STRATIGRAPHIC OBSERVATIONS ON CORED BOREHOLES IN THE MESOZOIC HARTFORD BASIN, HARTFORD, CONNECTICUT

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ABSTRACT. Stratigraphic observations were made on cored boreholes collected in south Hartford. Boreholes penetrated the upper 50 m of the early Jurassic Holyoke Basalt, all of the East Berlin Formation and Hampden Basalt, and the lower 650+ m of the Portland Formation. The Holyoke Basalt consists of two flows, herein designated (informally) the upper and lower Holyoke Basalt, separated by a 10 m thick sedimentary section, herein designated (informally) the South Hartford Member. The base of the lower Holyoke Basalt was not penetrated. The upper 30 m of the lower Holyoke consists of vesicular/amygdaloidal basalt. Much of the upper 10 m is brecciated with a volcaniclastic and scoriaceous fabric. The 10 m (26-32') thick South Hartford Member consists of a lower section of alluvial and playa facies, overlain by 1-2 m of lacustrine facies. The upper Holyoke Basalt has 30 m (84'-95.5') of non-vesicular basalt with a sharp erosional upper contact. Coarsely crystalline basalt occurs within 2 m of the contact, suggesting that erosion occurred prior to deposition of the overlying East Berlin Formation. The East Berlin Formation is almost 186 m (610') thick with seven saline lacustrine cycles. Biomarker analysis is ongoing. Profundal facies of many cycles contain magnesite crystals, as has been reported in the type section to the southeast. The Hampden Basalt is 35 m (115') thick; the upper 10± m is vesicular and brecciated and the lower 20+ m is massive and more coarsely crystalline. Boreholes penetrated more than 650 m (~2200') of the Portland Formation, including eleven lake cycles that correlate well with the section recovered from the Park River Auxiliary Tunnel a few kilometers to the north. Interpreted Portland paleosols contain desiccation cracks, slickensides, and nodules, similar to those in the East Berlin Formation.

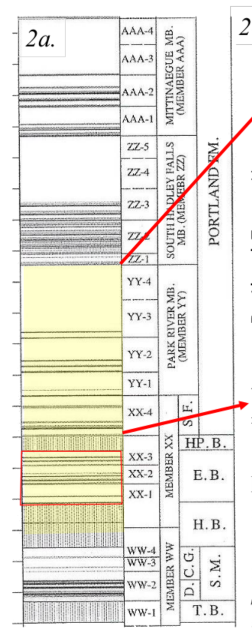
Several faults cut the section including a major fault, herein called the Cedar Mountain Fault, which is mapped from north of Trinity College to New Britain. This fault has approximately 1000 m of displacement, some of which occurred during the Holyoke events (interpreted from these cores) and some of which occurred during the Hampden event (documented in the Park River cores). Movement of this fault may have continued into the Cretaceous.

INTRODUCTION

The Metropolitan District Commission of Hartford will bore a tunnel beneath south Hartford (South Hartford Conveyance and Storage Tunnel, i.e., SHCST, see Figure 1). The tunnel is being designed to collect, store, and convey storm-water sewage overflow from various points of discharge in Hartford to the sewage treatment plant in south Hartford. Prior to construction of the tunnel, stratigraphic information was collected by drilling numerous cored boreholes. This report describes the stratigraphy encountered. The boreholes were all drilled in the northern part of the Hartford South Quadrangle.

PORTLAND FORMATION

The lower part of the Portland Formation underlies the eastern part of Hartford (see Figure 1) and overlies the Hampden Basalt. It is poorly exposed and our knowledge of the lower-Portland stratigraphy is derived from cored boreholes, mainly those drilled by the Army Corps of Engineers prior to boring of the Park River Auxiliary Conduit (PRAC) below downtown Hartford. The Portland Formation consists predominantly of "redbeds," punctuated by gray and black lacustrine layers (Figures 2 and 3.)



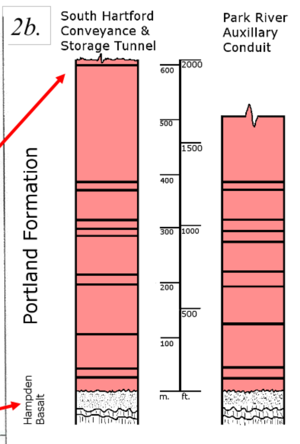
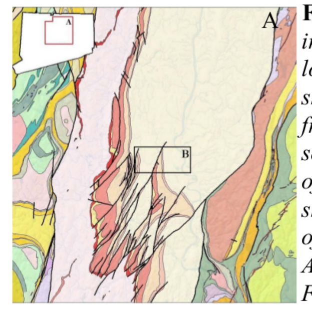


Figure 2a. *Jurassic stratigraphy of the Hartford Basin (from Olsen et al. 2005, Fig. 6) showing the stratigraphy encountered in the SHCST (yellow box) bore-holes. Scale is shown by ticks on left of column at 100 m intervals. Letter designations in middle column refer to magnetic time scale. Other abbreviations are: E.B. = East Berlin Fm., HP.B. = Hampden Basalt, H.B. = Holyoke Basalt, S.F. = Smiths Ferry Mbr. of the Portland Fm., and S.M. = Shuttle Meadow Fm. Red box indicates stratigraphic section of East Berlin Fm. Shown in Figure 5.*

Figure 2b. *Correlation of Portland Formation in the Park River Conduit (PRAC) cores with that of the south Hartford tunnel (SHCST). The number and stratigraphic spacing of the lacustrine (van Houten) cycles closely match. The stratigraphy found in the SHCST boreholes further confirms the cyclostratigraphic model of Olsen and his colleagues.*



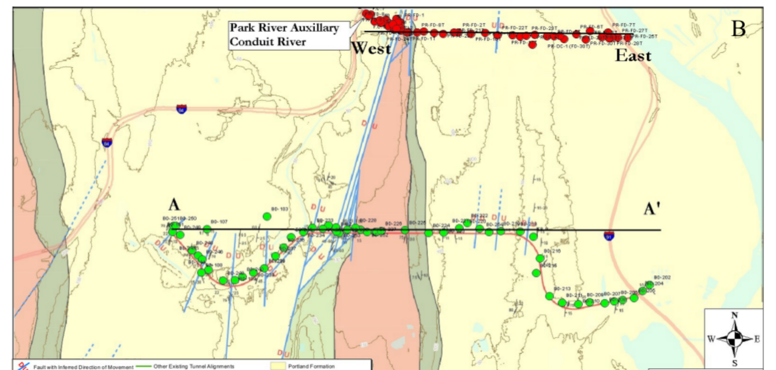


Figure 1A. *Index map (left); location shown as inset (after Rodgers, 1985).* **B.** *Map showing the location of cross-section A-A' below, location shown as box (B) on the index map (modified from Drzewiecki and others, 2012). Cross-section A-A' is shown below the poster. Location of cored-boreholes used as data for cross-section shown in green (this also is the approximate path of the proposed tunnel). Location of Park River Auxiliary Conduit cross-section (West-East, Figure 3) shown to north of A-A'*

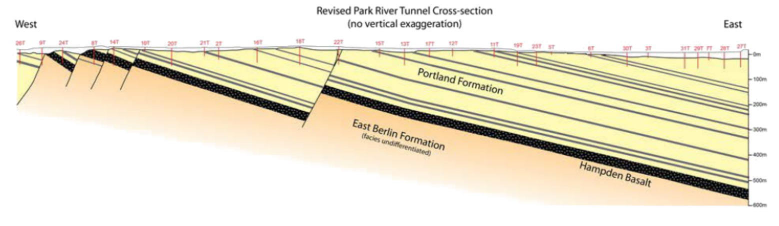


Figure 3. *PRAC cross-section from Lallier et al. (2012). See Figure 1 for location of cross-section.*

HAMPDEN BASALT

The Hampden Basalt (Figure 4) is seen in boreholes BD-223 and 224 underlying the Portland Formation, and possibly in boreholes within the Cedar Mountain fault zone. The top consists of a fairly sharp, but irregular contact with overlying basalt-clast bearing sandstone. The upper 30 m+/- of the basalt is vesicular (amygdaloidal). The upper 10 m+/- has an ashy, scoriaceous texture and has irregular sandstone-filled voids. The Hampden Basalt is 35 m (111-115') thick at this location.

Note: Depths in the images of cored rock are reported in feet because they were labeled that way by the field engineers.

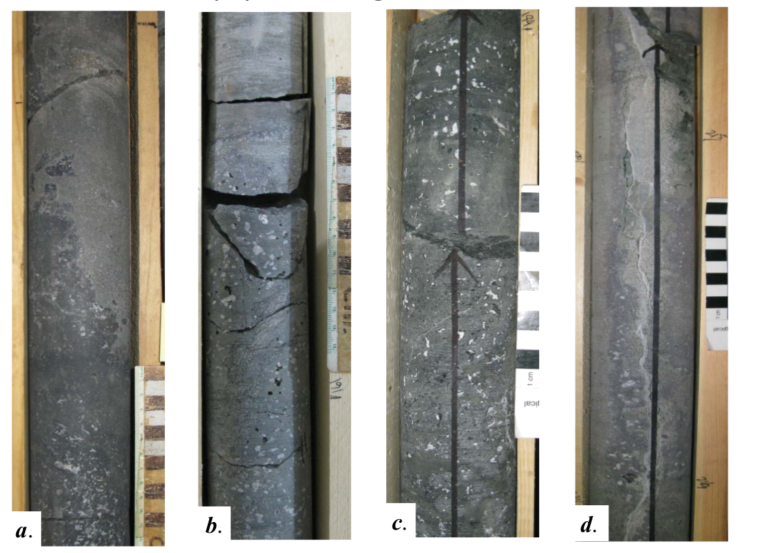


Figure 4a. *BD-224, 41.5' depth. Contact of basalt-clast bearing, fine-grained, gray sandstone of Portland Formation with Hampden Basalt. Note that some of the vesicles (amygdales) are filled with fine-grained sandstone.* ***b****. BD-223, 191' depth. Top of Hampden Basalt.* ***c****. BD-223, 193.8' depth. Upper part of Hampden Basalt ~2 ft (70 cm) below top. Note vesicular, brecciated, almost volcaniclastic appearance that is typical of the top of Hampden in these borings. Scale in cm.* ***d****. BD-223, 215' depth. Fracture along which hydrothermal fluids altered the basalt. Sulfide minerals locally line the wall of the fracture. This is the deepest occurrence of vesicles (amygdales) in this core. (24', ~8 m, below top of basalt) .*

EAST BERLIN FORMATION

The East Berlin Formation is best known in Connecticut for exposure along CT Route 9 just south of the classic type section. There road cut outcrops expose ~118 m of alternating red and gray sandstone, siltstone, and shale that form six (6) van Houten cycles (see Figure 5). The bore-holes for the SHCST reveal an additional 50 m of sedimentary layers and one or possibly two additional van Houten cycles. In general this confirms Olsen's cyclostratigraphy for the East Berlin Formation (see Figure 2).

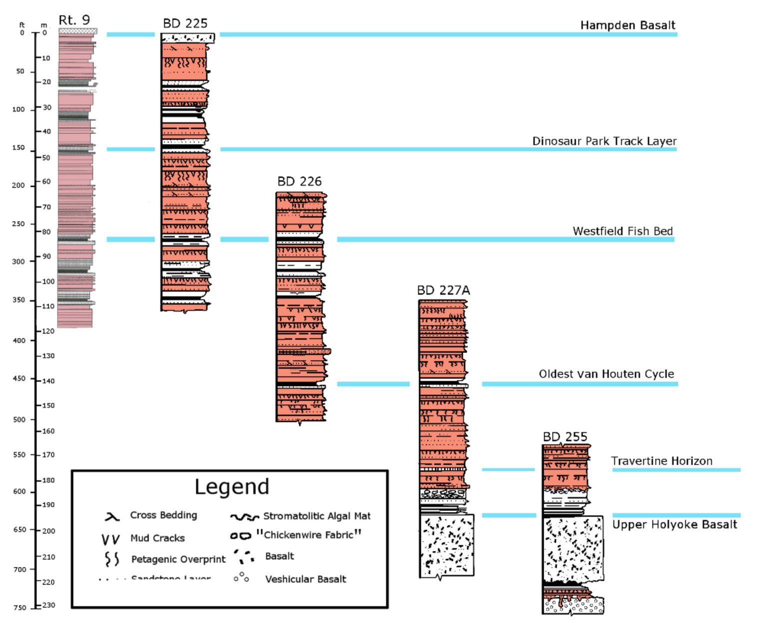


Figure 5. *Stratigraphy of the East Berlin Formation. Rte. 9 column is from Olsen et al. (2005). BD-225 recovered core of almost the same stratigraphic interval, penetrating the 6 youngest van Houten cycles. "Westfield fish bed" is used as a correlation horizon to BD-226, which penetrated an older van Houten cycle that is used to correlate with BD-227A. The top of the upper Holyoke Basalt is used to correlate with BD-255. Note lacustrine beds at the base of the East Berlin Fm. (equivalent to Jarvis Bed?) and also underlying the upper Holyoke Basalt (see Figure 10a).*

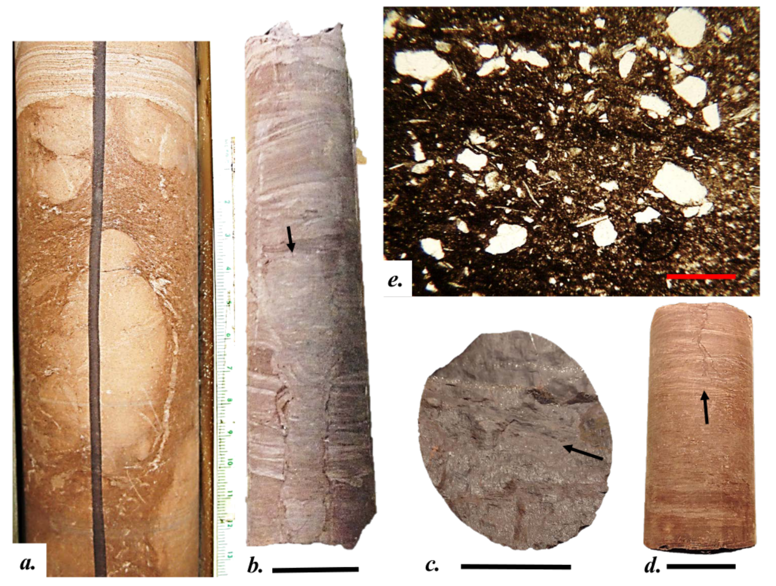


Figure 6 *Examples of pedogenic features in the East Berlin Fm.* ***a****. Carbonate nodules in paleosol overlain by sheetflood deposit. Scale (on right) in cm.* ***b****. Sediment-filled desiccation crack (arrow), scale bar = 4 cm.* ***c****. Slickensides (arrow), scale bar = 4 cm.* ***d****. Root trace (?) above arrow, scale bar=4 cm.* ***e****. Thin section micrograph showing disruption of bedding and bioturbated (?) fabric, plane light, scale bar = 0.5 mm.*

Figure 7a. *"Westfield Fish Bed" cored in BD-225, 267.6-271.7' (top) and BD-226, 268.8-272.6' (bottom). Colors have been altered to better show lamination. Core diameter is 2 1/8" (~5 cm). Small displacive evaporite crystals at about 269' in BD-226. Tuff bed, if present, is not obvious.* ***b****. Large displacive evaporate crystals from BD-225, 309'. Mineral identified (XRD) as magnesite by A.A. Conti. Sawed surface. Core diameter: 2 1/8" (~5 cm).*

HOLYOKE BASALT

The ***upper Holyoke Basalt*** is relatively non-vesicular and finely-crystalline. It has a sharp chilled contact and is overlain by dark gray to black mudrock of the East Berlin Formation. The upper Holyoke Basalt is ~30 m thick (84-95.5'). Coarse appearing basalt (Fig. 8b, e) occurs within 2 m of the upper contact. The lower contact is finely crystalline and has small pillow-like protrusions into the underlying calcareous mudrock (South Hartford Mbr.).

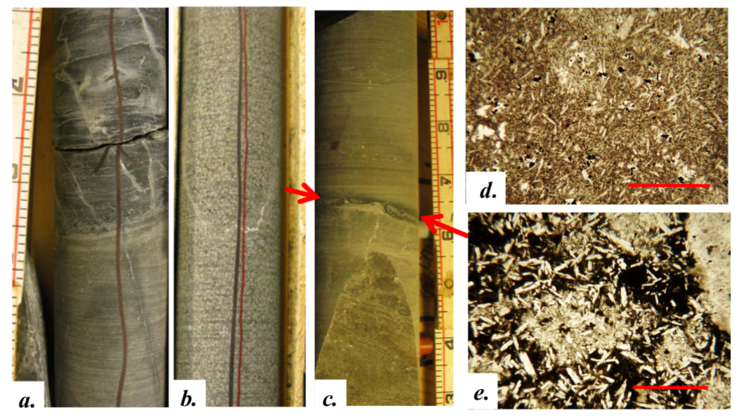


Figure 8. *Upper Holyoke Basalt.* ***a****. Dark gray mudstone overlying fine-grained upper Holyoke Basalt; note small clasts of basalt at contact; BD-255, 173' depth. Scale in upper left calibrated in tenths and hundredths of a foot.* ***b****. Coarse-grained appearing basalt 6' (~2 m) below top of flow. BD-227, 316' depth; core diameter 2 1/8" (~5 cm).* ***c****. Basal contact of upper Holyoke Basalt with South Hartford Member. Underlying mudrock at this location is gray (baked). Note small pillow-like protrusions of basalt. BD-228; scale in tenths and hundredths of a foot.* ***d****. Thin section micrograph of basalt ~1 cm below surface. Note fine-grained glassy nature. Plagioclase laths ~ 0.1 mm. Plane light, scale:1 mm. BD-227A, 310.4'.* ***e****. Thin section micrograph of basalt ~ 2 m below surface. Plagioclase laths ~ 0.3 mm and clumped, along with pyroxene, into somewhat spherical aggregates. The aggregates give the megascopic appearance of coarser crystal size. Plane light; scale: 1 mm. BD 227A-316' depth.*

The entire thickness of the ***lower Holyoke Basalt*** was not penetrated by any of the boreholes. BD-228 penetrated 36.9 m (127.1'). In contrast to the upper Holyoke basalt, the top of the lower Holyoke Basalt is vesicular/amygdaloidal and has a fine- to medium crystalline texture.

Figure 9 (left). *Contact of basalt-clast breccia of South Hartford Member with top of lower Holyoke Basalt. Note vesicular (amygdaloidal) nature of both basalt and clasts in South Hartford Member and contrast this with the top of upper Holyoke (Figure 8) BD-255, 294'; pencil ~7 mm in diameter.*

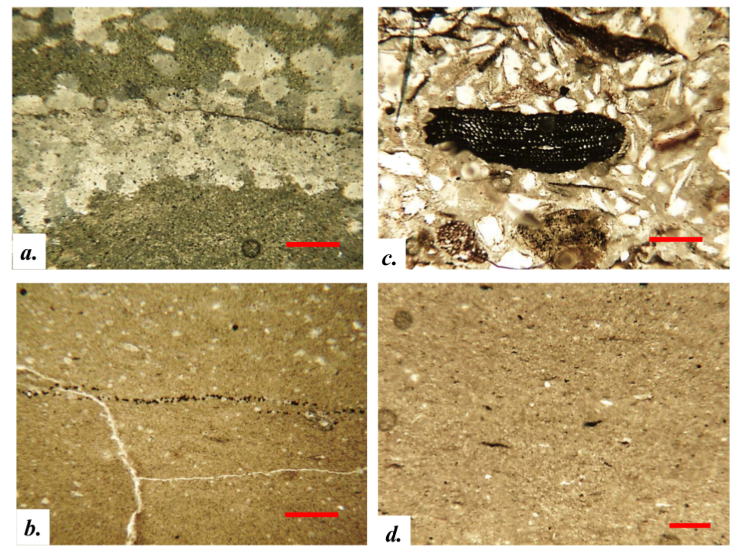


Figure 10. ***a****. Micrograph of contact metamorphosed carbonate lamina in black lacustrine mudrock of South Hartford Member. BD-255, 269+', x-nicols, scale bar = 0.5 mm.* ***b****.* Pyrite in calcareous mudstone, BD-255, 173.1', plane light, *scale bar = 0.5 mm.* ***c****. Carbonized fish scale BD-255, 274' (see Fig. 11d), plane light, scale bar = 0.5 mm.* ***d****. Mixed siliciclastic/CO_3 mudstone immediately underlying siliciclastic/carbonate breccia shown in Figure 10c and 11d.. BD-255, 274', plane light, bar = 0.2 mm (200 μm), South Hartford Member.*

SOUTH HARTFORD MEMBER

The South Hartford member of the Holyoke Basalt was encountered in two boreholes, BD-228 and BD-255 (see Figure 11). It consists of ~10 m of siliciclastic sedimentary rocks. They are composed of siltstone and very fine-grained sandstone that is reddish brown, maroon, and gray. The upper mudrock beds are lacustrine. The lower redbeds are composed of sandstone and mudstone of alluvial plain facies. The lowest sandstone beds contain clasts of the underlying scoriaceous basalt. Several beds near the middle of the South Hartford member have been altered by pedogenic processes. This suggests that deposition of the South Hartford Member spanned considerable time rather than being the quick filling of an anomalous low spot created by faulting and erosion.

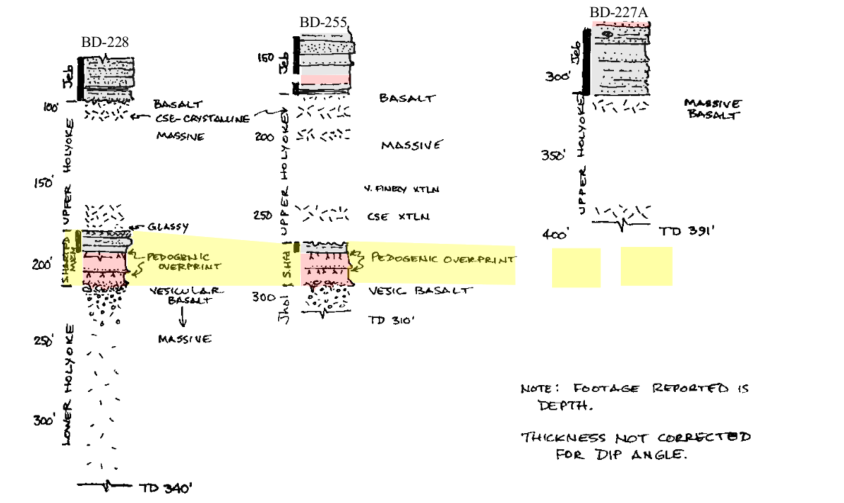


Figure 11. *South Hartford Member (yellow) was recovered in boreholes BD-228 and BD-255. It is 9.7 m (32')thick in BD-228 which is closer to the Cedar Mountain fault zone, and 7.9 m (26')thick in BD-255. Depth (indicated to left of each column) is measured below the surface in feet. The black bar to the left of the lithologic symbols indicates gray and dark gray pigmentation of the sediments.*

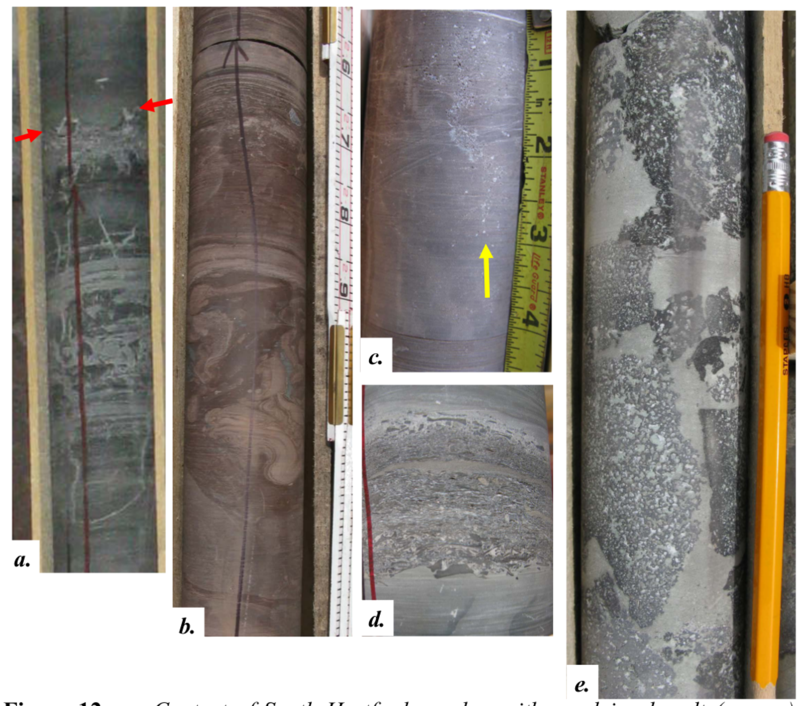


Figure 12. ***a****. Contact of South Hartford member with overlying basalt (arrows). Uppermost facies of member is black mudstone with millimeter beds of recrystallized calcite (see Fig. 10a). BD-255, 269+, width of core: 2 1/8" (~5 cm).* ***b****. Bioturbated siltstone and very fine-grained sandstone. BD-255, 285+/-'; ruler calibrated in tenths and hundredths of a foot.* ***c****. Sandy siltstone with pedogenic overprint; trace of former sand-filled mud-crack (yellow arrow) in center. BD-228 , scale in inches.* ***d****. Mixed siliciclastic/carbonate breccia in shoreline/shallow lake facies (see Fig. 10c). BD-255, 274', width of view 5 cm.* ***e****. Basalt-clast conglomerate above lower Holyoke Basalt. BD-228, 294' pencil for scale (width = 7 mm).*

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A MINIMUM LAKE DEPTH ESTIMATE: DATA

HOLYOKE BASALT

In select regions of the basin, the Holyoke Basalt contains two distinct flows. The South Hartford Member represents a zone of sediment that has been preserved between two basalt flows (Figure 13). The ***upper Holyoke Basalt*** is relatively non-vesicular and finely-crystalline (see Figure 14). It has a sharp chilled contact and is overlain by dark gray to black mudrock of the East Berlin Formation. The upper Holyoke Basalt is ~30 m thick (84-95.5 ft.). The lower contact is finely crystalline and has small pillow-like protrusions into the underlying black calcareous laminated mudrock (now hornfels and marble). The basalt does not appear to be pillowed.

Two important points to note:
First, the upper Holyoke Basalt was erupted onto black calcareous mudrock, normally thought to be the deposit of the deepest phase of the lacustrine cycle and is overlain by more black calcareous mudrock.
Second: the upper flow has a maximum thickness of 95.5 ft (29.1 m).

Note: Depths in the pictures of cored rock are reported in feet because they were labeled that way by the field engineers.

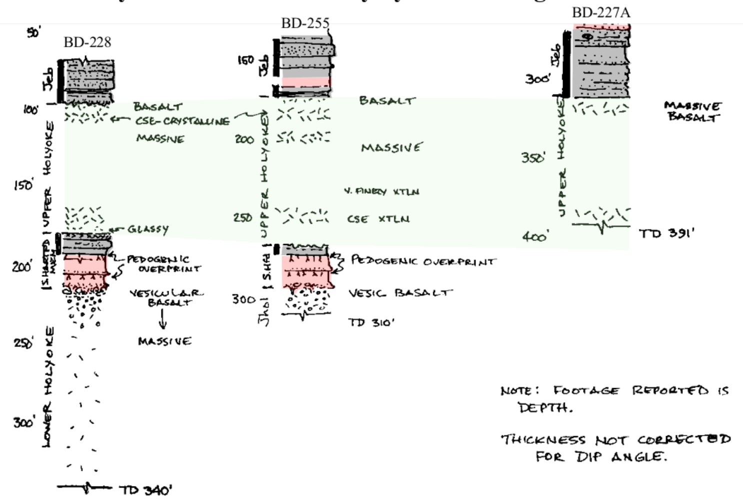


Figure 13. Upper Holyoke Basalt (pale-green) recovered in boreholes BD-228, BD-255, and BD-227A. It is 25.6 m (84') thick in BD-228 which is closer to the Cedar Mountain fault zone, and 29.1 m (95.5') thick in BD-255 (the base of the Holyoke was not penetrated in BD-227A). Depth (indicated to left of each column) is measured below the surface in feet

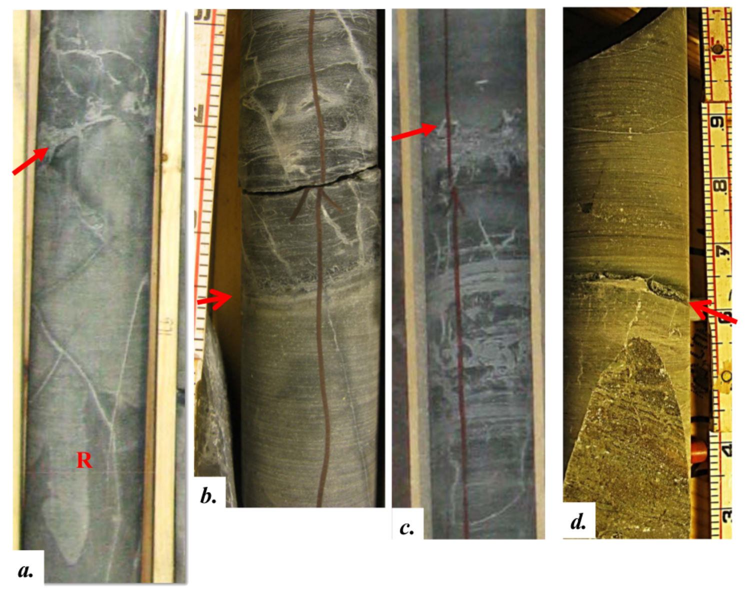


Figure 14 Upper Holyoke Basalt is overlain and underlain by black mudrock with carbonate laminae. ***a****. Contact with overlying dark-gray mudrock (arrow) and irregular reduction front, BD-227A: 96.5-97', core diameter 2 1/8" (~5 cm)* ***b****. Dark gray mudrock overlying fine-grained upper Holyoke Basalt; note small clasts of basalt at contact; BD-255, 173'. Scale in upper left calibrated in tenths and hundredths of a foot.* ***c****. Basal contact of upper Holyoke Basalt with dark gray laminated mudrock (now hornfels and marble), BD-255, 173+', core 2 1/8" diameter (~5 cm)* ***d****. Basal contact of upper Holyoke Basalt with South Hartford Member. Underlying calcareous mudrock at this location is light gray (baked?). Note small pillow-like protrusions of basalt. BD-228. Scale in tenths and hundredths of a foot.*

The basalt itself has two important features that testify to its eruption.
First, the lower contact is sharp and has slight pillow-like protrusions into the underlying mudrock. The glass at the contact contains 0.15 mm laths of plagioclase feldspar that normally would exhibit a flow alignment. Here, however, the plagioclase laths have a random orientation (Figure 15). The fact that crystals at the very base of the flow show absolutely no alignment

Thanks to A. R. Philpotts for igneous rock interpretation and Fig. 15 photomicrography.

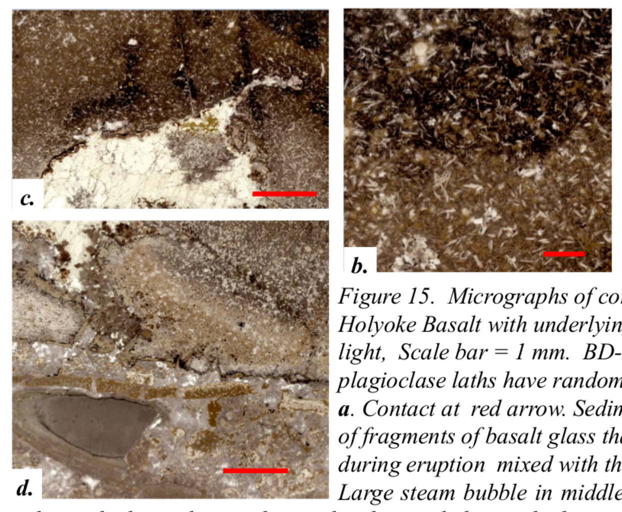
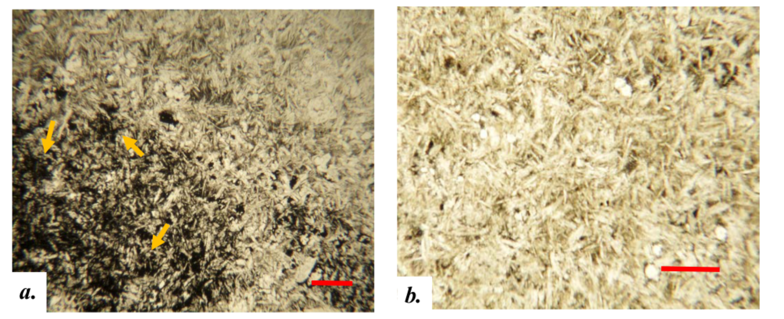


Figure 15. Micrographs of contact of upper Holyoke Basalt with underlying sediment. Plane light, Scale bar = 1 mm. BD-255, 258.2'. Note plagioclase laths have random orientations; ***a****. Contact at red arrow. Sediment below consists of fragments of basalt glass that spalled off during eruption mixed with the underlying mud. Large steam bubble in middle of view is filled with calcite which overlies mud particles that settled onto the bottom with geopetal fabric. Reduction front at yellow arrow. Areas of b., c., and d, shown by blue boxes. Scale bar = 5 mm.* ***b****. Reduction front: magnetite present above front but mostly absent below. Note random orientation of plagioclase laths. Scale bar = 1 mm.* ***c****. Notice reduction at bottom of is flow not as pervasive as at top. Plagioclase laths in random orientations. Scale bar = 5 mm.* ***d****. Sediment below flow is mixed with pieces of glass derived from the flow as it advanced over the sediment. Portions of sediment also became broken up and mixed with the basalt fragments. Scale bar = 5 mm.*

indicates that the lava came in contact with the underlying sediments with no shear. This must have occurred through a caterpillar tread-like motion (like the tracks on a tank), which means the top of the flow becomes the base as the flow advances. We interpret this to indicate rapid eruption of the lava with minimal flowage over the lower substrate. Such rapid eruptions rarely produce pillowed lavas which suggests that the upper Holyoke basalt could have been erupted into a lake. Thus, it is not a problem that we do not find pillow basalt structures in the cores.
Second, an irregular reduction boundary (Figure 16) is present from 8-15 cm (2-6") at the upper surface of the basalt. A thinner reduction zone occurs at the base of the flow (Figure 15a, b). Below this boundary the basalt contains magnetite crystals interstitial to the plagioclase; above the front magnetite is absent (Figure 16). This suggests that the basalt was erupted into an anoxic environment; the iron was reduced and was removed in solution rather than crystallizing as magnetite.



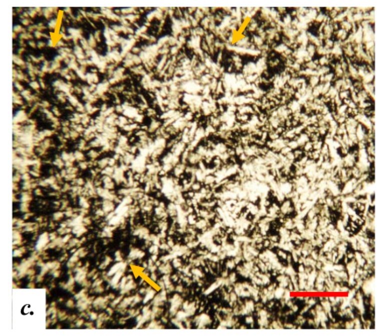


Figure 16. Reduction front. ***a****. Front runs diagonally from upper left to lower right. Reduced basalt, (upper right and as Figure 15-****b****)., contains little magnetite (Fe3O4). Reduced basalt (lower left, also Figure 15-****c****),contains abundant magnetite (arrows). This suggests interaction of basalt with anoxic environment above it early in history of basalt, most probably at time of eruption while the rock was still hot and reactive. Scale bar in each micro-graph = 0.5 mm; all in plane light. a. BD-227A, 97.0', approximately 0.5' (~15 cm) below top of basalt; b. BD-255, 173.3', approximately 0.2' (~6 cm) below top of basalt; c. BD-227A, 97.1', approximately 0.6' (~18 cm) below top of basalt.*

Could the upper Holyoke have been erupted into a lake in the profundal zone? If so, the lake had to be at least 95' (~30m) deep. The basalt was erupted on top of lake deposits and was covered by lake deposits early enough to reduce the iron during its crystallization; magnetite is not present as either holes or as limonite/hematite aggregates in the reduced zone but is present below the boundary. This suggests that both the bottom and the top of the basalt were erupted below the water level and that the top of the flow was affected by anoxic bottom water of the lake. The iron in the outer few centimeters of the upper flow surface was reduced and therefore solubilized before it crystallized to an iron-oxide in the rock. The basalt is 29.1 m (95.5') thick and therefore the lake had to be at least that deep. In addition no current deposited sediments are present on top of basalt, but rather thin graded beds of mud overlie basalt. The lake was probably much deeper than 29 m at the time.

Conclusion

Basalt was erupted into an anoxic lake that was deeper than the preserved basalt thickness. Therefore, thickness of basalt is a minimum depth for the lake at the time of eruption. Maximum basalt thickness observed is 95.5 feet (~29m). The depth of the lake was at least that deep and perhaps considerably deeper.