EARLY MESOZOIC BASALTS OF THE POMPERAUG BASIN, SOUTHWESTERN CONNECTICUT: REGIONAL, STRATIGRAPHIC AND PETROLOGIC FEATURES

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SUMMARY

In this study, the main 100-m thick "Orenaug basalt" unit of the Pomperaug basin is closely correlated by chemistry and petrography with Holyoke basalt of the Hartford basin and Preakness basalt of the Newark basin. No large dikes are evident in or around the Pomperaug basin, implying that the basin basalts were derived from fissure dike systems already identified for other basin basalts. Unlike the Holyoke basalt, the Orenaug basalt is divided into lower, middle, and upper flow members, with the middle member being very altered and amygdaloidal. Another 8 to 10-m thick flow (the "East Hill basalt" of LeTourneau and Huber, 1997) lies about 30 m beneath the Orenaug. This basalt is highly altered, but its element ratios place it as a thin distal portion of the Talcott basalt (Hartford basin) and Orange Mountain basalt (Newark basin). No equivalent to the higher Hampden basalt is recognized in the Pomperaug basin, even though the Bridgeport dike fissure source for the Hampden is less than 20 km to the east. Only a thin (30 m or less) sedimentary section remains above the Orenaug basalt, and it is possible that additional Early Jurassic strata, including a third basaltic unit, were removed by erosion.

A model of the same lavas flowing across all three basins requires low topographic relief, allowing the basalts to spread very widely before removal by uplift and erosion. It is therefore possible, even likely, that Early Mesozoic clastic sediments were also present across portions of inter-basin regions beneath the basalts. However, it is also evident that coarse alluvial fans formed directly above some of the lava flows, implying the onset of uplift and erosion that may have isolated the basins and limited stratigraphic connections in the Early Jurassic.

ACKNOWLEDGMENTS

Support for this study was provided by the State Geological and Natural History Survey of Connecticut, and by the U. S. Geological Survey. Ralph Lewis suggested this project and introduced me to several officers of the Pomperaug Valley Watershed Coalition, which has organized a major groundwater environmental study for the basin and watershed. Larry Pond loaned me copies of his maps, reports, and field data, and he provided an excellent tour over the basin in his small airplane. After two field trips arranged by the Connecticut Earth Sciences Teachers Association, additional and critical visits to traprock quarries were arranged by Mr. Ken Faroni of the O&G Corporation. Nancy McHone assisted with reference materials from the files of the state geological survey. William Burton of the U.S. Geological Survey provided chemical analyses and useful discussions about the rocks and structures of the basin. Anthony Philpotts and Norman Gray contributed data from their studies of Pomperaug basalts, as well as access to thin-section equipment at the University of Connecticut. I especially appreciate maps and other information about the geology of the Pomperaug basin provided by Peter LeTourneau and Phillip Huber, who are the reigning authorities on the Pomperaug basin.

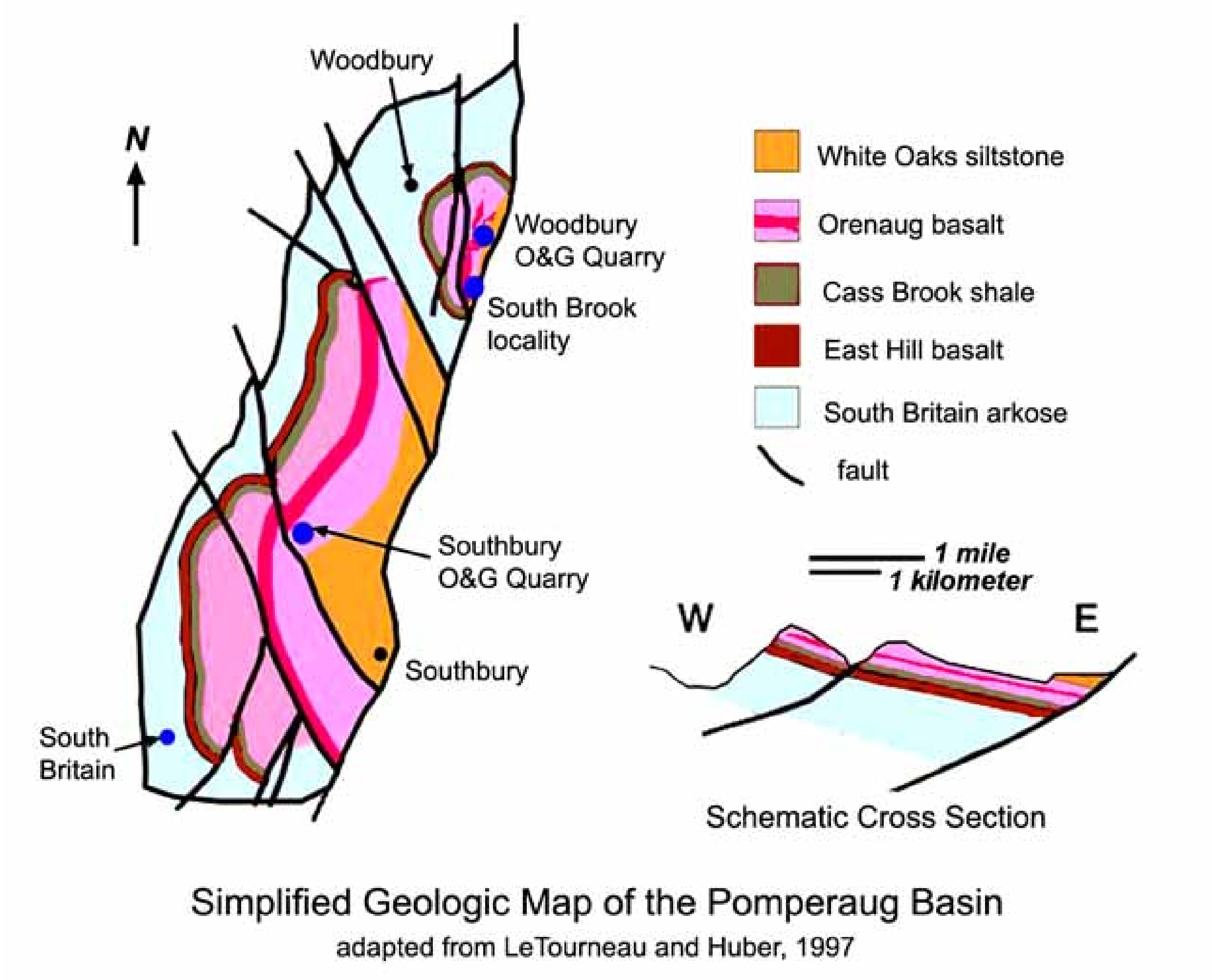


Figure 1. Geologic sketch map of the Pomperaug basin, adapted from a presentation by LeTourneau and Huber, 1997.

INTRODUCTION

Basalt ridges dominate the small (c. 3 km x 11 km) Pomperaug Mesozoic basin of southwestern Connecticut (Fig. 1). Because it is midway between much larger basins of central Connecticut and northern New Jersey, the Pomperaug basin has been studied for evidence for or against the “broad terrane” and “closed basin” models for Mesozoic rift strata in eastern North America. Several rather unsatisfactory mapping efforts took place between 1889 and 1986, but during the past ten years a more thorough stratigraphic study has been underway, and a new program sponsored by the U.S.G.S. will result in a modern published map of the geology of the Pomperaug basin (no. 16 in Fig 2).

This project to describe the basalts of the Pomperaug basin was requested in 2002 by Ralph Lewis, the Connecticut State Geologist. The work is related to a much larger project to analyze the effects that bedrock and surficial materials in the Pomperaug River basin have on groundwater aquifers, which provide water for many people in Southbury and Woodbury. Pomperaug River basin studies are sponsored by the local towns, and organized by the Pomperaug River Watershed Coalition (http://www.pomperaug.org/). William Burton of the U. S. Geological Survey is working (as of Fall 2003) on a multi-year program to map and compile data on the structures and strata of the Pomperaug basin, with the aim of producing an accurate bedrock map. Much information from previous years of field work by Phillip Huber, Peter LeTourneau, Nicholas McDonald, and others in the Pomperaug basin will be extremely valuable for this map project (by permission, their simplified map is Fig. 1).

For this basalt study, about 20 days of field visits were conducted from June 2002 through December 2003, including several visits to two large active traprock quarries in the basin. Literature and previous bedrock maps were compiled and studied, and samples were taken for petrographic thin sections and chemical analyses. The main goal is to demonstrate how basalts in the Pomperaug basin may, or may not, be well correlated with basalts of the Hartford basin.

MESOZOIC BASINS

A key to the stratigraphy in each of the Early Mesozoic basins (Fig. 2) in northeastern North America is the presence, age, and position of basaltic lava flows. After many years of uncertainty and confusion, the ages of all basalts within the basins are now reasonably well established to be between 200 and 201 Ma, with three major volcanic events possibly spanning about 600,000 years (Olsen et al., 1996; West and McHone, 1997; Hames et al., 2000). In addition, basalts within the larger basins are closely correlated by chemistry, paleomagnetics, and stratigraphy and so essentially are co-magmatic flows (Puffer et al., 1981; Hozik, 1992; Puffer, 1992). As shown in Figure 3, there are three separate basalts (some containing several flow units) in the Culpeper (Virginia), Newark (New Jersey) and Hartford (Connecticut) basins, and one large basalt group in the Fundy basin (Nova Scotia and New Brunswick). A similar basalt exists in Morocco, which prior to rifting was adjacent to eastern Canada. The Fundy basin basalt is identical to the lowest basalt of the other basins. Moreover, the lowest basalt in each basin is only a few meters above the Triassic-Jurassic boundary (Fig. 3), thus serving as an important stratigraphic marker for that event.

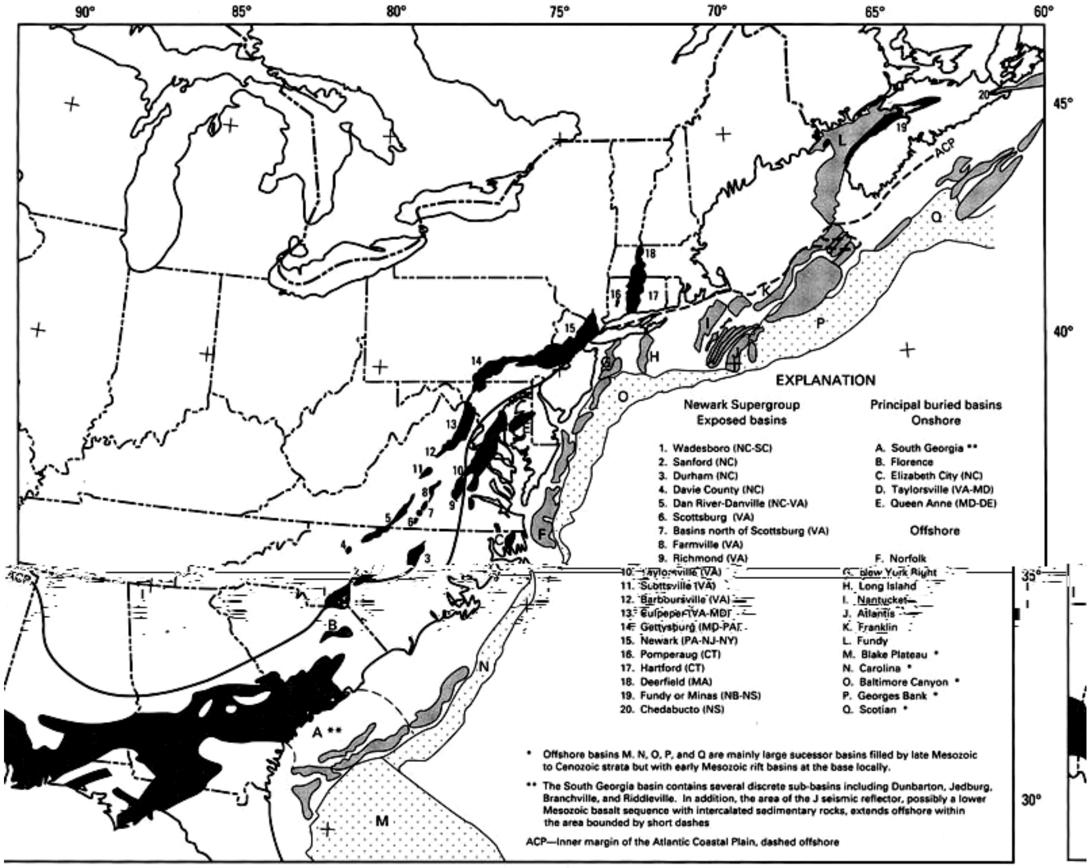


Figure 2. Early Mesozoic basins of eastern North America (Olsen, 1997).

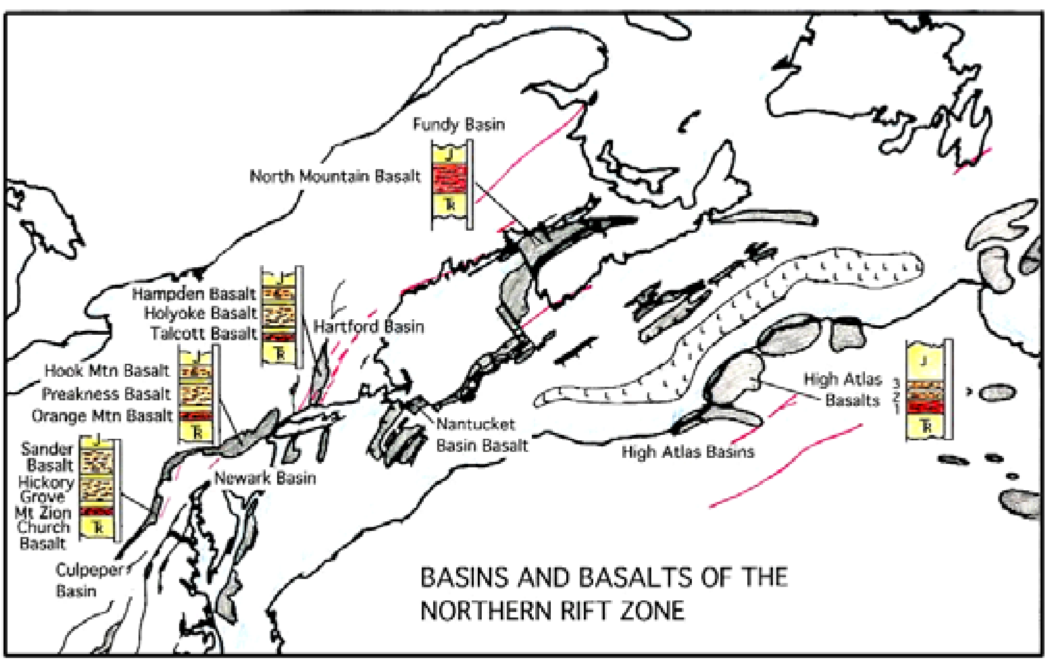


Figure 3. Stratigraphic correlations of basalts in major basins in the northern Pangaea rift zone, before the opening of the Atlantic Ocean. Red lines represent dike fissures that fed basin basalts. The Pomperaug basin is located below the column for the Hartford basin.

Many geologists have proposed that basalts and sedimentary strata could have been continuous, or at least partially connected, between basins (the "broad terrain hypothesis") prior to uplift and erosion (Russell, 1880; Hobbs, 1901; Barrell, 1915; Krynine, 1950; Longwell, 1922; Rogers et al., 1959; Sanders, 1969; Hubert et al., 1979; McHone, 1996; McHone and Puffer, 2003). Hubert and others (1979; abstract reproduced in Appendix II) summarized evidence for a fluvial sedimentary connection between the Hartford and Pomperaug basins. However, vigorous arguments for independent and continuously isolated depositional histories (the "closed basin model") for the basins were made by Klein (1969), Horne and others (1995), Huber (1997), and others. As support for his model, Klein (1969) described basalts in the Hartford and Newark basins as not co-magmatic, but rather formed from independent, local volcanic events. As related above, this finding has not been upheld by later work on the basalts. McDonald and LeTourneau (1996) summarized these arguments, concluding in favor of the closed basin model. However, recent results from fission-track data presented by Blevins-Walker and others (2001; reproduced in Appendix VI) indicate a common eastern Connecticut origin for sediments in both the Pomperaug and Hartford basins, thus at least a Triassic stratigraphic continuity.

If the basalts of the Pomperaug basin can be shown to have independent intra-basin origins (not co-magmatic with basalts of the Hartford and other basins), as promoted by Klein (1969) and Huber (1997), then an isolated-basin depositional model with elevated basement areas between the basins is supported. However, if the Pomperaug basalts are similar in petrology and sequence with basalts of the Hartford basin (and by inference with basalts of the Newark and other basins), and if no local Pomperaug fissure dike sources are present, then a model in which the same lavas flowed across and between the basins is supported. Such long-distance flows, from fissures already identified as dikes in southern and eastern Connecticut, could only occur if topographic and elevation differences between the Hartford and Pomperaug basins were much less than the thicknesses of the flows (60 to 100 meters). If lavas could flow between basins, perhaps fluvial sediments could also have been present between basins (essentially, the broad terrain model).

The Mesozoic bedrock geology of Connecticut is shown in simplified form in Appendix I. Figure 3 is adapted from Figure 1 of McDonald (1996) to show the locations of Mesozoic basins, basalts, strata, intra-basin faults, and fissure dikes in Connecticut and adjacent Massachusetts. As conclusively shown by Philpotts and Martello (1986), the Talcott basalt (the oldest) was derived from the Higganum dike and correlative intrusions within the basin; the Holyoke basalt (middle age) was derived from the Buttress dike, and the Hampden (youngest) basalt was derived from the Bridgeport dike. The three dike systems converge somewhat toward the southwest, and there is potential, but unknown, significance in the east-to-west sequence of oldest to youngest volcanic events. Large fissure dikes have not been mapped across the Pomperaug basin, and smaller dikes within the basin have not been found.

Before the 1970's, all strata in the basins were believed to be Middle to Late Triassic in age. After considerable micro-fossil and radiometric work in the 1960's and 1970's (Olsen, 1997), it became clear that the basalts, and sediments between and above them, are Early Jurassic (roughly 201 to 195 Ma), while the strata (such as New Haven arkose) beneath the lowest basalt (such as the Talcott) are mainly Middle to Late Triassic, or roughly 225 to 201 Ma. The Tr-J boundary lies within the New Haven arkose a few meters beneath the Talcott basalt, and the Talcott source, the Higganum dike, is dated about 201 +/- 1 Ma (West and McHone, 1997). A succinct summary of Pomperaug basin geology, as presently depicted on the Connecticut Bedrock Geology Map (Rodgers, 1985, reproduced in Appendix I), is presented here (Rodgers et al., 1959, p. 17):

> "The Pomperaug Valley outlier of Triassic rocks in Woodbury and Southbury appears to contain representatives of all the stratigraphic units in the main basin, including all three lava sheets, but the thickness is very much less — on the order of 2,000 instead of 15,000 feet — and each individual formation is also thinner. The east border of the outlier is clearly an important fault, and the south end may be cut off by another, but there is no evidence that they were active during deposition; on the contrary the rocks here were probably the thinned westward continuation of the rocks of the main basin, later downfaulted and preserved while the intervening rocks have been eroded away. The rocks of the Pomperaug Valley are apparently cut by a set of faults trending west of north (at an angle of 20° to 25° to the border fault on the east) and downthrown to the west.
>
> The state geologic map shows no faults in the metamorphic rocks around the Pomperaug Valley or between it and the main Triassic belt, except continuations of faults involving the Triassic rocks. Similar faults may well be common entirely within the pre-Triassic rocks, but they are difficult to recognize, especially as much of the area is as yet incompletely mapped. Some faults have indeed been observed in individual outcrops here and there, but none of these has yet been shown to be more than local; none shows silicification of its walls like that along the largest Triassic faults. On the other hand, a hitherto unreported patch of Triassic rocks, downdropped along a fault of considerable displacement, has been discovered in Canton 1½ miles north-northeast of Canton Center (Platt, 1957; not shown on state map)."

However, other studies indicated important differences between the strata of the Pomperaug and Hartford basins, including the presence of only two Pomperaug basalts as well as syn-depositional tectonism. In addition, applying the same stratigraphic names of the Hartford basin to the Pomperaug strata goes against the convention of using separate names for formations within each basin, even where one is only a sub-basin -- for example, the Deerfield basin of Massachusetts (Fig. 3). Other geologic work that followed the system of Rodgers and others (1959) was conducted by Schutz (1956; map reproduced as Plate III), Scott (1979; map reproduced as Plate IV), and Tolley (1986; abstract reproduced as Appendix IV).

Field studies in the Pomperaug basin by Phillip Huber and colleagues during the 1980's and 1990's (Huber and McDonald, 1992, Appendix V; LeTourneau and Huber, 1997, Appendix VI) led them to propose new stratigraphic names. In addition, they have argued, in agreement with the earliest work in the basin, that only two basalt formations are present. Field work in the Pomperaug basin is complicated by large areas of poor to non-existent outcrop, along with evidence for numerous faults in those areas where there are outcrop controls. Most outcrops are of basalt in ridges, but these are scattered and probably repeated by the faults. Mapping projects in the basin have all required much extrapolation, effort, and guessing. For that reason, new field mapping for this small basalt study would not improve results from earlier work and was not attempted, except for examinations of exposures in two traprock quarries.

A preliminary sketch map of the geology of the Pomperaug basin, used in a presentation by LeTourneau and Huber (1997), was adopted for use in this study, with the understanding that its nomenclature is not formally approved, and that their structural interpretations may be revised (perhaps greatly) by later work.

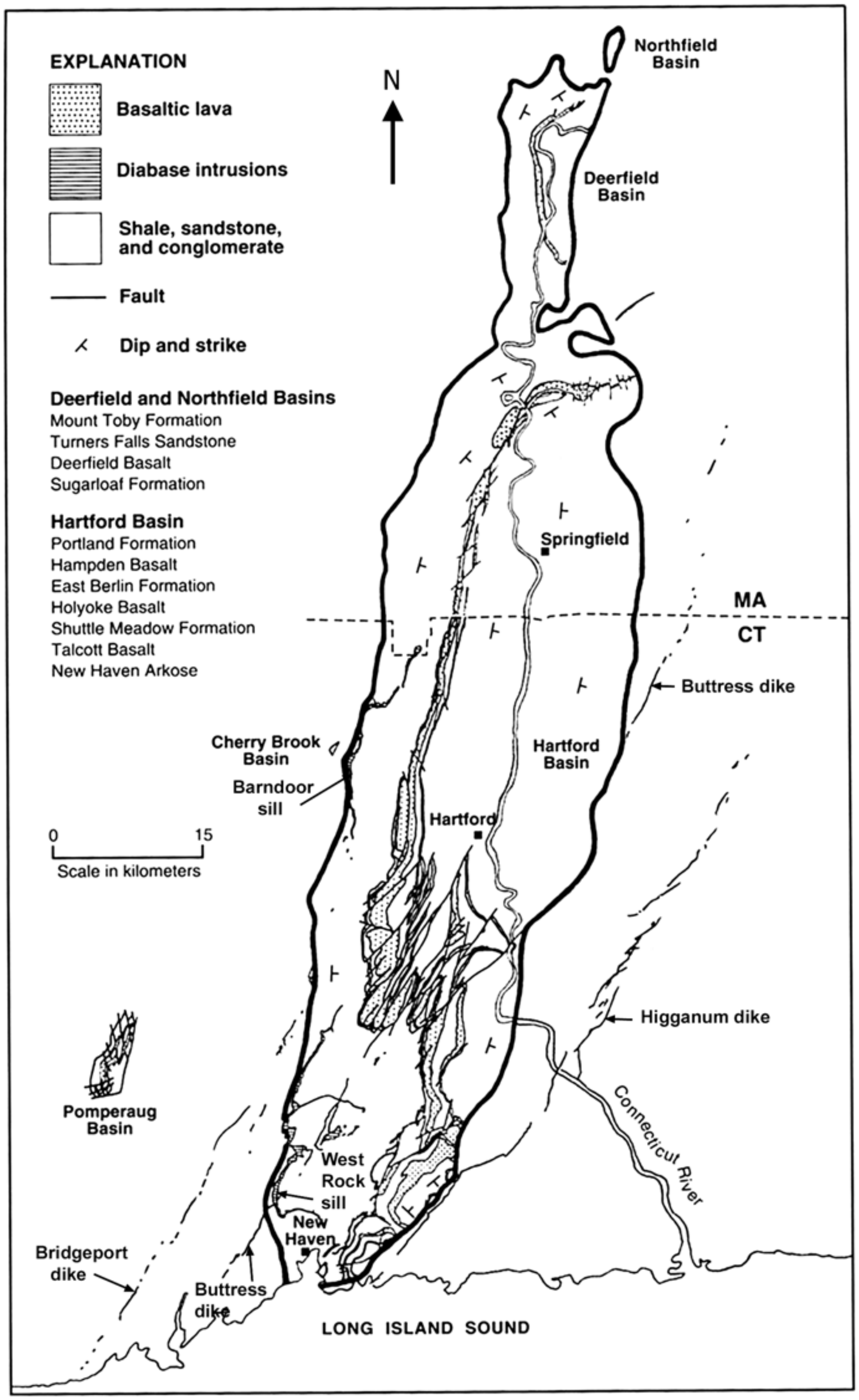


Figure 3. Outline of Mesozoic features of Connecticut and adjacent Massachusetts (adapted from Fig. 1 of McDonald, 1996).

FIELD STUDIES

Percival, 1842

James Percival conducted the first geological survey of Connecticut as a special project funded by the state legislature. Despite the early state of geologic knowledge, he made a number of clear and accurate observations of the general geology of the Pomperaug basin, including the arrangement of traprock ridges and division of the main basalt into a lower massive member and an upper amygdaloidal member. His work was not completely published, but this sketch map (below left) was reproduced by Hobbs (1901, p. 33):

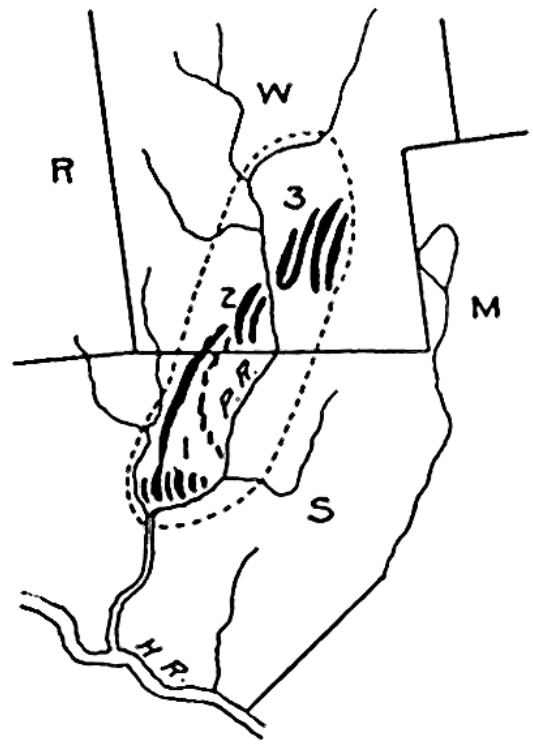


FIG. 2.—Basalt ridges of the Pomperaug Valley (after Percival).

Davis, 1888

Perhaps the best field observations and interpretations of Pomperaug basin geology were conducted by William M. Davis, a Harvard geologist who explained many features of Mesozoic basins that had remained unknown or misunderstood during the 19th century. Working in the 1880's and 1890's, Davis had the advantage of wide-open pastures and easy access across most of the basin, so outcrops could be easily located and observed.

Davis concentrated on two areas of the Pomperaug basin that today are still the best places to see the rock units and structures. The first area was around and east of South Britain, a small village in the western section of Southbury. This southwestern end of the basin has the only excellent and continuous exposures of sedimentary strata beneath and between basalt formations. Davis's sketch of the area shows a relatively thick lower sandstone unit along the Pomperaug River, a thin "amygdaloid" basalt east of the village that overlies a coarse to conglomeratic arkose, a thin unit of shale above the amygdaloid, and a thick "compact trap" and amygdaloidal basalt that forms the main ridges. He realized that several high-angle faults with N-S to NE-SW orientations must be present, which offset and repeat the stratigraphic package. Although perhaps obvious to a modern field geologist, Davis was the first to understand this structural repetition, and he applied this South Britain model to the Hartford basin traprock ridges near Meriden (the Hanging Hills) as well as to other Mesozoic basins. The sketch map remains as good as any made later, and it is reproduced here (Davis, 1888, p. 470):

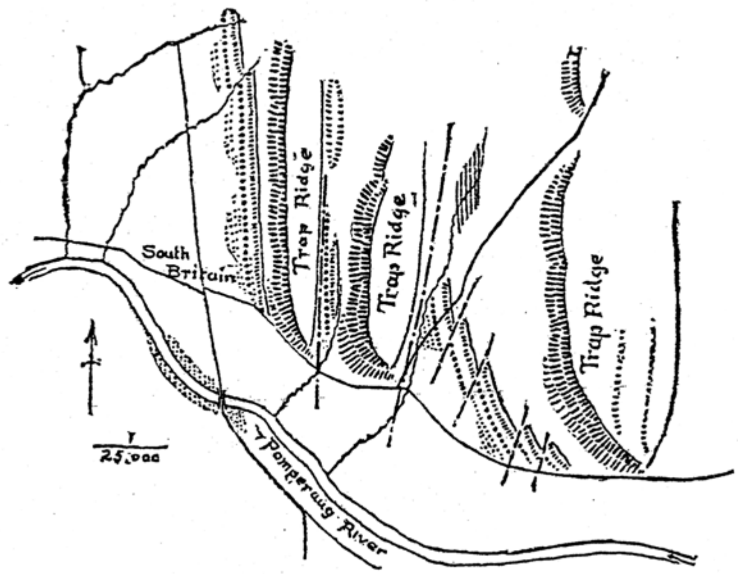


FIG. 97. Sketch map of the trap ridges near South Britain, in the Pomperaug Valley. The outcrop faces of trap ridges are marked with dark hachure lines; the amygdaloid is shown by short, faint hachures; conglomerate, sandstone, and shale are indicated by large dots, small dots, and lines. Four oblique faults dislocate the amygdaloid and conglomerate outcrops between the middle and eastern trap ridge. Larger faults separate the ridges themselves. A section of this district is given in Fig. 98.

In cross section, the South Britain area shows steep dips of 20º to 40º toward the east. At other exposures that allow measurements in the basin, dips tend to be closer to the lower angle. Davis's cross section is reproduced here (Davis, 1888, p. 472):

FIG. 98. Inferred structure of the district shown in Fig. 97. The two faults of larger throw, by which a single sheet of trap is repeated in three ridges, are proved by the threefold repetition of a series of beds comprising sandstone, conglomerate, amygdaloidal trap, shale, and heavy trap.

The other area described by Davis is called the Orenaug Hills, now a town park on the eastern side of Woodbury Village. The hills are steep north-south ridges formed by sharp, linear ravines that Davis recognized as due to faults. Although the coarse arkose, "amygdaloid" basalt, and shale are not exposed, Davis believed the same units and structures that he found at South Britain were present at the Orenaug Hills. He observed in different outcrops "compact trap" with an amygdaloidal basalt between them, and he inferred but did not observe the presence of shale between those basalt units. In fact, as can be seen in recently cut faces in the Southbury Quarry, an amygdaloidal basalt forms the middle of three members in one thick basalt formation, with no shale present between them. Davis's sketch of the Orenaug Hills and cross section is shown below (Davis, 1888, p. 478):

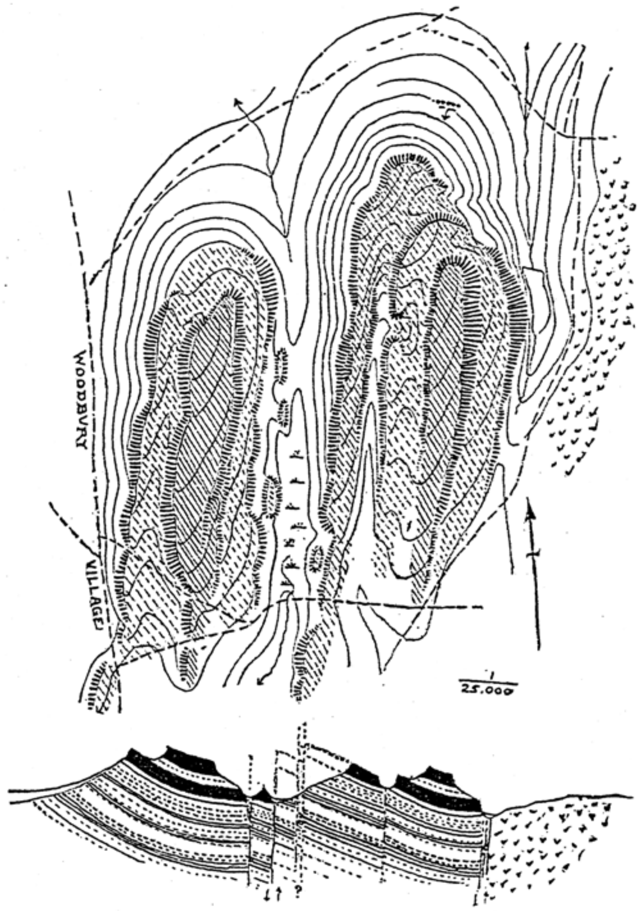


FIG. 99. Map and section of trap ridges near Woodbury. The topography is indicated by sketched contours, with hachures for trap bluffs. The lower sandstone slopes are all covered and the northern bluff of the western group of ridges is quite buried in drift. The crystalline rocks appear on the east. The section suggests an interpretation of the surface forms.

<u>Hobbs, 1901</u>

William Hobbs was assigned to map the Pomperaug basin as an employee of the U. S. Geological Survey. At that time he was also developing his somewhat infamous models of rectilinear systems of lineaments, which were loosely related to extremely straight fault traces. Hobbs did an admirable job of summarizing past geological ideas and work, especially by Davis, and he also provided many useful observations and details of the rocks of the Pomperaug basin. He claimed to have the goal of visiting every outcrop in the basin, which might have been more possible at that time than now, and he excavated an exposure of the contact between the basal arkose and basement gneiss west of South Britain.

Hobbs was also an able petrographer who made good descriptions of hand samples and thin sections of the basalts, and he listed two good-quality chemical analyses performed by the famous U.S.G.S. analytical chemist, W. F. Hillebrand. Both samples are from the Rattlesnake Hill area east of South Britain Village, but unfortunately, the lower amygdaloidal basalt appears to be highly altered at all outcrops. Like Davis, Hobbs found only two different basalt formations in the Pomperaug basin, but unlike Davis he believed that the lower, thin amygdaloidal flow did not continue more than a mile or so north of the South Britain Village along the west side of East Hill. His sketch map of the lower flow ("anterior basalt"), less than 50 feet thick, is shown below on the left (Hobbs, 1901, p. 43). It has a pattern that is reasonably well explained by the faults mapped by Davis (see above).

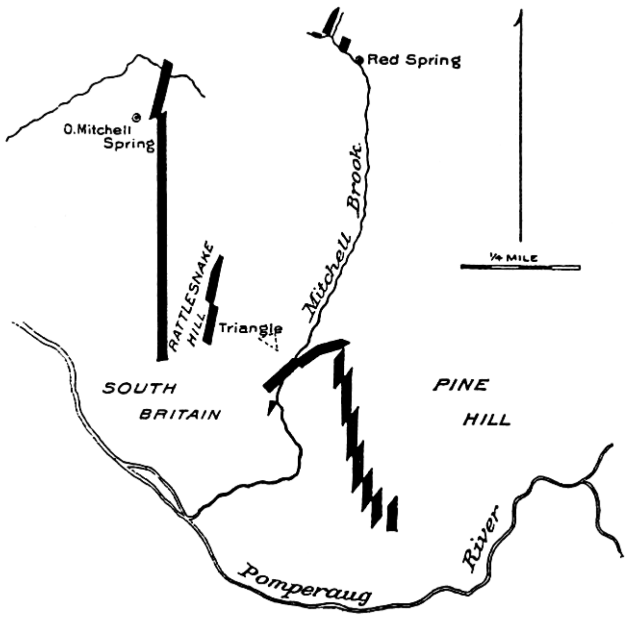


FIG. 7.—Map showing the areal development of the anterior sheet of basalt.

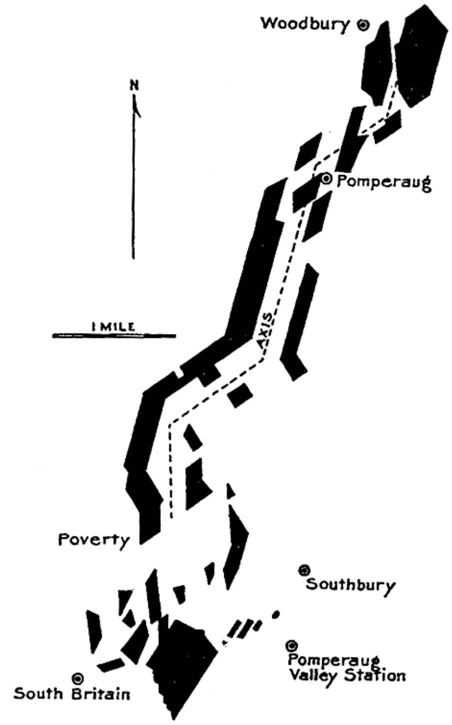


FIG. 8.—Map showing the areal development of the main basalt sheet.

Hobbs examined many outcrops of the "main or posterior basalt" and concluded that it is subdivided into a lower, compact, and massive to columnar member and a higher, amygdaloidal, and weathered upper member, together "several hundred feet thick" (p. 45). The western belt of basalt outcrops forms the highest ridges and contains the lower more solid member, while an eastern belt of outcrops is made from the upper amygdaloidal, friable member. These two belts are shown in another sketch map by Hobbs, reproduced above right (Hobbs, 1901, p. 45):

Hobbs supported his understanding of only two basalt flows in the basin by interviewing people who had observed the drilling of an "oil well" in the southeastern basin, which penetrated the entire Mesozoic section (Hovey, 1890; report reproduced as Appendix I). A quote from Hobbs is as follows (Hobbs, 1901, p. 58):

> "My own inquiries of persons living in the vicinity have elicited the information that the two basalt sheets mentioned by Dr. Hovey were encountered near the top of the shaft. It is probable, therefore, that they were the main and the anterior basalt sheets. As has already been pointed out, shale occurs as an outcrop within a few feet of the shaft, on the east, and amygdaloidal basalt (main sheet) a short distance to the west. The discovery in the dump of large specimens of reibungsbreccia composed entirely of basalt and calcitic cement (doubtless from the ancient coal shaft) is in harmony with the observation that several faults intersect at or very near to the oil shaft (see map, PI. VIII).

> On the basis of these observations, it seems to me to be probable that the thickness of the Newark to the top of the main basalt sheet is here not far from 1,200 feet, the average dip being reckoned as 15°."

Unfortunately, Hobbs' geological map of the basin (reproduced as Plate I) is nearly incomprehensible, partly because of the dark colors used but mainly because of his disregard for the conventional lines and symbols that are necessary for all good maps. Also, in spite of his claim to have visited virtually all outcrops, there is little detail of formation boundaries, and he completely missed important outcrops of basalt and conglomerate along South Brook in Woodbury. His structural interpretations, while imaginative to a brilliant degree, are grossly idealized. Hobbs' sketch maps and written descriptions appear to be relatively accurate and correct, and can be applied in much of this study.

Meinzer and Sterns, 1929

The geologic map by Meinzer and Sterns (Plate II) is mainly a generalized outcrop map, designed to assist their work of modeling sources and aquifers of groundwater in the Pomperaug River basin. Their locations of basalts and sedimentary formations conform well with observations by others, especially the pioneering map of Percival (1842), but their detail is not sufficient for interpreting structures.

Schutz, 1956

Donald Schutz was an undergraduate geology student at Yale University who mapped the Pomperaug basin for a senior research project. Although he was supervised by John Rodgers and John Sanders, this was an extremely ambitious project for a busy undergraduate, and his report has little detail about the observations and interpretations that are required to understand how his map (Plate III) was constructed. Although Schutz believed that he had found a higher, third basalt formation, his description of that basalt is a good match for the middle prehnite-rich member of the thick, second (main) basalt formation, as now seen in the quarries. This is the same unit as described by Percival and Hobbs as the upper member of the main basalt formation.

Scott, 1974

Robert Scott's map of the Southbury quadrangle includes the southwestern portion of the Pomperaug basin (Plate IV), which is the same well-exposed South Britain area studied by Davis and Hobbs. Scott attempted to apply the nomenclature and sequence of stratigraphy proposed by Sanders (1970) for an area of the southeastern Hartford basin, in which the three basalt flows (designated T_1, T_3, and T_5) and two intermediate shales (T_2 and T_4) are combined as members of the "Talcott formation." By adapting that as an operating model, Scott proposed a correlation of strata of the two basins, but with thinner units and finer-grained clastic rocks in Southbury.

Scott also proposed and mapped (1974, p. 32-35) a large number of faults that are needed to explain the repeated occurrences of basalt outcrops toward the east, but he did not provide much evidence for why some outcrops are a third flow, other than as an interpretation to reduce the number of faults. Where outcrops are good, Scott's Mesozoic map is relatively detailed and has been useful for this study. Otherwise, by necessity he conducted most of his work on the surrounding Paleozoic metamorphic rocks, which cover about 9/10 of the Southbury quadrangle.

Rodgers, 1985

John Rodgers and his associates performed an enormous and difficult task to compile a coherent bedrock geology map for Connecticut (Rodgers, 1985). As related in the previous excerpt regarding the preliminary version of the map (Rodgers et al., 1959), field studies around that time adopted a stratigraphy for the Pomperaug basin that was essentially a thinner version of the Hartford basin strata, despite the differences described by Davis (1888) and Hobbs (1901). This could still be correct, but the available evidence supports only two basalt formations overlain by a relatively thin unit of clastic sediments. Between the preliminary description and the 1985 map, several major Mesozoic faults were extended into the metamorphic basement formations around the basins (Tillman, 1982), as shown in Plate V.

Other work

An important student project was conducted by Donlon Hurtubise at Rutgers University, supervised by John Puffer (Hurtubise and Puffer, 1983; abstract attached as Appendix III). Hurtubise sampled several of the basalt outcrops mapped by Scott (1974) east of South Britain, and he followed the three-basalt "Talcott formation" system used by Scott. Chemical analyses of the lower amygdaloidal basalt, and samples considered to be an upper amygdaloidal basalt, were not satisfactory because of intensive alteration. The actual data and student report have been lost (Puffer, pers. comm. 2003) but an average of the best analyses, collected from the main "compact" basalt at Rattlesnake Hill near South Britain, is listed in their abstract (Hurtubise and Puffer, 1983). As they conclude, this basalt is a good match for the Holyoke basalt of the Hartford basin as well as the Preakness (Second Watchung) basalt of the Newark basin.

A study by William Tolley of Southern Connecticut State University was reported in a presentation and brief abstract (Tolley, 1986; abstract reproduced at Appendix IV). His summary of the stratigraphy of the Pomperaug basin is similar to Rodgers' (1985) model as used in the state bedrock geology map, with a "broad terrain" connection for all of the Hartford basin units. The original east-west width of the Talcott basalt was estimated as 50 km.

Huber, LeTourneau, and McDonald

Since the 1980's Phillip Huber and colleagues Peter LeTourneau, Nicholas McDonald, and Paul Olsen have been conducting stratigraphic and sedimentological studies of the Pomperaug basin (Huber and McDonald, 1992; Huber, 1997; LeTourneau and Huber, 1997; LeTourneau, 2002). Their arguments include a model in which the Pomperaug basin was formed in isolation and independently from the Hartford basin, in contrast to earlier conclusions that connect the stratigraphy over the gap between the basins. Toward this model, LeTourneau and Huber (1997) proposed new names for the formations of the Pomperaug basin, which do not include the third basalt and one of the upper clastic units of the Hartford basin. Their sketch map and nomenclature for the Pomperaug basin was used, with modifications, in Figure 1 of this report (permission of Peter LeTourneau, 2003).

South Britain Section

Because of its excellent outcrops and abundant previous descriptions, the South Britain area was visited several times in this study to collect data and samples of basalts. By air, the basalt ridges and fault-controlled valleys east of the village are very evident.

Figure 4. Air photo of the Platt Farm area southeast of South Britain, looking eastward. The hill to the left is Sherman Hill, and across the pasture to the right is Pine Hill. The southern end of Rattlesnake Hill is just visible at the far left. The sharp shadowed valley near the center is the fault-controlled Cass Brook, formerly known as Mitchell Brook. Only basalt is exposed in the low ridges in the distance. The airplane trip on Nov. 15, 2002 was courtesy of Larry Pond.

Eastward from the church parking lot in South Britain (across from the general store), the west slope of Rattlesnake Hill has exposures that confirm the sequence from bottom to top of "South Britain" arkose, a thin (c. 10 m) amygdaloidal "East Hill" basalt, about 30 m of gray-green to red "Cass Brook" shale, and thick, massive columnar "Orenaug" basalt (nomenclature as proposed by LeTourneau and Huber, 1997). Philpotts and others (1996) measured a minimum thickness of the Orenaug basalt at Rattlesnake Hill of 57 m, including a colonnade and entablature. The shale and lower amygdaloidal basalt are better exposed on-strike to the south between Rattlesnake Hill and Sherman Hill, and especially along Cass Brook. The same sequence is (reportedly) very clear along the western slope of Pine Hill as well, but that area is now posted against trespassing and was not visited in this study.

Hobbs (1901) believed that the uppermost portion of the South Britain arkose is indurated, or hardened by mineralization related to heating from the overlying basalts. This would account for the resistant ridge of conglomeratic arkose exposed high up on the slope of Rattlesnake Hill. All outcrops in this area show northerly strikes and steep dips of 20º to 30º eastward.

However, there are abrupt changes in the attitudes of basalts and sedimentary strata around Cass Brook, as described by Hobbs (1901) and Scott (1974). These are related to high angle faults with north-south to northeast-southwest trends and generally west-sides down. In addition, strata dips become less steep (10º to 20º) toward the east to southeast. Several faults are exposed along Cass Brook, some associated with "reibungsbreccia," which as described by Hobbs is an unusual tectonic breccia formed by fault activity between solid basalt and unlithified shale and siltstone.

Figure 5. Left photo: fault between East Hill basalt and shale in Cass Brook. Nancy McHone has her hand on red shale in the water. Right photo: reibungsbreccia developed by faulting between Cass Book siltstone and East Hill basalt in a gulley on the east side of Cass Brook.

Samples and observations of East Hill basalt and Orenaug basalt were taken from several outcrops on Rattlesnake Hill, the Platt Farm Preserve (including Cass Brook), and from Red Spring about 1 km to the north of Platt Farm. These areas are well described by Hobbs, 1901.

Southbury quarry

The Southbury quarry (formerly known as the Silliman quarry) is operated for crushed stone by the O&G Corporation. The quarry is just located south of the northern town line, just west of the Pomperaug River. It is a well-known source of fine prehnite samples and other minerals associated with amygdaloidal infillings of large gas vesicles. Quarry operations have penetrated the Orenaug basalt downward to a sedimentary exposure of red siltstone (the Cass Brook formation), which is capped by a white quartz arenite horizon that LeTourneau and Huber (1997) and LeTourneau (2002) have described as eolian.

Figure 6. Air photos of the Southbury quarry. Left: view toward the NE, taken in November of 2002. Right: high altitude image from www.mapquest.com. The Pomperaug River is held in several small dams not far to the east of the quarry.

The Southbury quarry provides a continuous section through about 70 m of the lower part of the Orenaug basalt. The basalts and sedimentary strata are tilted eastward about 15^{o}. As can be seen in the images below (Figure 7), its south-facing cuts expose boundaries that clearly define lower, middle, and upper members, which must be separate flow units. The lower member is about 18 m thick and is relatively massive to columnar, except near major fractures and the basal contact zone. The middle member, about 25 m thick, is highly altered to a gray-green color and contains abundant amygdales filled by calcite, quartz, prehnite, pumpellyite, apophyllite, and other minerals described by Garabedian and others (1996). There are several lens-shaped sections in this member that might represent separate lobes or lava tongues. The upper basalt member contains finger-sized basal tube vesicles directly over a brown weathered boundary surface. This upper member is very dark, non-vesicular and massive to columnar, although it displays pyrite roses on fracture surfaces.

These Southbury quarry observations essentially confirm the previous descriptions by Percival, Davis, and Hobbs that include several units of the thick second basalt, with a amygdaloidal prehnite-bearing member above a massive columnar lower member. The prehnite-bearing member and most likely the massive member above it are present in ridges through the central sections of the Pomperaug basin, including the Orenaug Hills, while the lower massive member must thicken to the south, where it forms the main ridges of East Hill and Bear Hill in the western basin. Some of the valleys between basalt ridges might be formed by erosion of the middle prehnite-rich member, leaving more resistant upper and lower members on either side.

Figure 7. Images of the Southbury traprock quarry. Upper left: prehnite "hearts" in a gas vesicle in the middle basalt member. Upper right: red siltstone and basalt breccia in a fracture, lower basalt member, probably caused by explosive steam discharges from wet sediment beneath the basalt. Lower left: view to the north showing boundaries that define the middle member. Note the lighter greenish color of the middle member. Lower right: red siltstone and white sandstone beneath the lower basalt member.

Woodbury Quarry

The Woodbury traprock quarry is also operated by the O&G Corporation. It cuts the "eastern twin" of the Orenaug Hills in the northeastern section of the basin. The quarry operations have exposed large pavements of white sandstone beneath the basalt, while the basalt itself is highly fractured and generally weathered. Although there may be a boundary exposed between the lower and middle members, in general the flow relationships are hard to define. The quarry has large piles of till that were bulldozed from the areas of quarry expansion, which contain abundant red siltstone cobbles and boulders. It is likely that these represent South Britain and/or Cass Brook sedimentary rocks from the northern end of the basin, which were carried over the quarry area by glacial actions.

Figure 8. Images of the Woodbury traprock quarry. Upper left: cast of wood (?) in basalt at the contact with sandstone. Upper right: breccia of white sandstone (quartzite) and basalt in a fracture. Lower left: sandstone pavement exposed beneath the basalt, NW end of the quarry. Lower right: fractures and highly-weathered zones in the quarry walls, with a gently-dipping parting that is not offset by the fractures.

Orenaug Hills

The Orenaug Hills form unusually straight and steep ridges of Orenaug basalt on the eastern side of Woodbury Village (figure 9). As noted by Davis (1888), the ridges have some features similar to the Hanging Hills in the Hartford basin near Meriden, where faults and fractures have created long, straight ravines that shape the hills. Both Davis and Hobbs described the presence of compact massive and columnar basalt as well as exposures of amygdaloidal basalt, which is apparently the middle member exposed at the Southbury quarry. Although Davis and Hobbs inferred the presence of shale between ridges of basalt, no sedimentary units were actually observed and none may exist. Trails on the southern and western sides of Orenaug Park provide good access, but only solid columnar basalt was observed in this study.

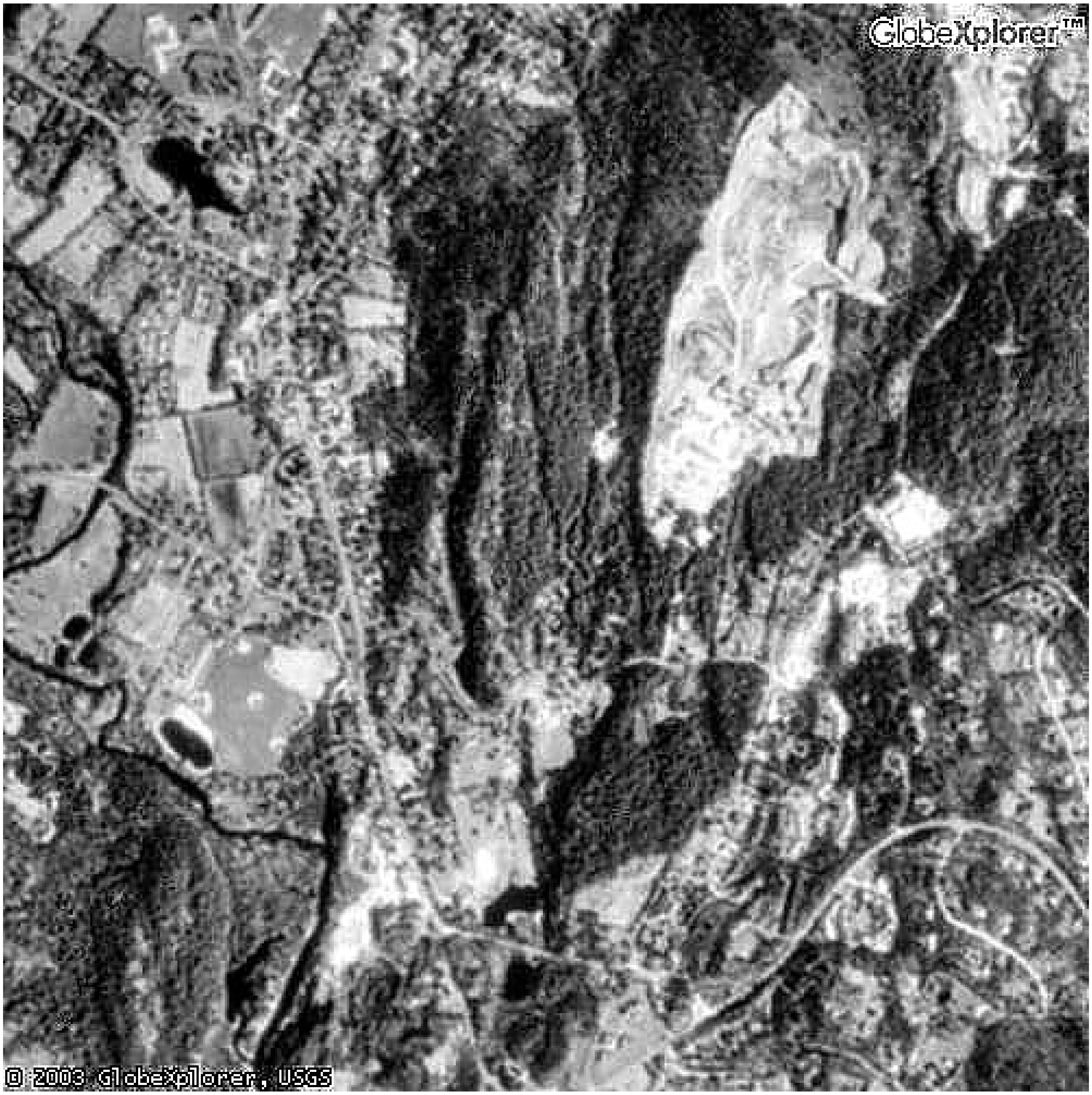


Figure 9. High-altitude air photo of the Orenaug Hills (center), downloaded from www.mapquest.com. Note the strongly developed ridge lines along faults. The large light zone in the northeastern area is the Woodbury (Park Road) traprock quarry.

PETROGRAPHY

Petrographic thin sections were prepared for samples from basalt outcrops in the South Britain area, the traprock quarries, South Brook in Woodbury, and the Orenaug Hills. In general, hand samples of the East Hill basalt show the highly-weathered state of this formation. All samples show abundant small (BB-sized) vesicles and amygdales filled with calcite or bluish-colored chalcedony. The basalt is generally soft and it crumbles when hammered, except for a few places not close to fractures. In some places the rock has disintegrated into "fish scales" that may be related to the shapes of gas bubbles. The basalt is very fine grained and may originally have been glassy, and few minerals other than amygdales are visible. In thin section, small laths of plagioclase are abundant and well preserved, and clinopyroxene crystals can be recognized by their crystal forms. No phenocrysts of orthopyroxene, such as can be found in unaltered Talcott basalt, were recognized although they may be present in altered forms.

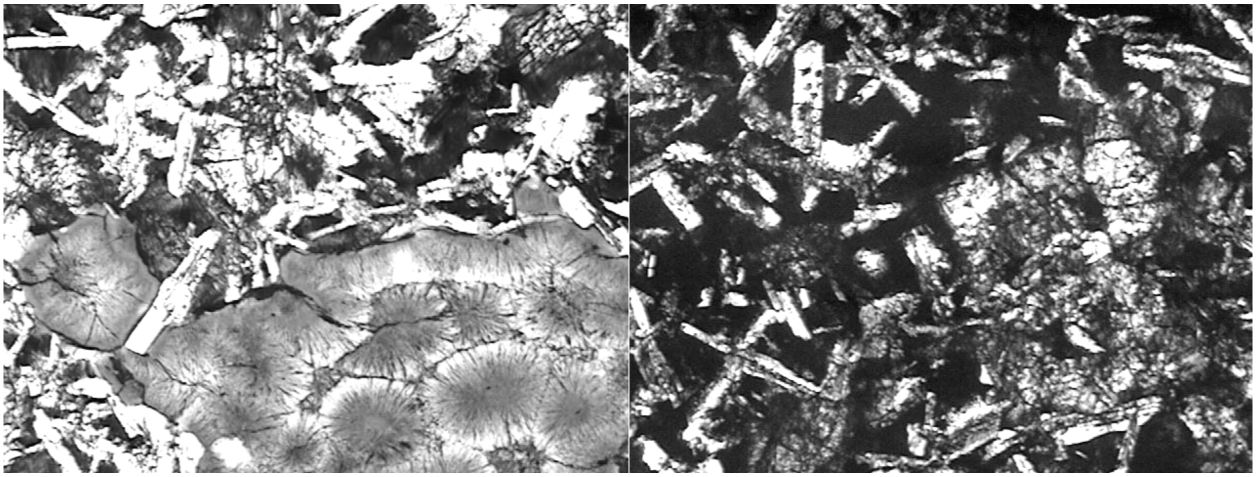


Figure 10. Thin section images (crossed-polars, gray scale) of the East Hill basalt at Red Spring. The left image show a chalcedony amygdale, with laths of plagioclase and altered equant grains of clinopyroxene. The right image shows plagioclase and altered pyroxene with interstitial black material that may be devitrified glass.

In contrast to the East Hill basalt, the upper and lower members of the Orenaug basalt are typically massive, medium grained, and relatively unaltered. Hand samples are hard, and fresh surfaces are dark gray with small feldspar crystals visible. In thin section, the basalt is subophitic, with fresh clinopyroxenes and abundant plagioclase, and scattered phenocrysts that might be relict olivines. The middle prehnite-bearing member is more altered, as expected.

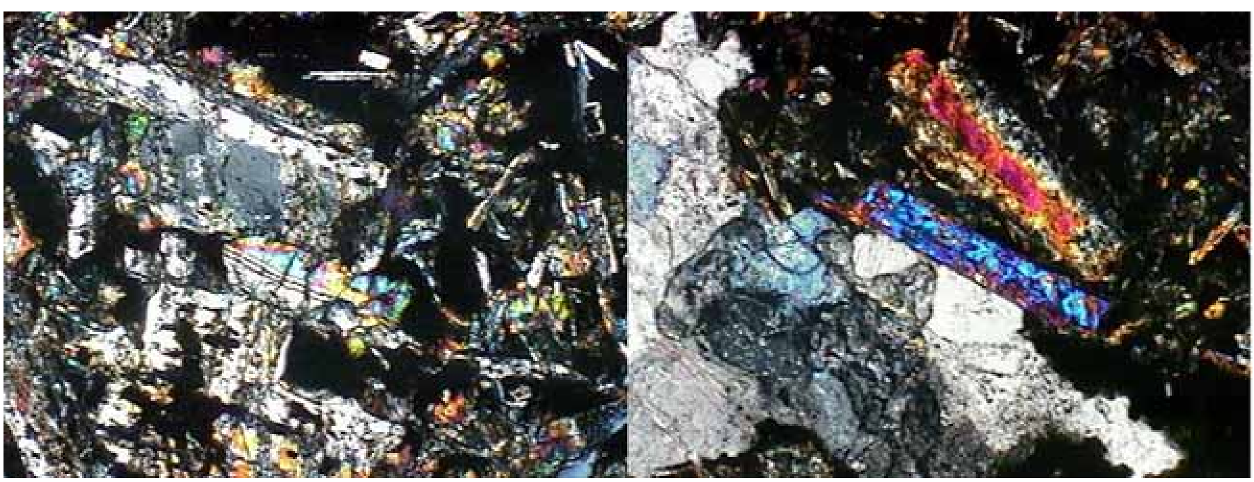


Figure 11. Thin section images of Orenaug basalt from the Southbury quarry (crossed polarizers, in color). Left: image of the lower member with dark patches of devitrified glass surrounded by plagioclase and clinopyroxene crystals. Right: carbonate-filled amygdales and plagioclase in the middle basalt member.

CHEMISTRY

It has already been shown by Hurtubise and Puffer (1983) and Philpotts and others (1996) that the Orenaug basalt at Rattlesnake Hill in South Britain is chemically and petrologically identical to the Holyoke basalt of the Hartford basin. As discussed above, field studies show this basalt to be main ridge-forming basalt throughout the Pomperaug basin. The analyses published by Hobbs (1901), Hurtubise and Puffer (1983), and Philpotts and others (1996) all overlap on chemical diagrams with the Holyoke basalt and also the Preakness basalt of the Newark basin.

The East Hill basalt has one analysis published by Hobbs (1901), which is evidently highly altered as shown by a high water content. However, TiO_2 and MgO are relatively independent of the effects of weathering because they are not very soluble, and their ratios have proven to be excellent tools for discriminating the different magma types in Mesozoic basins of eastern North America. The following TiO_2-MgO plot shows that the East Hill basalt analysis has the same ratio as the Talcott basalt of the Hartford basin.

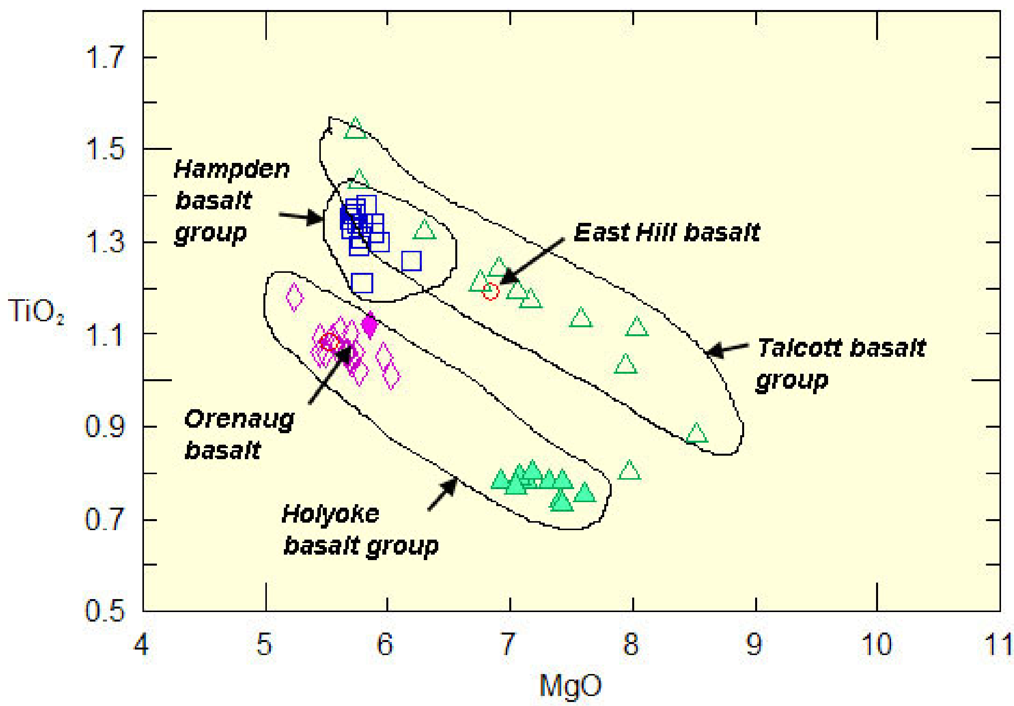


Figure 12. TiO2-MgO plot for basalts of the Hartford and Pomperaug basins. This diagram has been widely used to distinguish the three main basalt types of the northeastern basins (Philpotts and Martello, 1986; Puffer and Philpotts, 1992; McHone, 1996).

DISCUSSION

There are only two basaltic magma types in the Pomperaug basin, and they appear to be co-magmatic with the Talcott and Holyoke basalts of the Hartford basin. The East Hill basalt is much thinner than the Talcott basalt, indicating either the end of that flow or a rise in elevation from the Hartford basin to the Pomperaug basin, so that the top of the flow was more level than the base. This thinness and likely presence of water (as has been shown in the Hartford basin) caused the East Hill basalt to become volatile-rich, amygdaloidal, and quickly altered upon cooling.

Because of the leveling action of the lower lava flow and because of lacustrine sedimentary deposits, the elevation difference between basins may have been much less when the Holyoke flowed from the Hartford basin to the Pomperaug region. Thus, the Orenaug basalt has maintained more than 2/3 of the thickness of the Holyoke basalt, and probably flowed much farther as well. However, it developed several flow units before reaching the Pomperaug, with the second phase becoming volatile rich.

The sedimentary unit above the Orenaug basalt is thin and may have been mostly removed by erosion. A third flow representing the Hampden basalt of the Hartford basin may also have been present but subsequently removed, which also seems likely due to the nearness of the Bridgeport dike, which was the feeder to the Hampden basalt.

A cartoon illustrating the proposed correlation of basalts and strata between the Pomperaug and Hartford basins is shown in Figure 13.

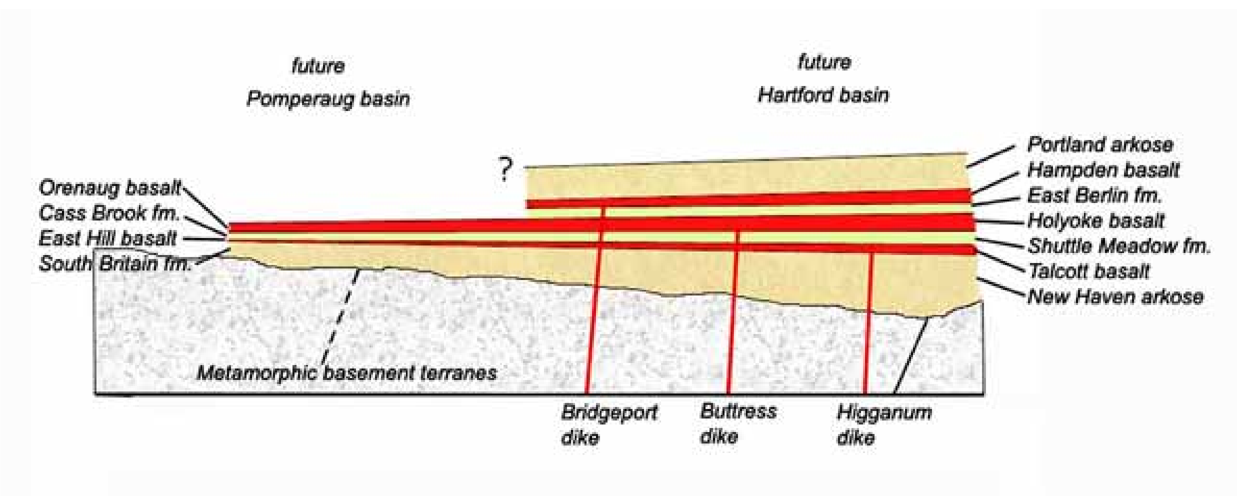


Figure 13. Cartoon of Early Mesozoic strata across southern Connecticut, neglecting tectonic features that later produced the modern geography of the basins.

CONCLUSIONS

Field studies have shown the presence of only two basalts in the Pomperaug basin, unlike the three-basalt correlations depicted on the state bedrock geology map. The two Pomperaug basalts are correlated via stratigraphy and chemistry with the Talcott and Holyoke basalts of the Hartford basin. This finding supports a partial broad-terrane model between the basins.

REFERENCES AND ADDITIONAL BIBLIOGRAPHY

Barrell, J., 1915, Central Connecticut in the geologic past: Connecticut Geological and Natural History Survey, Bull. 23, 44 p.

Blevins-Walker, J., Kunk, M. J., and Wintsch, R. P., 2001, An eastern provenance for the New Haven arkose and the Portland formation of the Hartford and Pomperaug basins: Broad terrane revisited: Geological Society of America Abstracts with Program, Northeastern Section, v. 33, no. 1, p. 81.

Chapman, R. W., 1965, Stratigraphy and petrology of the Hampden basalt in central Connecticut: Connecticut Geological and Natural History Survey, Report no. 3, 38 p.

Davis, W. M., 1888, The Triassic formation of the Connecticut Valley: U. S. Geological Survey, 7th Annual Report, p. 468-490.

Davis, W. M., 1898, The Triassic formation of Connecticut: U. S. Geological Survey, Annual Report no. 18, part 2, p. 1-192.

Ellefson, K. J. and Rydel, P. L., 1985, Flow direction of the Hamden basalt in the Hartford basin, Connecticut and southern Massachusetts: Northeastern Geology, v. 7, p. 33-36.

Garabedian, J. A., Gray, N. H., and Steinen, R. P., 1996, Secondary minerals in half-moon vesicles of the Mesozoic basalts of the Pomperaug basin, *in* LeTourneau, P. M. and Olsen, P. E., eds., Aspects of Triassic-Jurassic Rift Basin Geoscience: State Geological and Natural History Survey of Connecticut, Miscellaneous Reports 1, p. 13.

Gates, R. M., 1954, The bedrock geology of the Woodbury quadrangle, Connecticut: Connecticut Geological and Natural History Survey, Quadrangle Report no. 3, 32 p.

Gottfried, D., Froelich, A. J., and Grossman, J. N., 1991, Geochemical data for Jurassic diabase associated with Early Mesozoic basins in the eastern United States: Geologic setting, overview, and chemical methods used, U. S. Geol. Survey, Open-File Report, 91-322-A, 1991.

Grossman, J. N., Gottfried, D., and Froelich, A. J., 1991, Geochemical data for Jurassic diabase associated with Early Mesozoic basins in the eastern United States: U. S. Geol. Survey, Open-File Report, 91-322-K.

Gray, N. H., 1982, Mesozoic volcanism in north-central Connecticut, in Joesten. R. and Quarrier, S., eds., Guidebook for field trips in Connecticut and south central Massachusetts: Hartford, State Geological and Natural History Survey Guidebook No. 5, p. 173-190.

Hames, W.E., Renne, P. R., and Ruppel, C., 2000, New evidence for geologically-instantaneous emplacement of earliest Jurassic Central Atlantic magmatic province basalts on the North American margin: Geology, v. 28, p. 859-862.

Hobbs, W. H., 1901, The Newark System of the Pomperaug Valley, Connecticut: U. S. Geological Survey Annual Report, no. 21, pt. 3, p. 7-160.

Horne, G. S., McDonald, N. G., LeTourneau, P. M., and de Boer, J. Z., 1995, Paleo-environmental traverse across the Early Mesozoic Hartford basin, Connecticut: State Geological and Natural History Survey of Connecticut, Guidebook no. 7, p. B1-B37.

Hovey, E. O., 1890, The oil well at Southbury, Conn.: Scientific American, v. 62, p. 275.

Hozik, M. J., 1992, Paleomagnetism of igneous rocks in the Culpeper, Newark, and Hartford/Deerfield basins, in Puffer J. H. and Ragland, P. C., eds., Eastern North American Mesozoic Magmatism: Geological Society of America Special Paper 268, p. 279-308.

Huber, P., 1997, Comment: Broad-terrane Jurassic flood basalts across northeastern North America: Geology, v. 25, p. 191-192.

Huber, P. and McDonald, N. G., 1992, Revised stratigraphy and paleontology of the Early Mesozoic Pomperaug Basin (Newark Supergroup), western Connecticut [abstract]: Geological Society of America Abstracts with Program, Annual Meeting, v. 24, no. 7, p. 357-358.

Hubert, J. F., Dowdall, W. L., and Franz, A. J., 1979, Late Triassic paleogeography of redbeds in the Hartford basin and Pomperaug outlier, Connecticut and Massachusetts: Geological Society of America Abstracts with Program, Northeastern Section, v. 11, no. 1, p. 17.

Hurtubise, D. O. and Puffer, J. H., 1983, Geochemistry and petrology of the Pomperaug basin basalts, Connecticut [abstract]: Geological Society of America Abstracts with Program, Southeastern Section, v. 15, p. 91.

Klein, G. deV., 1969, Deposition of Triassic sedimentary rocks in separate basins, eastern North America: Geological Society of America Bulletin, v. 80, p. 1825-1832.

Krynine, P. D., 1950, Petrology, stratigraphy, and origin of the Triassic sedimentary rocks of Connecticut: Connecticut geological and Natural History Survey, Bull. 73, 247 p.

LeBas, M. J., LeMaitre, R. W., Streckeisen, A., and Zanettin, B., 1986, A chemical classification of volcanic rocks based on the total alkali silica diagram: Journal of Petrology, v. 27, p. 745-750.

LeTourneau, P. M. and Huber, P., 1997, Early Jurassic rift basin eolian strata, Pomperaug basin, Newark Supergroup, Connecticut [abstract]: Geological Society of America Abstracts with Program, Northeastern Section, v. 29, no. 1, p. 61.

LeTourneau, P. M., 2002, Eolian sandstones from the Pomperaug and Hartford rifts, Connecticut: Indicators of Early Jurassic paleoclimate gradients? [abstract]: Geological Society of America Abstracts with Program, Northeastern Section, v. 34, no. 1, p. 51.

Longwell, C., 1922, Notes on the structure of the Triassic rocks in southern Connecticut: American Journal of Science, v. 4, p. 223-236.

Margolis, Robinson and Schafer, 1986, Annotated bibliography of studies on the geology, geochemistry, mineral resources, and geophysical character of the early Mesozoic basins of the eastern United States, 1880 - 1984, USGS Bulletin 1688.

Mazzaferro, D. L., 1986, Ground-water availability and water quality at Southbury and Woodbury, Connecticut: U.S. Geological Survey, Water Resources Investigations Report 84-4221.

McDonald, N. G., 1996, The Connecticut Valley in the Age of Dinosaurs: A Guide to the Geologic Literature, 1681-1995: Connecticut Geologic and Natural History Survey, Bulletin 116, 242 p.

McHone, J. G, 1996, Broad-terrane Jurassic flood basalts across northeastern North America: Geology, v. 24, p. 319-322.

McHone J. G., 2000, Non-plume magmatism and rifting during the opening of the Central Atlantic Ocean, Tectonophysics, v. 316, p. 287-296.

McHone, J. G., 2003, Volatile emissions from Central Atlantic Magmatic Province basalts: Mass assumptions and environmental consequences, in Hames, W. E., McHone, J. G., Renne, P., and Ruppel, C., eds., The Central Atlantic Magmatic Province: Insights from Fragments of Pangea: American Geophysical Union, Monograph 136, p. 241-254.

McHone, J. G., and Puffer, J. H., 2003, Flood basalt provinces of the Pangaean Atlantic rift: Regional extent and environmental significance, in LeTourneau, P. M. and Olsen, P. E., eds.,

The Great Rift Valleys of Pangea in Eastern North America, Vol. 1: New York, Columbia University Press, p. 141-154.
Mikami, H. M and R. E. Digman, 1957, The bedrock geology of the Guilford 15-minute quadrangle and a portion of the New Haven quadrangle. State Geological and Natural History Survey, Bull. No. 86, 99 p.
Meinzer, O. E. and Sterns, N. D., 1929, A study of groundwater in the Pomperaug basin, Connecticut, with special reference to intake and discharge: U. S. Geological Survey Water Supply Paper, no. 597-B, p. 73-146.
Olsen, P. E., Schlische, R. W., and Fedosh, M. S., 1996, 580 Ky duration of the early Jurassic flood basalt event in eastern North America estimated using Milankovich cyclostratigraphy: Museum of Northern Arizona Bull. 60, p. 11-22.
Olsen, P. E., 1997, Stratigraphic record of the early Mesozoic breakup of Pangea in the Laurasia-Gondwana rift system: Annual Reviews of Earth and Planetary Sciences, v. 25, p. 337-401, 1997.
Percival, J. G., 1842, Report on the geology of the State of Connecticut: New Haven, Osborne and Baldwin, p. 308-451.
Philpotts, A. R., Carroll, M., and Hill, J. M., 1996, Crystal-mush compaction and the origin of pegmatitic segregation sheets in a thick flood-basalt flow in the Mesozoic Hartford basin, Connecticut: Journal of Petrology, v. 97, p. 811-836.
Philpotts, A. R. and Martello, A., 1986, Diabase feeder dikes for the Mesozoic basalts in southern New England: American Journal of Science, v. 286, p. 105-126.
Philpotts, A. R. and McHone, J. G., 2003, Basaltic sills, dikes, and lavas in the Hartford basin, Connecticut, in Brady, J. B. and Cheney, J. T., eds., Guidebook for Field Trips in the Five College Region: New England Intercollegiate Geological Conference, 95th Annual Meeting, Amherst and Northampton, Massachusetts, p. C2-1-C2-30.
Philpotts, A.R. and Reichenbach, I., 1985, Differentiation of Mesozoic basalts of the Hartford basin, Connecticut: Geological Society of America Bulletin, v. 96, p. 1131-1139.
Puffer, J. H., 1994, Initial and secondary Pangaean basalts, in Pangaea: Global Environments and Resources, Canadian Society of Petroleum Geology, Memoir 17, p. 85-95.
Puffer, J. H., 1992, Eastern North American flood basalts in the context of the incipient breakup of Pangaea, in Puffer J. H. and Ragland, P. C., eds., Eastern North American Mesozoic Magmatism: Geological Society of America Special Paper 268, p. 95-118.
Puffer, J. H., Hurtubise, D. O., Geiger, F. J., and Lechler, P., 1981, Chemical composition and stratigraphic correlation of Mesozoic basalt units of the Newark Basin, New Jersey, and the Hartford Basin, Connecticut: Geological Society of America Bulletin, v. 92, p. 155-159.
Rodgers, J., 1985, Bedrock geologic map of Connecticut: Hartford, Connecticut Geological and Natural History Survey, scale 1:125000, 2 sheets.
Rodgers, J., Bates, R. M., and Rosenfeld, J. L., 1959, Explanatory text for preliminary geological map of Connecticut, 1956: Hartford, State Geological and Natural History Survey, Bull. 84, 64 p.
Russell, I. C. 1880. On the former extent of the Triassic formation of the Atlantic states. American Naturalist, v. 14, p. 703-712.
Sanders, J., 1963, Late Triassic tectonic history of northeastern United States: American Journal of Science, v. 261, p. 501-524.

Sanders, J., 1970, Stratigraphy and structure of the Triassic strata of the Gaillard graben, south-central Connecticut: Connecticut Geological and Natural History Survey, Guidebook no. 3, 15 p.

Schutz, D. F., 1956, The geology of Pomperaug Valley, Connecticut: unpub. Senior Paper, Department of Geology, Yale University, New Haven, Connecticut, 44 p.

Scott, R. B., 1974, The bedrock geology of the Southbury quadrangle, with map: Connecticut Geological and Natural History Survey, Quadrangle Report no. 30, 63 p.

Silliman, Benjamin, 1820, Sketches of a tour in the counties of New Haven and Litchfield in Connecticut, with notices of the geology, mineralogy, and scenery, etc.: American Journal of Science, ser. 1, v. 2, p. 201-235.

Thomas, M. A., 1983, Effect of cooling rate and magma oxidation state on pyroxene chemical trends in a tholeiitic basalt [abstract]: Geological Society of America Abstracts with Program, Northeastern Section, v. 15, no. 3, p. 173.

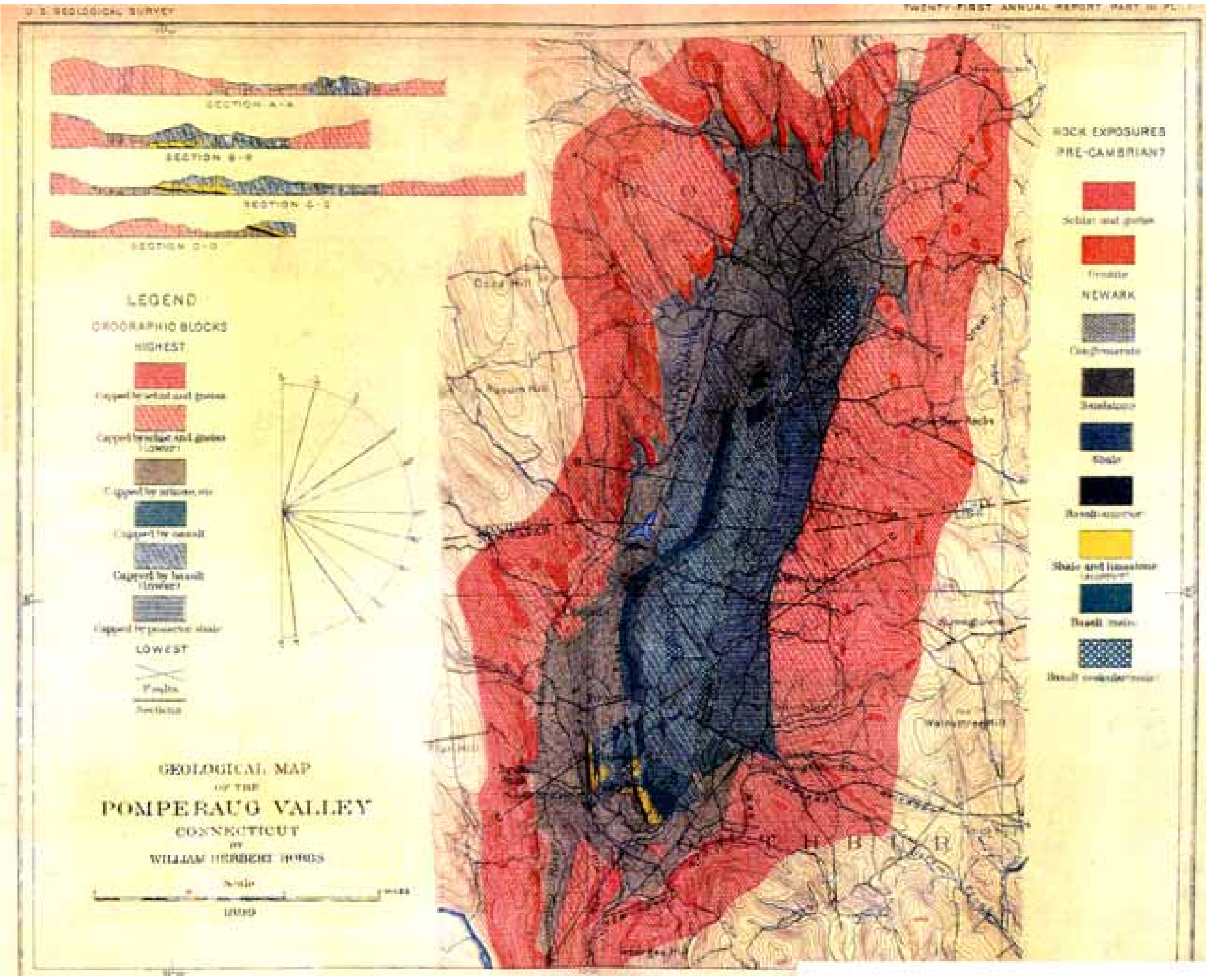
Tillman, J. E., 1982, Major fault zones and related seismicity in western Connecticut and southeastern New York [abstract]: Geological Society of America Abstracts with Program, Northeastern Section, v. 14, no. 1-2, p. 91.

Tolley, W. P., Jr., 1986, Stratigraphy of the Pomperaug outlier, Hartford Basin [abstract]: Geological Society of America Abstracts with Program, Northeastern Section, v. 18, no. 1, p. 72.

Tollo, R. P., and Gottfried, D., 1989, Early Jurassic quartz-normative magmatism of the Eastern North American province: evidence for independent magmas and distinct sources: International Association of Volcanology and Chemistry of the Earth's Interior, Continental Magmatism Abstracts, Bulletin 131, New Mexico Bureau of Mines and Mineral Resources.

West, David P., Jr., and McHone, J.G., 1997, Timing of Early Jurassic "feeder" dike emplacement, Northern Appalachians: Evidence for synchronicity with basin basalts: (King of Prussia, Pa.) Geological Society of America, Northeastern Section, Abstracts with Programs, v. 29, p. 89.

PLATE I. GEOLOGIC MAP BY HOBBS, 1901 (WITH ENLARGED SECTION BELOW)



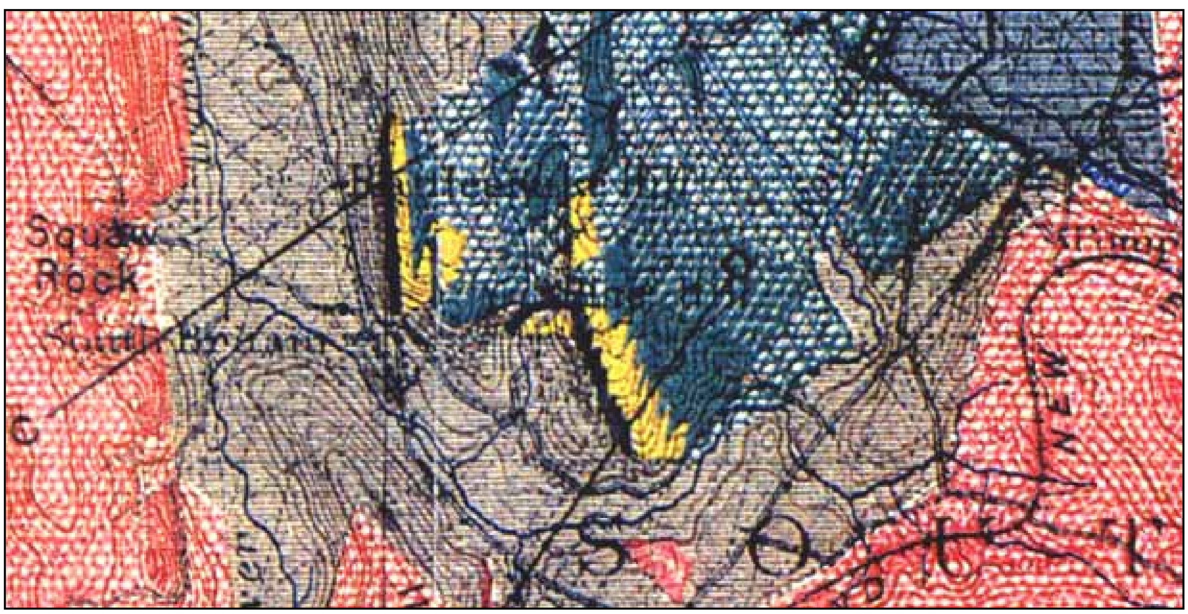


PLATE II. GEOLOGIC MAP BY MEINZER AND STERNS, 1929 (EXCERPT).

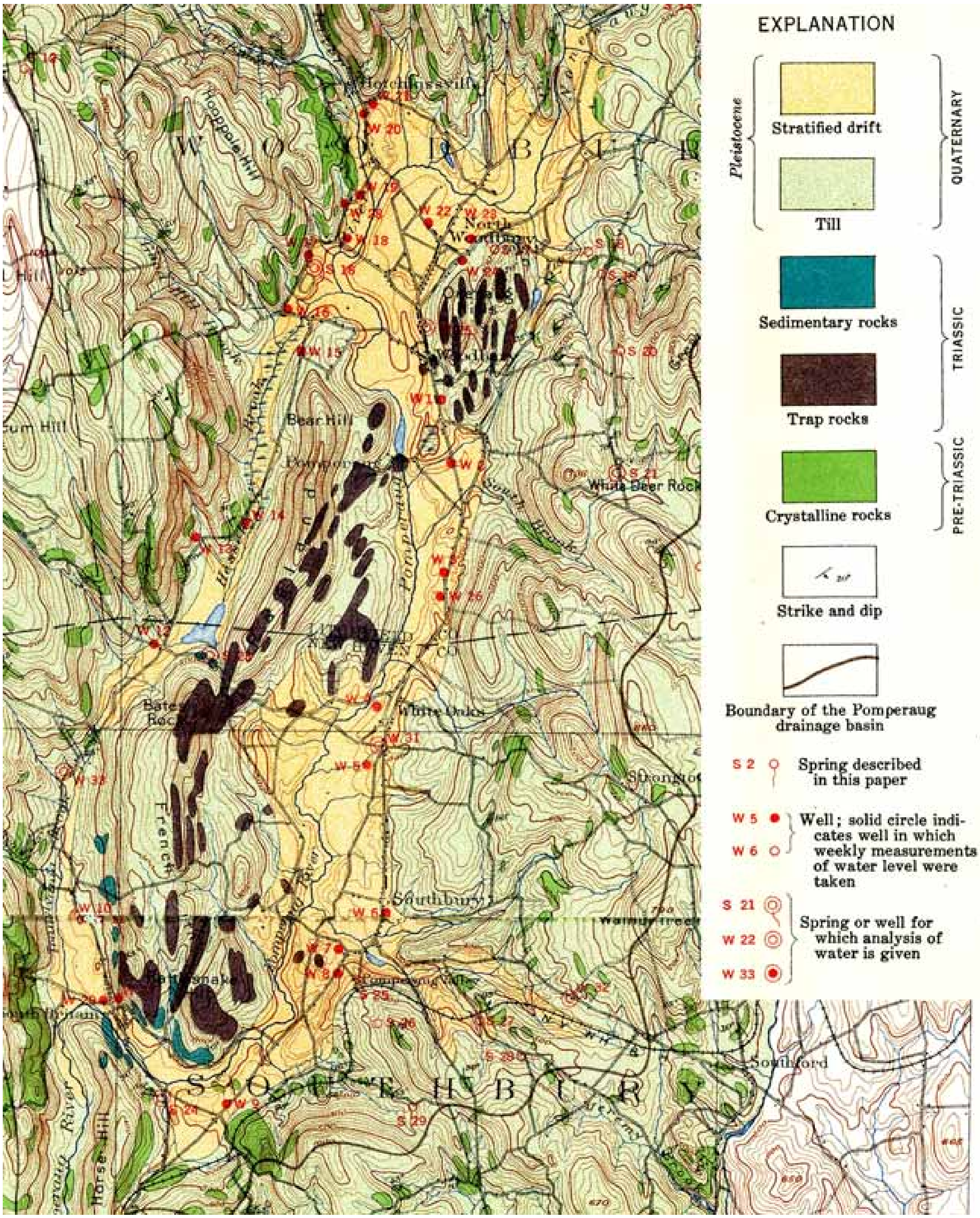


PLATE III. GEOLOGIC MAP BY SCHUTZ, 1956.

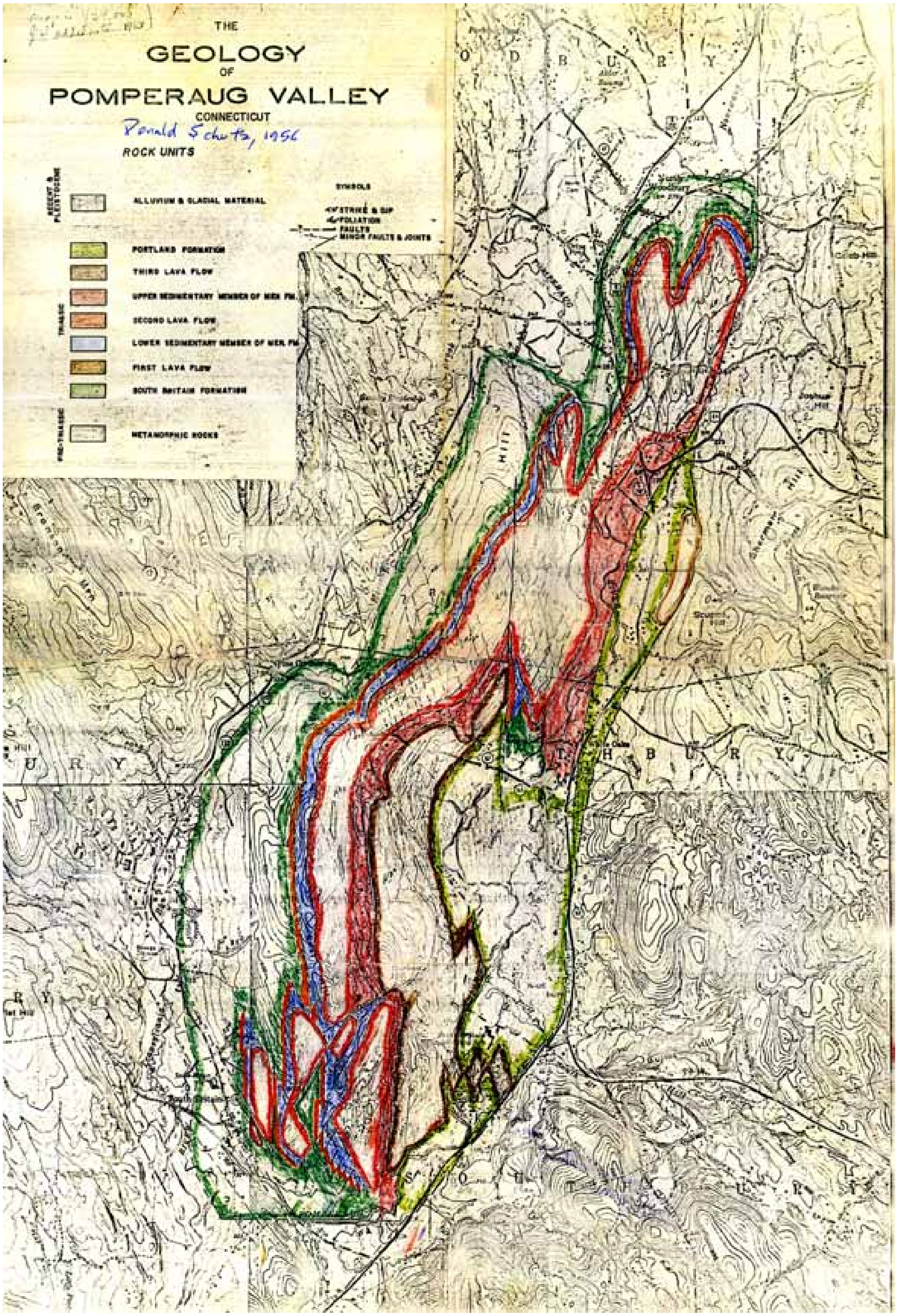


PLATE IV. GEOLOGIC MAP BY SCOTT, 1974 (EXCERPT).

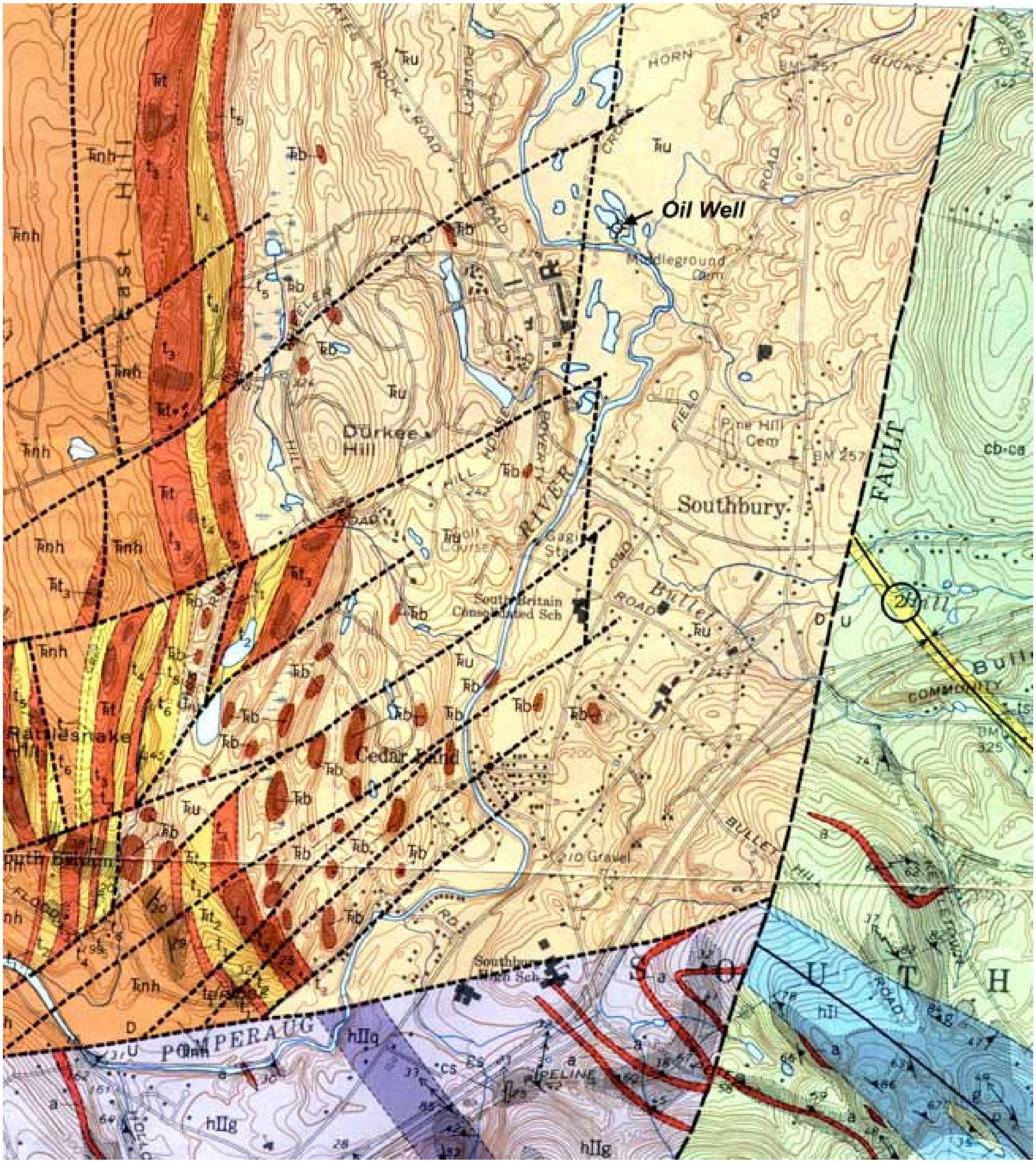
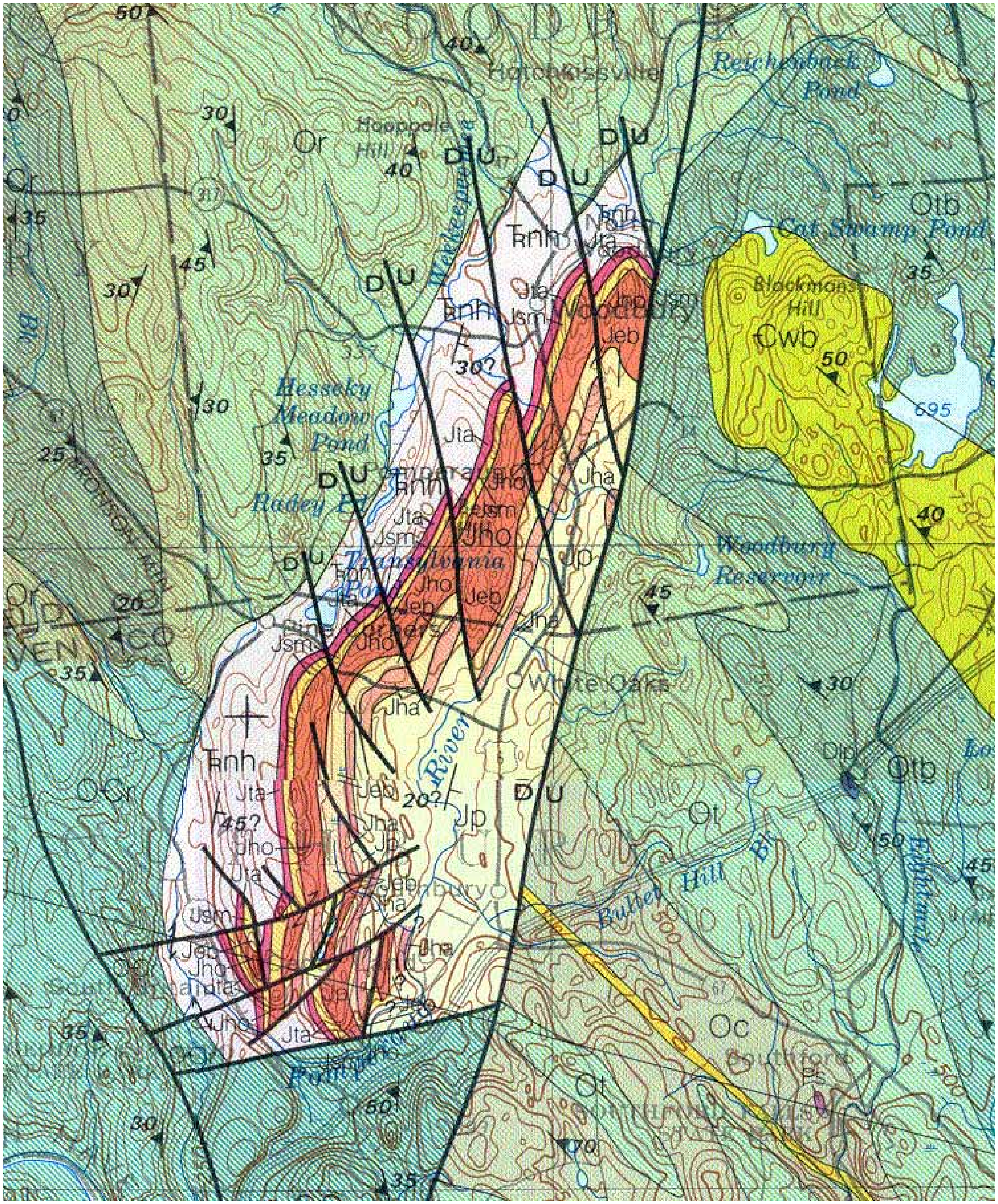


PLATE V. GEOLOGIC MAP BY RODGERS, 1985 (EXCERPT)



APPENDIX I. SCIENTIFIC AMERICAN OIL WELL ARTICLE BY HOVEY, 1890.

MAY 3, 1890.
THE OIL WELL AT SOUTHBURY, CONN. by E. O. Hovey.

Connecticut has had a peculiar history respecting mineral wealth. Many of the precious and baser metals have been found within her borders in sufficient quantities to lure men to spend thousands of dollars in mining and prospecting, but the deposits have always proved deceptive and unremunerative. Gold, silver molybdenum, bismuth, nickel, arsenic, copper, iron and lead, besides other minerals too numerous to mention, occur in many localities in the State; but, with the exception of the iron at Salisbury, Sharon, and Kent, the search for them has been disastrous to every one except the mineralogist, who has been well repaid for his labors.

Coal and oil also have received attention at the hand of eager enthusiasts. Many years ago a boring for coal was made with the diamond drill in the town of Durham, in the south central part of the State. When a depth of about 500 feet had been reached, and before the Triassic rocks had been pierced, the fruitless task was abandoned. Parts of the core from this boring may be found in many private collections in the State.

The occurrence of combustible black shales in the Pomperaug Valley, in the west central part of Connecticut, led some enterprising individuals in 1831 to sink a shaft for coal about a mile west of the village of Southbury, New Haven County. Welsh miners were employed, who sank a shaft six feet square one hundred feet into the rock. At this depth drilling was begun, and carried on for some scores of feet deeper, with the crude apparatus of the day. The story goes that one morning, after a depth of 250 feet had been reached, the miners on descending the shaft encountered a quantity of gas, which ignited from their lamps and exploded. This accident and the increase of water stopped the work, no genuine coal having been found.

About twenty feet from this old shaft a company of Waterbury capitalists began to sink a well in September, 1888, being influenced by the legend of the old well, and by the presence of oil on the waters of a brook near by, to think that oil or gas might be struck by a deep boring. A complete plant from Bradford, Penn., with a twenty horse power engine, was put in, and with a gang of experienced oil well drillers from Bradford work was pushed forward rapidly. Black bituminous shales and red shales smelling of petroleum encouraged the company in their undertaking, and gave even the drillers sufficient faith in the success of the project to lead them to try to lease all the land in the vicinity. The oil fever, however, had struck the Southbury farmers, and no land could be hired. After a series of the mishaps common in the making of deep borings, the depth of 1,525 feet from the surface was attained. Last summer (1889) the job of reaming out the lower half of the well was undertaken; but after it had been partly done the tools were lost, and no work has been done since, though the company has not abandoned the idea of drilling below the 1,525 foot level.

The well is in the south central part of the Woodbury-Southbury outlier of the Connecticut Triassic area. An account of the geology of the region, with map, by Prof. W. M. Davis, of Harvard University, may be found in the “Seventh Annual Report of the United States Geological Survey," issued in 1889. The well intersects red and black shales, red sandstones and conglomerates, and two trap sheets, and at about 1,235 feet passes from the fragmental Triassic rocks into the highly crystalline gneisses and mica schists so widely distributed throughout New

England. It is of interest to note that this is the first recorded instance of a boring which has pierced the Triassic rocks of this State.

At 1,250 feet free-milling gold and silver-bearing rock was struck, which assayed $10 worth of gold and $3 worth of silver to the ton, and the rock for ten feet above and twenty feet below this depth shows this amount or more of silver. If this rock occurs in considerable quantities, it would well repay the outlay necessary to mine it, and some of the oil well companies propose sinking a well with the diamond drill to obtain more definite knowledge of the strata and the occurrence of gold-bearing rock.

Speaking from geological premises, there is no chance whatever of obtaining either oil or gas from any boring here or elsewhere in Connecticut. The Triassic rocks are far above the strata which yield oil or gas in other States, while the crystalline rocks, which form the remainder of the State and are mostly of uncertain age, have been so highly metamorphosed that all volatile constituents like oil and gas—if ever there were any—have entirely disappeared from them.

APPENDIX II. NEGSA ABTRACT BY HUBERT AND OTHERS, 1979

LATE TRIASSIC PALEOGEOGRAPHY OF REDBEDS IN THE HARTFORD BASIN AND POMPERAUG OUTLIER, CONNECTICUT AND MASSACHUSETTS

HUBERT, John F., Department of Geology/Geography, University of Massachusetts, Amherst, Massachusetts 01003; DOWDALL, Wayne L., Weston Geophysical, Westboro, Massachusetts 01581; FRANZ, Arthur J., Texaco Oil Company, Midland, Texas 79701

In the Hartford Basin, the Upper Triassic redbeds are the 2000-m New Haven Arkose in Connecticut and the age-equivalent part of the Sugar-loaf Arkose, Massachusetts. The Pomperaug Outlier in western Connecticut preserves 138 m of New Haven Arkose. These fluvial rocks accumulated in a tropical rift valley at 15°N paleolatitude over an interval of about 9 million years from Early Norian through Rhaetian. The detritus was eroded from metamorphic-igneous highlands east of the fault-bounded valley. Numerous caliche paleosols demonstrate semi-aridity with about 100-500 mm of seasonal precipitation. The rivers deposited three facies in the valley. (1) Alluvial fans coalesced along the eastern escarpment in a bajada, 5-15 km wide, made of stream-flow conglomerate and pebbly sandstone interbedded with debris-flow pebbly mudstone. (2) Ephemeral braided rivers flowed southwest in a belt 20-30 km wide. Measured sections are dominated by plane beds and thick crossbeds (up to 1.4 m) of pebbly sandstone deposited on longitudinal bars. Less common are laterally continuous, planar crossbeds of sandstone that formed on slipfaces of linguoid bars. (3) A meander belt is recorded at North Haven in the Hartford Basin, and in the Pomperaug Outlier, by finding-up, point-bar channel sandstone (festoon crossbeds-plane beds-ripples) interbedded with floodplain mudstone. The Pomperaug Outlier was formerly continuous with the Hartford Basin, as shown by transitional map patterns for the facies belts, paleocurrents, maximum clast size, and maximum thickness of crossbed sets.

APPENDIX III. NEGSA ABSTRACT BY HURTUBISE AND PUFFER, 1983.

GEOCHEMISTRY AND PETROLOGY OF THE POMPERAUG BASIN BASALTS, CONNECTICUT

HURTUBISE, D.O., Mobil Oil Corporation, P.O. Box 5444, Denver, CO. 80217; and PUFFER, J.H., Dept. of Geological Sciences, Rutgers University, Newark, N.J. 07102

Eighteen basalt samples were collected at five locations within the Pomperaug Basin; seven were determined to be unaltered. The fresh samples are high-Fe_2O_3 types, according to Weigand and Ragland's (1970) classification of Eastern North America Dolerites. The average major and minor element composition of the unaltered samples is 52.58% SiO_2, 1.12% TiO_2, 13.22% Al_2O_3, 14.05% Fe_2O_3 total, 10.77% FeO, 5.75% MgO, 9.78% CaO, 2.64% Na_2O, 0.54% K_2O, 1.26% H_2O+, 0.40% H_2O-, 204 ppm Ba, 62 ppm Cu, 35 ppm Rb, 172 ppm Sr, 6 ppm Nd, and 385 ppm V.

The unaltered basalts are quartz-normative tholeiites that plot along the Palisades Fractionation Trend on Mafic Index versus SiO_2 and TiO_2 diagrams. They also closely resemble the chemical composition of the Second Watchung (Preakness) and Holyoke Basalts of the Newark and Hartford Basins, respectively. Based on our geochemical data and the geographical proximity of the Pomperaug to the Newark and Hartford Basins, we interpret the unaltered Pomperaug Basalts analyzed as rock-stratigraphic and probably time-stratigraphic equivalents of the Second Watchung and Holyoke Basalts.

Each of the unaltered samples are from a 100m thick massive columnar basalt unit (the t_3 unit of Scott, 1974). Two other flows found overlying and underlying the t_3 unit in the basin are relatively thin (<15m) and tend to be rather pervasively altered in outcrop. These thin altered flows cannot be correlated with either First Watchung-Talcott or Third Watchung-Hampden basalts on the basis of our geochemical evidence. Therefore, we differ with published interpretations that correlate each of the Pomperaug Basalt units with the Talcott Basalt and instead suggest the "t_3 - massive columnar basalt" is a Second Watchung-Holyoke equivalent.

APPENDIX IV. NEGSA ABSTRACT BY TOLLEY, 1986.

STRATIGRAPHY OF THE POMPERAUG OUTLIER, HARTFORD BASIN

TOLLEY, William P. Jr., Earth Science Department, Southern Connecticut State University, New Haven, CT. 06515

Mapping the 600 meters of Jurassic section in the Southbury and Woodbury quadrangles, Connecticut indicates that Pomperaug Outlier is a listric faulted half graben close to the western border of the Hartford Basin.

The revised seven unit stratigraphic section at Pomperaug consists of the New Haven Arkose 155-160 m., Talcott Basalt 6 m., Shuttle Meadow Formation 100 m., Holyoke Basalt 100 m., East Berlin Formation 100 m., Hampden Basalt 35-50 m., and Portland Arkose 110 m. The westward thinning of the Talcott Basalt across the whole basin suggests an initial Hartford Basin width of at least 50 kms. Geologic cross-sections reveal that the Pomperaug structure is controlled by listric normal faults and transverse folds.

APPENDIX V. GSA ABSTRACT BY HUBER AND MCDONALD, 1992.

REVISED STRATIGRAPHY AND PALEONTOLOGY OF THE EARLY MESOZOIC POMPERAUG BASIN (NEWARK SUPERGROUP), WESTERN CONNECTICUT.

HUBER, Phillip, Dept. of Geological Sci., Ohio Univ., Athens, OH 45701 and MCDONALD, Nicholas G., Dept. of Earth and Environmental Sci., Wesleyan Univ., Middletown, CT 06459.

The Triassic-Jurassic Pomperaug basin is a small half graben containing some 400 m of east-dipping fluvial and lacustrine strata and intercalated basalts. Previous studies regarded the Pomperaug as an erosional outlier 17 km to the west of the Hartford basin, and characterized both basins as possessing similar stratigraphies of four clastic units interbedded with three basalts. The revised stratigraphy recognizes the basal Pomperaug unit, the South Britain Fm., as consisting of 250 m of fluvial redbeds: the lower 200 m are largely stacked channel sequences of arkose and siltstone, while the upper 50 m are dominated by pebbly arkose and channel lag conglomerate containing extrabasinal clasts up to 20 cm in diameter and petrified wood. The succeeding 7 m of vesicular basalt are followed by 30 m of strata which include two carbonate-rich lacustrine cycles. The lakebeds contain Corollina-dominated palynofloras, megafossil plant fragments (conifers, cycadeoids and horsetails), and fishes (Semionotus and Redfieldius. The Triassic-Jurassic boundary occurs below the lowest lakebed. High in the unit are poorly-sorted pebbly arkose, cobble conglomerates with 23 cm clasts, and very fine grained (?eolian) quartzose sandstone. Molds and casts of ?sphenosuchian and dinosaur bones have been recovered from one of the conglomeratic horizons in the unit. The overlying 80 m of basalt is made up of multiple flows, above which are 20+ m of elastics which include at least one lacustrine cycle. The presence of higher strata, mapped by some previous workers, is doubtful.

The existence of cobble-sized, subangular clasts, distinctive beds of poorly-sorted fluvial arkose, and the abundance of schist and other readily-fragmented rock types in conglomerates refute prior regional paleogeographic maps which portray Pomperaug sedimentary units as fine-grained, distal, "meander belt" facies of west-flowing Hartford basin streams, and instead suggest local provenance for at least some of the basin fill. Pomperaug basin fluvial and lacustrine strata are clearly not marginal facies which delimit the original western extent of the Hartford basin, as formerly advocated.

APPENDIX VI. NEGSA ABSTRACT BY LETOURNEAU AND HUBER, 1997.

EARLY JURASSIC RIFT BASIN EOLIAN STRATA, POMPERAUG BASIN, NEWARK SUPERGROUP, SOUTHBURY, CONNECTICUT

LETOURNEAU, Peter M., Dept. of Earth and Environmental Sciences, Columbia University, Palisades, NY, 10964, letour@ldeo.columbia.edu; HUBER, Phillip, University of Bridgeport, Bridgeport, CT

While spectacular examples of rift basin eolian sandstones have been described from Late Triassic and Early Jurassic strata of the Fundy Basin, Canada (Hubert and Mertz, 1980, 1984;

Nadon, 1981), only one occurrence of eolian sandstone, has been noted in Tr-J rift basins south of the Fundy Basin (Smoot,1991a, 1991b).

Recent excavations in two basalt quarries have revealed the presence of thick (3 m) and laterally extensive (~ 5 km) eolian sandstone beds. The eolian strata rest on fluvial conglomerate and sandstone, and are overlain by the uppermost basalt flow. The sandstone consists of low- to high-angle wedge planar cross-strata with tangential lower contacts and a three-tier hierarchy of interstratal bounding surfaces. The well sorted sandstone consists of rounded to well-rounded quartz sand with minor feldspar and lithic fragments; mica is absent. Sedimentary structures and features include: 1) high and low angle, parallel to wedge-planar, inverse- and normal-graded laminae; 2) "pin stripe lamination and sub critically climbing translatent strata; 3) sandflow and grainfall cross-strata; 4) bimodal distribution of particle size between adjacent laminae; 5) high porosity and permeability; 6) high index ripples with coarser grains near the ripple crests; and 7) soft sediment deformation (slumps). Paleocurrent directions indicate sand transport to the northeast.

Features observed compare favorably with those observed in modern and ancient eolian deposits. The lateral extent of the eolian strata suggests a regional dune field rather than local feature. The eolian dune field may result from wind reworking of lacustrine littoral sand or fluvial sand from braided alluvial plains. Paleocurrent directions from dune cross-strata likely represent local wind directions influenced by basin configuration rather than large-scale atmospheric flow patterns. These strata are the youngest eolian sandstones in the Newark Supergroup found south of the Fundy Basin.

APPENDIX VII. NEGSA ABSTRACT BY BLEVINS-WALKER AND OTHERS, 2001.

AN EASTERN PROVENANCE FOR THE NEW HAVEN ARKOSE AND THE PORTLAND FORMATION OF THE HARTFORD AND POMPERAUG BASINS: BROAD TERRANE REVISITED

BLEVINS-WALKER, Jamie (1), KUNK, Michael J. (2), and WINTSCH, Robert P. (1), (1) Geological Sciences, Indiana University, Bloomington, IN 47405, jblevins@bloom.ivy.tec.in.us, (2) USGS, MS 963, Denver, CO 80225

Models of the provenance of Mesozoic basin sediments in New England call on eastward and westward transport of sediment forming the Late Triassic New Haven Arkose and the Early Jurassic Portland Formation in the Hartford and Pomperaug basins. The basins are half-grabens, bounded on the east by syn-depositional normal faults. Sediments most likely were shed from an escarpment to the east and from a peneplane to the west. Sediments derived from rocks to the east have Pennsylvanian (Alleghanian cooling) or younger white micas, whereas those from the west are all Mississippian (Acadian cooling) or older. Thus, the ages of detrital white micas can be powerful discriminators of provenance for sediments in the Hartford and Pomperaug basins.

We tested this model using single-grain laser fusion 40Ar/39Ar and age spectrum dating of detrital white micas from eight Hartford basin and two Pomperaug basin outcrops. Age spectra from four outcrops of the New Haven Arkose show dominantly Alleghanian cooling ages. Single grain data from five samples gave exclusively Alleghanian cooling ages and two gave exclusively Acadian cooling ages. Age spectra from five samples from Portland Formation

outcrops indicate ages ranging from 248 to 297 Ma and single grain data ranging from 250 to 310 Ma. These data show that Alleghanian white micas dominate the New Haven Arkose in the Hartford and Pomperaug basins, and overwhelm Acadian white micas in the Portland Formation. Therefore, provenance was dominantly from the east, and paleoslopes were dominantly to the west in the Late Triassic and Early Jurassic, even in western Connecticut. Thus, the eastern border faults of these two basins were indeed syn-depositional, but not in the extensional regime implied by the present eastern dip of these sediments. Rather, rocks under and west of the Hartford basin were more likely a foreland basin in a transpressional regime where rocks of the eastern New England hinterland (Bronson Hill terrane and east) had been continuously exhumed since late Pennsylvanian.

APPENDIX VIII. NEGSA ABSTRACT BY LETOURNEAU, 2002

EOLIAN SANDSTONES FROM THE POMPERAUG AND HARTFORD RIFTS, CONNECTICUT: INDICATORS OF EARLY JURASSIC PALEOCLIMATE GRADIENTS?

LETOURNEAU, Peter M., Lamont-Doherty Earth Observatory, Columbia Univ., Palisades, NY 10964, letour@ldeo.columbia.edu.

The recent recognition of eolian beds in Early Jurassic age rocks of the Pomperaug and Hartford rifts is noteworthy because, with the exception of a single eolian bed in the Late Triassic rocks of the Hartford basin (Smoot, 1991), eolian deposits in the Newark Supergroup are mainly found in the Fundy basin, Canada at about 14° -15° paleolatitude. The Pomperaug sandstone contains sedimentary features, including grainfall and grainflow layers, inverse-graded pinstripe laminae, and high sorting, that compare favorably with those observed in modern eolian dune sands. The eolian beds overlie caliche horizons in red, rooted and mud-cracked siltstone indicative of arid- to semi-arid depositional environments. The beds are part of a basin-wide eolian dune field traceable for at least 5km along the axis of the basin. The eolian beds, including the surface morphology of the dunes, were preserved by the overlying basalt flow.

Re-examination of sedimentary features reveal that eolian deposits are a significant component of the classic Portland brownstone quarries in Connecticut. 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. The eolian beds alternate with fluvial beds in intervals about 15m thick indicating possible cyclic climatic control on deposition.

Eolian sedimentation in the Pomperaug and Hartford rifts was promoted by both favorable paleolatitudinal position and deposition within relatively dry climatic intervals. These deposits formed at about 11° paleolatitude, on the arid side of the estimated 10° latitude arid-humid climate 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, contra Parrish (1993). 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.

APPENDIX IX. TABLE OF CHEMICAL ANALYSES BY PHILPOTTS AND OTHERS, 1996 (RATTLESNAKE MTN.)

Sample:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Height (m):	0.00	2.43	3.83	4.43	7.61	11.42	13.10	16.76	19.80	22.55	27.73	32.00	34.82	37.79	45.41	51.20	57.60
Si02	51.51	52.59	52.37	51.88	52.18	53.11	52.75	52.70	52.78	52.58	53.72	52.28	52.28	52.61	51.99	53.38	53.19
Ti02	1.18	1.07	1.06	1.05	1.10	1.01	1.02	1.06	1.04	1.05	1.06	1.09	1.11	1.06	1.08	1.06	1.09
AI203	15.75	14.42	14.64	15.26	13.81	14.31	14.26	13.93	14.08	14.11	14.17	13.80	13.98	14.08	14.01	14.11	14.05
Fe203	3.72	3.56	3.27	1.95	2.40	2.48	3.40	3.52	3.30	3.61	3.28	3.74	4.03	3.52	3.86	3.16	3.24
FeO	8.50	9.10	9.65	10.57	10.75	9.82	9.35	9.53	9.80	9.48	9.10	9.63	9.26	9.37	9.46	9.51	9.55
MnO	0.28	0.25	0.24	0.25	0.24	0.23	0.23	0.24	0.24	0.23	0.23	0.25	0.25	0.23	0.25	0.23	0.23
MgO	5.24	5.59	5.68	5.97	5.70	6.03	5.77	5.66	5.71	5.69	5.44	5.55	5.61	5.74	5.57	5.49	5.45
CaO	8.76	10.01	9.93	9.76	10.33	10.19	10.17	10.20	10.28	10.22	9.89	10.39	10.25	10.12	10.53	10.00	9.99
Na20	4.46	2.51	2.29	2.54	2.81	2.19	2.35	2.43	2.09	2.29	2.29	2.65	2.49	2.65	2.59	2.45	2.46
K20	0.34	0.65	0.59	0.48	0.43	0.41	0.44	0.45	0.43	0.46	0.57	0.35	0.47	0.35	0.36	0.35	0.46
P20S	0.15	0.15	0.17	0.19	0.13	0.11	0.16	0.16	0.14	0.17	0.15	0.16	0.16	0.15	0.19	0.16	0.18
	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
p.p.m.																	
Ti	7088	6430	6374	6320	6608	6056	6112	6356	6237	6295	6352	6554	6673	6370	6493	6359	6554
V	353	327	337	328	339	321	330	316	328	327	323	339	347	332	345	302	342
Cr	26	29	23	21	6	14	8	16	10	7	8	6	12	13	9	6	7
Ni	49	55	60	47	33	26	26	32	35	30	23	26	27	30	29	25	32
Cu	138	97	81	90	82	75	77	96	93	98	103	97	106	102	121	100	102
Zn	153	74	80	77	77	84	86	85	82	87	83	89	87	90	83	86	99
Rb	4	23	13	7	14	11	16	17	18	20	12	19	20	15	24	24	29
Sr	94	147	134	153	204	175	169	181	197	179	158	194	196	187	214	184	186
Y	25	24	21	21	25	19	20	22	22	20	24	22	24	21	22	26	26
Zr	107	97	90	85	94	86	88	92	89	92	94	100	98	100	101	97	103
Nb	15	9	8	7	9	6	9	13	9	8	16	3	7	20	5	16	11
Ba	30	155	111	60	119	136	117	146	129	107	184	176	144	156	159	118	186