1-1-1982

The Bonemill Brook Fault Eastern Connecticut

Pease, M.H. Jr.

P2-1

The Bonemill Brook Fault
Eastern Connecticut

by

M. H. Pease, Jr.
Waterville Valley, N.H.

INTRODUCTION

The crystalline rocks of eastern Connecticut (fig. 1) include parts of four regional geologic terranes. These are: 1) The Glastonbury-Killingworth domes, 2) the Merrimack eugeosyncline, 3) the Putnam-Nashoba thrust belt and 4) the Southeast New England platform. Each terrane occurs in a separate structural block, and no stratigraphic correlation has yet been possible between them.

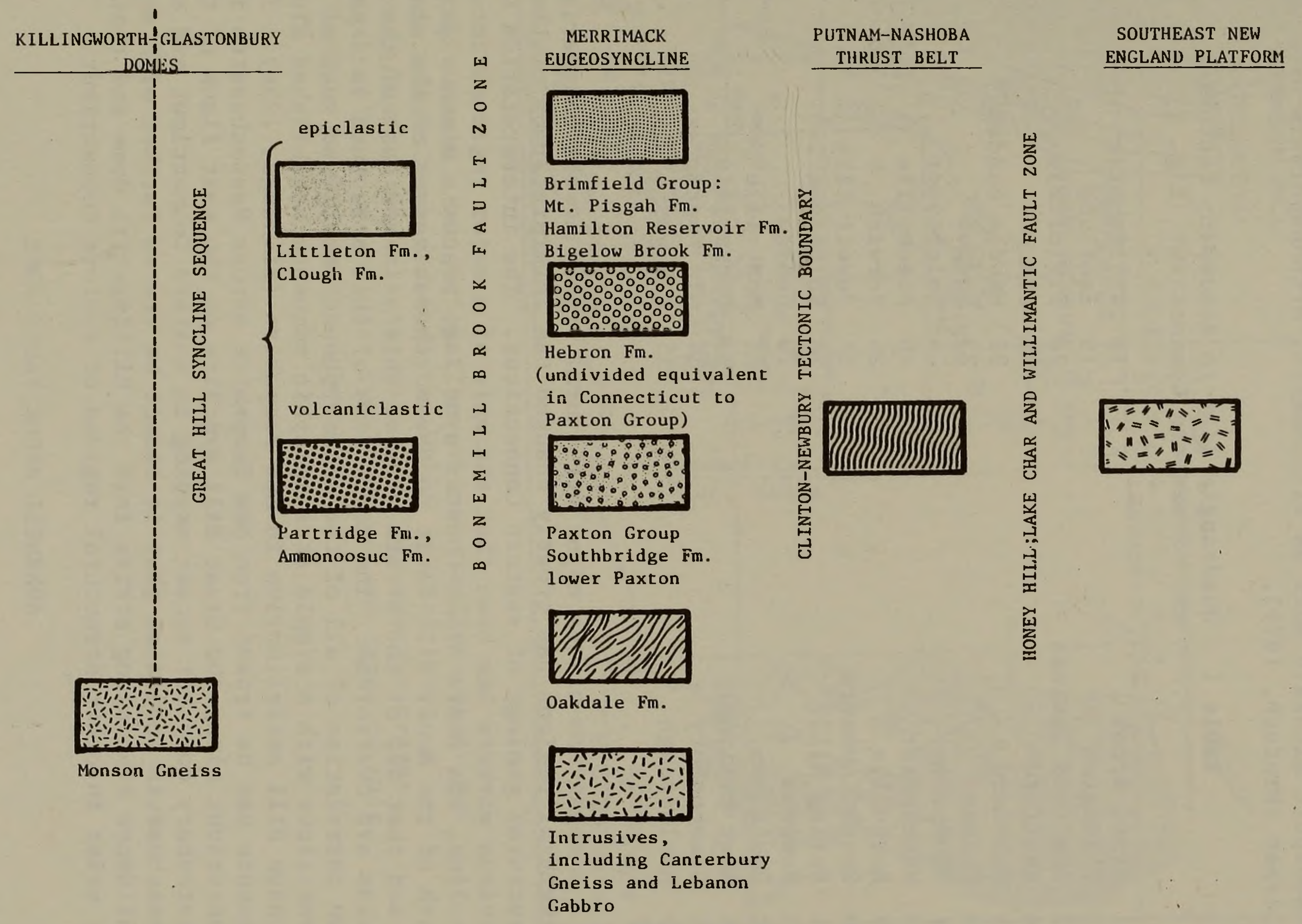
The boundaries are major fault zones along which regional tectonic transport has occurred. The Glastonbury-Killingworth domes structural region is separated on the east from the Merrimack eugeosyncline region along the steeply dipping northerly-striking Bonemill Brook fault zone. The eugeosynclinal rocks have overridden on the east rocks of the Putnam-Nashoba thrust belt at the structural position of the Clinton-Newbury fault zone of Massachusetts, this position being occupied in Connecticut almost entirely by the Canterbury Gneiss (see fig. 1 of field trip P-6 for the location of the Clinton-Newbury fault zone in Massachusetts). The western boundary of the Southeast New England platform is overlain by the Putnam-Nashoba thrust belt along the Lake Char fault, and the platform rocks south of the Honey Hill fault zone are overridden by eugeosynclinal rocks as well as thrust belt rocks.

The Willimantic dome (fig. 1) is a structural window in the core of which are exposed rocks correlated with those of the Southeast New England platform separated by the Willimantic fault from rocks correlated with the Putnam-Nashoba thrust belt. The Willimantic fault therefore lies in the structural position of both the Honey Hill and Lake Char faults warped across the dome. The Canterbury Gneiss again occupies the structural position of the Clinton-Newbury fault zone separating thrust belt rocks from structurally higher eugeosynclinal rocks.

It is becoming recognized that movement along these major breaks must have originally occurred at high metamorphic grade under extreme conditions of differential stress that produced ductile movement rather than brittle fracture. Features characteristic of brittle faults such as fault breccia, gouge, and closely spaced fractures are not present except where there has been reactivation under conditions of much lower pressure and temperature. Instead one finds conditions approaching melting that result in ductile attenuation and alignment of stratigraphic elements in the plane of transport. This commonly is accompanied by the development of migmatite and even gneissoid pegmatite and under slightly lower conditions of temperature and

Fig. 1. Geologic sketch map of eastern Connecticut showing the distribution of the four major structural regions and the tectonic boundaries between them. X-3: Field trip stop locations; heaviest lines separate the major structural regions; medium lines represent faults; thin lines are intrusive contacts. The 7½-minute quadrangles are numbered and listed in Table 2.

EXPLANATION



pressure, the formation of mylonite, mylonite schist and blastomylonite. Deformation appears to have continued over a significant period of geologic time along a pressure/temperature gradient of decreasing metamorphic grade. One finds such retrograde features as quartz-feldspar rodding and chlorite slickensides in fault zones where the major tectonic transport has apparently taken place under strain of sufficient intensity to develop high grade metamorphic minerals such as sillimanite, orthoamphibole or even potassium feldspar (Wintsch, 1979).

Table 1 Quadrangle list to accompany tectonic map of eastern Connecticut (fig. 1)

1	Broad Brook	18	Willimantic
2	Ellington	19	Scotland
3	Stafford Springs	20	Plainfield
4	Westford	21	Oneco
5	Eastford	22	Middle Haddam
6	Putnam	23	Moodus
7	Thompson	24	Colchester
8	Manchester	25	Fitchville
9	Rockville	26	Norwich
10	South Coventry	27	Jewett City
11	Spring Hill	28	Voluntown
12	Hampton	29	Haddam
13	Danielson	32	Montville
14	East Killingly	33	Uncasville
15	Glastonbury	34	Old Mystic
16	Marlborough	35	Ashaway
17	Columbia		

Recognition of the major structural breaks at the boundaries of structural regions has greatly changed the interpretation of the structural geology of eastern Connecticut. The interpretation of previous workers has been that the axis of a major regional recumbent syncline, the Hunts Brook-Chester syncline, traces a sinuous path from south of the Honey Hill fault to the northeast corner of the state (fig. 2) and that all of the strata west of this axis and east of the Monson Gneiss are overturned. The continuity of this structure is dependent upon correlation of all of the metamorphosed stratified rock of eastern Connecticut with a simple stratigraphic sequence established along the Bronson Hill anticlinorium in New Hampshire (Billings, 1956). This sequence can be traced from New Hampshire across Massachusetts into Connecticut along the Great Hill syncline on the east flank of the Glastonbury dome but recent mapping in eastern Connecticut and adjacent Massachusetts indicates that it cannot be traced farther with any confidence even along strike into the Killingworth dome and that it does not exist in other structural regions of eastern Connecticut.

BONEMILL BROOK FAULT ZONE

The purpose of this field trip is to examine one of these major tectonic boundaries, the Bonemill Brook fault zone (fig. 1). The fault

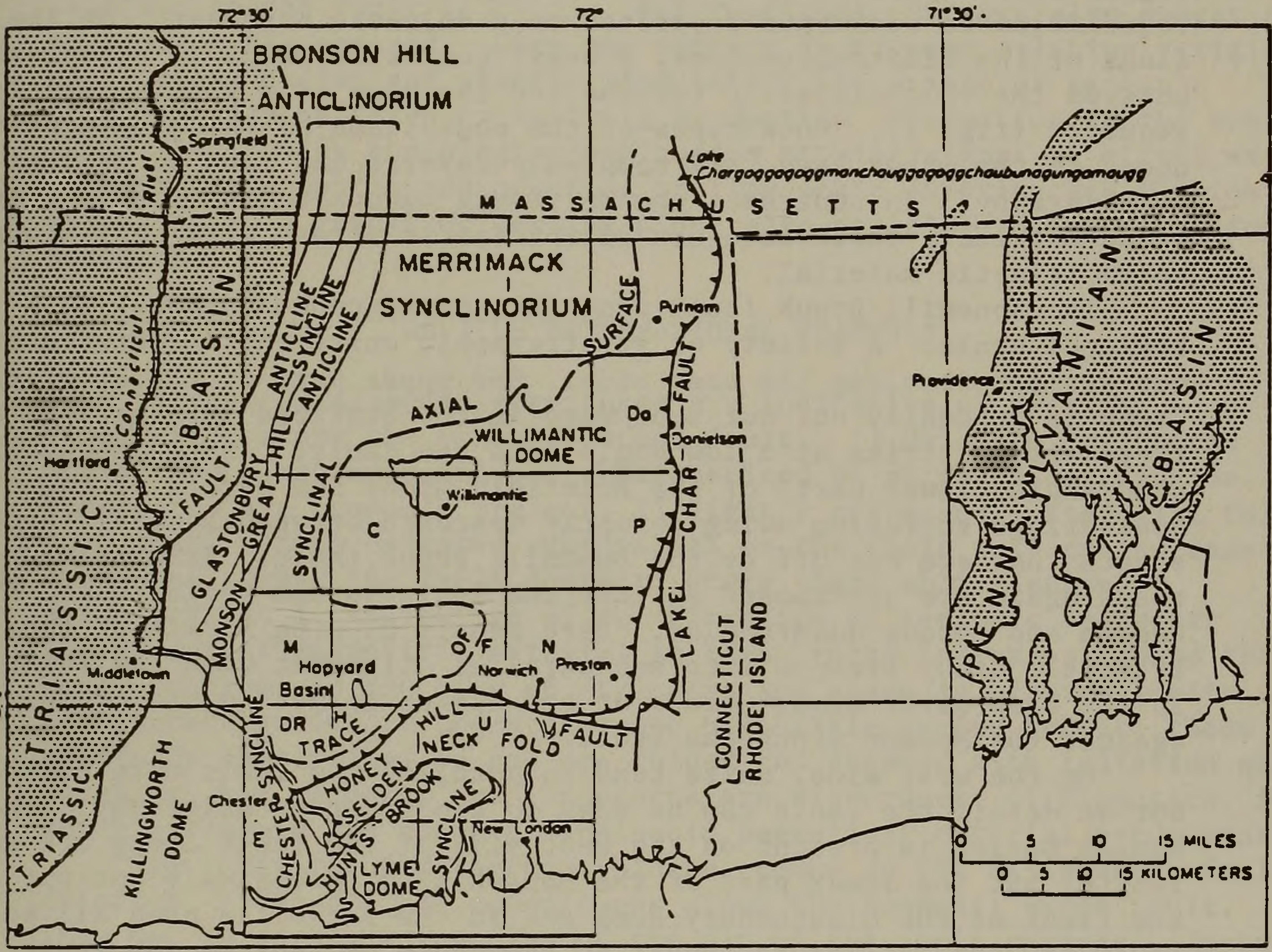


Figure 2. Generalized geologic map of eastern Connecticut and adjacent areas of Dixon and Lundgren (1968) showing their interpretation of the regional geology. Includes the traces of the Hunts Brook and Chester synclines and the trace of this axial surface across eastern Connecticut.

will be seen at several locations along its trace. The evidence for its existence will be reviewed and the difficulty in recognizing it in outcrop will be shown. The fault zone, trending in a generally northerly direction, separates the Glastonbury-Killingworth dome structural region from the Merrimack eugeosynclinal structural region. Rocks in the domal region were deposited as an island arc sequence of relatively thin volcaniclastic sediments deposited on a volcanic basement. On the east flank of the Glastonbury dome, a basal quartzite marks an unconformity between the volcaniclastic terrane and the base of a younger epiclastic sequence (fig. 1). Rock types on the east flank of the Killingworth dome, on the other hand, are complexly layered and lack a coherent stratigraphy. In contrast, the Merrimack eugeosynclinal basin consists of an extremely thick sequence of epiclastic strata with only minor volcaniclastic material.

The Bonemill Brook fault zone is a conspicuous boundary on a regional scale. A variety of stratigraphic units and structures are cut out against it along its east side. The upper part of the Brimfield Group is gradually cut out southward in the Stafford Springs area where these strata strike at a low angle into the fault. In the Rockville quadrangle, lower parts of the Brimfield Group and strata of the Southbridge Formation swing abruptly westward between several thrust sheets that are cut off by the Bonemill Brook fault. Brimfield Group rocks again are juxtaposed against the fault in the Marlborough, Middle Haddam and Moodus quadrangles. Here gently dipping strata of the Brimfield Group steepen into sub-parallel alignment with the fault zone. In the Deep River area, strata of the Hebron Formation are crumpled up against the Monson along the fault.

On the west side, units tend to parallel the fault more closely, but in detail the fault can be seen to cross-cut stratigraphy. The Monson Gneiss is present on the west side of the fault along its entire length, but the lower part of the Monson is progressively cut out along the flank of the Glastonbury dome and in the Rockville area all but the upper few tens of meters appear to have been cut out by the fault. Along the flank of the Killingworth dome, the Monson appears to be represented by a narrow belt of cataclastically deformed plagioclase gneiss caught up entirely within the fault zone.

The striking change in the grain of the bedrock geology across the Bonemill Brook fault zone permits easy recognition of the zone on most regional maps derived by remote sensing methods. The location of this tectonic boundary shows up well on the small scale aeromagnetic and gravity maps that include eastern Connecticut and the fault trace can be delineated along much of its trace on small scale air-photos and LANDSAT imagery.

Despite the fact that the Bonemill Brook fault is well defined on a regional scale, the zone itself may be difficult to identify as a major tectonic boundary when mapped in the field. Foliation and compositional layering on both sides of the fault commonly are warped into subparallel alignment with the fault. The contact itself is rarely exposed and where it can be located to within a narrow zone of cover, the outcrops on either side may not be conspicuously deformed (STOP 3). Cataclastic deformation, whether ductile or brittle, is not everywhere apparent and is not necessarily strongest right at the tectonic boundary (STOP 6).

Various features within the Bonemill Brook fault zone do show, however, that this is a fault boundary. The near parallel alignment of units on opposite sides of the fault may at first suggest a conformable stratigraphic contact, but the stratigraphic units do impinge at a low angle against the fault. Lithologies change as the fault is followed along strike, and attitudes across the boundary locally show an angular relation to the fault (STOP 3). Deformational features also appear to be sporadicaly exposed. When the contact is between relatively rigid plagioclase gneiss and plastic mica schist the strain of tectonic transport may be taken up entirely by ductile deformation in the schist (STOP 1), leaving the plagioclase gneiss showing almost no effect except perhaps for a subtle accentuation of fine scale layering and fluxion streaking as a result of bedding plane slip parallel to the direction of movement.

DUCTILE DEFORMATIONAL FEATURES

Various small scale structures are indicative of ductile deformation along the Bonemill Brook fault. 1) Mylonite, mylonitic schist and blastomylonite all characterized by streaked out fluxion structures are commonly present. 2) Tightly appressed intrafolial folds with axial planes oriented subparallel to the fault surface increase in abundance toward the fault contact; where these show a sense of asymmetry, it is indicative of the direction of tectonic transport. 3) The amount of pegmatitic material in these rocks increases toward the fault, whether in the form of stringers and augen in blastomylonite or as discrete gneissoid pegmatites and pegmatitic gneiss bodies; these lie generally subparallel to and are folded and sheared with foliation and layering, but in detail most contacts are discordant. 4) Migmatite, in which stringers and augen of gneissoid pegmatitic material predominate.

The large rotated tectonic blocks common on the Willamantic fault (Wintsch, 1979) are not conspicuous along the Bonemill Brook fault. This may be partly a function of the dip of the fault surface. Tectonic blocks might be more likely to tear loose and rotate along a near horizontal thrust surface whereas shearing will be more likely along high-angle faults.

CONCLUSIONS

A thick sequence of eugeosynclinal strata that covers a large part of northeastern and east-central New England has been jammed into eastern Connecticut. This sequence of the Merrimack eugeosynclinal structural region has been progressively cut out southward along the Bonemill Brook fault zone, against the volcanic rock of the Glastonbury and Killingworth domes. This large scale tectonic transport evidently occurred at high metamorphic grade. The strain at these high temperature and pressure conditions approached plastic flow. Stratigraphic units are warped into subparallel alignment along the fault zone, and lithologic contacts at many places along the fault zone are tightly bonded, showing little evidence of major tectonic transport.

The sense of regional transport appears to be right-lateral with the east side (eugeosynclinal rocks) moved south. The east side also appears to have moved up relative to the west side, considering that rocks of the highest metamorphic grade are restricted to the east side of the fault.

The orientation of asymmetric folds and mineral lineation can be interpreted to support this regional sense of transport, but the amount of dip-slip relative to strike-slip movement is not known and appears to vary along the fault. The total amount of transport also is not known, but, considering the juxtaposition of rock formed in such contrasting environmental conditions, the order of magnitude may be 10s to 100s of kilometers.

The principal deformation along the Bonemill Brook fault zone probably occurred during the Acadian orogeny because rocks above the Silurian unconformity in the Great Hill syncline have been squeezed into a narrow belt subparallel to the fault.

ROAD LOG

MAPS- 7.5-minute quadrangle maps covered in this road log are the Stafford Springs (STOPS 1 and 2), Rockville (STOP 3), Middle Haddam (STOPS 4 and 5) and Deep River (STOPS 6 and 7).

Road log begins in the parking lot at the McDonald's Restaurant in the Stafford Shoppers Plaza on Rt. 190 between Stafford Springs and West Stafford. To get to Stafford Springs from Storrs take Rt. 195 northwest to Rt. 32. Follow Rt. 32 north to Stafford Springs.

	0.0	Start road log facing west on Rt 190 at shopping plaza.
0.2	0.2	Turn right on road to Orcutts.
1.0	0.8	Turn left just past railroad crossing.
1.5	0.5	Turn left (north) on Rt. 32.
2.4	0.9	Turn right (east) on Sunset Road.
3.1	0.7	Culvert under road at Steep Gutter Brook. Turn cars around facing west.

STOP 1 - Steep Gutter Brook.

The trace of the Bonemill Brook fault in this area follows a prominent topographic trough trending about N 10° E, crossing the road at the culvert. Pelitic schist and gneiss of the Hamilton Reservoir Formation of the Brimfield Group lies east of the trough, felsic gneiss and amphibolite of the Monson Gneiss lies west of it. The trace of the fault in these exposures is pinned down to within 20 m by outcrops on opposite sides of the trough.

Features to note in these exposures are:

1. Subparallel alignment with the fault of foliation and layering in both formations (a common feature

along many ductile fault zones).

2. Conspicuous cataclastic textures in the pelitic schists of the Hamilton Reservoir Formation and lack of conclusive evidence for cataclastic deformation of the Monson. Is deformation entirely absorbed by the more pelitic rocks, or is the thinly parted felsic gneiss of the Monson near the contact wholly or in part the result of ductile attenuation?

3. Down dip lineation of sillimanite and quartz feldspar rodding in the Hamilton Reservoir Formation and similar down dip mineral lineation of amphiboles and biotite in the Monson. What does this say about the direction of movement on the fault?

Examine the outcrops of Hamilton Reservoir Formation on the north side of the road east of the fault. Note the mylonitic fluxion structure in these rocks - best observed on joints normal to foliation. Note the down-dip quartz-feldspar rodding and similar aligned orientation of sillimanite needles. Many sillimanite needles are kinked with apparent crinkle axes approximately parallel to lineation.

Walk west and then south along the west side of the trough to outcrops of Monson Gneiss, mostly layered felsic gneiss with amphibolite. The amphibolite outcrop in the stone wall appears to be a steeply plunging fold nose but a unique orientation of axis or axial plane could not be determined. Walk to the southeast corner of the field behind the house. Note that the attitude of foliation and layering along the ridge is about N 10° E parallel to the trough. In an outcrop just below the break in slope, the distribution and alignment of brown amphibole on a north-facing joint surface faintly outlines asymmetric folds with an east-side-moving-up sense of movement. Is ductile deformation responsible for the formation of the brown amphibole? Is the sense of the folds indicative of sense of movement on the fault?

Walk upstream for about 50 m to a low outcrop of thinly layered plagioclase gneiss exposed beneath a maple tree almost at stream level. This appears to be the nearest outcrop of Monson Gneiss to the Hamilton Reservoir schist exposed on the ridge to the east. The N 30° E strike of foliation and layering suggests that the exposure might have been detached and rotated slightly, but it appears to be essentially in place. The gneiss is fine-grained with closely spaced planar partings. Down-dip quartz-feldspar streaking is evident and brown amphibole needles are aligned with a persistent down-dip lineation except for fan-shaped aggregates on some foliation surfaces. How much of the fabric in this rock is the result of ductile deformation? Why is the brown amphibole present instead of black hornblende that is characteristic of the Monson?

Return to cars along the ridge of pelite schist east of the trough. Note the same fabrics and orientation of structures along this ridge as is exposed in the road cuts.
Return to Rt. 32.

3.8	0.7	Turn left (south) at Rt. 32.
6.1	2.3	Pass intersection with Rt. 190. Continue on 32 to Stafford Springs.
7.1	2.0	Center of Stafford Springs. Turn right (south) on Rt. 32.
8.9	1.8	Bridge over Willimantic River. Turn right immediately beyond bridge.
9.2	0.3	Entrance to Girl Scout Camp - Turn right and drive along north side of Sweetheart Lake to parking lot just beyond west end of lake.

STOP 2 Bonemill Brook (fig. 3)

In this area for which the Bonemill Brook fault was named the fault again separates the Hamilton Reservoir Formation on the east from the Monson Gneiss. Rocks of the Hamilton Reservoir Formation are overturned on the west flank of the Mt. Pisgah syncline. The Mt. Pisgah Formation, the youngest formation of the Brimfield Group, lies along the axis of the syncline. The Furnace Brook fault follows the syncline and cuts out the trace of the axis here (fig. 3). The entire syncline itself is cut out to the south against the Bonemill Brook fault and the Hollow Brook fault, a splay from the Bonemill Brook.

Exposures are sparse close to the fault boundary in Bonemill Brook valley. We will look at four localities. Walk along the woods road to an area with picnic tables. Climb the hill on the north to a hiking trail blazed and marked by the symbol for Sweet Heart Camp. A very small low outcrop on the way to this trail shows the best cataclastic textures, but it is difficult to find. Follow the trail north to about the 500 ft. contour. The

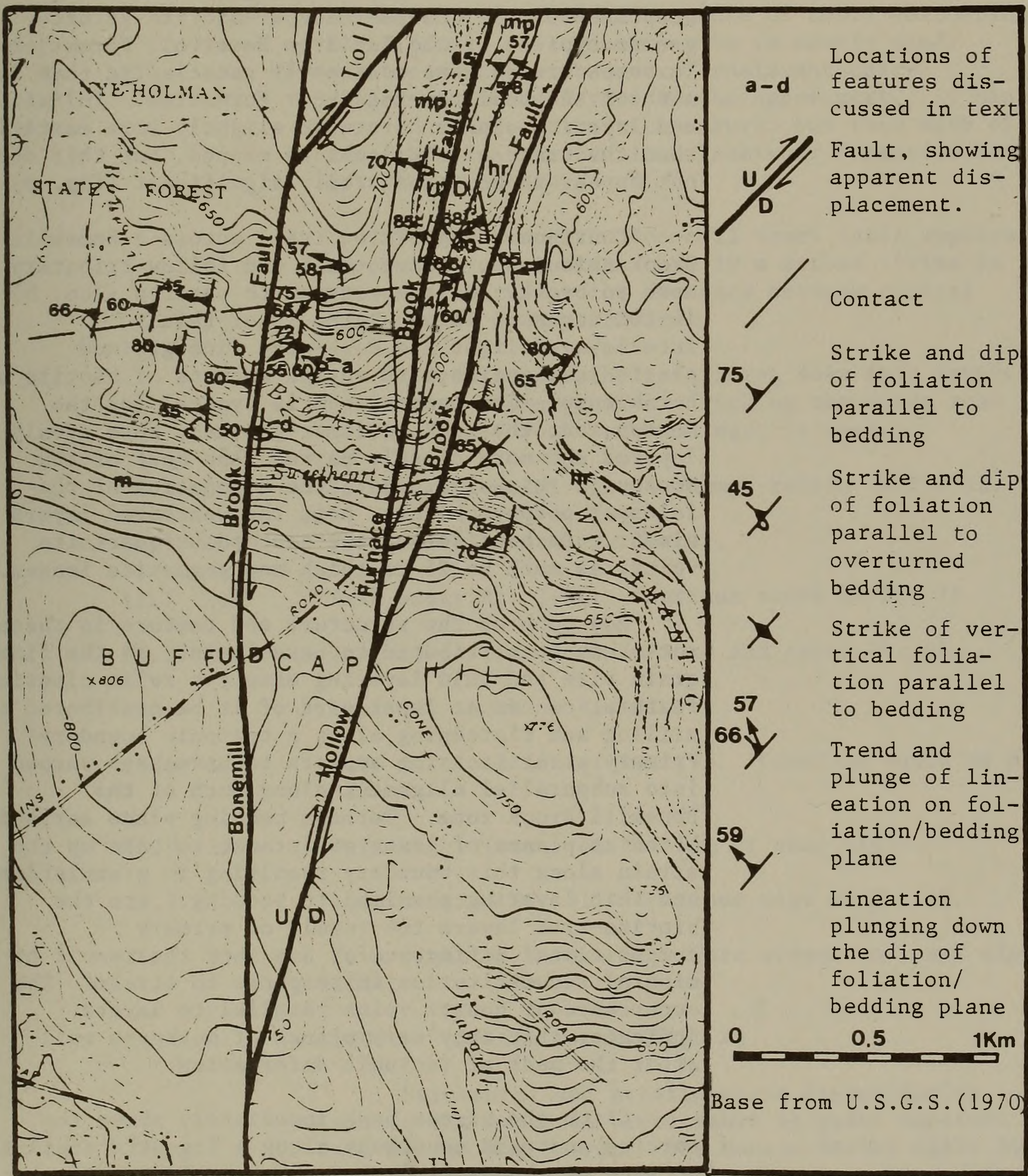


Figure 3 - Stop 2. Geology of the Bonemill Brook fault zone in the Bonemill Brook area, Stafford Springs quadrangle, Connecticut.

outcrop (loc. a) is above the trail to the east and about 150 m from the picnic area.

The rock is rusty-weathering sillimanite-graphite-bearing quartz-feldspar-biotite-garnet-gneiss typical of the Hamilton Reservoir Formation. Textures are no more noticeably cataclastic than in most of the Hamilton Reservoir Formation. Foliation and layering appear to strike slightly more easterly than the trace of the fault as mapped, but this does not appear to be structurally significant (fig. 3).

Continue along hiking trail across a Bonemill Brook tributary. Leave trail and follow tributary down to brook. Walk up stream to outcrop (loc. b) in the stream. This outcrop is of thinly interlayered light-and dark-gray fine-grained plagioclase gneiss with varied amounts of biotite and hornblende. The composition is typical for the Monson, but the rock is finer-grained, more evenly layered and more closely parted than most of the Monson in this area. Note the elongation of the feldspar porphyroblasts, note the weathered layers of almost pure biotite and the concordant quartzite veins, as much as 25 cm thick and pegmatite lenses.

How much of the structure and texture in these rocks can be attributed to cataclasis? Is the fine grain size and thin layering simply a relic clastic feature, or can at least part of it be attributed to milling and flattening along a tectonic boundary? Primary stratification appears to have been warped into subparallel alignment along much of the Bonemill Brook zone. Perhaps bedding plane surfaces acted as planes of least resistance to take up the strain along this boundary resulting in granulation and thin layering parallel to bedding. Are the biotite-rich layers the result of primary compositional difference or are they the result of a mineral reconstitution in response to stress? The occurrence of quartz veins parallel to layers indicates that they were planes of weakness well after the peak of tectonic deformation.

Climb the stream bank immediately above the outcrop and walk southwest along a log-skid trail to an area of abundant blocks of Monson Gneiss (loc. c). The largest block here appears to be attached or nearly attached bedrock sticking up above the float. Its attitude of N 5° E 65° W would indicate this. This rock, about 150 m west of the fault trace, is more typical of the Monson Gneiss, coarser grained and less thinly parted than that exposed in the stream.

Walk eastward, maintaining approximately the same contour, for about 200 m, to the first ravine. Follow this down to an exposure of rusty weathering schist (loc. d). The exposure is mostly sandy pelitic schist with several resistant calc-silicate-bearing layers in the upper part. It has an apparent blastomylonitic texture, but then much of the schist in the Hamilton Reservoir Formation has a mylonitic texture.

The trace of the Bonemill Brook fault appears to be pinned down to less than 50 m across strike in this area although the distance between control outcrops is perhaps 200 m.

Return to cars by continuing down this ravine and across a swampy area. Pick up the woods road north of the brook and walk east to cars.

9.2	0.3	Starting from entrance to camp, return to Rt. 32.
0.5	0.3	Turn right (south) on Rt. 32.
11.7	2.2	Pass under Rt. I-86. Continue south on Rt. 32.
13.2	1.5	Veer to left at fork in road and cross Rt. 44. Continue south on Rt. 32.
16.6	3.4	Pass intersection of Rt. 195. Continue south on Rt. 32.
18.9	2.3	Turn right (west) on Rt. 44A at stop light.
22.7	3.8	Intersection Rt. 31. Continue west on Rt. 32.
26.1	3.4	Turn right at Vernon Rd. Turn around and park along side.

STOP 3 - Bolton Notch (fig. 4).

Structural and stratigraphic discontinuity across the Bonemill Brook fault is quite apparent in the Bolton Notch area. The Monson Gneiss again lies on the west side of the fault, but here less than 10 m of the felsic plagioclase gneiss is exposed beneath layered amphibolite of the Ammonoosuc volcanics. A complete section of the Great Hill syncline sequence striking generally parallel to the strike of the fault is well exposed in roadcuts and along the railroad grades in this area. The sequence

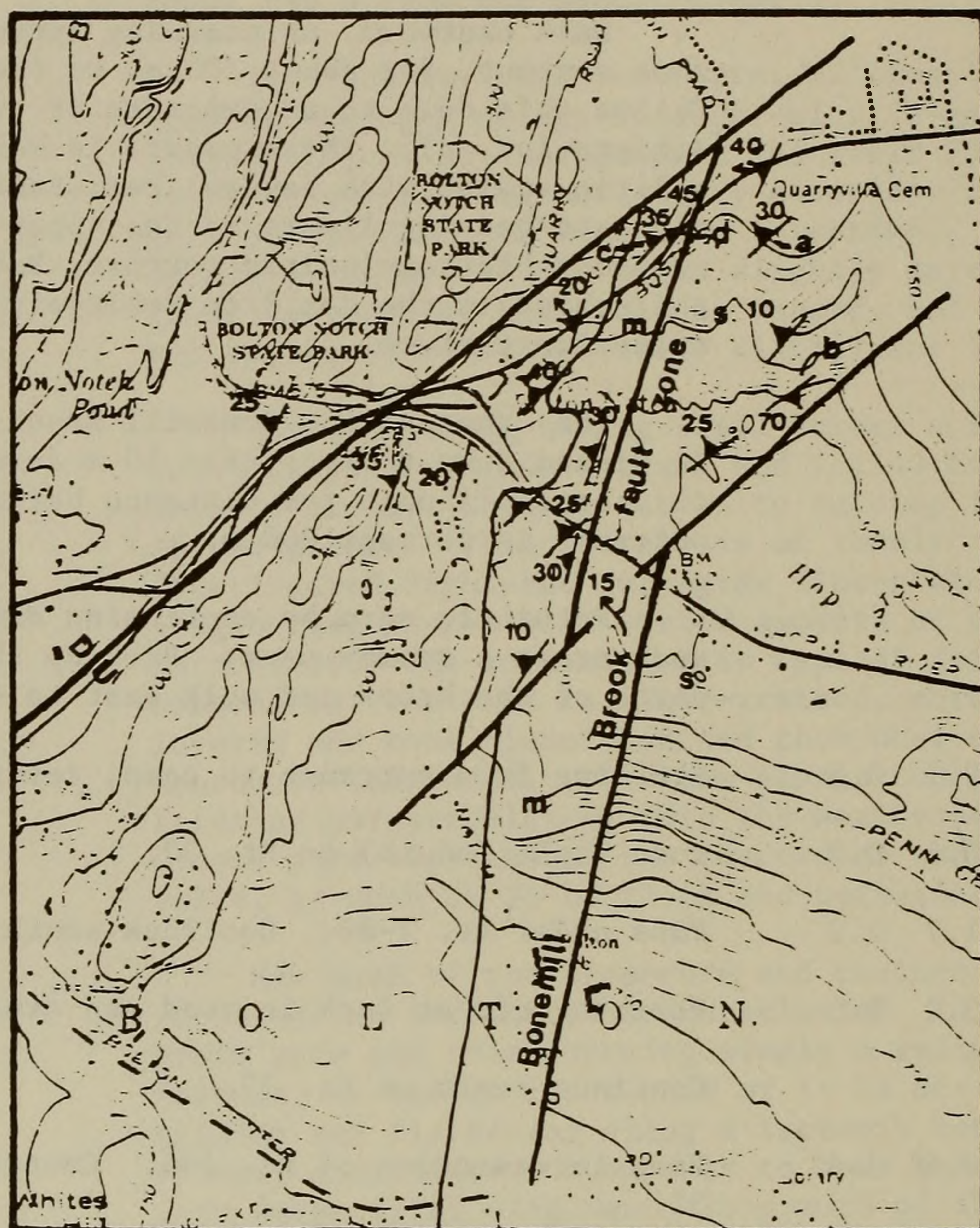


Figure 4 - Stop 3. The trace of the Bonemill Brook fault zone in the vicinity of Bolton Notch, Rockville quadrangle, Connecticut. (See explanation, figure 3.)

above the Monson, including the Ammonoosuc, Partridge, Clough and Littleton Formations is less than 250 m thick. The Southbridge Formation lies east of the fault. The Southbridge is poorly exposed but the strike of slabby layering in a few low outcrops shows a distinct angular relation to the trace of the fault (fig. 4). The Bonemill Brook fault appears to be offset in the Bolton Notch area by at least one northeast-trending high-angle fault (fig. 4). The geologic mapping is incomplete here and additional work is needed along the ridge to the north and south of the notch to determine the presence or absence of similar offset of the Great Hill syncline sequence.

Walk south into the woods across highway Rt. 44A from the junction of Vernon Road. Find low exposures of slabbym, friable, somewhat rusty-weathering, calc-silicate-bearing, granular biotite schist. This is the Southbridge Formation, quite unlike the pelitic rocks of the Hamilton Reservoir Formation exposed against the fault at the previous 2 stops. Note the gentle northwest-dipping rock striking toward the trace of the fault (loc. a). Continue walking due south for about 300 m across a swampy area to the next knobs. A heterogenous assortment of slabby rock typical of the Southbridge is found mostly as float but with some in place; the strike here is also toward the trace of the Bonemill Brook fault. In an outcrop (loc. b) at the break in slope on the south side of this series of knobs, layering dips steeply to the southeast and the strike is turned more easterly. This abrupt steepening of attitude appears to be the result of drag along the northeast-trending fault that is believed to offset the trace of the Bonemill Brook fault farther southwest.

Return to Rt. 44A and walk west to the large outcrop of Monson Geniss exposed north of the road (loc. c). This thickly-layered felsic gneiss is typical of much of the Monson Gneiss exposed to the north. The layering in this outcrop does not look far removed from normal sedimentary stratification. One might expect to see relict sedimentary structures, but no cross bedding or graded bedding has been identified.

Cross the road to the easternmost exposure of felsic gneiss (loc. d). This is a relatively massive, weakly foliated gneiss with little compositional banding or parting parallel to the foliation. It is a quartz-plagioclase gneiss;

the mafic has gone to chlorite and much of the feldspar is pink. Examination of the naturally weathered surface on the back side of this outcrop shows a fairly prominent fluxion streaking of the quartz and feldspar. This outcrop is the closest exposure to the fault and the retrograde mineralization suggests that late movement in this area may have occurred at lower temperatures and pressures than were in effect during the principal movement on the fault.

Return west along Rt. 44A to the rusty schist exposures of the Partridge Formation exposed on the north side of the road. The covered area between the Monson and Partridge presumably is underlain by layered amphibolite of the Ammonoosuc Volcanics that is well exposed around the corner on Rt. 6.

Additional points of interest in the Bolton Notch area are in the canyon behind the shopping center across the highway and on the back side of the 100 ft high northeast-trending knob to the south of the canyon. Among the features to see are a large rotated block of Monson Gneiss, the significance of which has not been determined, a 2 m thick quartzite vein that traverses a southeast-facing exposure at the north end of the knob and lies at the approximate contact between Ammonoosuc amphibolite and overlying rusty Partridge schist, and evenly thinly layered felsic Monson Gneiss less than 10 m thick with some suggestion of catalcastic texture lined up parallel to the trace of the fault.

Drive west on Rt. 44A through Bolton Notch.

27.2	1.0	Bear right off 4-lane highway onto Rt. 6.
28.9	0.8	Turn left at light and drive south on Rt. 85.
30.4	1.6	Turn right where Rt. 85 turns right.
31.2	0.8	Pass road intersection. Continue south on Rt. 85.
35.9	4.1	Turn right (west) onto Rt. 94 where Rt. 85 ends.
36.0	0.1	Turn immediately left (south) on West Street.
37.5	1.5	Turn right (west) onto Martin Road (West Road).
38.6	1.1	Turn left (south) onto Jones Hollow Road.
40.8	2.2	Cross under Rt. 2 overpass.

41.1	0.3	Turn left (southwest).
41.4	0.3	Turn right (south) onto Rt. 66 at stop light.
42.9	1.5	Pass Intersection Saner Road. Continue west on Rt. 66.
45.1	2.2	Enter East Hampton. The next stop is the lunch stop. If you have not brought a lunch you can probably get lunch fixings in town.
45.8	0.7	Turn left (south) on Rt. 196 at light in East Hampton.
46.3	0.5	Stop sign in East Hampton Center.
46.4	0.1	Bear right with Rt. 196.
47.2	0.8	Turn right (west) onto Rt. 16 at stop light.
47.7	0.5	Park cars in side road subparallel to Rt. 16 south, On the left side. This is the lunch stop. We can eat somewhere along the abandoned railroad grade that we will be following.

Walk west to outcrops on either side of Rt. 16.

STOP 4 - East Hampton.

At this locality we shall again cross the Bonemill Brook fault zone. The boundary again is between thinly-layered felsic gneiss and amphibolite of the Monson on the west and rusty-weathering schist and gneiss of the Brimfield Group on the east. The Monson in this area is thinly-layered; it strikes consistently about N 10° W and dips very steeply to the west. Primary layering in the Brimfield Group is difficult to find and appears to be highly contorted by an abundance of gneissoid pegmatite, but the general strike appears to be more easterly and the dip less steep to the west than is true of the Monson. A large block several meters across of banded gneiss in the Brimfield rocks appears to be rotated into the plane of the fault zone in a manner similar to the tectonic blocks along the Willimantic fault described by Wintsch (1979).

Examine the outcrops of Monson Gneiss on both sides of the highway. These outcrops are just west of the trace of the Bonemill Brook fault which trends about S 10° W down the valley on the east. Thinly interlayered felsic plagioclase gneiss and amphibolite with smooth planar parting surfaces again are exposed west of the fault. The layering appears to represent relict stratification in meta-volcaniclastic rocks. No relict primary sedimentary features appear to be present within the layers nor is there any evidence of the cataclastic deformation that might be expected so close to a major fault zone. Is it possible that the strain has been taken up along relict stratification planes, these planes having been accentuated by movement and alignment of mineral grains parallel to them?

Note the isoclinal fold axes plunging steeply to the southwest and the similarily plunging mineral lineation that may be related to movement on the Bonemill Brook fault. These axial planes are believed to be aligned in the plane of the fault surface and movement on the fault to be normal to the plunge. The steep plunge of fold axes and mineral lineation then would indicate that the principal movement is strike-slip with a minor dip-slip component. If the strike slip was right-lateral, the dip-slip would be down on the west side.

Walk north to the railroad grade and turn east. A small low outcrop on the north side of the grade consists of biotite muscovite schist and amphibolite. It belongs to the metavolcaniclastic rocks of the Glastonbury dome, not to the Brimfield Group rocks exposed east of the fault. There is evidence of moderate cataclastic deformation in this outcrop.

Continue along the railroad grade, east along the valley and across the fault to extensive exposures of rusty-weathering, sulfidic, graphitic schist and gneiss of the Brimfield Group. Bedding features are not evident except for a few resistant calc-silicate bearing lenses. Quartz and feldspar in the form of stringers and augen of gneissoid pegmatite several meters thick make up the bulk of the rock in these exposures. Schistosity anastamoses around large bodies of pegmatite and layering is comparably warped. The variable attitudes of foliation, N 45° to 75° E, dipping 25° to 75° W, strike generally more easterly than the regional trend of the fault.

Near the east end of this railroad cut at the north side nearly vertical compositional layering trends about N 15° E through a width of about one meter. This attitude is sharply discordant with adjacent compositional layering and the structure is not apparent in exposures on the south side. This may represent a tectonic block aligned subparallel to

the trace of the Bonemill Brook fault.
Retrace steps along the railroad grade back to cars.

Continue west on this side road.

48.3 0.5 Turn left (south) onto Chestnut Hill Road.

49.3 1.0 Pass old Chestnut Hill Road intersection.

50.2 0.9 Turn around at top of steep hill and park.

STOP 5, Pine Brook.

At this locality outcrops within 75m of each other on opposite sides of the Bonemill Brook fault can be seen. Walk due west. Almost continuous exposures extend from just over the lip of the hill to the base of the steep slope. Gneissoid pegmatite predominates near the top and sills of pegmatitic material are abundant throughout these outcrops. They invade brownish-gray weathering, weakly layered, irregularly foliated sillimanite schist. Fresh exposures of the schist are seen in the excavation for a new house about 200 m to the south off the right side of the road. It is a biotite-muscovite-sillimanite schist with stringers and augen of feldspar and quartz. Foliation is conspicuous, but quite irregular. The dip is essentially vertical and the strike appears to vary from N 40° W to north. A vein quartz layer lies in the plane of foliation. It thins from about a meter at the base to less than 20 cm at the top of the outcrop. No striking evidence of cataclastic deformation can be seen.

The schist at the base of the hill appears to be finer-grained, with thinly-parted intervals as much as 20 cm wide. It is the nearest outcrop to the contact and the attitude is N 20° W near vertical, parallel to the trace of the contact, but no more evidence of cataclastic deformation occurs here than to the east.

Walk due west for about 75 m to a small knob with outcrops of layered light-and medium-gray plagioclase gneiss with amphibolite layers. This is the thinly evenly layered gneiss typical of Monson in most places adjacent to the fault. Again it looks like relict sedimentary bedding.

Surprisingly little obvious deformation is noticeable in rocks so close to a major fault zone. Could a zone of more intense deformation be confined to the narrow covered area between outcrops, or is the abundant pegmatitic material the result of deformation and feldspathization in the fault zone with shearing taking place along folia in the schist?

Climb back up the hill and return to the cars.

Return north on Chestnut Hill Road.

51.1	0.9	Turn right (east) onto Old Chestnut Hill Road.
51.8	0.7	Turn right on Young Street - Rt. 196.
54.7	2.9	Pass intersection Rt. 151 - Continue south on Rt. 196 & 151.
55.1	0.4	Cross Salmon River bridge.
56.4	1.3	Turn right onto Jonesville Road.
57.1	0.7	Turn right onto Rt. 149.
58.3	1.2	Outcrops of relatively undisturbed Hebron Formation on left.
60.9	1.6	Join with Rt. 82 in East Haddam.
61.1	0.2	Cross bridge over Connecticut River.
62.0	0.9	Turn left at stop light onto Rt. 9A at Tylerville.
62.4	0.4	Turn right onto Rt. 82, which connects to Rt. 9.
63.3	0.9	Park cars along right, north, side of road west of large road cuts.

STOP 6, Rt. 82 connector - eastern exposures.

A ductile fault zone, the Cremation Hill fault zone of David London (see Barosh and others - Trip P-7, this guidebook) is well exposed. It lies east of the Bonemill Brook fault zone entirely within the Merrimack eugeosyncline structural region, separating rocks of the Hebron Formation from rocks of the Brimfield Group on the west. These western strata correlate best with the upper part of the Brimfield Group. There may thus be several kilometers of apparent stratigraphic separation across this fault zone. The tectonic boundary that separates the eugeosynclinal rocks from the domal rocks, the Bonemill Brook fault zone, is exposed at STOP 7 about one kilometer to the southwest along this road.

The Cremation Hill fault zone appears to coalesce with the Bonemill Brook fault zone to the south in the Deep River area where the Hebron lies in direct contact with the Monson Gneiss. Both the Hebron and Monson in this area exhibit a cataclastic fabric.

Rock types on either side of and within the Cremation Hill fault zone are well exposed in these roadcuts along the Rt. 82 connector. Minor structures are well displayed. Strata of the Hebron Formation exposed east of the Connecticut River dip gently to moderately westward and are essentially undeformed. On the west side of the river, however, the Hebron has been crumpled by east-over-west compression in a broad zone against the east side of the fault zone. Foliated gneiss and gneissoid pegmatite occurs in this crumpled zone and increases in abundance as the Cremation Hill fault zone is approached.

The fault contact is marked by exposures of migmatitic gneiss with numerous stringers and porphyroblasts of pegmatitic material. The pegmatitic stringers and augen decrease in abundance to the west away from the boundary and the rock becomes more schistose, but most of the schist exposed in road cuts from here to STOP 7 exhibit a distinct blastomylonitic fabric. The migmatization is believed to have been developed as a result of ductile strain along the Cremation Hill fault zone (see Barosh and others, this guide book). This entire belt of blastomylonitic rusty schist and gneiss might be considered a fault slice of Brimfield Group rock caught between the Cremation Hill fault zone and the Bonemill Brook fault zone.

Sillimanite lineations are relatively consistent in the schist between the Cremation Hill and Bonemill Brook fault zones. They plunge 20°-25°, S 5°-30° E. The direction of movement appears to be normal to this lineation. Such a direction of movement would produce a right-lateral component on a near vertical northerly-trending fault. A few isoclinal folds on both sides of the fault observed in plan view also indicate a right-lateral sense of movement. The subhorizontal crinkle fold axes and mineral lineation trend in a N 10° W direction in the Hebron Formation. The sense of asymmetry of these crinkle folds and of large scale folds suggests an east-over-west sense of transport normal to the trace of the fault and to mineral lineation. This is compatible with sillimanite lineation that plunges gently north or south within the migmatite where foliation is near vertical. All of these small scale structures indicate a general movement of east over west with a right-lateral component, with only a minor difference in trend indicated on either side of the fault.

The sense of movement on outcrop scale folds with sheared limbs, that are exposed in the outcrops of Hebron nearest the fault, however, suggest that upper rocks have slid down to the east or possibly have been underthrust to the west. This may represent later movement or the result of adjustments when the asymmetric folds were jammed against the fault.

In order to get a better view of the deformation in the Hebron as the fault zone is approached, it is best to climb to the top of the large road cut on the northwest side. From the top we can see a vertical section in the northwest-facing roadcut exposures (light permitting) and underfoot is exposed the plan view. The Hebron consists of medium-gray, granular biotite schist with 1 to 5 cm thick interlayers that are lighter brownish-gray calc-silicate bearing. Light gray stringers and pods of feldspar and quartz pegmatitic material are conspicuous in the outcrop and bring out the configuration of the layering with which they are folded. The felsic stringers conform in general to the calc-silicate layering, but boundaries do vary and offshoots that cut across the foliation are common.

The dominant structural pattern in the vertical face is of asymmetric folds with amplitudes larger than the height of the outcrop showing east-over-west transport and near vertical western limbs. A prominent crinkle fold pattern is superposed on the large amplitude folds but a consistent sense of asymmetry is not readily apparent. Small scale, near vertical, tight isoclinal folds are commonly shown by calc-silicate layering, but these too show no sense of asymmetry in the vertical face.

In the plan view exposed here on top of the road-cut, the crinkle fold axis has a much more consistent trend than is apparent in the vertical exposure. It is the most persistent structure on the outcrop surface, trending N 5° E to N 20° W and nearly horizontal. Where compositional layering is steeply dipping, the strike is persistently N 10° W indicating that the axes of the crinkle folds are oriented the same as large scale folds Axes of small scale isoclinal folds in the calc-silicate layers also trend about N 10° W and a few show a distinct asymmetry in plan view that indicates the east side has moved south.

Walk back to road level and examine exposures of Hebron in lower outcrops to the west on both sides of the road. Note the large scale asymmetric folds with sheared-off limbs. The apparent sense of asymmetry seems to indicate that the rocks on the west have slid down over rocks to the east.

Note the thick pegmatitic bodies folded with the folds and the increasing amount of syntectonic pegmatitic material incorporated in the rock as the fault contact is approached.

Walk southwest around the corner from the large exposures of pegmatitic gneiss. A knob exposed in the woods here is the nearest outcrop to the Hebron of the Cremation Hill migmatite. It is micaceous migmatite unlike the pegmatitic gneiss of the Hebron. Pavement exposures in the cleared area west of the knob are less quartzo-feldspathic, but are still migmatitic with a strong blastomylonitic fabric. A small asymmetric fold shows a right-lateral east-moving-south sense of transport. The steep dip of the migmatite is exposed in a small trench just south of the pavement outcrop.

Walk across to the northwest side of the road to exposures below the culvert. Layering in the schist here appears to be severely stretched out. Fluxion structure is apparent, but the schist contains few pegmatitic layers. Continue northwest to exposures of blastomylonitic rock just beyond an abandoned paved road. Layers of pegmatitic material make up a large part of this outcrop. The pegmatitic layers are aligned with the foliation in a general sense but cross-cut the foliation in detail.

Return to cars.

Drive southwest along the connector road. Observe outcrops of blastomylonitic schist of the Brimfield Group on either side of the highway.

64.4 1.1 Park cars on the northwest side of highway before the large outcrop.

STOP 7 - Rt 82 Connector at north ramp Rt. 9.

The Bonemill Brook fault zone, forming the tectonic boundary between the Monson plagioclase gneiss and amphibolite of the Killingworth dome structural region and the Brimfield rusty-weathering biotite-sillimanite schist of the Merrimack eugeosynclinal structural region, is exposed in this outcrop. The contact appears to be a simple welded metamorphic contact, but cataclastic deformation does exist along it and it is quite possible that the strain of tectonic dislocation is spread out across the entire width of the blastomylonitic schist that lies between this contact and the Cremation Hill fault zone. The narrow belt of Monson on the east flank of the Killingworth dome also shows the effects of compression and stretching parallel to the Bonemill Brook fault. Plagioclase gneiss with thinly-laminated and attenuated layering and curviplanar foliation surfaces can be seen in all the exposures of Monson along Rt. 9 south of this exit.

The contact is exposed for several meters along the face of this outcrop. The surface is broadly warped in a near vertical plane. Tightly appressed isoclinal folds with axial planes subparallel to the contact are present on both sides of the contact. The schist on the east is exceedingly contorted over the width of the outcrop. Contorted stringers of pegmatitic material are abundant. The felsic Monson Gneiss is tightly folded for about 25 cm on the west side of the contact. Tongues of schist appear to be folded into the gneiss at the contact. The orientation of the axes and sense of asymmetry of the folds is not at all consistent along the fault boundary, but there is some indication of right-lateral, east-side-moving-south movement as on the Cremation Hill fault.

Climb to the top of the roadcut from the northeast end. Use extreme caution in walking on this exposure. A non-layered, dark gray biotite granulite is exposed in the first low outcrops. This lithology commonly is interlayered with rusty weathering biotite-sillimanite schist in the upper part of the Hamilton Reservoir Formation of the Brimfield Group in the Stafford Springs area.

At the top of the outcrop, highly contorted schist with pegmatite stringers is exposed. Walk southwest along the outcrop to where the contact forms the cliff face. Tightly appressed, exceedingly irregular folds have disrupted the compositional layering in felsic Monson Gneiss right along the edge of the cliff face. Rusty schist of the Brimfield is plastered along the cliff face. An isoclinal fold with a subhorizontal axis is exposed in the schist half way down the face. The contact is quite sharp, but tongues of schist appear to be squeezed into the gneiss along sheared folds.

The felsic gneiss grades into a migmaetitic schist west of the contact. This in turn grades into an interval of rusty granular mica schist. This is not the Brimfield lithology. It appears to be a cataclastically deformed migmatitic rock. The schist grades westward into more felsic gneiss which is in sharp contact with banded amphibolite.

Walk southwest down the outcrop across felsic gneiss, amphibolite, pegmatite and granite gneiss. Return to car along the base of the outcrop. Look for the fault surface. It begins about the end of the bushes. END OF FIELD TRIP. The best way to return to Storrs, CT, is north on Routes 9, I-84, I-86 and 195. Rt. 9 east on I-84 and I-86 to Rt. 195 and thence north to Storrs.

REFERENCES

Barosh, P.J., London, David, and deBoer, Jelle, 1982, Structural geology of the Moodus seismic area, south-central Connecticut: in New England Intercoll. Geol. Conf., 74th Ann. Mtg., Univ. of Connecticut; Connecticut Geol. and Nat. History Survey Field Trip P-7.

Billings, M.P., 1956, Bedrock geology: part 2 of The geology of New Hampshire, State Plan. Devel. Comm., 203 p.

Dixon, H.R., and Lundgren, L.W., Jr., 1968, Structure of eastern Connecticut: in Zen, E-an, White, W.S., Hadley, J.B., and Thompson, J.B., Jr., Studies of Appalachian geology-northern and maritime: New York, Interscience Publishers, p. 219-229.

Wintsch, R.P., 1979, The Willimantic fault; a ductile fault in eastern Connecticut: American Jour. Sci., v. 279., p. 367-393.