T. K. Meyers

STRATIGRAPHY, STRUCTURE, AND METAMORPHISM IN THE MIDDLE HADDAM QUADRANGLE AND VICINITY, CONNECTICUT

By

John L. Rosenfeld, U.C.L.A. and Gordon P. Eaton, Wesleyan

STRATIGRAPHIC RELATIONS

Four anticlines of gneiss, mantled by predominantly schistose metamorphic rocks, crop out in the area immediately east of the Triassic Border Fault near Middletown, Connecticut. The stratigraphic section in this area is remarkably like that found many miles to the north, in western New Hampshire. Within the mantling strata are two major unconformities, characterized by superimposed strata of a coarsely clastic sedimentary facies.

The upper of these unconformities is believed to represent the Taconic orogeny. A syncline containing rocks of the Bolton group*, which overlies this unconformity, has been traced northward to Quabbin Hill in central Massachusetts, only a few miles from areas where Siluro-Devonian rocks, dated by fossils, strike southward from New Hampshire. The similarity of the Bolton group, both in lithology and sequence, to the Clough, Fitch, and Littleton formations of western New Hampshire is indisputable. It is improbable that structural complications in the area of Quabbin Reservoir could alter correlation of these formations with the Bolton group.

The lower of the two unconformities is distinctive in that superjacent metasedimentary rocks rest on others of predominantly volcanic origin and also on massive granitoid rocks which show a discordant relationship with the metavolcanics, but which do not cut the overlying metasediments. The rocks above this unconformity (Collins Hill formation) are similar to those of the Partridge formation of southwestern-most New Hampshire and southeastern Vermont.

The unconformity at the base of the Collins Hill formation does not parallel that at the base of the Bolton group. The areal distribution of the Collins Hill formation relative to that of the Bolton group suggests that the major axis of folding in the Collins Hill formation is oriented slightly counter-clockwise to the axis around which folding took place in the Bolton group (at a later time).

---

* For names of stratigraphic units and locations of geologic structures, reference should be made to the accompanying stratigraphic section, geologic map, and structural cross sections.

Beneath the lower unconformity there is considerable contrast in the composition of the separate masses of gneiss. In the southern portion of the Glastonbury "dome," the rock is predominantly a massive granitic gneiss in which one occasionally finds dark-colored, mafic-rich schlieren. In the Killingworth dome, the amphibole-rich, stratified rocks of the Middletown formation are separated from the underlying and conformable stratified plagioclase gneisses of the Monson gneiss with difficulty. Similar relations obtain along the west side of the band of Monson gneiss that extends northward toward the type locality in Massachusetts. The smallest gneiss mass, centered at Maromas, seems to have had a hybrid origin. In it, granitic gneiss similar to the Glastonbury gneiss exhibits numerous apophyses which extend into gneisses and amphibolites along its eastern margin. The latter rocks have been mapped as Middletown formation because of compositional similarity to that unit in its type locality. It would seem reasonable to infer that the Monson gneiss is missing in this dome as a result of intrusive transection.

STRUCTURE

Structurally, the anticlines of the Middle Haddam area are similar to the mantled gneiss domes of Eskola (1949). These domes form a portion of a long chain to which Billings (1956) has given the name, "Bronson Hill Anticline." Actually, in the Middle Haddam area, only the mass centered about Killingworth appears to be a dome in the classical sense of the word. The two anticlines in which the Glastonbury and the Monson gneisses appear in the northern part of the Middle Haddam area, are highly elongate, extending northward across most of central Massachusetts. The mass of gneiss centered about Maromas appears to occupy the core of a recumbent fold. In cross section, all of the domes appear to have radii of curvature that are large relative to those of the rather tightly-folded, bounding synclines. Minor structural elements associated with the domes, such as drag folds and deformed pebbles (the pebbles are stretched over the domal crest of the Killingworth dome, as well as the flanks), suggest that in large part, the central masses of gneiss moved upward relative to the mantling strata. J. B. Thompson (1952) has suggested that this upward movement of the gneiss cores might possibly have resulted from buoyant forces dependent on the relatively low density of the gneiss. Shear phenomena show some exceptions, however, and it is possible that these exceptions reflect a classical type of deformation dependent on regional horizontal compression.

One of the most distinctive features of the Bronson Hill Anticline is the en echelon character of many of the gneiss domes. This en echelon character shows up very well in the Middle Haddam area and far to the north in New Hampshire. It is also evident in other chains of domes in areas to the west. Evidence of a possible cause of this en echelon arrangement appears on a regional scale north-northeast of Great Hill in Portland. Along the east side of the Bolton group, the Collins Hill formation disappears northward as a result of pinching out beneath an angular unconformity. The Collins Hill formation is not present along the west side of the Bolton group within the Middle Haddam area or in areas immediately to the north. It reappears farther north along the west side of the Bolton group, and is well exposed in the Ellington Quadrangle. This suggests that the Collins Hill formation was folded about an axis counter-clockwise to the axis around which folding took place in the Bolton group. If this difference in orientation of axes reflects a change in the direction of maximum principal stress, it might be possible to explain the en echelon character of the domes as the result of two stages of deformation (evidence for which is presented). This interpretation contrasts with the one presented previously by the writers (Rosenfeld and Eaton, 1956).

METAMORPHISM

The distribution of metamorphic grade relative to the axis of the Bronson Hill Anticline and the anticlinal axis extending northward toward Monson, Massachusetts, is of considerable significance. Metamorphism is symmetrically disposed about the Bronson Hill Anticline, with rocks in the sillimanite zone appearing along its axis and rocks in the kyanite zone appearing along the axes of the bounding synclines. Rocks of the sillimanite zone also appear to the east, along the western boundary of the Monson gneiss. The isograds do not spread apart in areas adjacent to the Glastonbury gneiss to any greater extent than they do around the Killingworth dome which has a core of stratified rocks including recognizable metasedimentary types. This would seem to be a further argument against a syntectonic origin for the granitic rocks that now constitute the Glastonbury gneiss. If this gneiss had been a granitic magma at the time of metamorphism, its higher temperature should be reflected in the metamorphism of the surrounding rocks, and in particular, in the expansion of the higher grade zones adjacent to such granitic rocks. Thus it would seem that the metamorphic evidence is consistent with the stratigraphic evidence which suggests that the rocks now represented by the Glastonbury granitic gneiss were in place (and cold) at the time the overlying sedimentary rocks were deposited.

An additional feature of interest is the nature of the sillimanite isograd. Instead of a sharp line on the surface of the earth, on one side of which kyanite appears and on the other side of which sillimanite appears, the sillimanite isograd has, on its "high grade" side, a rather broad zone in which both kyanite and sillimanite can be observed to co-exist. In many cases, fine-grained clots of sillimanite show by their approximately-equivalent size and shape that they are pseudomorphs after the kyanite porphyroblasts with which they co-exist. This type of occurrence clearly indicates a sequential relationship in which sillimanite developed later than kyanite. At other places within the sillimanite zone, the finely dispersed sillimanite apparently resulted directly from chemical reactions that took place within the sillimanite zone rather than by polymorphic transition from kyanite porphyroblasts. It would appear that tectonic movement along the anticlinal axes carried rocks from the kyanite stability field into the higher temperature field in which sillimanite was stable. Consideration of the stability fields of these two minerals, as determined from experimental work by Clark and others (1957) does not tell us whether such a transition resulted from the predominant influence of falling pressure or rising temperature. The direction of polymorphic transition is contrary, however, to that expected as the result of increasing depth of burial under conditions of a "normal" geothermal gradient. If the writers can evaluate the importance of the buoyant mechanism of doming mentioned above, it may be possible to show that falling pressures played an important role in the transfer of kyanite-bearing rocks into the sillimanite field of stability. Current petrologic study is aimed at the determination of the direction of the horizontal thermal gradient at the time of metamorphism. Elsewhere in western New England there is ample evidence around some domes that thermal gradients are directed away from the anticlinal axes. If a similar relationship holds for the Bronson Hill Anticline within the Middle Haddam area, then it is probable that the "arrival" within the sillimanite zone was the simultaneous result of falling pressures and rising temperatures.

Simultaneous consideration of metamorphic facies variations, reasonably-constructed structure sections, and an examination of the pebbles and cobbles in the immediately-adjacent rocks of Triassic age along the Eastern Border Fault suggests a functional relationship from which it should be possible to deduce a certain amount of information concerning the vertical distribution of metamorphism.

The Bolton group occurs in a tightly-folded syncline extending for many tens of miles north of Great Hill (in Portland). As a result of its northward plunge at Great Hill, this group is not found anywhere in the Eastern Highlands to the south. In the Triassic rocks immediately west of the Border Fault, clasts representative of certain distinctive lithologies in the Bolton group are not found in recognizable abundance south of Duck Hill, near the straits of the Connecticut River. They are very abundant north of that area. This evidence leads to the conclusion that the Triassic rocks of the Portland formation immediately adjacent to the Border Fault were derived largely from an area only a little more than three miles wide, directly to the east.

Examination of the clasts derived from the Bolton group indicates that they represent a distinctly lower grade of metamorphism than that now observed in the provenance area to the east. In the eastern area, the distinctive schists of the Bolton group contain large staurolite porphyroblasts. The clasts in the Triassic conglomerate derived from this same member of the Bolton group do not contain staurolite, although they are quite abundant. Furthermore, these clasts are remarkably similar to the same member of the Bolton group as it appears in lower grades of metamorphism in areas far to the north. This contrast in metamorphic grade implies that a lower grade of metamorphism existed in the provenance area at the time the Portland formation was deposited, and because of erosion since late Triassic time, metamorphic rocks formed at an equivalent level in the crust are no longer exposed in the Eastern Highlands.

The disparity in the grade of metamorphism of the clasts and the grade of metamorphism in the provenance area is a measure of the amount of erosion to which both the Bolton group and the Portland formation have been subjected since the time of sedimentation. The disparity likewise indicates that the slope of the isogradic surfaces was less than that of the stratigraphic surfaces. It remains to determine the amount of erosion of the metamorphic rocks of the Eastern Highlands since the close of deposition of the Triassic rocks. The flat nature of the Killingworth dome and the presence of clasts in the Portland formation that are diagnostic of distinctive strata in the Killingworth dome suggest that there can have been scarcely more than one mile of erosion in the straits area since the close of Triassic deposition. It would seem, therefore, that there was a relatively steep vertical metamorphic gradient in the Bolton group near Great Hill. The writers are engaged in a study of the sedimentary inversion represented by clasts in the successively older formations of the Triassic and the relationship of this inversion to the skyward extrapolation of metamorphic and stratigraphic structure sections*

---

* Study of the clasts in some of the older Triassic strata suggests a distinct breach in metamorphism within the Eastern Highlands provenance area at the time of sedimentation. The co-existence of clasts of fine-grained dolomite, limestone, and anthracite (?) coal, with clasts of garnetiferous mica schist and microcline pegmatite, highlights the possibility that Carboniferous rocks may have rested unconformably on the higher grade metamorphic rocks of the Eastern Highlands during the early part of Triassic deposition. As corroborative evidence, a possible fusulinid was found in one of the dolomite clasts. Further study is being carried on to clarify the meaning of these recent finds.

POSSIBLE ORIGIN OF PEGMATITES

Considerable interest attaches to the relationships of the pegmatites of the Middle Haddam area. They have been much studied, and there has been considerable theorizing concerning their origin. Furthermore, there have been continuing studies of the radioactive ages of certain minerals within these pegmatites, leading to recent values in the neighborhood of 260 million years.

Rather large, semi-concordant pegmatites are found throughout the Middle Haddam area, but they appear to be particularly abundant within the Collins Hill formation. The stratigraphic studies discussed above indicate that these pegmatites did not have a magmatic origin related to the granitic gneisses such as the Glastonbury. The rocks that are now Glastonbury and Maromas gneiss were in place before the Collins Hill formation was deposited.

Field study has yielded little evidence that the lenticular pegmatites have roots extending to a deeper magmatic source. In recent years, many geologists have been attracted to a metasomatic origin for certain pegmatites. This would seem to be ruled out for microcline-bearing pegmatites within the Collins Hill formation. To create microcline from pre-existing muscovite schist would involve a considerable change in the potassium: aluminum ratio, and it is difficult to see how this could take place without similar alteration occurring in the highly-aluminous kyanite and/or sillimanite schist member, low in the Collins Hill formation. The writers have been considering the possibility that the pegmatites originated as a result of local lateral secretion during metamorphism. With this hypothesis, the greater abundance of pegmatites within the Collins Hill formation might be explained as the result of fluxing action due to the evolution of carbon dioxide and H_2O, both of which must have been given off in great quantities during the metamorphism of the pelitic rocks and "dirty" carbonate rocks of the Collins Hill formation.

GEOPHYSICAL DATA

More than 300 observations of gravity have been made in the Middle Haddam area to aid in the interpretation of geologic structure. To date, corrections have not been made for all of the stations occupied, but those lying along a closely-spaced profile across the overturned syncline containing the Bolton group indicate the following:

a) The syncline containing the Bolton group and the syncline lying unconformably beneath it, containing the Collins

Hill formation, extend to a combined depth of nearly 9,000 feet.

b) The axial plane of the syncline is overturned at the surface, but assumes a more nearly vertical attitude at depth.

c) The Mount Parnassus Basin of Lundgren is relatively shallow, the combined thicknesses of the Brimfield (Cremation Hill schist) and Hebron formations not exceeding 2,500 feet at Marlborough.

ACKNOWLEDGEMENTS

In conclusion, we would like to acknowledge our debt to previous workers in the area, and to contemporaries in adjacent areas with whom the writers have worked very closely. Of former workers, the writers are particularly indebted to J. G. Percival, whose report on the geology of Connecticut remains a classic of descriptive geology, and to Lewis G. Westgate, whose unpublished manuscript on the crystalline rocks of the Farmington Folio was made available to the writers. Westgate's text and map included most of the area studied. Percival's most important contribution was his separation of the rocks mapped by the writers as Bolton group and those mapped as Collins Hill formation. Westgate, and later investigators, "lumped" these rocks into a single unit. Westgate's contribution lay in an accurate delineation of the schist-gneiss boundaries of the area. A judicious synthesis of Westgate's and Percival's maps would result in a geologic map very similar to the one presented here.

Of contemporaries working in adjacent areas, the writers are particularly indebted to Lawrence Lundgren, George Snyder, Richard Goldsmith, Roberta Dixon, and John Sanders. Many of the hypotheses tested by the writers in the Middle Haddam area owe their origin to the work of M. P. Billings and J. B. Thompson many miles to the north, in western New Hampshire. *

All of the research in the Middle Haddam area was supported by a grant from the National Science Foundation to Wesleyan University.

In addition, the writers received considerable help from Wesleyan undergraduates during this study. Of particular value was the help received from Gerald Dyer, John Berry, James Dover, Enrique Garcia, Paul Hadzima, and Elliot Snow. Joe Webb Peoples and John Rodgers have been most helpful with their counsel and comments in regard to many aspects of the project. Elspeth Cowie has been more than helpful with regard to the many operations connected with the written word.

---

* The writers have also benefited from discussion with Norman Herz.

BIBLIOGRAPHY

Billings, M. P., 1956, "The Geology of New Hampshire, Part II - Bedrock Geology," New Hampshire State Planning and Development Commission, 200 pages.

Clark, S. P., Robertson, E. C., and Birch, Francis, 1957, "Experimental determination of kyanite-sillimanite equilibrium relations at high temperatures and pressures," Amer. Jour. Sci., vol. 255, pp. 628-640.

Eskola, P., 1949, "The Problem of Mantled Gneiss Domes," Quart. Jour. Geol. Soc. London, vol. civ, pp. 461-476.

Thompson, J. B., Jr., 1952, "Southern Vermont" in Guidebook for Field Trips in New England, Geol. Soc. Amer., 65th Annual Meeting, pp. 14-23.

Rosenfeld, J. L. and Eaton, G. P., 1956, "Metamorphic geology of the Middle Haddam area, Connecticut: A progress report," Geol. Soc. Amer., vol. 67, p. 1823.

ITINERARY FOR TRIP A

50th Meeting - New England Intercollegiate Geological Conference

Trip Leaders: John L. Rosenfeld and Gordon P. Eaton

October 11, 1958

STOP 1. (This stop is north of the northeast corner of the geologic map.) New London Turnpike, northwest of Marlborough.

The purpose of this stop is to examine the lithologic units and associated structural and metamorphic features that can be seen in crossing the overturned syncline that extends north-northeastward from Great Hill in Portland toward the state line. The field excursion will proceed from the Monson gneiss (?) on the east (normal) limb to the Glastonbury gneiss on the west (overturned) limb. On the east limb, the three members of the Bolton group display the following thicknesses (including tectonic repetition): Great Hill quartzite, 175′; Mine Brook calc-silicate, 600′; Camp Jenkins staurolite schist, 1,450′.

STOP 2. (Optional) (E-9). On north side of Carr Brook, just east of Highway 17 near Gildersleeve. Here one can see the distinctive, highly-aluminous kyanite-rich schist and gneiss that characterize the lower part of the Collins Hill formation. A short distance west, on the east side of Highway 17, is an exposure of Maromas microcline gneiss.

STOP 3. (C-11) Exposures of coarse conglomerate of the Triassic Portland formation on west side of Highway 17, about one-third of a mile north of U.S. Highway 6A east of Portland. The clasts in this outcrop are of interest for the light they shed on the nature of the provenance area and its relative location at the time of deposition. Of particular interest is the contrast in grade of metamorphism between the clasts of schist and their higher grade equivalents at Stop 1. In this outcrop, and in nearby exposures, it is possible to find large angular blocks and cobbles of Great Hill quartzite, Mine Brook carbonate rocks, and representative types from units below the Bolton group, including fine-grained garnet quartzites from the Collins Hill formation and anthophylite or cummingtonite rocks of the Middletown formation. Clasts that are believed to have been derived from the Bolton group are not found south of Duck Hill (just south of the Connecticut River). A few miles south of the river, clasts of a type of rock not found today in the Eastern Highlands appear rather abundantly. Boulders of gneissoid garnetiferous quartz porphyry are abundant. Their source, which must have been limited in its areal extent, has been eroded away. It seems logical to expect that feeder dikes will be found in the Eastern Highlands, but they have not, as yet, been discovered.

STOP 4. (N-13,14) South end of Great Hill, about 3 miles east of Portland. This is an area in which plunging structures allow one to prove that the quartzite on the east side of the schists of the Bolton group is the same as that on the west side, thereby proving that the formation is involved in a large fold. The truncation of the unconformity between the Collins Hill formation and older rocks by the basal quartzite of the Bolton group, and the downward convergence of dips in this quartzite in areas to the north, prove that this fold is a syncline. At this locality the Great Hill quartzite is 450′ thick, and the Mine Brook calc-silicate, 400′, but both units display isoclinal folds.

STOP 5. (P-28) Picnic ground north of Hurd Brook and Hubbard Brook syncline, in Hurd State Park, south of Middle Haddam. The rock at this locality is typical Maromas granitic gneiss. To the south, rocks in the lower part of the Collins Hill formation dip gently north in the core of the overturned,isoclinal Hubbard Brook syncline.

LUNCH STOP. (R-29) One-half mile beyond Stop 5, on the Hurd Park loop. For those who are interested, just beyond the picnic ground, at the summit of the road, one of the large diabase dikes that trend quasi-parallel to the Eastern Border Fault, is exposed. It is possible that this dike, and others like it, represent the feeders for the lava flows in the Triassic lowland. Their composition is similar to that of the lavas. Furthermore, the presence of clasts of vesicular basalt in the Triassic Portland formation suggests that lavas were present in the Eastern Highlands during its deposition. The orientation of tilted pipe vesicles in the lavas also indicates an eastern source.

STOP 6. (R-26) Exposures located northeast of the entrance to Hurd Park. Outcrops of the Middletown formation, with numerous sills and cross-cutting dikes of Maromas gneiss, are well exposed here. Although these discordant masses of Maromas gneiss are abundant in the Middletown formation at this locality, they are nowhere found in the Collins Hill formation in nearby areas. Furthermore, the line of cut-off of these discordant masses is parallel to the strata within the Collins Hill formation. Because of the presence, elsewhere, of coarse conglomerate at the base of the Collins Hill formation, and also because of the above-mentioned termination of dikes, it is believed that the Maromas gneiss and older meta-sedimentary and metavolcanic rocks lie unconformably beneath the Collins Hill formation.

STOP 7. (S-30) Hill 366, east of White Mountain, just south of Hurd Park: delineation of the Hubbard Brook syncline using the Hurd Park member (diopside-hornblende rocks)of the Collins

Hill formation as a marker horizon. Minor structural features such as folds, boudinage, mineral lineation, and fracture cleavage are well exposed. The rocks at this locality are in the sillimanite zone of metamorphism. Tracing the Hurd Park member of the Collins Hill formation across the Hubbard Brook syncline proves the stratigraphic equivalence of the sections mantling the Maromas gneiss and the Killingworth dome.

STOP 8. (S-32) This exposure is just west of Alexson Brook, on the road south of Hurd Park: typical exposures of the distinctive anthophylite-bearing and cummingtonite-bearing gneisses and amphibolites of the Middletown formation. Some of the anthophylite here is asbestiform, and is difficult to distinguish from sillimanite.

STOP 9. (F-26) This locality lies along the power line just south of the Hubbard Brook road, about one mile east of Highway 9 in the town of Middletown. The exposure includes the lower, highly-aluminous member of the Collins Hill formation and the underlying rocks of the Middletown formation. The Collins Hill formation is distinctive at this point for the coexistence of kyanite and small clots of fibrous sillimanite believed to have been derived from the alteration of the kyanite. The underlying Middletown formation displays large lensoid masses of epidote. These masses also occur in the Glastonbury gneiss near its contact with the Collins Hill formation, and it has been suggested that they may represent meta-caliche.

STOP 10. (Optional) (H-25) This locality is on the north side of Hubbard Brook road, about one-half mile east of Stop 9. The basal conglomeratic gneiss of the Collins Hill formation, characterized by numerous small quartz pebbles, is well exposed. Flattening of the pebbles within the plane of schistosity suggests considerable distention over the northward plunging nose of the Killingworth dome.

STRATIGRAPHIC SECTION OF MIDDLE HADDAM AREA

Intrusive diabasic rocks (Triassic)

Portland formation: Feldspathic conglomerate and arkose (Triassic)

MAJOR ANGULAR UNCONFORMITY
(also Metamorphic "Unconformity")

Camp Jenkins formation (Littleton): Gray non-rusty garnet-staurolite-binary schist; some platy quartz-sericite schist and quartzite particularly in lower portion (Lower Devonian).

Mine Brook formation (Fitch): Laminar calcareous biotite gneiss, diopside granulite, and schist showing deep pits on the weathered surface due to the solution of calcite marble masses. Rusty weathering aluminous schist in upper part. (Middle Silurian)

Great Hill formation (Clough): Conglomeratic quartzite in the lower portion overlain by well-banded granular quartzite and quartz sericite schist (late Lower Silurian)

ANGULAR UNCONFORMITY

Collins Hill formation: Rusty-weathering graphitic garnetiferous binary schist commonly containing sillimanite and/or kyanite. In its lowest portion this formation commonly contains a basal conglomerate gneiss associated with an overlying well-banded unit, consisting of: fine-grained quartzite, containing manganiferous garnet and cummingtonite; and laminar amphibolite, occasionally containing relatively large garnets. Interbedded calc-silicate bands and fine-grained biotite-muscovite gneiss are increasingly abundant to west. Horizons consist of persistent amphibolites and calc-silicate bands in lower part of formation (Middle Ordovician?).

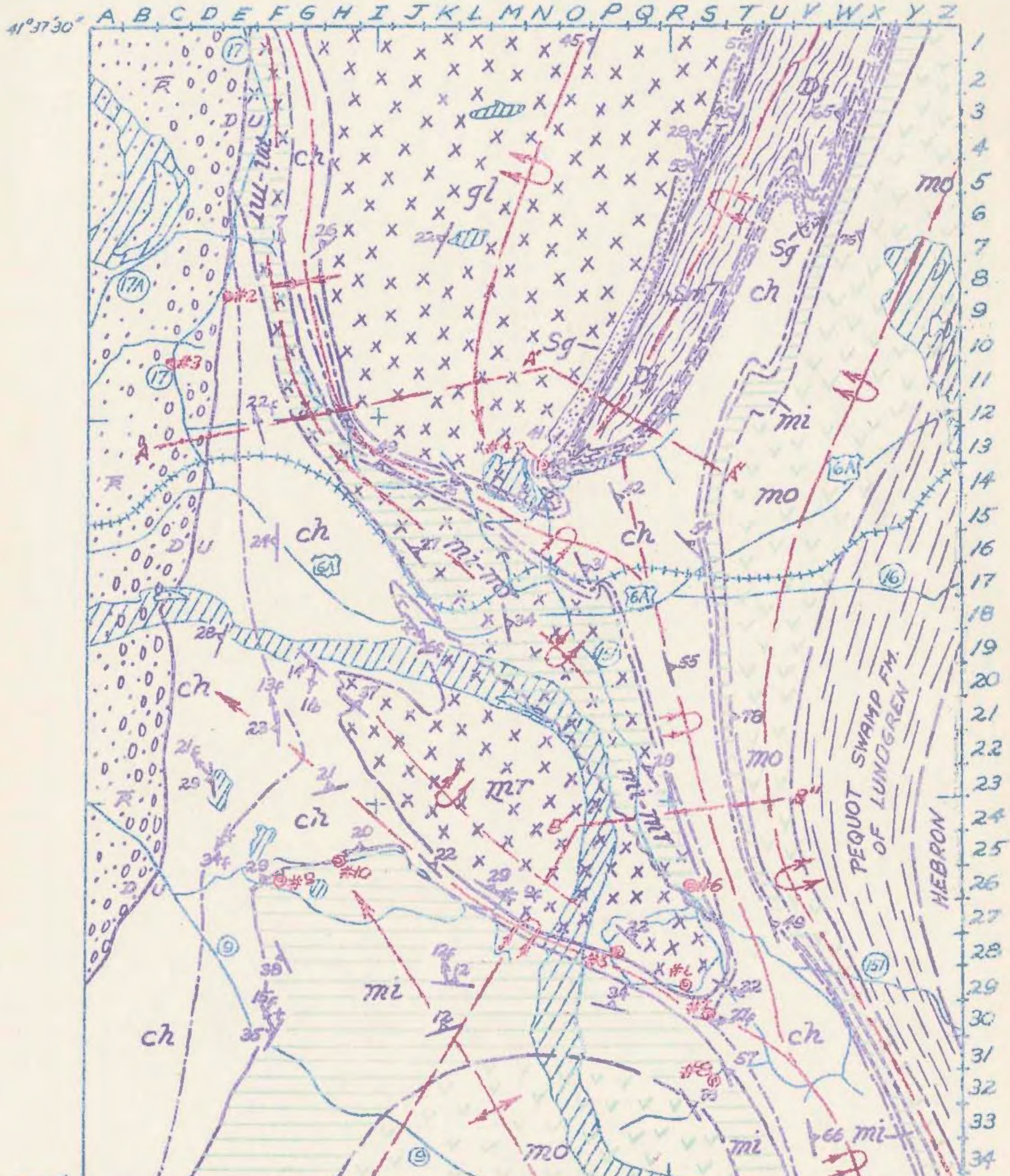
UNCONFORMITY

Glastonbury and Maromas gneisses: Biotite and hornblende granitoid gneiss of probable igneous origin showing intrusive relationships into the Middletown formation and a sedimentary contact with the overlying Collins Hill formation (Lower Ordovician?).

INTRUSIVE CONTACT

Middletown formation: Amphibolites and heterogeneous biotite-oligoclase gneiss, commonly well-banded and characterized by the presence in many places of cummingtonite, hornblende, and anthophyllite (Cambro-Ordovician?)

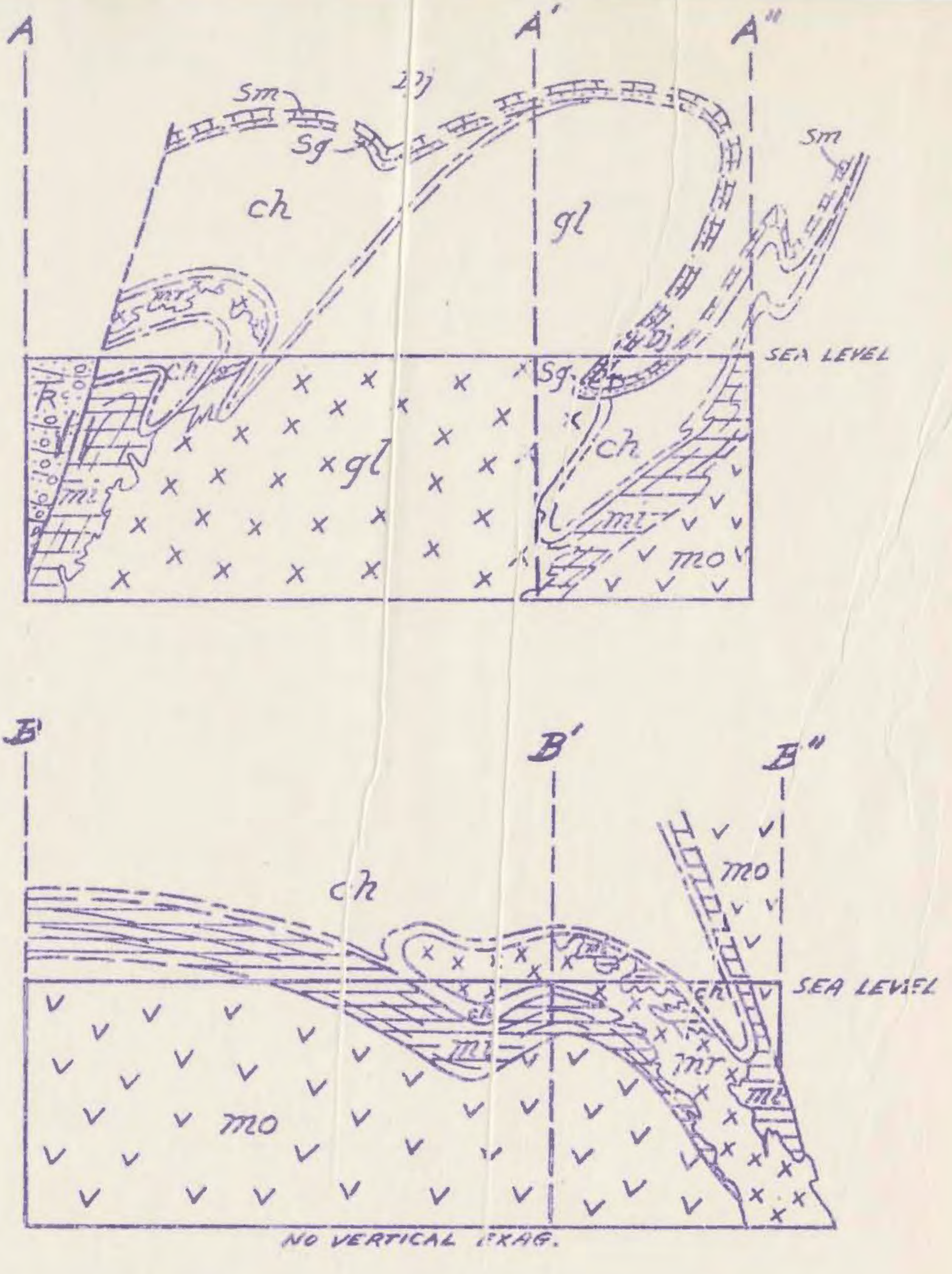
Monson or Haddam gneiss: Well-banded oligoclase-rich gneisses with subordinate amphibolite bands (probably of sedimentary origin). This unit is separated with difficulty from the overlying Middletown formation to which it appears to be related (age questionable; pre-Ordovician?)



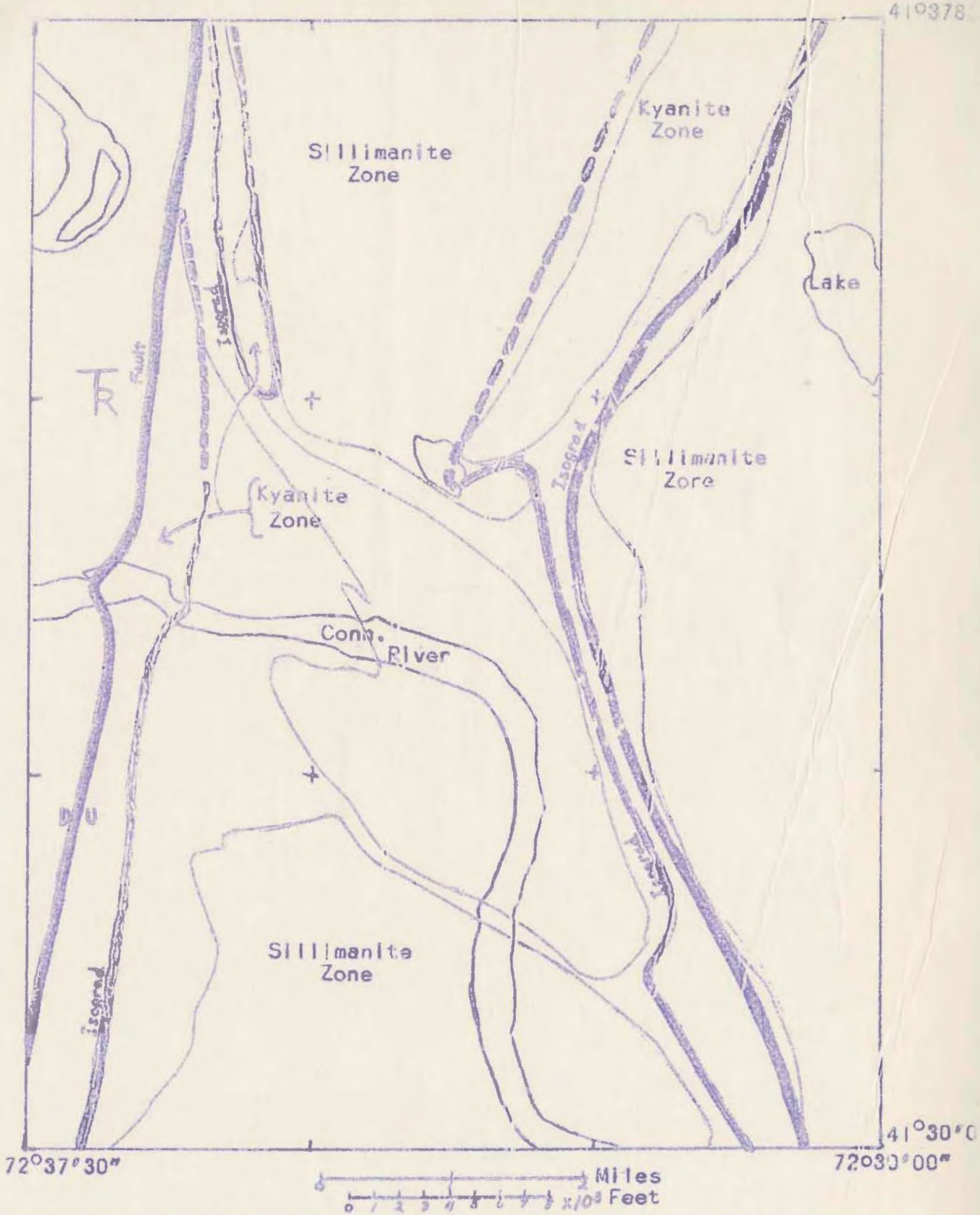
GEOLOGIC MAP OF THE MIDDLE HADDAM QUADRANGLE

By John L. Rosenfeld & Gordon P. Eaton

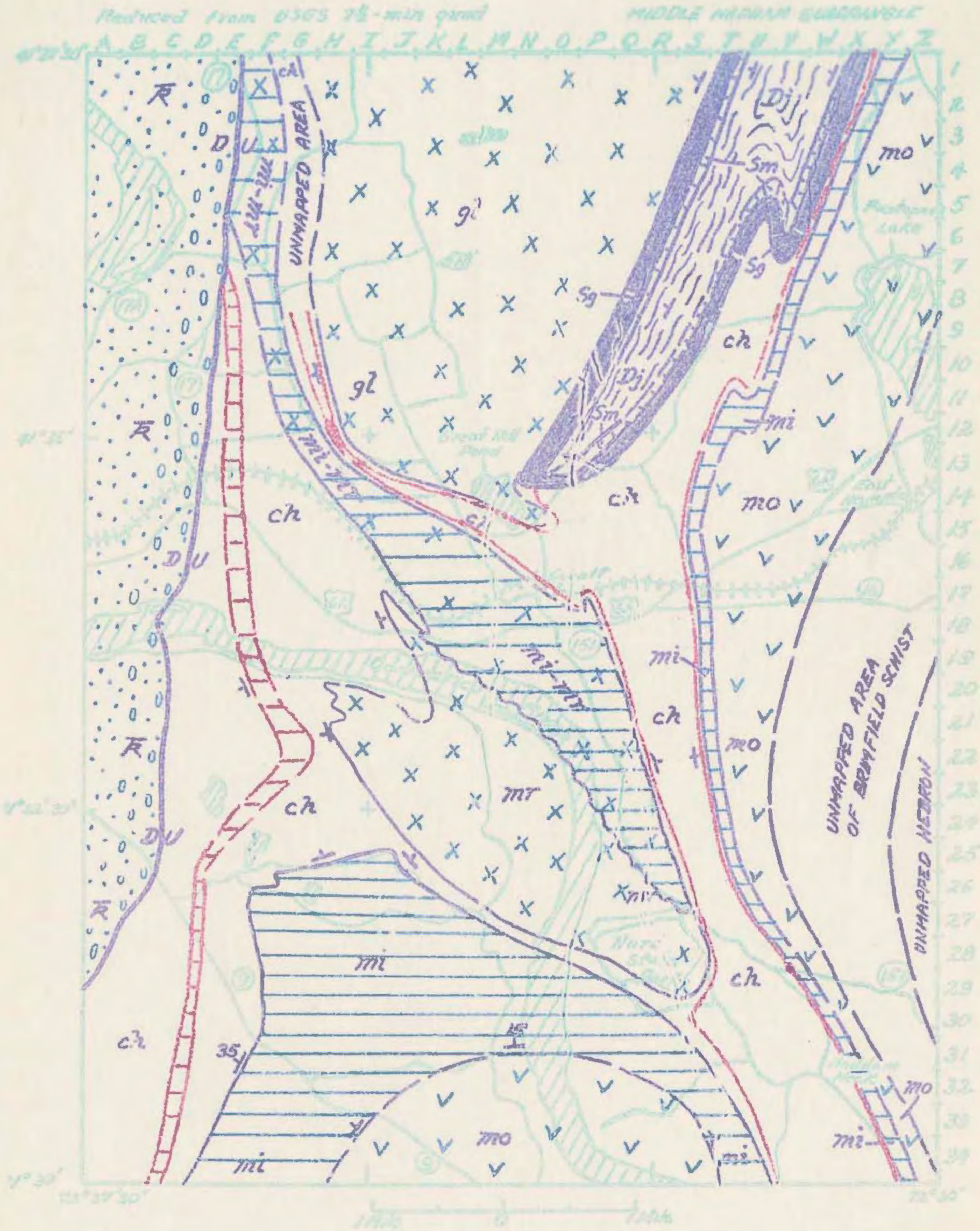
1958



STRUCTURE SECTIONS OF THE
MIDDLE HADDAM AREA



Metamorphism
Middle Haddam Area



GEOLOGIC MAP OF THE MIDDLE HADDAM QUAD.
BY John L. Rosenfeld & Gordon P. Eaton
1957

NEW ENGLAND INTERCOLLEGIATE GEOLOGICAL FIELD CONFERENCE
50th Annual Meeting, 1958

TRIP B. Stratigraphy and Structure in the Triassic Rocks of Central Connecticut

John E. Sanders
Department of Geology
Yale University

Introduction.

The purpose of this trip is to visit selected outcrops of the stratigraphic units which comprise the prism of Triassic rocks in Central Connecticut and to evaluate a new interpretation of the major structural configuration and structural history, which the leader will outline and attempt to defend.

Trip details. The trip will begin at 8:30 A.M., from Portland, on the east bank of the Connecticut River opposite Middletown, under the east end of the highway bridge across the river on U. S. Route 6-A. In general, the line of travel will be westward down the section, beginning near the top. After viewing most of the stratigraphic units, we will proceed northward to the Cedar Mountain structure and outskirts of Hartford, then drive to the Meriden area to see the rest of the stratigraphic units and observe the Hartford fault.

General Geologic Setting.

Considered from the point of view of natural regions, Connecticut, like all of Gaul, is divided into three parts: and Eastern Upland, Central Lowland, and Western Upland (fig. 1). The Eastern and Western Uplands are underlain by pre-Triassic metamorphic and igneous rocks; the Central Lowland, by Triassic rocks. The boundaries between these physiographic entities are sharp and the topographic contrasts are considerable. Though much of the Central Lowland forms a region of low relief and stands at low altitudes, parts of it form ridges, which rise as high as or higher than the surface of the adjacent Uplands areas.

The Connecticut Valley outcrop belt of Triassic rocks extends across Connecticut and Massachusetts from Long Island Sound to northern border of Massachusetts. This belt is 95 mi. long and 15-18 mi. wide.

Stratigraphy

The Triassic rocks consist of a thick prism of non-marine sedimentary strata which contain three intercalated persistent basaltic lava flows and sundry generally tabular intrusive masses, whose composition closely resembles that of the lava flows. Owing to the monotonous yet laterally variable characteristics of the exposed sedimentary rocks and their lack of topographic expression and scarcity of outcrops, stratigraphic subdivision is possible only by utilizing the lava flows as key beds. The basaltic lava flows form prominent ridges and can be distinguished from each other with substantial confidence on the basis of thickness. The geologic "facts of life" are such that one most commonly has to deal with linear ridges of basalt formed by erosion of the tilted edges of the lava flows, and strike valleys between them which are largely covered intervals.

The stratigraphic units thus defined by the lava flows are therefore contemporaneous throughout (= time-stratigraphic units). They are referred to everywhere by the same name, even though their petrographic attributes may change completely from one locality to another, of even if these attributes are totally unknown, as is commonly the case. A broad, three-fold subdivision is immediately apparent, consisting of: 1) all the deposits below the lowest lava flow, 2) all the strata above the highest lava flow, and 3) the lava flows and sedimentary beds intercalated between them. This order was first acknowledged by James Gates Percival (1842), a man of consummate genius, who made the first geologic map of Connecticut with such skill and accuracy that only after issuance of the new U. S. Geological Survey 7½-minute quadrangle maps beginning in 1946 have any important revisions been demonstrated in Percival's mapping.

The basis of the present nomenclature was laid by Krynine (1950), who proposed New Haven arkose for all the strata below the lowest lava flow, Portland formation for all the rocks above the upper lava flow, and Meriden formation for the lava flows and interbedded sedimentary rocks. Although Krynine's nomenclature has been widely accepted, it is not without objections. The name "New Haven" has been long preoccupied by a limestone of Pennsylvanian age in Illinois and "Portland" is a long-standing name for one of the standard stages in the Upper Jurassic. Both of Krynine's terms can be defended on the grounds of local utility, but unequivocal acceptance of them perpetuates practices in stratigraphic nomenclature which generate confusion. The term "Meriden," on the other hand, though very useful, seems destined to fall by the wayside for want of sufficient hierarchichal terms above the rank of "formation." The lava flows of Krynine's Meriden "formation" were earlier named by B. K. Emerson (1891; 1898): Talcott (1898), for the lower; Holyoke (1891), for the middle; and Hampden (1898), for the upper. Lehmann (Ms. on Middletown quadrangle) proposes Shuttle Meadow formation for Krynine's Lower Sedimentary member of the Meriden formation, and East Berlin formation for Krynine's Upper Sedimentary member, and advocates that these and the lava flows be given the rank of "formation." Meriden as a "group" name for these five formations runs afoul of the term Newark "group," which has been applied for the entire prism of Triassic rocks.

Though each unit of the sedimentary rocks displays distinctive characteristics of composition, texture, and primary structures in its type exposures, considerations of the framework of deposition during the Triassic, present conditions of outcrop, and close study in areas away from the type localities indicate that these differences are more the products of natural bias than of fundamental reality. Many rock types occur at different stratigraphic levels away from the eastern border of the Triassic outcrop belt, but nearly all of them pass laterally into coarse conglomerate as the eastern border is approached at nearly any stratigraphic level. The parameter of distance from the eastern border, therefore, is an important control on the aspect of the rocks; owing to the rapidity of the lateral facies changes, this parameter cannot be overlooked.

The following table shows the names of the stratigraphic units, their thickness in Central Connecticut, and composition.

Name	Thickness (feet)	Description
Portland formation	An unknown number of thousands	Medium- to coarse-grained red arkose and pebbly arkose. Bedding regular. Boulder conglomerate near eastern border.
Hampden basalt	75-125	Vesicular and amygdoloidal basalt. Locally contains pillows, according to Lehmann (ms.). Several flows present.
East Berlin formation	600-900	Fine-grained sandstones, siltstones, and silty carbonate rocks; local black shales. Even bedding and much lamination. Boulder conglomerate near eastern border.
Holyoke basalt	600	At least two separate flows of basalt; locally as coarse as dolerite.
Shuttle Meadow formation	350	Evenly bedded, mostly red siltstone and sandstone, with thin limestone in areas away from border fault; coarse red sandstone and conglomerate near border fault.
Talcott basalt	100	A complex of several basalt flows and interbedded sediments; pillows are a noteworthy feature.
New Haven arkose	An unknown number of thousands	Pebbly red arkose and associated red siltstone; bedding generally is not regular.

Table 1. Triassic formations in central Connecticut. (Descriptions largely after Krynine, 1950, p. 32).

STRUCTURE

Introduction.

The outcrops of the lava flows (referred to as "trap sheets" in the earlier literature), which form the key beds for interpreting the geologic structure, were accurately shown on Percival's (1842) map, but he was not able to synthesize the structure, even though he clearly indicated his belief that most of the trap ridges were outcrops of the same three sheets (now known to be lava flows), which were found together everywhere in the same stratigraphic order and bore the same relationships to beds below and above. Percival spoke of the offsets of the ridges in terms of "advancing-" or "receding" order, depending on whether the south end of the more northern member of two adjacent ridges was located farther west or farther east, respectively, than the north end of the southern member of the pair.

Little interest was shown in the structure of the Triassic rocks during the decades when the "trap sheets" were regarded as being intrusive, for no basis for structural interpretation could be found in the poorly exposed sedimentary rocks. In 1882 W. M. Davis became convinced that certain of the "trap sheets" are ancient lava flows and could be considered as key beds for mapping, as if they were distinctive sandstones, for example. In a series of brilliant papers that extended over a period of nearly 20 years, Davis unraveled the structure of the Connecticut Triassic and demonstrated that tilting, warping, and faulting of an originally horizontal mass of strata had occurred and that the present topographic distribution of most of the basalt outcrop ridges could be explained by fault offsets of only three intercalated lava flows. Davis also proved the eastern contact of the Triassic rocks is a border fault.

Davis, however, supposed that only one episode of faulting had taken place, i.e., that which produced what will be here called the Lowland fault system and at the same time established the border fault. He held that these faults occurred after the depositional trough (which he considered to have formed by downwarping) had been filled and after gentle folding of the originally horizontal strata had occurred. Davis thought that the Triassic beds once extended further east than their present eastern termination against the border fault. One of his arguments for the existence of the border fault was the abrupt truncation of the warped structures against the metamorphic terrane at the eastern border. Davis presumed that these structures were simply cut in two by the border fault and that their eastern parts were destroyed by erosion after uplift on the raised block east of the border fault. Though the remarkable hypothesis of origin of the faults in the Triassic strata as a result of straightening out of curved slabs of the underlying metamorphic rocks by lateral compression which was championed by Davis (1886; 1888; 1898) has not attracted many adherents, the existence of the Lowland fault system and the eastern border fault have become permanent fixtures in the interpretation of the Triassic rocks.

Burrell (1915) believed the trough formed initially by downwarping, but was the first to show that significant movement took place on the eastern border fault during Triassic deposition. The importance of syn-sedimentation faulting was further demonstrated by W. L. Russell (1922) and C. R. Longwell (1922; 1937). Russell proved that the Triassic strata never extended further east than the border fault and that repeated uplift of the Eastern Uplands block rejuvenated topographic relief to supply coarse sediment throughout the entire depositional history. (For further details on this subject, Trip E, on Sunday, is recommended.) Russell suggested that the warped structures, instead of being cut off randomly by the border fault, as Davis believed, were in fact related to drag on the fault and originated as a consequence of fault displacement. Russell was not specific about the details, but I get the impression from reading his paper that he thought the eastern border fault, which now dips westward, was always a "normal" fault and that the post-depositional faulting was not much different from the syn-sedimentation faulting, but that somehow in between sedimentation stopped and the warped structures formed during post-depositional movement. Longwell (1922; 1937) also elaborated the case for faulting during Triassic deposition on the basis of the coarse sediment found along the border fault, which he was able to compare with alluvial fan deposits of Cenozoic age in southern Nevada. In these papers Longwell argued that the eastern border fault is a "normal" fault and presumably always was, in spite of his own remark that the border fault would dip southeast (i.e., be a reversed fault) if the strata were rotated back to their initially horizontal or slightly west-dipping position from their present eastward dip (1922, p. 231). Bain (1932) insisted that the border fault in Massachusetts is a reversed fault, but met with firm opposition from all quarters and has found few supporters of his interpretation.

Girard Wheeler (1939) followed up W. L. Russell's (1922) suggestion that a genetic connection exists between warped structures in the Triassic rocks of Connecticut (and New Jersey) and movements on the border fault. Wheeler proposed a theory of origin which relates the warped structures to changes in strike and dip of the border fault. According to Wheeler, narrow "anticlines" with axes perpendicular to the border fault, occur opposite "bumps" on the fault surface, whereas "half-synclines" ("half-basins" of this paper) occur opposite re-entrants in the fault surface. Wheeler examined the problem of the dip of the border fault in Connecticut in great detail and concluded that it is a "normal" fault and everywhere dips westward, and that it also had this dip when the warped structures formed. In my opinion, Wheeler's hypothesis of the origin of the warped structures is accurate as far as it goes, but does not sufficiently consider the significance of the syn-sedimentation faulting emphasized by Russell and Longwell, nor does it explain why sedimentation ever stopped if the Lowland block moved downward during deposition and also afterward.

It seems to me that the following interpretations are well enough established to serve as guideposts for any structural history and that none of the previous syntheses of the structural history adequately explains all of them:

1) Syn-sedimentation faulting took place on a large scale. During this episode of movement, the Lowland block moved relatively downward a total distance of some tens of thousands of feet, but <u>no warped structures formed</u> (as proved by the present parallelism of outcrops of the lava flows and absence of angular discordance between exposed sedimentary strata).
2) Sedimentation stopped. (This point might be disputed on the grounds that any further sediments in the trough were eventually eroded away, as the top is not known even now. This I readily concede, but at least on the present level of exposure, the record is of deposition, and then of an end of deposition.)
3) Further downward movement of some thousands of feet of the Lowland block along a west-dipping (= "normal") eastern border fault caused the warped structures to form.
4) At some time the strata acquired their eastward dip.
5) The warped structures were offset by movements on the Lowland fault system. Movement on the Lowland fault system post-dates both warped structures and eastward dip, for essentially vertical displacement caused the lateral offset of warped and tilted beds.
6) All deformation involves the "basement" primarily, and the Triassic strata have behaved relatively passively atop their foundation. It seems probable, therefore, that the depth of deformation extends through the entire thickness of the Earth's "crust."

Before elaborating my own ideas on the structural chronology, I will describe the structural arrangement in more detail.

Description.

The Triassic rocks of Connecticut are customarily described as comprising an eastward-dipping monocline which is terminated on the east by a border fault. Although this remark is generally true, it tends to obscure the fact that the Triassic strata have been bent into a series of "folds," whose presence is shown by curvature of the ridges underlain by the basaltic lava flows as well as by the strike and dip of the sedimentary rocks.

These warped structures are most clearly expressed in the topography of the Branford quadrangle, south of the area of this excursion. Altogether, five "half basins" and four intervening narrow "anticlines" can be identified in the Connecticut Valley outcrop belt. The following list names the structures, beginning with those in the south and proceeding northward; the names in parentheses are the authors of the terms: Saltonstall "half basin" (Davis), North Branford "anticline" (Sanders), Totoket "half basin" (Davis), unnamed "anticline," much faulted, Middletown "half basin" (Davis), Cedar Mountain "anticline" (Davis), Springfield "half basin" (Davis), Amherst "anticline" (Davis), and Deerfield "half basin" (Davis). See Fig. 2.

The warped "half basin" structures vary in size from Saltonstall, the smallest, which is 5 miles long and 1 3/4 miles wide, to Springfield, the largest, which is 52 miles long and 10 miles wide. Structural relief on these warped features is on the order of thousands of feet. The basement is clearly involved in the Amherst "anticline" and doubtless also participates in all the others, though "basement" rocks are not elswhere exposed at the present topographic surface.

The warped structures have been displaced by faults of the northeast-trending Lowland fault system, which are for the most part "normal" faults with steep northwestward dip. Essentially vertical displacement on these faults has caused offset of the previously tilted and warped strata.

My own unpublished studies of the Saltonstall and Totoket "half basins" and the North Branford "anticline" in the Branford quadrangle, under the auspices of the Connecticut Geological and Natural History Survey, indicate that the warped structures end abruptly on the west along a fault (Foxon fault) and that beds west of the fault are not warped. From this observation, I have concluded that an essential prerequisite for the warped structures is the existence of a block bounded on both sides by a fault, thus allowing the strata on the block to deform independently of those on adjoining blocks. A possible explanation of the different size of the warped structures may be found in the different widths of the faulted blocks on which the warped structures occur. Such faults represent an earlier period of movement on parts of the Lowland system, for they are contemporaneous with warping and earlier than the main Lowland system, along which the warped structures have been displaced.

Considering Davis' knowledge of the warped structures, it is surprising to me that he placed so much emphasis on the Lamentation block as a major structural element and considered it to be displaced from the Hanging Hills block. Davis' view of the Lamentation block is presented in fig. 3, and on the geologic map, fig. 4. The Lamentation block has been doing duty in the literature for many years and is also the source of the oft-quoted figure of 5000-6000 feet for the thickness of the New Haven arkose (1898, p. 101; see also Longwell, 1928, p. 262). Davis arrived at this figure by measuring the horizontal distance obliquely along the block from the base of the Talcott lava flow to the western border of the Triassic outcrop and by trigonometric calculation of the thickness from an assumed average dip of 15° and projected distance perpendicular to the strike, on the assumption that no other faults are present. The existence of the faults presumed to bound the Lamentation block as extended southwestward from Lamentation Mountain by Davis into the Mt. Carmel quadrangle is stoutly denied by C. E. Fritts, of the U. S. Geological Survey, (personal communication) who is studying this quadrangle as part of the co-operative mapping program in Connecticut. I also question the validity of the Lamentation block hypothesis on grounds of the geometry of the warped structures. I think that the Lamentation and Chauncey Peak blocks are merely slightly displaced parts of the Middletown "half basin" and that they have nothing directly to do with the Hanging Hills block, which I consider to be a part of the much larger Springfield "half basin," which lies next north of the Middletown structure. Using the "half basins" as the controlling structural pattern, I have suggested that the major fault of the Lowland system is the Hartford fault and that along it essentially vertical movement has caused displacement of the Springfield "half basin" from the outskirts of Hartford north of the Cedar Mountain anticline to the Hanging Hills in Meriden (fig. 5). Though I feel the geometry of the warped structures demands this interpretation, I have not as yet solved all the problems concerned with it. For example, as my colleague, John Rodgers, points out, if the axial plane of the Cedar Mountain anticline is essentially vertical (and I might add, if it extends across the Hartford fault), then only strike-slip movement can explain any offset of it. As I have other reasons for doubting large-scale strike-slip movement, I must turn elsewhere for the explanation of the supposed offset. Perhaps the solution lies in the change of size from the Middletown to the Springfield "half basins." The Middletown structure is 15 miles long and 6 miles wide, whereas the Springfield structure measures 52 by 10 miles. According to my present view of the origin of these warped structures, such a change may be brought about by a change in the width of the fault block concerned. The Cedar Mountain "anticline," which intervenes between these two "half basins," may be only as long as the width of the block which contains the Middletown "half basin." The larger Springfield block may not contain the Cedar Mountain "anticline." If this be true, then essentially vertical movement on a north-northeast-trending "normal" fault could cause southwestward displacement of the wider western part of the Springfield "half basin," where the beds strike northwest and dip northeast, but need not offset the Cedar Mountain "anticline," which would never have extended farther northwest than this fault.

Interpretation of structural history.

To recapitulate the results of previous students of the structure of the Triassic of Connecticut: Percival (1842) recognized the curved and offset basalt ridges; W. M. Davis proved that the basalt units could be used for key beds and demonstrated that some kind of post-depositional warping and faulting had operated on a prism of Triassic rocks whose stratification was essentially parallel throughout at the end of deposition; Barrell (1915) indicated the border fault was active during deposition; W. L. Russell (1922) related the warped structures to movement on the border fault; and Girard Wheeler (1939) carried this suggestion forward to a detailed theory of a genetic connection between the position of the warped structures and changes of attitude on the border fault and showed how this origin required downward movement of the Lowland block along a west-dipping "normal" border fault.

Although I accept the principal conclusions of these workers, I contend that they have all insufficiently considered the consequences of the now well-established interpretation that the border fault was active during Triassic deposition, as well as afterward, an idea suggested by Barrell (1915), and afterward elaborated by W. L. Russell (1922) and C. R. Longwell (1922; 1937). If, as Russell and Wheeler state, the warped structures resulted from post-depositional movements on a "normal" border fault, in which the Central Lowland block moved downward relative to the Eastern Upland block along a westward-dipping fault surface, why did no such warped structures form during the long period of syn-sedimentation faulting, in which the Lowland block also moved downward relative to the Upland block?

The field facts clearly demonstrate that downward movement of the Lowland block took place both during and after deposition of the Triassic strata; but the subject of whether the border fault was "normal" or reversed in each episode is not so clearly established. Longwell (1922), Girard Wheeler (1939), and R. E. Digman (1950) have proved that the facts obtained from Connecticut require the conclusion that steep west dip is the present attitude of the border fault. Downward movement of the Lowland block along such a west-dipping fault is by definition "normal" faulting. By association, the conclusion that earlier downward movement of the Lowland block must have also occurred on a "normal" fault has been assumed, even in the face of a statement by Longwell (1922, p. 231) that the border fault would dip eastward if the beds were rotated back to horizontal and contrary to arguments advanced by Bain (1932) that the border fault in Massachusetts is a reversed fault.

If we accept the interpretation that the border fault acted as a "normal" fault during the post-depositional episode of downward movement of the Lowland block which gave rise to the warped structures, then perhaps we can explain why syn-sedimentation downward movement of this same Lowland block did not cause warped structures by the assumption that the border fault was not behaving as a "normal" fault at this time. If the border fault were a reversed fault during sedimentation, but afterward became a "normal" fault by a change of dip of the fault surface, then downward movement of the Lowland block in each case would be accompanied by different structural conditions.

Closer inspection of this possibility indicates it has many merits. Consider next the problem of the end of sedimentation. Granting the usual assumptions that the border fault was always a "normal" fault and that movement on it was more or less continuous, though intermittent, and that no other particularly important structural episodes were involved in the total deformation, then how can the apparent cessation of Triassic deposition be explained? If the Lowland block moved downward during sedimentation and collected the debris eroded from the uplifted Upland block, why did further movement in this same sense not give rise to more sediment? If we adopt the hypothesis that the border fault was an eastward-dipping reversed fault during sedimentation, then it is necessary to call upon some additional structural event to change the border fault so that it later became a westward-dipping "normal" fault. Regional eastward tilting seems to be a ready-made event. Barrell (<u>in</u> Longwell, 1922) and J. B. Woodworth (1932, p. 158-159) advocated the idea that uparching along the "Taconic geanticline" (Barrell's term) was responsible for the eastward tilting the Triassic strata in the Connecticut Valley belt; might not this same uparching along an axis west of the present Triassic outcrop area have been responsible for changing the dip of the border fault from eastward to westward? And at the same time, might not this regional uplift in the midst of the former depressed area have reversed the drainage and thus have ended the Triassic cycle of sedimentation?

The structural history of Central Connecticut was further complicated by yet a third episode of faulting: that represented by the Lowland fault system along which the warped structures have been offset. Longwell (1922) demonstrated that these Lowland faults (whose existence had been earlier shown by W. M. Davis) form a regional system whose orientation is parallel to that of the border fault and is not due to torsion during warping. The offsets caused by these faults can best be explained as the result of vertical "normal" displacement on a system of faults whose dip is westward. As most of the Lowland faults are "normal" Longwell concluded that the border fault, with which the Lowland faults are parallel, is also a "normal" fault.

The following structural chronology is advocated as one which best fits the facts and interpretations discussed previously:

1) Triassic trough and adjacent upland are initiated by a system of reversed faults. Presumably, this means regional compression. (Though I will not enter into it in detail here, I prefer the "broad terrane" interpretation of the Connecticut Valley and New Jersey Triassic areas. I visualize the original trough as consisting of a large graben. If one applied Bullard's (1936) analysis of the gravity measurements made over the East African Rift Valleys, then he would infer that this Triassic graben originated as a block as thick as the Earth's crust, and that it was forced downward into the subcrust by pressure from the sides. The width of the graben is a function of the thickness of the crust involved. Material at depth must be moved laterally to make room for such a depressed block.)
2) In Connecticut, the Lowland block moved downward and the Upland block to the east moved intermittently upward during the Late Triassic. Material was eroded from the uplifted block and deposited on the downdropped block.
3) At some later time, the formerly downdropped block began to rise, eventually forming the "Taconic geanticline" of Barrell. (Perhaps this episode is the first indication of "relaxation" of crustal compression. The depressed central block, having displaced heavier material below, would tend to rise in order to try to restore isostatic equilibrium.)

This uparching of the formerly dropped block caused the drainage to be reversed (this may have an important bearing on the origin of the drainage pattern of the Atlantic slope), tilted the strata in Connecticut to the east, and rotated the east-dipping border fault to its present westward dip.

4) After arching, the Lowland block again moved downward along the border fault, which now dips westward. In addition, other faults are formed, notably those related to the blocks on which the warped structures are located. The western border fault (Bristol fault) came into being at this time. During this episode of downward movement of the Lowland block, the warped structures formed in positions as diagnosed by Wheeler (1939).
5) Warped structures are displaced by faults of the Lowland fault system, by largely "normal" movement on west-dipping faults, many of which are more or less parallel to the attitude of the border fault.

(Many dikes have been intruded along these Lowland faults, indicating a late episode of magmatic activity unrelated to the three lava flows. That these dikes are not connected to the flows is further suggested by the discovery of the tops of many of them.)

(The last two stages seem to be mechanically related to loss of support from below and general collapse. In the early stages, large blocks moved downward, but afterward considerable fragmentation took place.)

REFERENCES

Bain, G. W., 1932, The northern area of Connecticut Valley Triassic: Am. Jour. Sci., 5th series, v. 23, p. 57-77.

Barrell, Joseph, 1915, Central Connecticut in the geologic past: Conn. Geol. and Nat. History Survey Bull. 23, 44 p.

Bullard, Sir E. C., 1936, Gravity measurements in East Africa: Royal Soc. London, Phil. Trans., (A), v. 235, p. 445-531.

Davis, W. M., 1882a, Brief notice of observations on the Triassic trap rocks of Massachusetts, Connecticut, and New Jersey: Am. Jour. Sci., 3rd series, v. 24, p. 345-349.

__________, 1882b, The structural value of the trap ridges of the Connecticut Valley: Boston Soc. Nat. Hist., Proc., v. 22, p. 116-124.

__________, 1883, On the relations of the Triassic traps and sandstones of the eastern United States: Mus. Comp. Zool. Bull., v. 7, p. 249-308.

__________, 1886, The structure of the Triassic formation of the Connecticut Valley: Am. Jour. Sci., 3rd series, v. 32, p. 342-352.

__________, 1888, The structure of the Triassic formation of the Connecticut Valley: U. S. Geol. Survey, 7th Ann. Rept., p. 455-490.

__________, 1889, The faults in the Triassic formation near Meriden, Connecticut: Mus. Comp. Zool. Bull., v. 16, p. 61-86.

__________, 1896, The quarries in the lava beds at Meriden, Conn.: Am. Jour. Sci., 4th series, v. 1, p. 1-13.

__________, 1898, The Triassic formation of Connecticut: U. S. Geol. Survey, 18th Ann. Rept., p. 1-192.

__________ and Griswold, L. S., 1894, Eastern boundary of the Connecticut Triassic: Geol. Soc. America, Bull., v. 5, p. 515-530.

__________ and Whittle, C. L., 1889, The intrusive and extrusive Triassic trap sheets of the Connecticut Valley: Mus. Comp. Zool., Bull., v. 16, no. 6, p. 99-138.

Digman, R. E., 1950, An exposure of the Triassic eastern border fault in Connecticut: Am. Jour. Sci., v. 248, p. 37-45.

Emerson, B. K., 1891, On the Triassic of Massachusetts: Geol. Soc. America Bull., v. 2, p. 451-456.

____________, 1898, Description of the Holyoke sheet: U. S. Geol. Survey Geol. Atlas of the United States, Folio 50.

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

Lehmann, Elroy, Ms., Bedrock geology of the Middletown quadrangle: Conn. Geol. and Nat. History Survey.

Longwell, C. R., 1922, Notes on the structure of the Triassic rocks in southern Connecticut: Am. Jour. Sci., 5th series, v. 4, p. 223-236.

____________, 1928, The Triassic of Connecticut: Am. Jour. Sci., 5th series, v. 16, p. 259-263.

____________, 1933, The Triassic belt of Massachusetts and Connecticut: 11th Int. Geol. Congress, Guidebook 1, p. 93-103.

____________, 1937, Sedimentation in relation to faulting: Geol. Soc. America Bull., v. 48, p. 433-442.

____________ and Dana, E. S., 1933, Walks and rides in central Connecticut and Massachusetts: New Haven, Tuttle, Morehouse & Taylor Co., 229 p.

Percival, J. G., 1842, Report on the geology of the State of Connecticut: New Haven. Osborn & Baldwin, 495 p.

Reeside, Jr., J. B., and others, 1957, Correlation of the Triassic formations of North America exclusive of Canada: Geol. Soc. America Bull., v. 68, p. 1451-1514.

Rodgers, John, and others, 1956, Preliminary geological map of Connecticut: Conn. Geol. and Nat. History Survey Bull. 84.

Russell, W. L., 1922, The structural and stratigraphic relations of the Great Triassic fault of southern Connecticut: Am. Jour. Sci., 5th series, v. 4, p. 483-497.

Wheeler, Girard, 1939, Triassic fault-line deflections and associated warping: Jour. Geology, v. 47, p. 337-370.

Woodworth, J. B., 1932, Contributions to the study of mountain building: Am. Jour. Sci., 5th series, v. 23, p. 155-171.

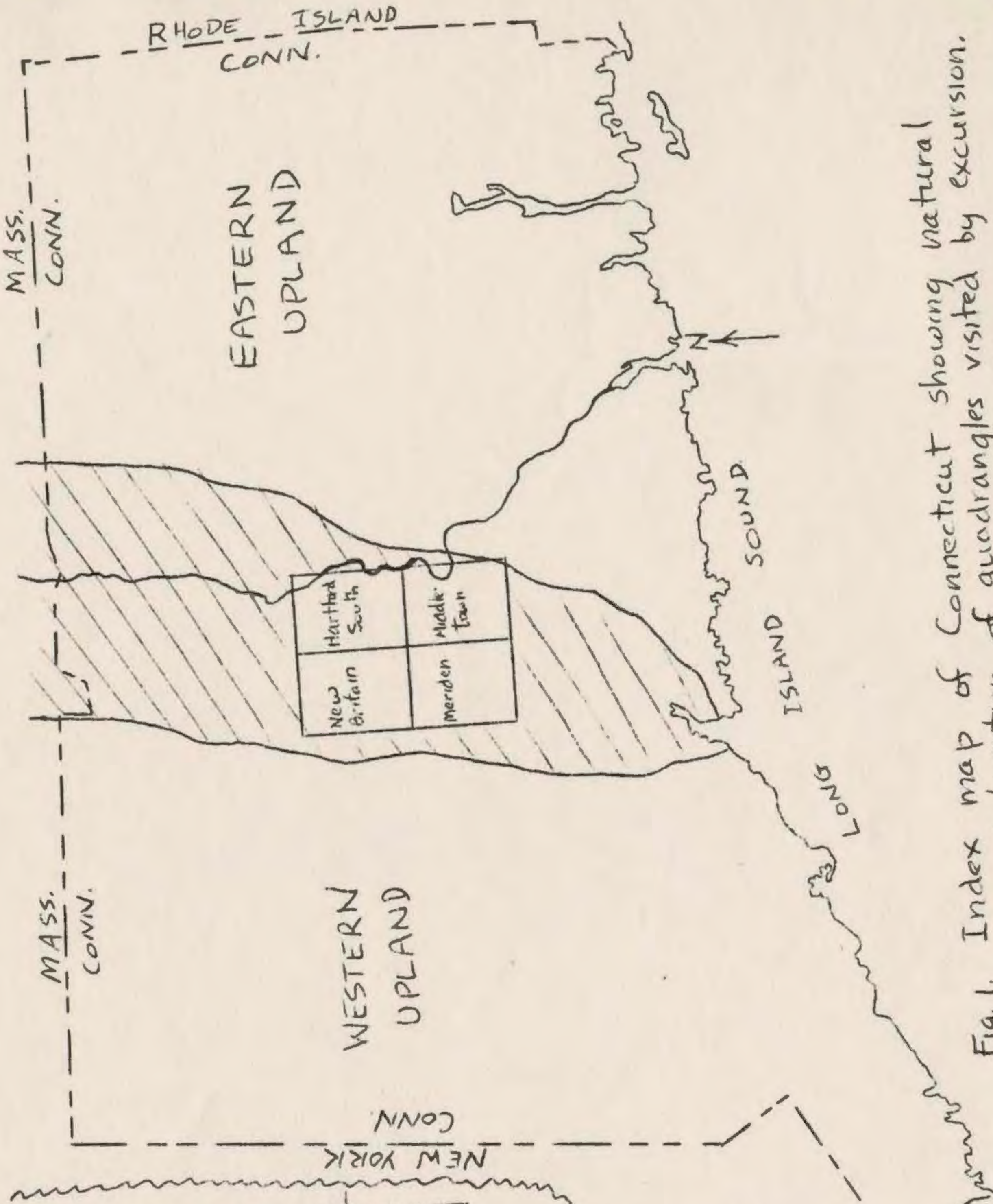


Fig. 1. Index map of Connecticut showing natural regions and location of quadrangles visited by excursion. Central lowland shown by diagonal lines.

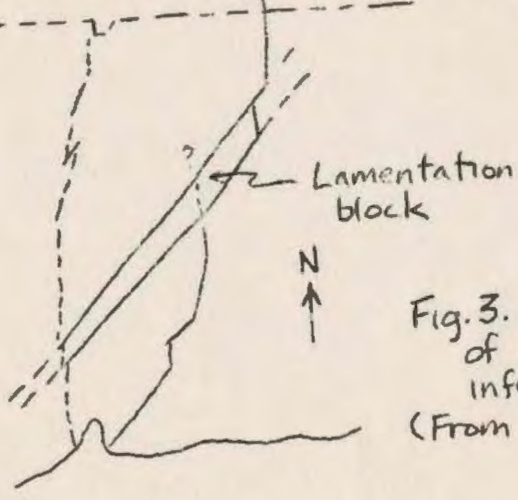


Fig. 3. Sketch map of location of Lamentation block as inferred by Davis.
(From W M Davis, 1898, fig. 25, p. 123)

JES 10.58

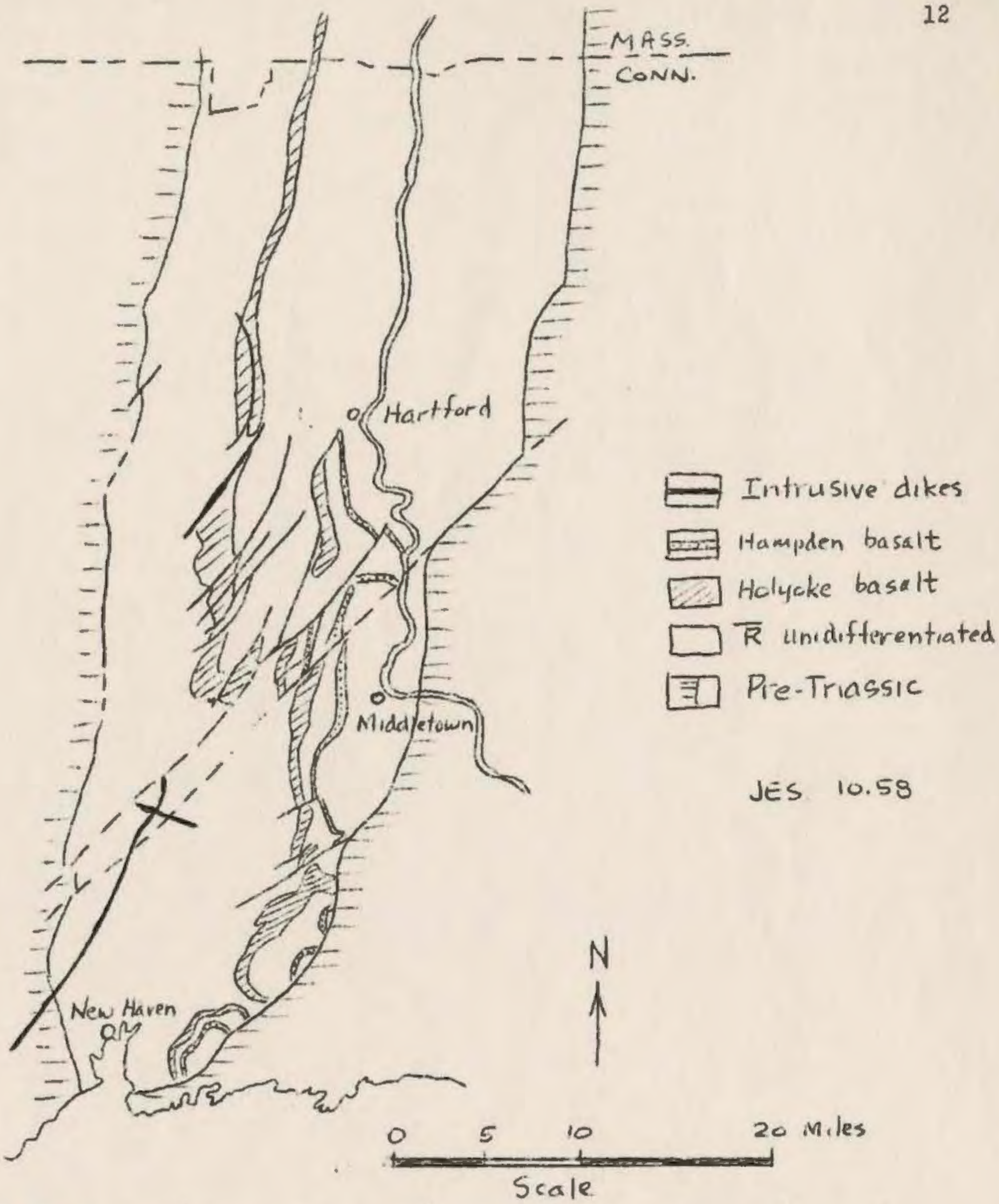


Fig. 4. Partial geologic map of central Connecticut showing W.M. Davis' interpretation of the structural blocks. (Modified from Longwell & Dana, 1933, Pl. I)

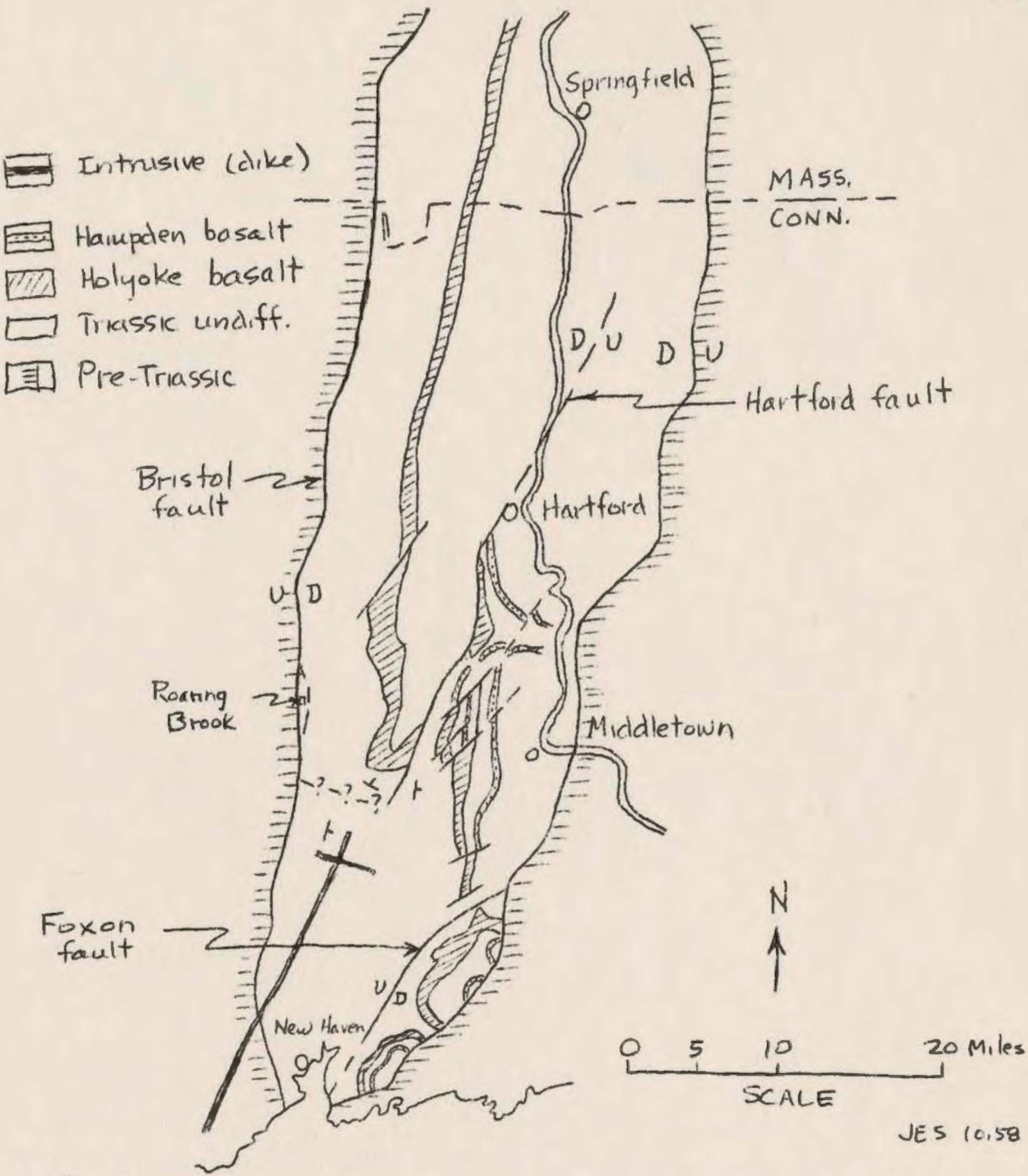


Fig. 5. Revised schematic geologic map of parts of central Connecticut Triassic, showing Hartford, Bristol, and Foxon faults and major offsets of warped structures.

ROAD LOG

MIDDLETOWN QUADRANGLE

	Cumulative milage	Individual distance	
21.5	0.0	0.0	Turn Right into Willow Street.
	0.1	0.1	Turn Left into Silver Street.
	0.2	0.1	(View into Portland brownstone quarries; Brazos quarry)
	0.3	0.2	Turn Right into Brownstone Avenue (slow through oil depot)
	0.5	0.2	(View across quarry to right)
			Bear Right beyond last building.
	0.7	0.2	End of paved road; proceed slowly.
22.4	0.8	0.1	Turn Right into old quarry road.
	STOP 1.	(Prepare to turn cars around here.)	Type locality of Portland formation. Retrace route back to Silver Street;
	1.2	0.4	Turn Left into Silver Street
	1.5	0.3	STOP STREET. Turn Right onto U.S. 6-A, Conn. 17, cross Connecticut River bridge.
	2.4	0.9	Make first Right turn at west end of Bridge (Spring Street)
	2.7	0.3	STOP STREET. Turn Left into High Street.
	2.9	0.2	STOP for Grand Street. Continue on High St.
	3.2	0.3	Traffic light, turn Right on Washington Street.
	3.3	0.1	Traffic light, continue westward on U.S. 6-A.
	4.4	1.1	(Railway underpass)
	4.8	0.4	Blinker light; turn Left on Conn. 157 (West Street)
26.4 -	4.9	0.1	Right turn in Rte. 157.
	5.7	0.8	Left turn in Rte 157 (Forest Street)
	5.8	0.1	Railroad crossing.
	6.2	0.4	Right turn in Rte 157 (Wadsworth Street)
	6.3	0.1	(Entrance to Wadsworth Falls State Park)
	6.9	0.6	(Railroad grade crossing (Rockfall))
	7.2	0.3	Bear Left on Conn. 157.
	7.4	0.2	Junction Conn. 157-159; turn Left on Rte 159.
	7.6	0.2	Parking space on left side of road.
29.3	**STOP 2.**	Wadsworth Falls	(Hampden basalt and base of overlying Portland formation).
			Continue south on Conn. 159
	7.7	0.1	Railroad grade crossing; bear right going up hill, but road soon
29.5	8.0	0.3	curves to left.
			Turn right on unmarked road by Garden Hill estate. (Cherry Hill on left is a double drumlin.)
	8.3	0.3	Cross railroad tracks.
	8.5	0.2	STOP STREET; bear Left on Conn. 157.
	8.9	0.4	STOP STREET, junction Conn. 217-157. Follow Conn. 157 to Left (Road to Durham).
	9.0	0.1	Cross Railroad tracks
	9.4	0.4	Turn Right into Conn. 147 (road to Meriden).
	9.5	0.1	Railroad underpass and Ellen Doyle Brook; bear Right on Conn. 147 at underpass.
/	9.6-9.7	0.1-0.2	[Exposures of Hampden basalt (near base) on left side of road; top beds of underlying East Berlin formation exposed in Creek bed on right by curve sign. Road is on contact here. Beds in creek strike N 15°E, dip 15°E.]
	9.9	0.2	Road from Durham enters on left; bear Right on Conn. 147.
	10.0	0.1	Cross roads at Baileyville. Turn left on un-numbered road (Powder Hill Road; follow signs to Happy Acres and Sauna). Keep to left going uphill (avoid road marked Dead-End).

	Cumulative milage	Individual distance	
	10.1	0.1	Pass Happy Acres (on R.) [Ridge on right, to west, is Beseck Mountain, underlain by Holyoke basalt]
	10.5	0.4	Pass Sauna (on R.); Long Hill Road enters on left; continue south on Powder Hill Road.
	10.7	0.2	Dinosaur footprint locality.
32.4	**STOP 3.**		(Parking a problem here, we may have to visit the outcrops in shifts and ask those who have seen them to move cars on ahead.) About middle of East Berlin formation.
			Continue south on Powder Hill Road. (Powder Hill is a drumlin. Large orchard here illustrates common southern Connecticut practice of using drumlins for orchards.)
	11.3	0.6	(View ahead, to south, of Reed Gap quarry in Holyoke basalt. At top of hill notice Beseck Mountain, underlain by Holyoke basalt, on the right, and Eastern uplands, underlain by igneous and metamorphic rocks, in distance to left.)
			DURHAM QUADRANGLE
	11.5	0.2	Turn Left on unmarked road. Proceed slowly past orchard buildings. (View of Eastern Uplands in distance to east)
	12.1	0.6	Turn Left on road toward Lyman Farm.
			MIDDLETOWN QUADRANGLE
✓	12.6	0.5	"T" intersection, turn Left.
	13.1	0.5	Lyman Gunsight Factory.
	13.3	0.2	STOP. Junction Conn. 147. Baileyville Bear Left on Rte 147.
	13.4	0.1	Baileyville cross-roads. Continue straight ahead on 147, which then bears left and soon curves to right.
35.5	14.0	0.6	(Beseck Lake on left; outcrops on right side of road are near base of East Berlin formation.)
	14.9	0.9	Road curves to left.
	15.0	0.1	(Outcrop near top of Holyoke basalt on left side of road.)
	15.2	0.2	TRAFFIC light, Junction Conn. 147 and U. S.6-A. Turn Left on 6-A. (Outcrops of Holyoke basalt on left and along Rte 6-A for next mile)
	15.8	0.6	(Cuts in Holyoke basalt on both sides of highway)
	16.1	0.3	(Black Pond on left; left turn to newly discovered dinosaur bone locality.)
	16.2	0.1	(Enter Meriden) -
			MERIDEN QUADRANGLE
	16.4	0.2	(Outcrops of Talcott basalt, showing pillows and pipe-stem amygdules.)
	16.6	0.2	BLINKER Light; turn Right (Preston Avenue).
	16.8	0.2	(Outcrops of Talcott basalt in driveways on right) (Peaks in distance to left are part of Hanging Hills)
38.5	17.0	0.2	(View of Chauncey Peak ahead) -
	17.6	0.6	(View of Beseck Mtn. on right, Chauncey Peak ahead, and Hanging Hills in distance to left; all are underlain by Holyoke basalt.)

			(Preston Avenue is on Talcott basalt, but no outcrops are present here.)
	17.8	0.2	Turn Left on unmarked road (Baldwin Avenue). (Outcrops of Talcott basalt on right.)
	18.1	0.3	(Outcrops of pebbly New Haven arkose in bank on right side of road, just beyond Preston Drive.)
	18.6	0.5	STOP Street. Turn Right on Bee Street.
	18.8	0.2	Railroad crossing.
	19.0	0.2	STOP Street. Bear right and continue straight ahead (following signs to York Hill Trap Rock Company); road soon curves to right.
	19.2	0.2	(Outcrops of Talcott basalt in creek bank to left)
	19.4	0.2	(Entrance to International Silver Company Bradley Hubbard Reservoir on left)
	19.9	0.5	(Large quarry in Holyoke basalt of Chauncey Peak block on left)
	21.1	0.2	Enter Middletown. (Exposures of stratified drift in 280-ft terrace on right by Benny's Miniature Golf Course) -
	21.2	0.1	(Basalt outcrop on left of road is near the top of the Holyoke flow of the Chauncey Peak block.)
	21.3	0.1	MIDDLETOWN QUADRANGLE
43.5	22.0	0.7	Highland. Turn left on Country Club Road. (From here northward for next 2.7 miles the road follows a strike valley in the East Berlin formation. Several prominent drumlins are found in this valley, the largest being Snow Hill. Note the orchard on it.)
	24.4	2.4	(View of Hanging Hills in distance to left.)
	24.7	0.3	Intersection Savage Hill Rd and Spruce Brook Rd. Turn Left on Spruce Brook Rd.
	25.0	0.3	Hanson dairy farm (turn into yard beyond new barns)
46.8	STOP 4.		Contact of top of Holyoke basalt and base of East Berlin fm. in bend of Spruce Brook. Walk down farm lane, pass gate, and follow to end of cleared cowpath which leads west along fence line. Cross fence at end of path and descend to stream level.
	25.3	0.3	Turn around and proceed eastward on Spruce Brook Road, retracing route to jct. of Savage Hill Rd. Turn Left on Savage Hill Rd.
	25.6	0.3	(Savage Hill, a drumlin)
	25.9	0.3	STOP Street. Turn Left onto Route 72 (Mill Street).
	26.6	0.7	Roadcuts in Hampden basalt.
	26.7	0.1	Roadcuts in East Berlin fm.
48.3	STOP 5.		Pull over to the right as far as possible for parking. East Berlin fm. and Hampden basalt. Be careful of traffic. (This will be a long stop and is planned to coincide with lunch. The diners on Highway 15 provide rest rooms, coffee, etc.)
			HARTFORD SOUTH QUADRANGLE
	26.9	0.2	Entrance to Wilbur Cross Highway (Conn. 15). Turn Right (toward Hartford).
	27.0	0.1	Enter northbound lanes of Wilbur Cross Highway. Proceed northward.
	28.1	1.1	Jct. Deming Rd (Conn. 160); turn Right, following signs to Rocky Hill.

	28.9	0.8	Wethersfield Rd enters from Right. Route 160 curves gently to Left (Road now follows a strike valley in the East Berlin formation on the Cedar Mountain "anticline." Hampden basalt underlies wooded ridge south of highway; Holyoke basalt forms Vexation Hill to the north).
	29.7-29.9	0.8-1.0	(Holyoke basalt in hills to left).
51.6	30.1	0.2	(Outcrops of East Berlin fm in driveway on Right side of road)
	30.7	0.6	(More outcrops of East Berlin fm)
	30.8	0.1	(Hayes Rd enters from left. Outcrops of East Berlin fm present in cuts 0.1 mi N. on Hayes Rd) -
	31.5	0.7	STOP Street. Turn Right onto Conn. 3 and 160 (Cromwell Ave.) following Rocky Hill signs.
	31.7	0.2	Bear Right on Conn. 3
	32.3	0.6	Turn Left on West Street, toward Conn. State Veterans' Hospital.
	32.8	0.5	(Powerline crosses overhead)
	33.1	0.3	(Ditch by new house on Right exposes contact between top of East Berlin fm and base of Hampden basalt, which has been offset to south)
	33.2	0.1	(Gilbert Ave. enters from left; continue on West St.).
	34.4	1.2	Jct. Conn. 9. (Silas Dean Hwy) - Turn Left toward Rocky Hill.
	35.1	0.7	Multiple intersection; bear Right on Conn. 160, but then immediately turn a 45° right (not a 90° right, as does Conn. 160) following street which passes to the right of a white frame church.
56.2	35.3	0.2	Crossroads. Turn Left on Main Street. (Ridge just ahead is underlain by Hampden basalt on the northeast limb of the Cedar Mtn "anticline." An abandoned quarry is present on the NE side of the ridge.)
	36.2	0.9	(outcrops of Hampden basalt on Right) -
	36.5	0.3	(Railway grade crossing)
	36.9	0.4	Jct. Middletown Ave. and Mill St.; turn Left on Mill St.
	37.1	0.2	Intersection Mill St., Conn. 9. Continue west on Mill St.
	37.3	0.2	Jct. Conn. 3. Mill Street ends. Turn Right on Conn. 3 (Maple St.)
	37.7	0.4	Turn Left on Prospect St.
	38.8	1.1	Intersection Prospect St.-Ridge Rd. Turn Right on Ridge Rd.
	39.0	0.2	Outcrops of Hampden basalt in rock gardens on Left.
	39.5	0.5	STOP Street. Conn. 175 (Wells Rd). Turn Left on Conn. 175. (Ridge Road continues north along outcrop belt of Hampden basalt, as part of Springfield "half basin."
	40.5	1.0	Pass under Wilbur Cross Highway on Conn. 175; proceed west toward New Britain
	40.7-41.2	0.2-0.7	Outcrops of Holyoke basalt of Cedar Mtn.
	41.7	0.5	Newington Main Street intersection and traffic light. Turn Right on Main Street.
	42.7	1.0	Turn Right on Conn. 176 (Hartford Ave.)
	43.4	0.7	Edw. Balf Co. quarry in Holyoke basalt of Cedar Mtn on right.
	44.1	0.7	(Holyoke basalt on Right)
	44.6	0.5	Traffic light at Jct. U.S. 6 (New Britain Ave.). Turn Right (Holyoke basalt on Right).
	44.8	0.2	Move into Center lane for Left turn at next traffic light. Turn Left on Truck Route U.S. 6, following signs to Trinity College (New Britain Ave.).
	45.5	0.7	Turn Left at Zion Street (Traffic light here)
	45.8	0.3	Traffic Light. Bear Right on College Terrace. (Contact of East Berlin fms and Hampden basalt is exposed in Rock Ridge Park on Right).
67.4	45.9	0.1	Right turn on Summit Street
	46.3	0.4	Traffic light at New Britain Ave. Continue straight across intersection.

	46.4	0.1	STOP Street. Bear Left on Fairfield Ave.
	46.6	0.2	(Glacially polished surface and grooves on Hampden basalt on Right).
	47.4	0.8	STOP at blinker light. Intersection of Maple Ave. Bear Right following U.S. 5-A.
	48.5	1.1	(Overpass for southbound lane of Wilbur Cross Highway.)
	49.5	1.0	(Jct. Wilbur Cross Hwy and Conn. 175).
71.7	50.2	0.7	(Outcrop of Holyoke basalt on Right).
	52.6	2.4	(Profile view ahead of Lamentation Mtn. Bench on west side is underlain by Talcott basalt, Main ridge by Holyoke basalt.
	54.9	2.3	(Jct. Wilbur Cross Hwy and Conn. 72)
			MIDDLETOWN QUADRANGLE
			After 1.7 mi. enter MERIDEN QUADRANGLE
	58.3	3.4	Turn off Wilbur Cross Hwy at U.S. 5-A, following Meriden sign (Broad Street)
	59.4	1.1	(Outcrop of New Haven arkose on left)
	59.6	0.2	Blinker light.
	60.4	0.8	Railroad underpass. New Haven arkose outcrops beyond on Right.
	60.6	0.2	Bear Right onto New Colony St.
	60.6	0.3	(Railway grade crossing)
			After crossing, turn Right onto Kensington Avenue.
	60.9	0.3	(R.R. overpass; New Haven arkose exposed at street corner on right).
	61.0	0.1	(More New Haven arkose on Right). Kensington Ave. curves Right, then Left.
	61.2	0.2	Turn Right into Bailey Ave.
	61.4	0.2	Turn Left into Gay St. Proceed to end of street.
	61.5	0.1	Sangavani Sand and Gravel Pit, near cor. Gay and Summary Sts.

83 <u>STOP 6.</u> Exposure of Hartford fault.
New Haven arkose faulted against Holyoke basalt of Cathole Mtn block.
Exposure also reveals typical stratified drift.

			Turn Right into Summary St.
	61.6	0.1	"T" intersection with Kensington Ave.; turn Right.
	61.9	0.3	(Outcrop of Shuttle Meadow fm on Cathole block on left)
	62.1	0.2	"T" intersection with Conn. 71 (Chamberlain Hwy). Turn Right.
	62.2-62.7	0.1-0.5	Outcrops of Holyoke basalt. (Berlin Town line, New Haven-Hartford County line at 0.5)
	63.3	0.6	Turn Left on Butler St.
	65.5	0.2	Turn sharp Left into Park Drive.
87.5	66.0	0.5	(Road enters on right)
	66.9	0.9	Sharp Right turn. Bear around to Right and cross small bridge at head of Merimere reservoir.
	67.4	0.5	Sharp Left turn in road.
			(From here to top, the road nearly follows a dip slope of Holyoke basalt of the Hanging Hills.)
	68.3	0.9	"Y" intersection in road, bear Left for East Peak.
	68.7	0.4	<u>STOP 7.</u>

Stone tower at East Peak.

If clear, the view from here is very instructive. To the east are Lamentation Mtn, Chauncey Peak, Higby and Beseck Mtns and Reed Gap underlain by Holyoke basalt of the Middletown "half basin"; to the south are Mt. Carmel and East Rock (intrusive masses); to the southwest is West Rock ridge (tilted sill of dolerite), and to the west, the metamorphic rocks of the Western Uplands.

Retrace route to head of Merimere reservoir.

	70.5	1.8	Turn right on Park Drive, following along east side of Reservoir.

70.9	0.4	(Outcrops of Holyoke basalt on left)
71.2	0.3	(Outcrops of Shuttle Meadow fm on left opposite island in Reservoir).
71.4-71.5	0.2-0.3	(Outcrops of Talcott basalt on left)
71.9	0.4	Reservoir Ave. enters on left; make Left turn into Reservoir Ave.
72.5	0.6	(Outcrops of New Haven arkose just west of intersection of Fowler Ave. and Reservoir Ave.)
72.6	0.1	Corner Fowler Ave. and Reservoir Ave.; turn Right on Fowler Ave.
72.8	0.2	"T" intersection; Fowler Ave. ends against U.S. 6-A (Main St.) Cross 6-A to study outcrop of sandstone by Dari-Queen.
94.5		STOP 8. New Haven arkose. Strike and dip indicates this outcrop is on the Middletown block and that the Hartford fault passes northwest of this hill. We will proceed east on 6-A from here.
73.0	0.2	(Traffic light; Conn. 71 enters on left)
73.2	0.2	Traffic light. Turn Right on divided parkway, Conn. 71 (Bradley Ave.)
73.5	0.3	STOP Street. Continue on Bradley Ave.
74.0	0.5	(Large street enters on left; continue straight on Bradley Ave.)
75.0	1.0	Intersection Conn. 71-70; Turn Right on Conn. 70 (New Haven Ave.) Cross Quinnipiac River. Hanover Pond on Right.
75.5	0.5	Traffic light; turn Right with caution on continuous green arrow when main signal is red.
75.7	0.2	Hanover Pond outcrops of New Haven arkose on left around curve in road.
75.9	0.2	Turn Right, across bridge and park in open space beyond.
97.6		STOP 9. New Haven arkose of Hanging Hills block (NW strike, NE dip). Note coarse channel deposits and finer grained floodplain sediments. Many small faults are present here and on the south side of the Quinnipiac River, with abundant slickensides.
END OF TRIP.		Best way back to Middletown: Retrace route on Conn. 70 past Hanover Pond.
76.3	0.4	Traffic light. Turn left on Conn. 70.
76.8	0.5	Jct. Conn. 71-70; turn Right on Conn. 71.
77.4	0.6	Outcrop of basalt dike on left, opposite cemetery
77.6	0.2	Jct. Conn. 71, U.S. 5-A. "T" intersection. Turn Right on U.S. 5-A.
78.6	1.0	Intersection U.S.5-A and South Broad St. U.S. 5-A turns Left and passes under narrow R.R. overpass. LEAVE MERIDEN QUADRANGLE.
78.8	0.2	Blinker light at Jct. U.S. 5-A and U.S. 5. Enter U.S. 5 (going South).
79.2	0.4	Jct. U.S. 5 and Wilbur Cross Parkway. Pass under Parkway and take second left (Hartford signs).
81.4	2.2	Exit from Parkway to U.S. 6-A. Follow Middletown signs.
87.7	6.3	R.R. overpass at edge of Middletown. Continue on U.S. 6-A.
88.2	0.5	Wesleyan campus on right.

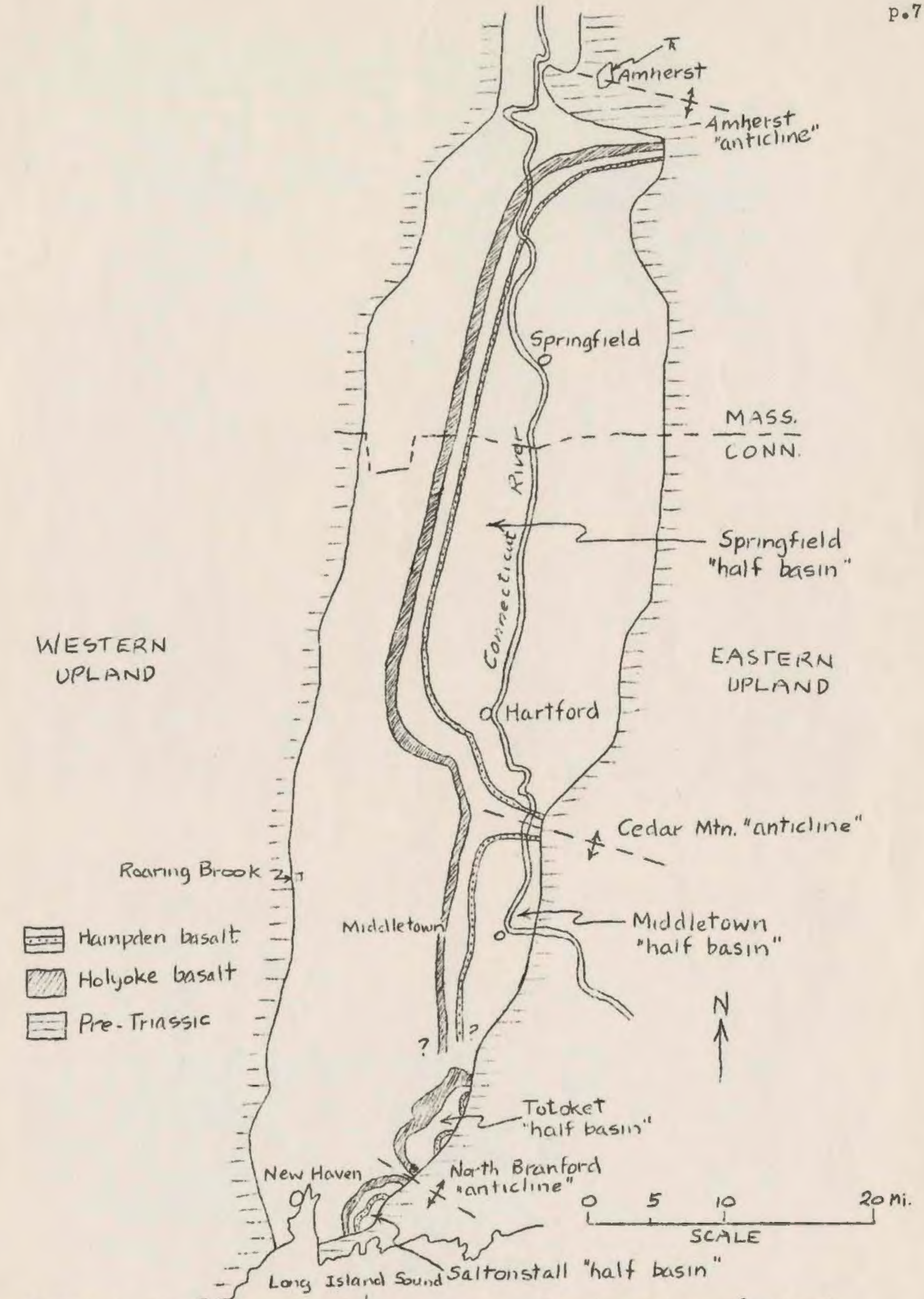


Fig. 2 Partial, schematic geologic map showing inferred position of warped structures in Connecticut valley Triassic prior to displacement on Lowland fault system. (Base from Longwell & Dana, 1933).

JES 10.58

TRIP C - PLEISTOCENE GEOLOGY OF THE LOWER QUINNIPIAC VALLEY

0.0 Assemble in the vacant lot on the north side of Sackett Point Road, North Haven, 0.9 miles east of Route 5 and immediately east of the railroad tracks. Go west to Route 5 and turn left (south). Continue along Route 5 to the entrance of the North Haven Brick Company pit on the left side of the road (0.7 mi). Turn left onto dirt road and follow it to the east side of the pit.

2.0 STOP 1 - North Haven Brick Company pit. Recent excavations have exposed a fine section of the New Haven clay. This unit consists of rhythmic layers of reddish silt and clay believed to have formed in a late-glacial lake. In the southwest corner of the pit a small exposure of gray fluvial sand directly overlies the New Haven clay and represents part of the outwash valley train which filled the Quinnipiac Valley near the close of the last glacial age. Tidal-marsh sediments directly overlie the New Haven clay and outwash sand. Presence of tidal marsh vegetation near the excavation shows that this unit is still forming.

Leave the pit and return to route 5. Turn right (north) and proceed along Route 5 through North Haven.

6.0 Turn left immediately beyond the Shell gas station on the north side of town and proceed along dirt road to excavations.

6.5 STOP 2 - Rice sand pit. Two stratigraphic units are exposed - (1) Reddish ice-contact stratified drift (mainly sand) which is characterized by relatively poor sorting and by abrupt changes in grain size both vertically and horizontally. The sediment was deposited mostly marginal to and under wasting bodies of stagnant ice; (2) Yellow to gray outwash lying above the ice-contact stratified deposits and consisting of well-sorted sands showing cut-and-fill stratification. Topographic relief of the contact between these two units is well exposed.

Continue to the north side of the pit (0.4 mi) where sedimentary structures in the stratified drift and outwash can be examined.

Return to Route 5 (0.9 mi) and turn left (north). Route 5 follows the nearly featureless top surface of the outwash valley train, at this point having an elevation of 50 feet above sealevel.

9.3 Turn right (east) on Bradley Street and proceed east and northeast.

9.9 Make sharp left turn onto dirt street and proceed to top of hill.

10.1 STOP 3 - This hill is composed of ice-contact stratified deposits and probably represents an elongate kame, the top of which projects above the outwash valley fill. This is one of three small kame-like features of red ice-contact stratified drift in the immediate vicinity which are exposed above the outwash sediments. The hill is completely surrounded by yellow outwash sand which lenses out against its sides.

Return to Bradley Street and turn left (northeast).

10.6 Turn left on Scrub Oak Road and go west to Route 5 (0.7 mi). Turn right onto Route 5 and proceed to entrance of Wharton Brook State Park.

11.4 LUNCH STOP - Wharton Brook State Park.

11.7 Turn left onto Toelles Road and proceed west along top of outwash body. As the road descends to the bridge across the Quinnipiac River, abandoned meander channels may be seen on the east side of the river. The river-cut terraces are veneered with a thin deposit of reworked outwash and stratified drift. The lowest surface constitutes the river flood plain and is underlain by silt.

12.6 Turn right onto Old Hartford Turnpike and proceed north. Roadside outcrops of weathered dolerite mark the easternmost extent of the Mt. Carmel igneous body.

13.1 STOP 4 - Pull off in field just beyond small bridge. Polished and striated dolerite is exposed in the stream gully. The exposed rock lay on the upstream side for the advancing glacier and hence displays a polished stoss-slope surface. Tilted rhythmic clay and silt and overlying sediments of ice-contact and outwash origin are exposed 100 feet upstream.

Continue north along Old Hartford Turnpike. To the left of the road striated arkose is exposed on the hill-slope, overlain by till and outwash.

15.2 Turn right at Amoco gas station and pull off into field next to Toll House Motel.

15.3 STOP 5 - Red ice-contact stratified drift is exposed south of the motel and probably constitutes part of a kame terrace lying along the western margin of the valley. Arkose bedrock is overlain by sandy till, red sand and gravel, and yellow outwash sand. A conspicuous pebble and cobble layer lies at the contact between the red and yellow sand bodies.

Follow road back to Old Hartford Turnpike and proceed north to Ridgeland Road.

16.1 Turn left onto Ridgeland Road and proceed west.

16.3 STOP 6 - Section exposed in stream gully behind houses on west side of road. Striated arkose is overlain by till, red ice-contact stratified drift, and yellow outwash.

Return to Old Hartford turnpike and turn left. Proceed north through Yalesville to Church Street.

17.8 Turn right on Church Street and go east across the Quinnipiac River. Gravel pits on the left side of road are in ice-contact stratified drift which underlies the surface of this lower terrace. Proceeding eastward, the road climbs to intersect the railroad tracks on top of the outwash body. Elevation above sealevel at this point is 80 feet.

18.3 Just before reaching railroad tracks turn right onto dirt road and go south and west into gravel pit.

18.8 STOP 7 - Meriden-Wallingford Washed Sand and Stone Co. pit. Ice-contact stratified drift is seen underlying outwash sands. Alternation of the two units is seen near the contact. Sedimentary structures are well displayed in several of the recent cuts.

END OF TRIP. Proceed east out of pit and cross railroad tracks to Route 5 which may be followed north to the parkway or south to New Haven.

Stratigraphy, structure, and metamorphism

Deep River area, Connecticut

Commentary prepared by L.W.
Lundgren, University of Rochester

for

TRIP D

50th Annual Meeting

NEW ENGLAND INTERCOLLEGIATE GEOLOGICAL CONFERENCE

WESLEYAN UNIVERSITY

October 11-12, 1958

Introduction

The Deep River area lies on the southern end of a chain of gneiss domes that extends northward through Connecticut and Massachusetts into Vermont and New Hampshire. The domes in New Hampshire and Vermont have been given the greatest amount of study to date (see Billings, 1956 and references cited there; Thompson and Rosenfeld, 1951). The Deep River area and the nearby Middle Haddam area provide excellent samples of the kind of relationships seen in and around gneiss domes in eastern Connecticut and some interesting comparisons with the domes further north.

The following commentary is abstracted from a Yale thesis (Lundgren, 1957) and incorporates modifications in stratigraphic nomenclature made as a result of work done since 1956. The figures have been redrafted from similar figures used in the thesis. The mapping of the Deep River and Essex quadrangles was done with the generous support of the Connecticut Geological and Natural History Survey under the directorship of John Lucke. The metamorphic problems are now being studied under a grant from the Geological Society of America (Grant GSA 799-8). Formal proposals for the stratigraphic nomenclature used here will be presented in a paper now in preparation and in quadrangle reports of the Connecticut Survey, also in preparation.

The continuing work of John Rosenfeld and Gordon Eaton in the Middle Haddam area, and of George Snyder and Richard Goldsmith of the U.S. Geological Survey in the quadrangles east and northeast of the Hamburg quadrangle has served as a basis for continuous stimulating discussion with these people, all of whom have been extremely helpful. In addition, the commentary of and discussions with John Rodgers and Matt Walton of Yale have helped me to place the Deep River area in perspective with respect to the regional setting and to other similar areas.

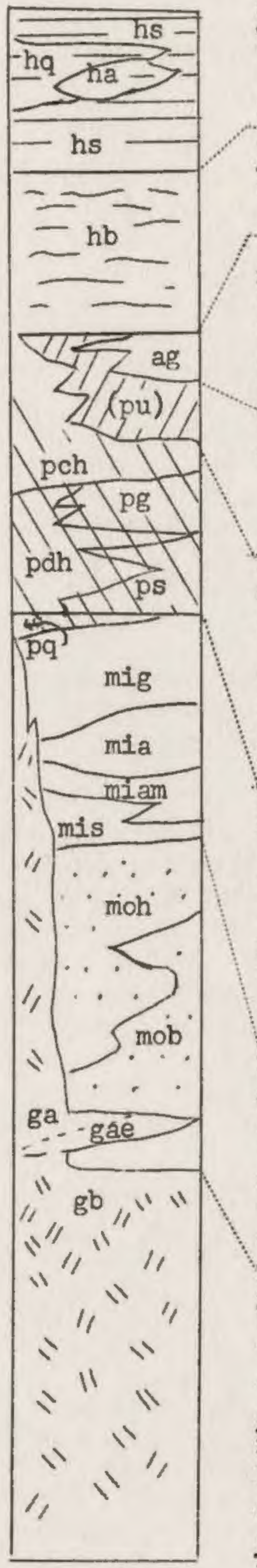
Structural setting

Three domes (Killingworth, Selden Neck, and Clinton) of quartzo-feldspathic gneiss dominate the structure of the area and its immediate surroundings (Fig. 1 and 3). Each is a domal mass of heterogeneous plagioclase gneisses; the Selden Neck and Clinton domes have cores of pink, microcline-bearing biotite granite gneiss.

The domes are separated from one another by a narrow belt of tightly folded stratified rocks that lie along a sinuous isoclinal syncline, the Chester syncline. The Chester syncline opens out to the northeast and east into a broad structural basin, the Mt. Parnassus basin. This basin and the Chester syncline might be regarded as the southern termination of the Merrimack synclinorium in New Hampshire and Massachusetts.

The southern margin of the Mt. Parnassus basin is marked by a mile-wide zone of cataclastic and mylonitic gneisses and schists marking the trace of a major thrust fault, the Honey Hill fault, which extends east of the area for twenty miles or more (Lundgren, Snyder, and Goldsmith, 1958). This fault separates the dome sequence from the synclinal sequence and is parallel with bedding and foliation in these rocks on both sides of the fault. Thus it is essentially a bedding-plane fault in the Deep River area. The fault retains its bedding-plane character even where the contact between the two sequences is folded and overturned along the east limb of the Chester syncline. The fault does not cut the Chester syncline; instead it bends at Chester (Fig. 2 and 3) to become parallel with the overturned limb of the syncline as indicated by the presence of laminar cataclastic gneisses along this limb immediately south of Chester. The displacement along the fault is negligible in the area around Chester and increases to the east.

INTERPRETATIVE COLUMNAR SECTION



Hopyard fm.- Gray Bi-Ms-Q-Pl-Gt schist with sillimanitic and rusty sulfide-bearing facies in upper part (hs). Garnetiferous Bi-Q schist (hq) and calcareous amphibolite (ha) common in upper part of Hopyard fm.

Hebron fm.- Thin-bedded Bi-Pl-Q schist and calc-silicate (Di-Act-Pl) granofels (hb). Along Honey Hill fault these rocks are mylonitic and commonly contain augen of plagioclase and microcline.

Augen gneiss along Honey Hill fault.- Cataclastic and mylonitic gneisses consisting of pink Mi (Or)-Pl-Q-Ms-Bi-Gt granite gneiss intercalated with dark-gray Pl-Q-Bi-Hbld gneiss containing abundant augen of plagioclase and orthoclase. Probably a mixture of Canterbury and Putnam gneisses.

Putnam fm.(?).- Dark-gray Bi-Pl-Q-Ms-(Gt) schist with interbedded sillimanitic quartzite, hornblende gneiss, and rusty binary schist (pu ?). Along Honey Hill fault these rocks are mylonitic and commonly contain augen of plagioclase and quartz.

Pequot Swamp fm.- Heterogeneous unit consisting of conglomeratic quartzite (pq), laminar Di-Hbld amphibolite with interbedded Bi-Q-Pl-Gt schist (pdh), Bi-Ms-Pl-Q-Gt-(Sill) and Bi-Pl-Q-Or-Sill-Gt schists (ps) with interbedded pink spessartite-quartz granulite. Uppermost schist containing abundant pegmatite laminae is the Cremation Hill schist member (pch). Garnetiferous Pl-Q-Mi-Bi gneiss with interbedded amphibolite (pgn).

Middletown fm.- Heterogeneous unit characterized by widespread occurrence of anthophyllite and cummingtonite. Consists primarily of anthophyllitic Pl-Q-Bi-(Hbld) gneiss with abundant amphibolite layers (mig), and rusty Pl-Q-Bi gneiss containing abundant anthophyllite, garnet, and quartz-tourmaline pods (mia). Also present are thin layers of garnetiferous binary schist and rusty binary quartzite (mis), diopsidic marble and amphibolite (miam), and quartz-rich gneisses containing nodular masses of quartz and sillimanite.

Monson gneiss.- Gray Pl-Q-Bi-Mt and Pl-Q-Hbld-Mt gneisses in which plagioclase is generally the only feldspar. Hornblendic gneisses (moh) more abundant in upper part, and biotitic gneisses (mob) more abundant in the lower part of the Monson. Monson gneiss adjacent to the abundant layers of alaskitic granite around the Selden Neck dome contains some microcline. Amphibolite layers common throughout.

Microcline-bearing granitic gneisses.- Pink to light-gray microcline-bearing gneisses in which the foliation is marked by parallel orientation of platey quartz and feldspar as well as by the parallel orientation of biotite, magnetite, and hornblende. Alaskitic granite gneiss (ga): Medium to fine-grained leucocratic gneiss in which magnetite is the principal mafic mineral. Total mafic mineral content less than 2%. Aegerine-augite granite gneiss (gae): Weakly gneissic aegerine-augite and riebeckite-bearing alkalic granite. Biotite granite gneiss (gb): Heterogeneous medium-grained pink granite gneiss in which microcline generally less abundant than plagioclase. Biotite is the principal accessory; hornblende is locally abundant, particularly near amphibolite layers.

Sequence, age, and correlation of the rocks in the Deep River area

The inferred stratigraphic sequence in the Deep River area is illustrated in the columnar section on the facing page. This sequence may be conveniently divided into two parts, a domal and a synclinal sequence so named on the basis of their respective structural positions.

The domal sequence (Middletown + Monson + microcline granites) is a complex of weakly foliated to sharply layered quartzo-feldspathic gneisses and relatively minor amounts of mica- and amphibole-rich schists and gneisses. It presumably includes metamorphosed sedimentary, volcanic, and intrusive rocks. Most of the rocks in this sequence map as if they were true stratigraphic units, and, on a large scale, they behave as a basement complex on which the synclinal sequence lies.

The synclinal sequence comprises mica-, calc-silicate-, and amphibole-rich schists and gneisses. The upper part of this sequence consists of metasedimentary rocks that display marked lateral uniformity; the Hebron can be followed without a break from the northern part of the Mt. Parnassus basin into and along the tortuous axis of the Chester syncline. This part of the sequence is only locally in contact with the dome sequence; it may be described as the mantle (in the sense in which this word has been used by Eskola, (1949), as it effectively mantles or is draped around the domes and is not cut by rocks belonging to the dome sequence. This may indicate that the mantle lies unconformably on the dome sequence.

The Pequot Swamp formation and the Putnam formation occupy a somewhat ambiguous position in this scheme. They too may lie unconformably on the dome sequence. (Note that the Honey Hill fault is localized along the contact between the Putnam and the Monson.)

The inferred sequence in the Deep River area is similar to the sequence around most of the gneiss domes from Long Island Sound to New Hampshire. One possible gross correlation with the well known New Hampshire section (by way of Massachusetts) is as follows.

(Hebron fm. + Hopyard fm.) = (Fitch + Littleton fms.) = Siluro-Devonian

(Middletown + Pequot Swamp fms.) = (Ammonoosuc + Partridge fms.) = Ordovician

(Monson gn. + biotite granite gn.) = (Oliverian magma series)

Monson = Ordovician or older; biotite granite gneiss = pre-Silurian.

However, we (Snyder, Rosenfeld, Eaton, Lundgren) have not yet been successful in correlating the rocks east of the Monson with those west of the Monson (see Fig. 1), so that any comparison of the Deep River section with the New Hampshire section is speculative.

As is well known, there are still problems involved in correlating the western New Hampshire section with the section in eastern New Hampshire and Massachusetts (see Billings, 1956, p. 99-105) across the broad expanse of the Merrimack synclinorium. This problem becomes acute in southern Connecticut where the Merrimack synclinorium apparently dwindles into the quantitatively insignificant Chester syncline. The Hebron and Hopyard could be equivalent to the Carboniferous (?) rocks on the east side of the Merrimack synclinorium in Massachusetts, or to the Silurian (?) Merrimack group in southeastern New Hampshire. Similarly, they might be equivalent to the rocks on the west side of the synclinorium in central Massachusetts that Hadley (1949) has equated with the Siluro-Devonian section of Western New Hampshire. However, Rosenfeld and Eaton have carried the New Hampshire section down to the Middle Haddam quadrangle (Fig. 1), and they do not find equivalents of the Hebron and Hopyard there, just as I find no equivalent of the Great Hill (= Clough) quartzite associated with the Hebron and Hopyard. If the Hebron is Silurian or younger, then the apparent lack of correlation with the Middle Haddam section may be a consequence of major sedimentary facies changes from west to east combined with the presence of north-south isoclinal folds. On the other hand, the rocks east of the Monson may not be equivalent to the Great Hill section but may be younger or older. From this it is clear that we simply do not know the age and correlation of these rocks with any exactness, and, when the correlations have been made it will still be necessary to have more data on the enigmatic Worcester phyllite and associated rocks than is yet available.

The plagioclase gneisses (Monson gneiss) form the base of the local sequence and probably are Cambrian or Ordovician equivalents of similar dome rocks to the north. The overlying Pequot Swamp formation may be equivalent to the Collins Hill formation in the Middle Haddam area and quite possibly is Ordovician. The granite gneisses are intrusive in part into the plagioclase gneisses; they are restricted to a position below the Pequot Swamp formation and are considered to be older than this and the overlying units. All the rocks are more than 260 million years old on the basis of radioactive age determinations on minerals from pegmatites in the Middle Haddam and Glastonbury quadrangles (Rodgers, 1952, p. 413-415).

Origin of the rocks in the Deep River area

The nature of the parent rocks from which the Deep River rocks were formed has been obscured by the effects of intense metamorphism and deformation, and the deeper we go in the section, the more numerous are the origins that may be attributed to these rocks. The principal guides to satisfactory interpretation are a) correlation with less-metamorphosed equivalents, b) the composition, internal structure, and associations of each unit, and c) analogies with less metamorphosed sequences seen in the axial region of geosynclines (marked by the familiar chain of alpine ultramafic rocks).

The Hopyard formation represents the metamorphic equivalent of a sequence of shale with interbedded siltstone and highly impure calcareous sedimentary rocks. The underlying Hebron formation probably originated from the metamorphism of a sequence of well bedded fine-grained sandstones and siltstone with interlayered calcareous and dolomitic siltstones. This interpretation is based on the chemical and mineralogic composition of those units and on correlation with less metamorphosed rocks to the north.

The Pequot Swamp formation seems to be the metamorphic equivalent of the varied sequences of banded tuffs, flows, agglomerates, bedded manganiferous cherts, and clastic sediments commonly deposited in the middle stages of geosynclinal sedimentation. The Baie Verte and Cape St. John groups in the Ordovician of northern Newfoundland (Baird, 1951) and the middle part of the Franciscan-Knoxville group in California (Taliaferro, 1943, p. 144-153) are examples of such sequences, as parts of the Ammonoosuc volcanics (Billings, 1937, p. 475-480) in New Hampshire may also be. Such an origin is suggested by the great variety of rock types, the rapid changes along strike, and the widespread occurrence of beautifully banded amphibolite (= banded pyroclastic rocks) associated with well bedded spessartite-quartz granulite (= bedded manganiferous chert).

The dome complex consists of rocks that have generally been regarded as magmatic intrusives (see e.g. Mikami and Digman, 1957); the same is true of their probable equivalents to the north (e.g. the Oliverian magma series). The composition, associations, and widespread occurrence of rocks similar to the Monson in a similar stratigraphic position in other domes suggests that the Monson is a product of metamorphism of a geosynclinal suite of quartz keratophyre and andesitic volcanics and associated sedimentary rocks. The Middletown formation probably evolved from a similar sequence in which basaltic volcanics and associated chert and limestone were more abundant.

The microcline-bearing granite gneisses are heterogeneous; modal analyses indicate a continuous gradation to adjacent plagioclase gneiss. The granite gneisses were metamorphosed concurrently with the other rocks and thus are of indeterminate origin. They probably represent metamorphosed intrusives surrounded by granitized plagioclase gneiss. Modal analyses of alaskitic and aegerine-augite-bearing granite, which occurs in layers peripheral to the core of the Selden Neck dome, illustrate the uniform composition of these rocks, which is equivalent to the composition of the "granite minimum" in the system Ab-Or-Q-H_2O. These rocks are of magmatic origin and may represent both metamorphosed rhyolites and products of melting of older granites.

Metamorphism

Sillimanite is present in aluminous schists occurring within the Hopyard, Pequot Swamp, Putnam, and Middletown formations throughout the entire area. Thus the rocks are entirely within the sillimanite zone of metamorphism (upper amphibolite facies). The metamorphic grade increases from north to south as indicated by changes in mineral assemblage in stratigraphic units lying along the Chester syncline. The most striking changes are shown by the Cremation Hill schist member of the Pequot Swamp fm., which can be followed continuously from the Middle Haddam quadrangle southward to Long Island Sound and around the south side of the Selden Neck dome. In most of the Deep River quadrangle (e.g. STOP 4) this schist is a binary schist, which locally contains sillimanite and generally contains pegmatitic Q-Pl-Ms laminae. In the Essex and Hamburg quadrangles the same unit contains no muscovite but does contain orthoclase and sillimanite and abundant pegmatitic Q-Pl-Or-Gt-Sill laminae (STOP 7). These changes are summarized in the following table. Other units show comparable, though less obvious changes from north to south.

Modal analyses of sections of
Cremation Hill schist

	Q	Pl	Bi	Ms	Sill	Or	Gt	Acc	Metamorphic facies
DR-78-5	37.4	9.8	36.5	11.5	tr	–	2.8	tr	"Sillimanite-muscovite" subfacies of the amphibolite facies
DR-44-5	31.2	19.3	29.4	18.5	tr	–	1.1	tr	
E-111-6	37.3	23.9	24.4	–	4.0	6.1	4.0	tr	"Sillimanite-orthoclase" subfacies of the amphibolite facies

These changes can be explained as products of progressive metamorphism effected by progressive dehydration and decarbonation of sedimentary rocks lying along the Chester syncline. The changes in the Cremation Hill schist, for example, may be related to the dehydration of muscovite in an initially muscovitic schist resulting in the development of a somewhat "drier" schist containing orthoclase and sillimanite. The following reaction probably is a crude expression of what really happened.

$$\begin{array}{lllll} & \mathrm{KAl_2AlSi_3O_{10}(OH)_2} + & \mathrm{SiO_2} & = \mathrm{KAlSi_3O_8} + & \mathrm{Al_2SiO_5} + \mathrm{H_2O} \\ & \text{muscovite} & + \text{ quartz} & = \text{orthoclase+sillimanite+water} & \\ \text{mol volume} & 142 \text{ cc} & 22 \text{ cc} & 105 \text{ cc} & 44 \text{ cc} \end{array}$$

The interpretation favored is that the rocks in the southern half of the area were raised to a temperature (ca. 600° C) high enough that the Ms + Q reaction occurred, with the resultant replacement of every 10 percent muscovite initially present by about 6 percent orthoclase and 4 percent sillimanite. Biotite also seems to have been involved in dehydration reactions of a similar though more complicated nature. The temperature increase required resulted primarily from the upward displacement of isotherms around rising masses of once deeply buried hotter dome rocks. The narrow belt of tightly folded rocks lying along the Chester syncline was thus pinched between large volumes of somewhat hotter rock and also was continuously deformed, thus facilitating the escape of the large volume of water released by the dehydration of muscovite.

One corollary of this hypothesis is that the pegmatitic laminae in many high-grade schists are a product of metamorphism and simply represent a product of reorganization of material already present. Many geologists have favored the diametrically opposite hypothesis that the metamorphism is a product of the intrusion of pegmatite to form a lit-par-lit gneiss or schist.

Structural evolution

The structural problems present in the Deep River area are those common to gneiss-dome terrains throughout the world. Folds similar to the Chester syncline are common; they typically have highly sinuous axes and an axial "plane" that is actually a convoluted surface. The way in which such folds evolve, and thus, the relationship between such folds and the development of the domes is a structural problem of some interest. Of added interest in the Deep River area is the relationship between the Honey Hill fault and the other major structures.

The formation of the domes is here interpreted as a result of vertical upward movement, in the well known salt-dome style, of masses of rock having relatively low density and high plasticity. The rocks in the domes reached their present positions primarily as a result of plastic flow effected by recrystallization in the solid state, although relatively minor amounts of silicate melt may have facilitated the rise of the granitic domes in the areas of highest metamorphic grade. Such a mechanism was proposed by Eskola (1949) and has since been adduced by Thompson and Rosenfeld (1951), Walton (1955) and others as an explanation of similar relationships in other areas. The widespread occurrence of boudinage in amphibolite layers in the dome sequence is an indication of plastic flow in the gneisses; the size, shape, and extent of separation of individual boudins provides some measure of the minimum amount of flow in the gneisses.

The configuration of the mantle or synclinal sequence may be simply explained as consequence of vertical movement of the domes concomitant with movement along the Honey Hill fault. The mantling rocks were literally pinched between the rising cores of the domes, and folded isoclinal folds such as the Chester syncline were formed as a result of vertical movement of the dome rocks, with lateral compression being of secondary importance. The unsystematic extreme contortion of the rocks in the vicinity of STOP 8 (Connecticut Turnpike x Rt. 153) is presumably related to the differential rate and extent of upward movement of the domes. In this area, which lies at the center of a mass of rock surrounded by three (possibly four) gneiss domes, the synclinal sequence was tightly pinched and simultaneously twisted so that the syncline is here a twisted trough.

Other structural features of related interest are the V-shaped mass of Middletown formation northwest of Ivoryton and the remarkable little basin of Middletown around Vincent Pond, which appears (Fig. 3) as a feature with the configuration of a hole in a doughnut in the southeast sector of the Killingworth dome.

This part of the Killingworth dome was squeezed between the Clinton and Selden Neck domes; a pair of synclinal structures were thus superimposed on the gross structure of the dome.

The relationship between the rise of the gneiss domes and movement along the Honey Hill fault is an important problem. The field evidence, particularly in the structural knot around Chester (STOPS 1, 2, and 3) seemingly requires that the initial movement along the Honey Hill fault was contemporaneous, or nearly so, with the doming and metamorphism. The mantle was thrust southward over the dome sequence, the knot around Chester serving as the hinge point. Movement along the Honey Hill fault undoubtedly continued after the peak of metamorphism as indicated by the presence of mylonitic rocks containing mineral assemblages of somewhat lower grade than the rock from which the mylonite formed. One speculation that is being considered is that the rocks along the fault were being mylonitized at the same time as more deeply buried rocks to the south were being continuously folded and metamorphosed. In other words, it is possible that the entire structural and metamorphic evolution of the Deep River area took place more or less continuously during a long period of deformation centered around the time 260 million years B.P.

REFERENCES

Baird, D.M., 1951, The geology of the Burlington Peninsula, Newfoundland: Geol. Survey Canada Paper 51-21.

Billings, M.P., 1937, Regional metamorphism of the Littleton-Moosilauke area, New Hampshire: Geol. Soc. America Bull., v. 48, p. 463-566.

____________, 1956, The geology of New Hampshire, Pt. II, Bedrock geology: New Hampshire State Planning and Development Commission, Concord, N.H.

Eskola, P.E.; 1949, The problem of mantled gneiss domes: Geol. Soc. London Quart. Jour., v. 104, p. 461-476.

Hadley, J.B., 1949, Bedrock geology of the Mt. Grace quadrangle, Massachusetts: U.S. Geol. Survey Quadrangle Map Series.

Lundgren, L.W., 1957, The geology of the Deep River area, Connecticut: Ph. D. thesis, Yale University.

Lundgren, L.W., Snyder, G.L., and Goldsmith, Richard, 1958, A major thrust fault in southeastern Connecticut: Geol. Soc. America Program Abstracts for Annual Meeting, St. Louis (in press).

Mikami, H.M., and Digman, R.E., 1957, The bedrock geology of the Guilford 15-minute quadrangle and a portion of the New Haven quadrangle: Conn. Geol. and Nat. History Survey, Bull. 86.

Rodgers, John, 1952, Absolute ages of radioactive minerals from the Appalachian region: Am. Jour. Sci., v. 250, p. 411-427.

Taliaferro, N.L., 1943, Franciscan-Knoxville problem: Am. Assoc. Petroleum Geol. Bull., v. 27, p. 109-219.

Thompson, J.B., Jr., and Rosenfeld, J.L., 1951, Tectonics of a mantled gneiss dome in southeastern Vermont (abst): Geol. Soc. America Bull., v. 62, p. 1484.

Walton, M.S., 1955, The emplacement of granite: Am. Jour. Sci., v. 253, p. 1-18.

ITINERARY FOR TRIP D

50th Meeting - New England Intercollegiate Geological Conference
Trip Leader - Larry Lundgren
October 12, 1958

STOP 1: (a) Gillette Castle State Park - main parking lot. Typical exposure of interbedded biotite-quartz schist and calc-silicate granofels of the Hebron formation.

(b) Gillette Castle State Park - north of Castle on the east bank of the Connecticut River. Recumbent isoclinal fold in calc-silicate beds surrounded by biotite-quartz schist. Fold is within the Honey Hill fault zone and may have formed during the initial stages of thrusting. Slightly cataclastic calc-silicate beds are well exposed along cliff walk immediately below.

Proceed to Park entrance; turn right and continue to the east landing of the Chester Ferry. Turn right onto dirt road at the ferry landing to enter the grounds of Gillette Castle State Park along the east shore of the Connecticut.

STOP 2: (a) Cliffs immediately below the Castle. Cliff exposures of laminar mylonitic Hebron. Laminar structure offset along ultramylonite-filled shears indicating a late stage of movement in the reverse sense from that of the inferred direction of major movement.

(b) Small quarry immediately south of ferry landing. Cataclastic and mylonitic augen gneisses in contact with mylonitic Hebron. Three-dimensional exposure of layer of rotated pegmatite boudins in cataclastic gneiss, which lies immediately above the Honey Hill fault.

Return to cars and board the ferry. (If you back out of the dirt road you will be facing west and thus can board the ferry with a minimum of maneuvering.) Cross the Connecticut on the ferry (25 cents for car and driver, 5 cents for each passenger), and proceed southwest on Ferry Road across Rt. 9 and along Rt. 148. Turn right 0.25 miles west of Rt. 9 and proceed to point immediately north of Hearse Hill Cemetery.

STOP 3: Southwest end of Story Hill. Minor fold in porphyroclastic augen gneiss immediately above the Honey Hill fault. The sense of movement indicated by this fold is the same as that indicated by every minor fold in this structural knot (see Fig.2), and these folds apparently are reliable guides to the major structure. The overlying Hebron formation behaves in the same way on a large scale, and it is at this point that it is abruptly pinched into the Chester syncline.

(3a) Slightly cataclastic gneisses with an extraordinarily well developed banding are well displayed in a series of quarries along the east limb of the Chester syncline. One of these quarries will be visited if time permits.

Return to cars and proceed to the village of Chester. Turn west along Rt. 148 and proceed as far as Bochim Hill Road. Turn south along Bochim Hill Road to a point on the road just west of hill 240 (Deep River quadrangle).

STOP 4: Corner of Cockaponset State Forest. Condensed section across the Pequot Swamp formation on the west limb of the Chester syncline. Here the characteristic association of basal Di-Hbld amphibolite, garnetiferous biotite-quartz schist and gneiss, and binary schist is displayed. The binary schist is the Cremation Hill schist member, which locally contains sillimanite in association with muscovite. This assemblage (Bi-Ms-Q-Pl-Gt-(Sill)) is typical of this unit below the second-sillimanite isograd. Higher-grade equivalents of these units will be seen later.

Return to cars and proceed southeastward to Rt. 9, and follow Rt. 9 south to Kelsey Hill Rd. (Essex quadrangle). Turn right (west) onto Kelsey Hill Road. Rt. 9 runs along the east side of the keel of Hebron formation lying along the axis of the Chester syncline. Kelsey Hill Road takes you across this syncline just south of the second-sillimanite isograd, which lies along the boundary between the Deep River and Essex quadrangles. Proceed westward along Kelsey Hill Rd. for 0.5 mile.

STOP 5: North side of Kelsey Hill Rd. Discordant pegmatite cutting well bedded Hebron calc-silicate granofels. Pegmatites are particularly abundant along the narrow belt of Hebron lying along the axis of the Chester syncline, but they generally appear as concordant lenses.

Proceed westward on Kelsey Hill Rd. to the Valley Regional High School for lunch. Milk and ice cream available here but nothing else. After lunch proceed west on Kelsey Hill Rd. to Rt. 80. Turn right (north) on Rt. 80; follow 80 west to small roadside picnic area on north side of Rt. 80 adjacent to the Deep River town dump.

STOP 6: Short stop to be made if time permits. Extremely coarse anthophyllite rock in banded Pl-Q-Bi gneiss of the Middletown fm.

Proceed west to Stevenstown Rd. (Rt. 145) at the west edge of the Essex quad. and proceed south along 145 to the interchange over the Connecticut Turnpike.

STOP 7: Connecticut Turnpike exit to Rt. 145. The cuts in the exits and entrances and along the Turnpike itself display the association of amphibolite, biotite-quartz schist, and sillimanitic schist characteristic of the Pequot Swamp formation. Pale-pink spessartite-quartz-cummingtonite granulite is well exposed here also. These rocks are the stratigraphic equivalent of the rocks seen at STOP 4, but are at a higher metamorphic grade. Here Orthoclase and Sillimanite are common and may be regarded as the high-grade equivalent of muscovite (+ quartz). Part of the abundant pegmatite is regarded as a product of the dehydration of muscovite.

Proceed eastward along the Connecticut Turnpike to the next exit east. Cuts along the turnpike exhibit highly contorted amphibolite and gneiss along the axis of the Chester syncline. Exit onto Rt. 153, and park in the parking area at this exit.

STOP 8: Roadcut and natural outcrops in well banded amphibolite in which extensive boudinage has occurred. Three-dimensional exposure of one boudin. Please do not damage. Note pegmatite filling in the neck area of the boudins.

Proceed east along Connecticut Turnpike (here the Turnpike follows the axis of the Chester syncline and runs nearly parallel with the strike of the Hebron fm.). Long road cut on the north side of Beacon Hill (south side of Turnpike) displays Hebron biotite-quartz schist spotted with large poikiloblastic garnet). Cross the Baldwin Bridge (10 cent toll) and take exit immediately east of bridge. Turn north on Rt. 156 and proceed north to the village of Hamburg. Take first left north of Hamburg (Old Hamburg Rd.) and proceed westward on Joshuatown Rd. to the south end of Mt. Archer south of Candlewood Ledges.

STOP 9: (a) Southeast of Ledges are outcrops of crumpled quartzite, amphibolite, and biotite gneiss (Plainfield ?) lying along the bottom of a syncline pinched against the south side of the dome.

(b) Candlewood Ledges. Top displays glacially polished outcrops of crumpled biotite granite gneiss and alaskitic granite forming the core of the Selden Neck dome. Glacial chatter marks are well displayed. End of trip.

New England Intercollegiate Geological Conference, 50th Annual Meeting

TRIP E: Triassic border fault and associated sedimentary rocks.

Leader: John Rodgers, Yale University, with aid of Gordon P. Eaton, Wesleyan University.

Trip starts at Church and High Streets, Middletown, the southeast corner of the Wesleyan University campus, at 8:45 a.m. on Sunday, 12 October 1958.

0.0 Proceed southward on High Street.
0.5 Continue southward (now Highland Ave.).
1.3 Intersection with Conn. Route 17; bear right uphill.
1.8 Intersection with Conn. Route 155; continue straight ahead on 17.
2.2 Turn obliquely left off Route 17 onto Coleman Road.
3.2 Intersection; keep ahead (slightly to right) on paved road.
3.4 Turn left into dairy barnyard and park.

STOP 1. Conglomerate high in Portland formation. In addition to phyllitic schist, like but lower grade than the schist exposed to the east across the border fault, there are pebbles of rhyolite (unknown to east) and basalt (known to east in dikes).

3.6 Start back on paved road.
3.8 Bear right on unpaved road (Kelsey Road).
3.9 Bear right, still on unpaved road (Kelsey Road).
4.5 Turn sharp right onto Arbutus Street (paved).
5.3 Turn left off Arbutus Street onto unpaved road.

SLOW: the outcrops along this road show first a dip of 15-20 degrees and then gradually increasing dips; also some suggestion of increasing coarseness eastward. At about 5.9 STOP 2. Coarse conglomerate or breccia dipping about 60 degree eastward. Valley in front is fault-line valley and hills beyond are crystalline rocks of Eastern Highlands. Proceed on unpaved road.

6.0 Turn right on Millbrook Road (paved), and follow fault-line valley (valley of Sumner Brook).
6.5 Fault is now about 200 feet to east.
6.9 Entering Durham town and Durham quadrangle (see Conn. Geol. Survey Bull. 86).
7.1 Bear right on Johnson or Maiden Lane. Road is now nearly on fault.
7.4 Outcrops of Triassic on right.
7.9 Straight across crossroads. Just beyond road turns away from fault.
10.2 Durham village. Turn left onto Route 17.
10.6 Outcrops of cross-bedded sandstone on bank over stream 500 feet to right; slabs of dark sandy shale in roadbank on north side of stream. Proceed on Route 17.
11.1 Bear right on Route 17.
11.3 Bear left on Route 77.
11.4 Outcrops of coarse conglomerate on either side of road. Basalt pebbles have been found here.
12.3 Here road again enters fault-line valley (Coginchaug River). On right across meadow is quarry in basalt, probably part of Hampden lava flow. It is somewhat brecciated and was called a volcanic vent by Foye.
13.4 Road runs just east of a small hill of crystalline rock; fault lies to west in open valley.
13.6 Enter town of Guilford. Outcrops across valley to right are probably Talcott lava flow. Holyoke flow, dipping south, makes prominent scarp ahead (fire tower on Bluff Head, part of Totoket Mountain).
15.4 Just after passing through gap between Totoket Mountain (Holyoke flow) and Broomstick Ledges (crystalline rocks), park at entrance to small quarry on right.

STOP 3. Low outcrops on left side of road are crystalline rock (Collins Hill schist). Quarry is in basalt of Holyoke flow, but exposes large block of phyllitic schist (lower grade than rocks to east) engulfed in flow.

15.4 Proceed on Route 77 for 0.3 mi.
15.7 Park in wide sight-line cut.

STOP 4. Sight-line cut is floored by crystalline rocks, which also appear, very badly brecciated and altered low in south end of cut. Main part of cut is badly brecciated and altered basalt of Holyoke flow. Contact between dips 55 degrees west. For full description, based on exposure when fresh, see Digman, R. E., 1950, An exposure of the Triassic eastern border fault in Connecticut: Am. Jour. Sci., v. 248, p. 37-45. (Conn. Geol. Survey Misc. Ser. 2)
15.7 Proceed on Route 77 for 0.8 mi.
16.5 Park along road.

STOP 5. To south, Hampden lava flow dipping south. To north fanglomerate at top of East Berlin formation (cf. rock in same stratigraphic position in type locality of the formation on Route 72, seen on Trip B on Saturday). Across Lake Quonnipaug, large outcrops of crystalline rocks (Collins Hill schist and pegmatite).
16.5 Proceed on Route 77.
16.9 Coarse fanglomerate on right, now in lower part of Portland formation.
17.7 Hampden lava flow, now dipping east, crops out on hill to right. Fault underlies valley to left, and crystalline rocks (with a dike of Triassic basalt) underlie hills beyond.
18.2 Enter Guilford quadrangle.
18.6 Hampden lava flow, again dipping south, crops out in road cut just beyond side road on right.
19.0 Fanglomerate in lower Portland formation in bank on right just short of side road. At this point the fault angles to the right; the road leaves it and turns into the crystalline rocks, which are exposed in the road cut on the next rise.
19.7 Dike of Triassic basalt crosses road; best seen in knobs on either side.
19.8 Intersection. Turn right on Conn. Route 80.
20.0 Basalt exposed in road cut which cuts diagonally across dike.
21.1 Enter town of North Branford.
21.5 Road reenters fault-line valley, here rather broad. Enter Branford quadrangle.
22.3 Fanglomerate in cuts and blocks on right of road. This is in East Berlin formation, as Hampden flow is cut off by fault before road returns to it.
22.9 Center of North Branford; traffic light. Bear left on second road to left, Conn. Route 139. Hill to right of Route 80 is roughly dip slope on Holyoke lava flow, dipping east (south end of Totoket Mountain).
23.4 and beyond. View to right (northwest) between scarps of Holyoke flow facing each other across an "anticline" perpendicular to the border fault (which cuts off both ridges; abrupt end of western ridge is prominent). Road proceeds into crystalline rocks (Collins Hill and Middletown formations).
24.4 Road crosses Triassic dike again.
24.6 Enter town of Branford.
24.9 Cross New Haven trap rock railroad, connecting quarry in Holyoke flow at south end of Totoket Mountain with main line of New Haven Railroad and shore.
25.3 Hill on left partly underlain by Triassic dike.
25.5 Intersection. Turn right on U. S. Route 1. Branford granitic gneiss, part of East Haven granite dome, directly ahead.
25.7 Access to Connecticut Turnpike. Continue ahead on U.S. 1.
There are excellent exposures in the access roads of the border phase of the Branford gneiss.

26.6 Bear right with U. S. 1

28.0 Road reenters fault-line valley. Ridge to right is underlain by basalt, probably Talcott lava flow, in a separate fault slice along the border fault, beyond which some of the Portland formation (mainly fanglomerate) is preserved.

28.5 Intersection. Follow U. S. 1, under railroad underpass and up hill to right, turning away from fault into Triassic basin.

29.3 and beyond. Ridge ahead is Saltonstall Ridge, Holyoke lava flow dipping east. This ridge is continuous northeastward to the abrupt end seen at 24.4.

30.3 Enter town of East Haven.
Note road cut on right beyond; we will come back to it.

30.5 Turn right into narrow road and proceed till all cars are off U. S. 1; park.

STOP 6. Return to road cut in U. S. 1. The ridge above is underlain by the Holyoke flow, but the flow is offset to the east by a cross fault, and the sediments in the road cut are in the upper part of the Shuttle Meadow formation beneath, which here contains considerable fine conglomerate. The cross fault can be located very closely on the upper part of the exposure.

30.5 Proceed on narrow road to T.

30.6 Turn left at T onto Saltonstall Place, return to U. S. 1, and turn left onto its farther lane. If instead one turns right at T and proceeds to end of street, one can approach cuts along New Haven Railroad and Connecticut Turnpike that show cross faulting, more complex than that seen at Stop 6, but producing a similar offset in Saltonstall Ridge.

30.8 Turn back to right onto Conn. Route 142. From this point, follow signs leading to Trolley Museum.

31.1 East Haven green on right; turn left with Route 142 at far corner of green.

31.2 Turn left off Route 142 around back side of green.

31.2 Southeast corner of green; continue ahead (bearing slightly right on River Street.

31.5 End of street; turn left into parking lot.
Proceed to Trolley Stop and board next trolley (fare 35¢). Trolley line crosses Farm River into town of Branford, proceeds through Trolley Museum and past end of low ridge underlain by Talcott flow, then approaches and runs along foot of Beacon Hill, the continuation of Saltonstall Ridge south of the offset at U. S. 1 (seen at Stop 6). Ask conductor to let you off where line swings around south end of this ridge, or travel to end and walk back (0.1-0.2 mi).

STOP 7. The end of Beacon Ridge is the point where the Holyoke lava flow is cut off by the Triassic border fault. The flow itself can be seen in the quarry in the southeast corner of the ridge, and coarse conglomerate is well exposed on its southwest face, in the same beds as those seen as fine conglomerate and sandstone at Stop 6 on U. S. 1, less than a mile north. The low hill across the trolley line is underlain by Lighthouse granite gneiss in the East Haven gneiss dome; it is strongly silicified close to the fault.

When you are through, hail a trolley and return to your car. You can return to U. S. 1 as you came or, if you are headed west, turn left into the center of East Haven at point 31.1 above and follow Connecticut Turnpike signs. One saves a 25¢ toll on the Turnpike by entering it from U. S. 1 in East Haven if going west and in Branford if going east.

NOTE: The trolleys run only on Sunday afternoons (and sometimes Saturday afternoons) during the season when people may be expected to come ride them for an outing. If you take this trip at another time, you can either walk the tracks for 0.7 mi to reach Stop 7, or you can follow the itinerary below:

At 31.2 on the above log, continue straight on Route 142.

31.9 Bear left with Route 142. To left across marsh, Beacon Hill (Holyoke flow) is visible, ending abruptly at the fault. Ahead, the low hills are made of Lighthouse granite gneiss in the East Haven gneiss dome; the road crosses the fault and enters these at about 32.3.

33.0 At foot of short but steep hill, where Route 142 turns right, turn sharp left off it.

33.3 End of street; turn left and park at open space, beyond house on right close to corner. The butt end of Beacon Hill is facing you, with the fault at its foot (quarry is visible). Cross foot bridge at tidal dam over Farm River (into town of Branford), bear right across marsh and then turn left on higher ground, with exposures of granite, much of it strongly silicified. Proceed to trolley line and STOP 7.

LEGEND

POLITICAL SUBDIVISIONS

State line
County line
Town line

Approximate populations of cities and towns

Over 50,000
25,000 to 50,000
10,000 to 25,000
5,000 to 10,000
2,500 to 5,000
1,000 to 2,500
500 to 1,000
Under 500

TRANSPORTATION

Parkways, expressways and divided highways
Other paved routes
Surfaced connecting roads
Unimproved connections
U. S. route numbers
State route numbers
Parkway or expressway traffic interchanges
R. R. and passenger station
Hiking trails

MISCELLANEOUS

Forest Fire lookout towers
Airports
Heliports
Seaplane bases
Toll bridges
Ferries
2500 Elevations

GEOLOGICAL EXPLANATION

TRIASSIC ROCKS

Newark Group

T̄R d	Triassic intrusive rocks
T̄R p	Portland arkose
T̄R m	Meriden formation
T̄R mha	Hampden lava member
T̄R mu	Upper sedimentary member
T̄R mho	Holyoke lava member
T̄R ml	Lower sedimentary member
T̄R mta	Talcott lava member
T̄R n	New Haven arkose

Geologic contact
Fault
Possible fault
× × × Silicified rock along late fault
Granite bodies in Hartland and Waramaug formations

PRE-TRIASSIC ROCKS

Western Connecticut

bk	Brookfield diorite gneiss
br	Bristol gneiss
cm	Canaan Mountain schist
co	Collinsville gneiss
db	Danbury granite gneiss
fd	Fordham gneiss
gg	Gneiss domes in Granby
gx	Gneiss complex of the Highlands
hg	Hornblende gneiss
hr	Harrison gneiss
ht + gr	Hartland formation and associated granitoid gneiss
in	Inwood marble
lt	Litchfield mafic intrusives
mf	Milford chlorite schist
mh	Manhattan formation
ng	Nonewaug granite
or	Orange phyllite
pp	Prospect gneiss
pq	Poughquag quartzite
rx	Roxbury granite gneiss
sl	Salisbury schist
st	Stockbridge marble
ts	The Straits schist member of Hartland formation
wb	Waterbury gneiss
wg	Waramaug formation
wm	Woodville marble

Eastern Connecticut

bm	Brimfield schist
bn	Branford granitic gneiss in East Haven granitic body
bo	Bolton schist
cb	Canterbury granitic gneiss
cl	Clinton granitic gneiss
ef	Eastford granitic gneiss
gb	Gabbro in Somers and Tolland
gl	Glastonbury gneiss
hb	Hebron gneiss (including Scotland, Woodstock, and Pomfret units)
hd	Haddam gneiss
lb	Lebanon gabbro
lh	Lighthouse granitic gneiss in East Haven granitic body
ly	Lyme granitic gneiss
mi	Middletown gneiss
mm	Mamacoke gneiss
mo	Monson gneiss
mr	Maromas granitic gneiss
pf	Plainfield quartz schist
pr	Preston gabbro
pu	Putnam gneiss
rd	Redstone granite
sc	Stony Creek granitic gneiss in East Haven granitic body
sn	Stonington gneiss
sr	Sterling granitic gneiss
wi	Willimantic gneiss
wt	Westerly granite

PRELIMINARY
Geological Map of CONNECTICUT
1956

CONNECTICUT GEOLOGICAL AND NATURAL HISTORY SURVEY

Compiled by

John Rodgers
Robert M. Gates
Eugene N. Cameron
Reuben J. Ross, Jr.

SCALE OF MILES

ONE INCH EQUALS ABOUT 4 MILES
1: 253,440

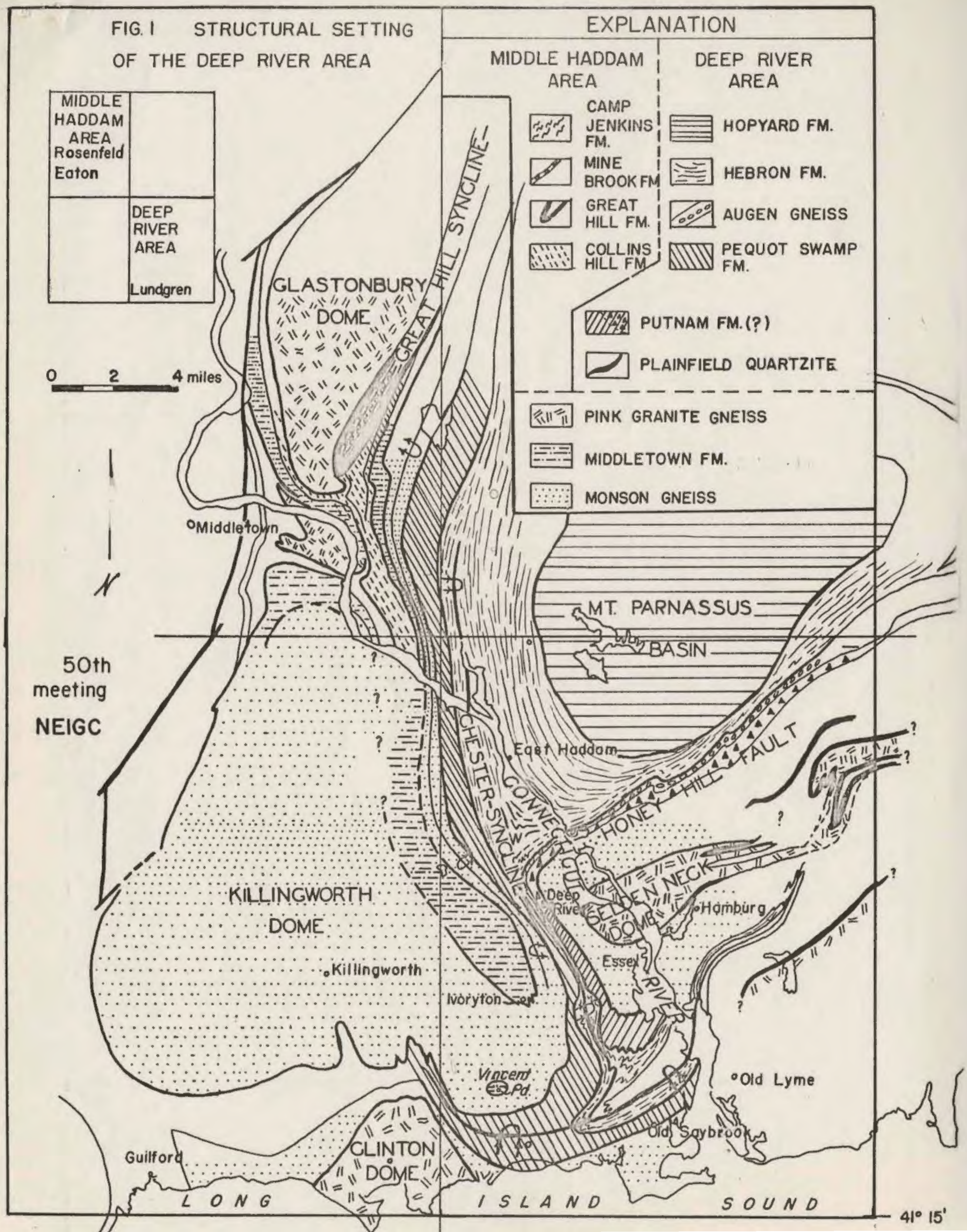
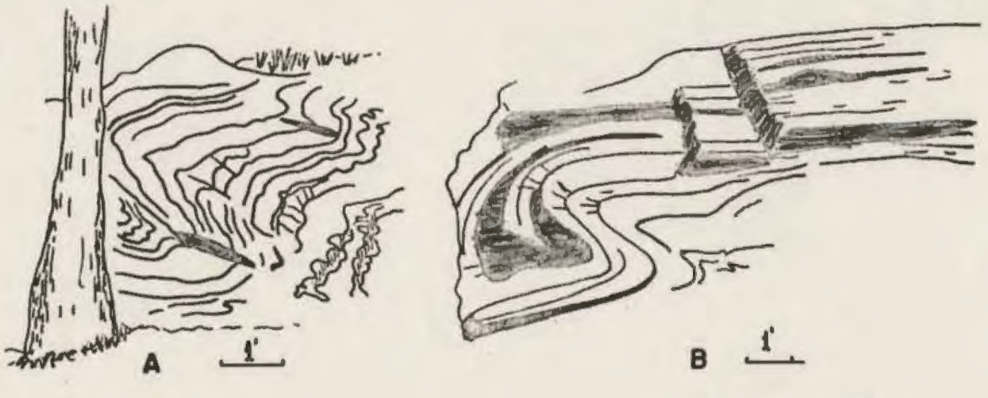


FIG. I STRUCTURAL SETTING OF THE DEEP RIVER AREA



A. Folds in Hebron calc-silicate granofels

B. Fold in cataclastic augen gneiss

C. Fold in cataclastic Putnam gneiss

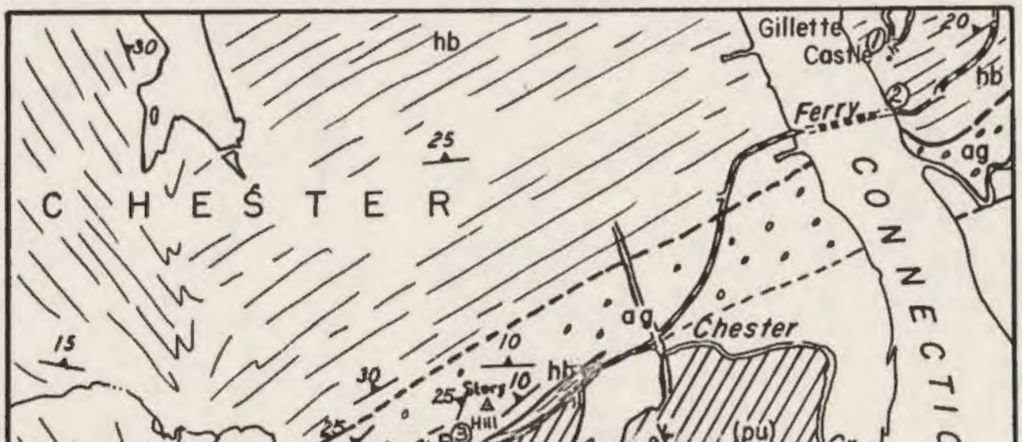


Fig. 2 Map of the structural knot around Chester with sketches of representative minor folds (A, B, and C). Route of trip.

0 1/4 1/2 mile

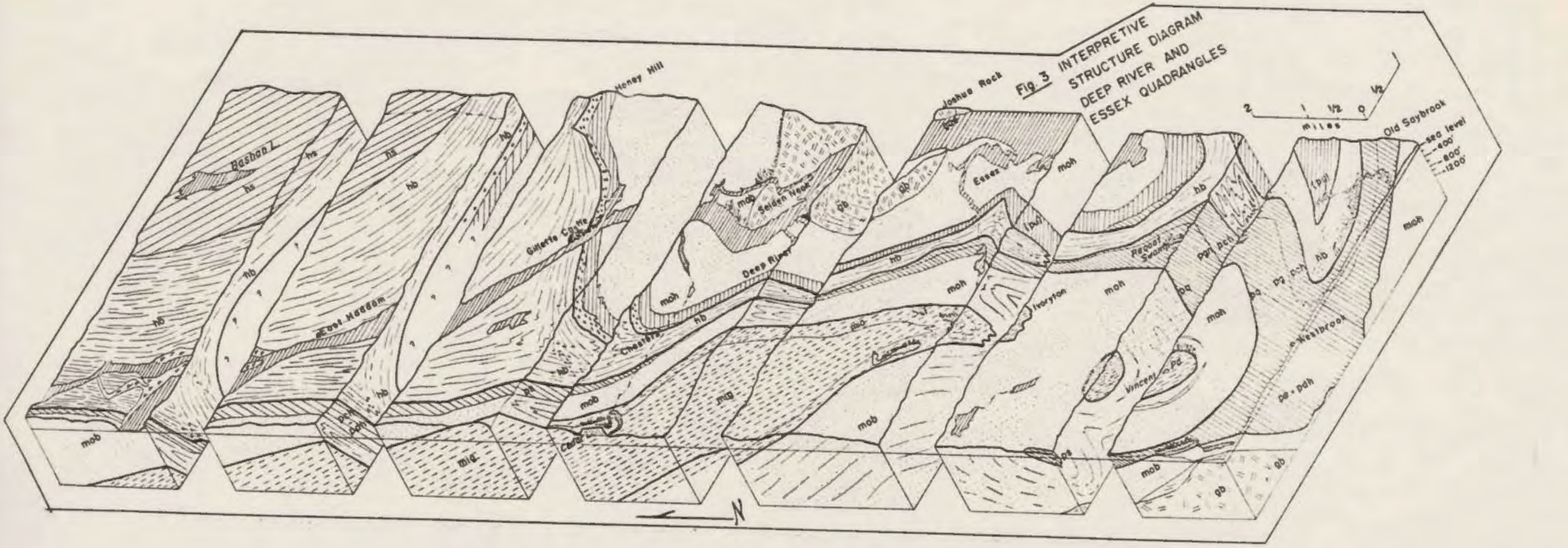


Fig. 3 INTERPRETIVE STRUCTURE DIAGRAM DEEP RIVER AND ESSEX QUADRANGLES