ferns to quickly repopulate devastated landscapes.

Two other features of strata from the ETE hint at possible causes of the catastrophe. Core and outcrop samples from both the Newark and Hartford Basins contain organic matter that shows a large negative carbon isotope excursion at 201.4 Ma (Whiteside et al., 2010). As a result of photosynthesis, plants contain carbon isotopes that reflect atmospheric levels. The negative carbon isotope anomaly measured in preserved plant matter indicates an increase in atmospheric CO_2. In addition, an increase in iridium (Ir) above background levels was found within a clay layer at four localities in the Newark basin (Fig. 4.2). The Ir anomaly tightly correlates with the timing of both the fern spike and the overall extinction (Olsen et al., 2002)

Widespread, voluminous lava flows could account for the CO_2 increase, the iridium anomaly, and the extinction. The Hartford Basin contains three formations of tholeiitic basalt correlated with Earth's largest continental flood basalt eruptions,

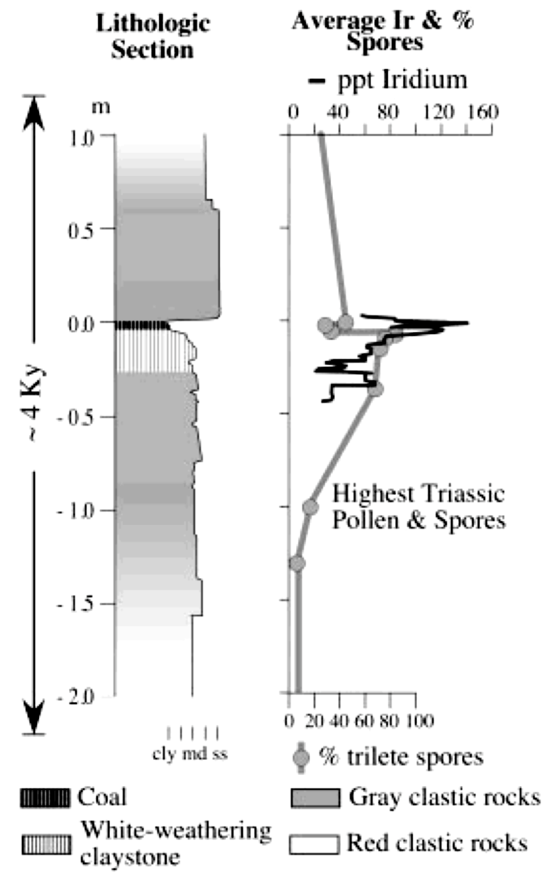

Figure 4.2. Fine-scale correlation between the Ir anomaly and fern spike (trilete spores) from the Jacksonwald syncline section of the Newark basin. Figure from Olsen et al. (2002).

those of the Central Atlantic Magmatic Province (CAMP). Paleomagnetic and geochronologic data indicate that within a period of a few million years, outpourings of lava covered an area that exceeded 7 million square kilometers (Marzoli et al., 1999). Although the first lava flows in the Hartford Basin post-date the ETE by about 20 ky (Olsen et al., 2002), older CAMP flows in other areas could account for the initiation of the ETE (Whiteside et al., 2010).

Early Jurassic Stratigraphy

In the Hartford Basin, CAMP basalts spanning a period of ~600 ky are interbedded with sedimentary strata which record the changing environment of the earliest Jurassic (Olsen et al., 1987). In contrast with the fluvial New Haven Formation of the late Triassic, Early Jurassic units are made up of finer-grained lacustrine deposits. The shift to primarily lacustrine environments most likely reflects a period of rapid extension and footwall uplift (Olsen, 1997; Olsen et al., 2005) which resulted in a deep, closed drainage basin. The Shuttle Meadow and East Berlin formations, which include the strata exposed at Dinosaur State Park, consist of lake deposits from this time.

These lacustrine strata show a remarkable cyclicity that reflects Milankovitch climate forcing. Changes in cloud cover and precipitation directly affected lake level and salinity, producing lithologically distinct sedimentary layers over time as the climate changed. Several different cycles can be recognized within the Hartford Basin. Van Houten cycles consist of three recognizable divisions which reflect periodic expansion and contraction of large, perennial lakes: lake transgression (division 1), high-stand (division 2), and regression and low-stand facies (division 3) (Olsen, 1986) (Fig. 4.3). Strata in each Van Houten cycle were deposited over a period of ~20 ky, with thicknesses of 10 to 30 m (~11m in the East Berlin formation). The lake transgression-regression cycles match periodic changes in the direction of Earth's axis of rotation (precession), which directly affects climate. Van Houten cycles are in turn modulated by 100 ky, 405 ky, and 1.75 and 3.5 my cycles that match changes in the eccentricity of Earth's orbit around the Sun (Olsen et al., 2005).

Cyclicity within the Newark Supergroup can be used to correlate strata within and between basins, and more importantly, to place strata within a high-resolution, astronomically-tuned time scale. As a result, the timing of events in the aftermath of the ETE can be understood in great detail despite the absence of reliable radioisotope dates in the Hartford Basin. Though consistent with a Jurassic age, K-Ar and ^{40}Ar-^{39}Ar dates for Hartford Basin basalts exhibit substantial scatter (Seidemann et al., 1984) due to postcooling alteration. Basalts in the Newark basin have been more reliably dated, and correlate with those in the Hartford Basin on the basis of paleomagnetic and geochemical data (Kent and Olsen, 2008).

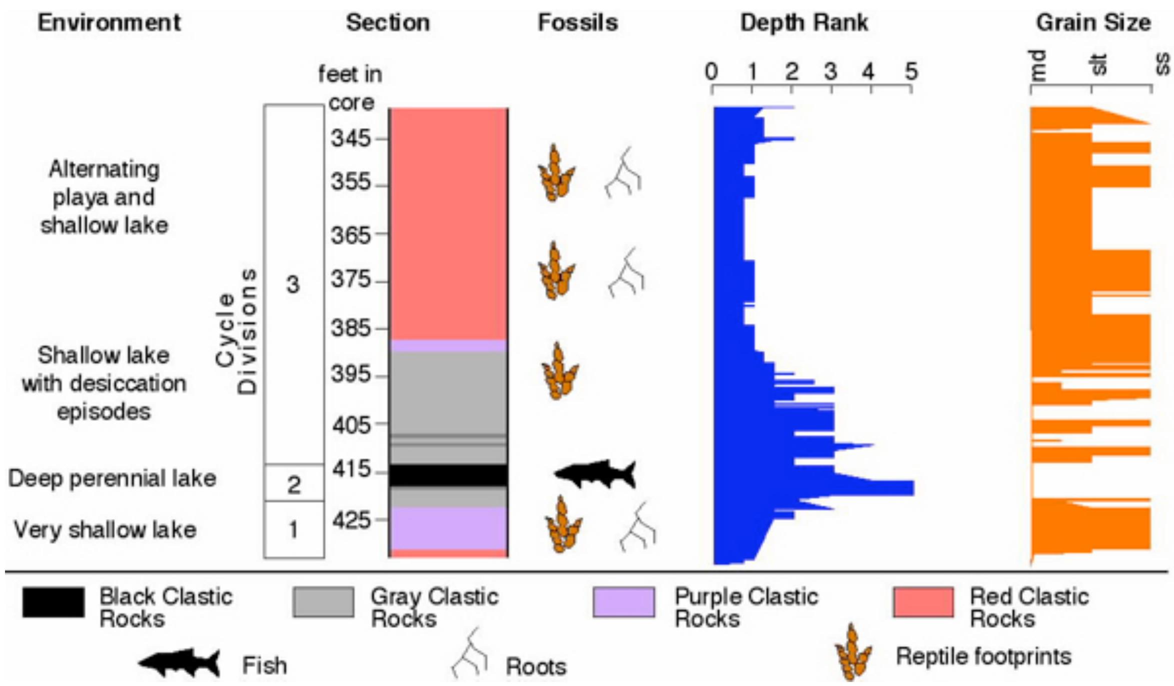

Figure 4.3 Lacustrine strata in the Newark and Hartford basins show cyclical changes in color, sediment fabrics, fossil preservation, and total organic carbon content. Shallow-water lacustrine and playa (dry-lake bed) deposits tend to be red and massive (from repeated bioturbation and mudcracking); very deep-water lacustrine deposits tend to be black and laminated or microlaminated. A Van Houten cycle records a complete cycle of the lake-level rise (division 1), lake high-stand (division 2), and lake-level fall (division 3). Depth rank is a relative index of water level (0=very shallow and 5=deep). Stratigraphy shown represents core data from the Towaco Formation of the Newark Basin, correlative with the East Berlin Formation in the Hartford Basin. Diagram by Paul Olsen.

The tracks exposed at Dinosaur State Park date to approximately 550 ky following the ETE, based on the cyclostratigraphy of outcrops and cores at the Park. The Hampden Basalt forms a ridge along the south and west boundaries of the Park (Fig. 4.4) along the yellow and blue trails. This basalt, formed during the last of the CAMP eruptions in the Hartford Basin ~600 ky ago, lies stratigraphically above the main track-bearing layer by ~38 m (Olsen et al., 2005).

The inferred thickness of strata between the basalt and the track layer spans ~ 60 ky, or three Van Houten cycles. Neither the top nor the base of the basalt is exposed, and the exact stratigraphic position of the track layers below the Hampden Basalt is based on correlation with extensive exposures of the East Berlin Formation along Route 9.

The outcrop preserved in place within the Exhibit Center shows a black shale layer overlying the gray sandstone containing the tracks. The black shale layer and track-bearing sandstone are also visible in a small outcrop to the east of the entrance to the Exhibit Center first described by Byrnes (1972), although only the top of the sandstone unit containing the main track surface is exposed there.

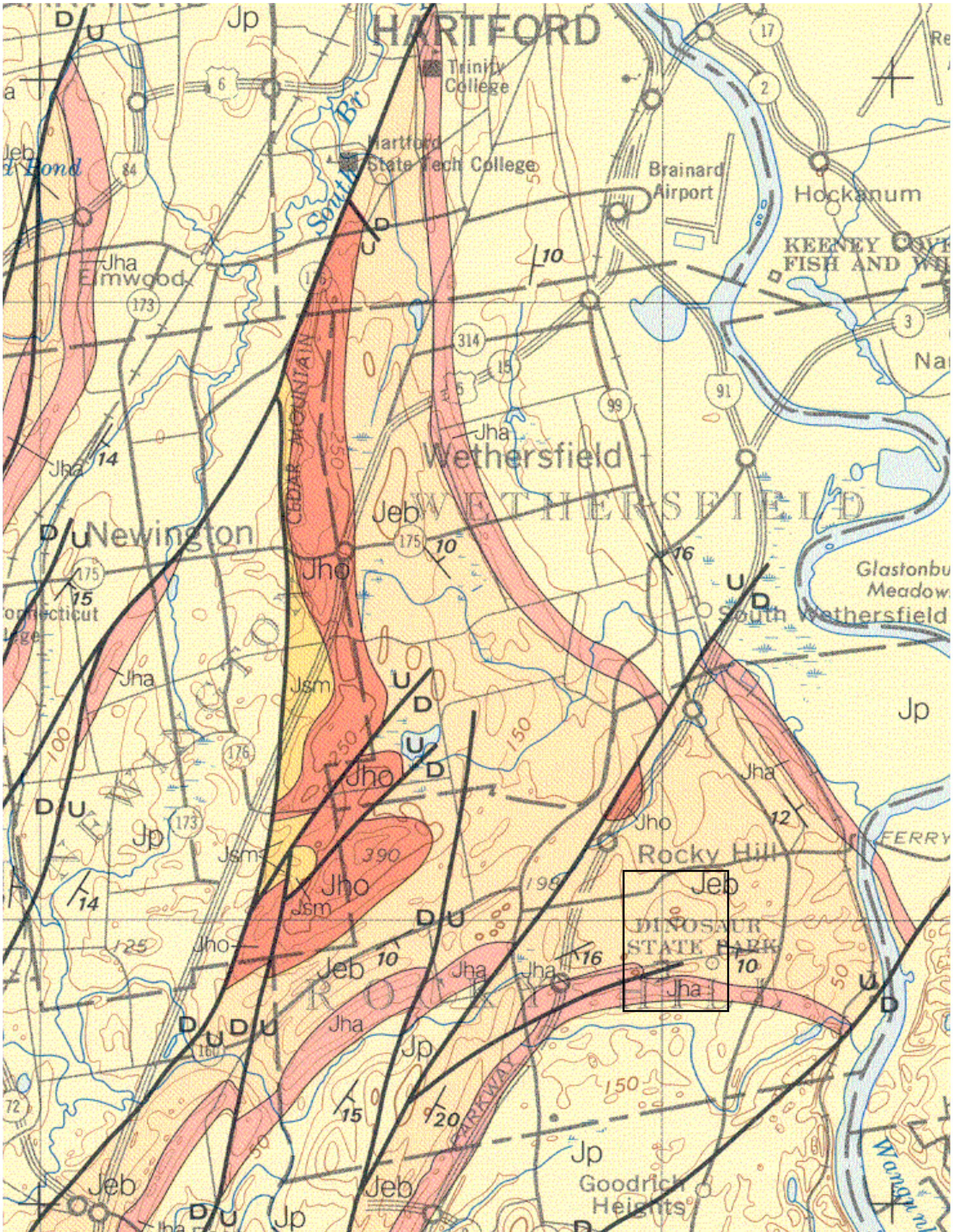

Figure 4.4 Geologic map of Dinosaur State Park and vicinity. Black square is approximate location of park. **Jeb** = East Berlin Formation, **Jha** = Hampton Basalt. Dark lines indicate faults. Map is portion of Connecticut State Bedrock Map by John Rodgers (1985).

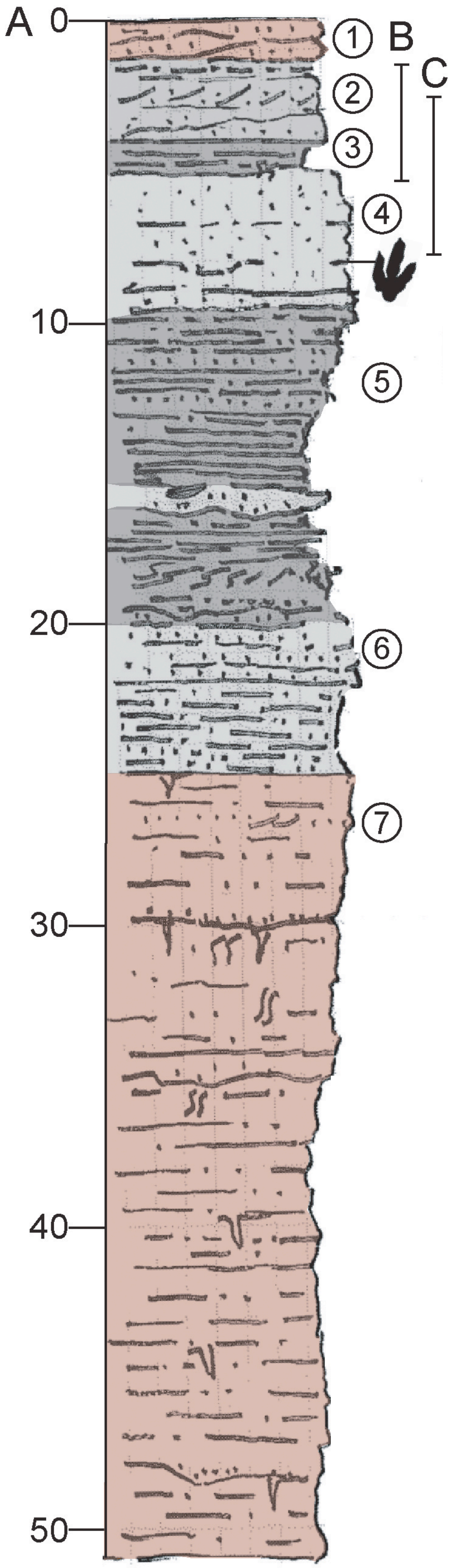

Figure 4.5
Description of Dinosaur State Park Core No. 2. Coordinates: 72° 03′ 36″ W / 41° 40′ 40″ N. (Byrnes, 1972). Core is south of the fault described in Ostrom and Quarrier (1968). Diagram by R. Steinen, based on observations by R. Steinen, N. McDonald, P. Drzewiecki, and M. Soares in 2007.
Note: Depth in feet not corrected for slight thickness exaggeration caused by 11° dip.

B. Section exposed at outcrop east of Exhibit Center entrance.

C. Section exposed inside Exhibit Center.

Unit Descriptions:

1 Reddish-brown and gray medium to coarse-grained sandstone with siltstone partings.
2 Gray sandstone, fine to medium-grained, ripple-laminated, interbedded with gray siltstone.
3 Gray laminated siltstone/claystone; some disrupted bedding at base.
4 Light gray fine to medium-grained sandstone with siltstone interbeds; several disrupted horizons. Gray siltstone beds thicker towards the base. *Eubrontes* track layer at 8 feet.
5 Gray and dark gray mudstone with fine to coarse-grained sandstone interbeds. Mudstone laminated in places. Coarse layers with erosional bases and rip-up clasts. Prominent shear zone at 18 feet with slicken surfaces and “dead horses.”
6 Light gray, thin-bedded, fine to medium-grained sandstone with some gray siltstone interbeds. Grading downward to gray thin-bedded siltstone with minor very fine-grained sandstone interbeds.
7 Abrupt color change; reddish-gray and brown playa sequences ranging from several inches to a foot in thickness. Coarse to medium-grained sandstone or fine-grained ripple-laminated sandstone with erosional bases, overlying desiccated/turbated mudstone surface, grading up to fine-grained sandstone or siltstone and mudstone at top of each sequence. None of sandstones more than 1-2″ thick. Some mudcracks 6-10″ deep. Compaction distortions. Purple mudstone toward base.

Two cores drilled at Dinosaur State Park and described by Byrnes (1972) revealed a second black shale layer below the track surface, as well as a distinctive thick red sandstone unit (Fig. 4.5). The gray sandstone subdividing two black shales, underlain by thick red sandstone, most likely correlate with the third Van Houten cycle from the top of the East Berlin Formation as seen in both the Cromwell and Berlin roadcuts on Route 9 (Olsen et al., 2005). The "red-bed" sequences were deposited during a dry period in the Van Houten cycle, followed by lake transgression and high stand during wetter climate. The gray sandstone that contains the tracks represents a shallow-water and shoreline environment. The fact that the gray sandstone is sandwiched between two black shale units suggests that was a time of temporary lake shallowing during the overall high stand period (division 2) of the Van Houten cycle.

Recent digging associated with construction of a subdivision across from Dinosaur State Park to the west uncovered fish-bearing, black micro-laminated shale. The shale contained thin layers of dolomite, some discontinuous and resembling the "dead horses" of Olsen (1989).

This shale layer is tentatively correlated by Steinen (2006, pers. comm.) to the second lake cycle below the Hampden Basalt, stratigraphically above the main track layers. Another outcrop containing typical East Berlin Formation stratigraphy is found along West Street just to the west of the park, but the outcrop is overgrown and a detailed study has not been conducted. Several hand specimens from this outcrop show ripple-laminated very fine-grained sandstone and bioturbated siltstone (Steinen 2006, pers. comm.).

The tracks exposed at Dinosaur State Park can be seen on two beds of gray sandstone in the Exhibit Center which strike N85E and dip 7-10 degrees S, located on the south flank of a broad anticlinal structure gently plunging to the east toward the border fault (Ostrom and Quarrier, 1968). The upper bed averages 4 cm in thickness and consists of light gray, fine- to coarse-grained sandstone. Over 30 individual trackways, containing more than 500 tracks, have been identified on the exposed upper bed. The lower sandstone bed, visible near the walkway, resembles the upper bed in color and composition, and contains extensive ripple marks indicating shallow-water deposition.

Figure. 4.6 Type specimen of *Eubrontes giganteus* from Holyoke, Massachusetts, first described by Edward Hitchcock in 1836. Track length is about 15 inches. Photo by Paul E. Olsen.

The Early Jurassic in Connecticut

Nearly all of the 2000 tracks uncovered at Dinosaur State Park have been identified as *Eubrontes giganteus (*Fig. 4.6), attributed to a large bipedal theropod dinosaur based on track size, shape, and distinct claw marks. No bones of this dinosaur have been found in the region, but measurements of track lengths suggest that the *Eubrontes* trackmaker stood about six feet tall at the hip (Thulborn, 1989). The earliest examples of *Eubrontes giganteus* were discovered in Early Jurassic strata of the Newark basin in New Jersey. These *Eubrontes* tracks first appear just ~10 ky after the ETE (Fig. 4.7), yet they are 20% larger than any theropod tracks from the Triassic. The increase in track length roughly scales to more than a doubling of mass. This sudden increase in theropod size after the ETE could have resulted from a significant drop in competitive pressure following the extinction event, allowing large theropods to thrive (Olsen et al., 2002).

Overlooking the tracks in the Exhibit Center is a mural and diorama depicting the shoreline of an Early Jurassic lake in the Hartford Basin. A life-size model of the theropod dinosaur *Dilophosaurus* forms the centerpiece of the diorama. There are no bony remains of *Dilophosaurus* in the region, but *Dilophosaurus* has been found in strata of the same age in Arizona. The size and foot anatomy of *Dilophosaurus* make it the best match, among fossils of earliest Jurassic age, for *Eubrontes* tracks.

Other Early Jurassic dinosaurs shown in the diorama include several turkey-sized ornithischians with distinctly bird-like beaks and feet. No skeletal remains of ornithischian dinosaurs have yet been unearthed in the region, but their presence is strongly indicated by small fossil tracks known as *Anomoepus*. *Anomoepus* footmarks first appear in early Jurassic strata, becoming abundant within 50 ky after the ETE (Olsen and Rainforth, 2003).

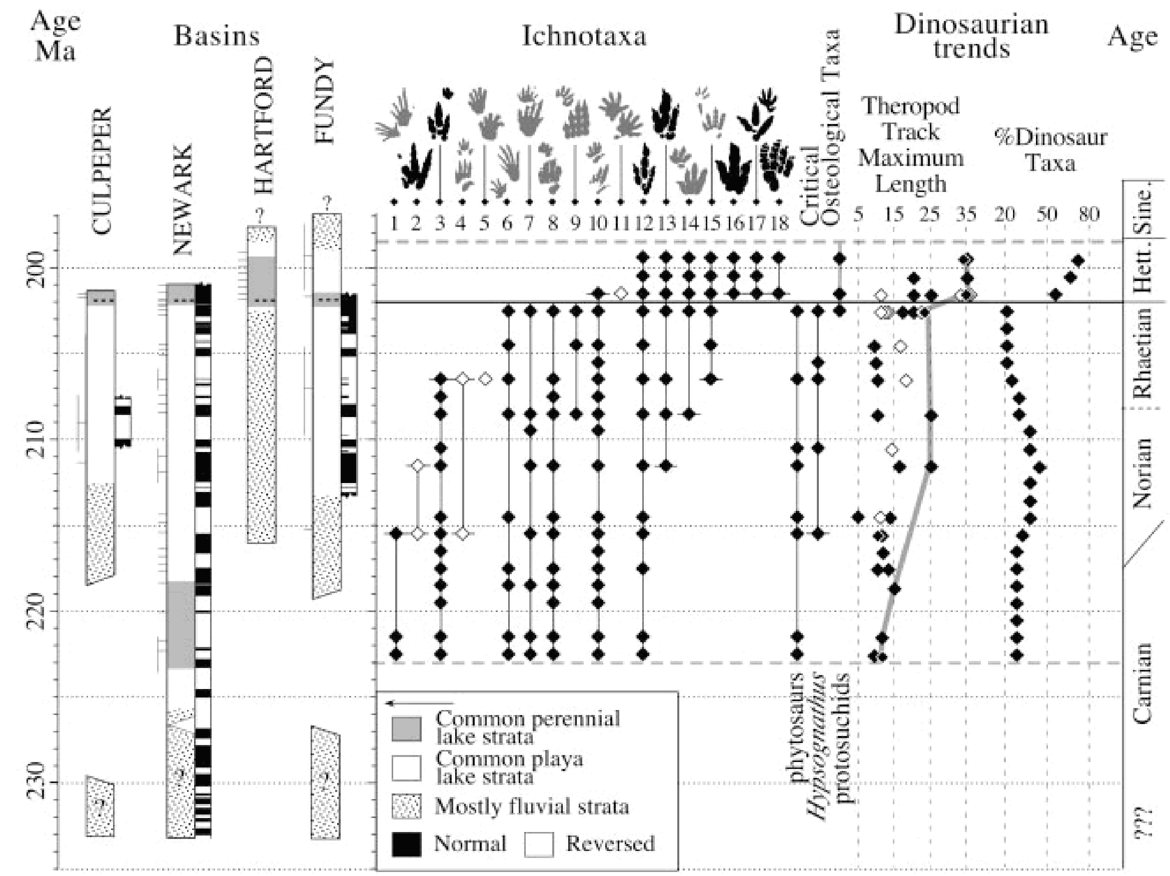

Figure 4.7 Correlation of strata from four key basins of the Newark Supergroup showing the temporal ranges of footprint ichnogenera and key osteological taxa binned into 1-My intervals showing the change in maximum theropod dinosaur footprint length (line drawn through maximum) and percent at each 1-My level of dinosaur taxa. Short, horizontal lines adjacent to stratigraphic sections show the position of assemblages, and the attached vertical lines indicate the uncertainty in stratigraphic position. Solid diamonds indicate samples of footprints, and open diamonds indicate samples with <10 footprints. Horizontal, dashed gray lines indicate the limits of sampling; thick gray line indicates trend in maximum size of theropod tracks; ?= age uncertain. Ichnotaxa are as follows: 1, *Rhynchosauroides hyperbates*; 2, unnamed dinosaurian genus 1; 3, *Atreipus*; 4, *Chirotherium lulli*; 5, *Procolophonichnium*; 6, *Gwyneddichnium*; 7, *Apatopus*; 8, *Brachychirotherium parvum*; 9, new taxon B; 10, *Rhynchosauroides* spp.; 11, *Ameghinichnus*; 12, "*Grallator*"; 13, "*Anchisauripus*"; 14, *Batrachopus deweyii*; 15, "*Batrachopus*" *gracilis*; 16, *Eubrontes giganteus*; 17, *Anomoepus scambus*; and 18, *Otozoum moodii*. Ma, million years ago; Hett., Hettangian; Sine., Sinemurian. Figure from Olsen et al. (2002).

Three larger prosauropod dinosaurs are shown among the cycadeoids and ferns at the far left of the diorama. The prosauropod *Anchisaurus* is known from several skeletons discovered in the Portland Formation in Manchester, Connecticut.

Evidence for the existence of the large freshwater lake shown in the diorama comes from Early Jurassic lacustrine deposits and abundant fossils of freshwater fauna. The black shales found in the Shuttle Meadow, East Berlin, and Portland Formations formed from layers of mud that accumulated in the deeper, anoxic portions of perennial lakes. The lack of oxygen at depth and the extremely fine-grained sediments created ideal conditions for preservation of organic matter.

Over 10,000 specimens of freshwater fishes have been collected from black shales of the Hartford Basin; several spectacular examples are on display in the Exhibit Center. Small bivalved crustaceans known as conchostracans and ostracods have been found at nearly every locality that produces fossil fishes. These crustaceans likely made up a major part of the fishes' diet. Bivalved mollusks also thrived in the shallow waters of the lakes. Gray sandstone beds of the Portland Formation in Suffield, Connecticut contain detailed external and internal molds of clams as well as numerous burrows excavated by the mollusks.

Other fossil evidence completes the picture of life in the earliest Jurassic. The very first specimens of Mesozoic insects discovered in North America were the aquatic larvae *Mormolucoides articulatus* found in Jurassic deposits near Gill, Massachusetts in the 1850s. Subsequent excavations described in Huber et al. (2003) produced over 5,000 larvae and beetle remains. Well-preserved adult insect remains, including the elytra (stiff wing covers) of beetles and a cockroach wing, were collected from claystone in the Portland Formation near Suffield, Connecticut.

Carbonized leaves and stems are moderately abundant in most of the Jurassic gray-black lithologies in the region, with carbonized wood and stem fragments preserved in coarser deposits. Plant remains are widespread in the Hartford Basin, but most specimens are poorly preserved and fragmentary (McDonald, 1992). Early Jurassic plant fossils on display in the Exhibit Center include cycadeoid (*Otozamites)* foliage, conifer (*Pagiophyllum*) foliage and cones, gingko (*Baiera)* leaves, fern *(Clathropteris)* fronds and fiddlehead, and horsetail (*Equisetites*) stems. Detailed studies of fossilized pollen from this time period indicate that conifers were the major constituent of Early Jurassic flora (Cornet and Traverse, 1975).

Conclusion

The rocks of the Hartford Basin have revealed numerous clues to a changing environment in the Triassic and Early Jurassic, including direct evidence of one of the largest extinctions known in Phanerozoic time. The tracks at Dinosaur State Park formed less than 600 ky after the End-Triassic Extinction and represent a dramatically larger dinosaur than any before the extinction. These and other tracks, along with fossils of fish, inverterates, insects, and plants, help us reconstruct the environment in the aftermath of the extinction. Dinosaur State Park provides visitors with a detailed look at this fascinating time period

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