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The Norumbega Fault Zone between Bath and Freedom, Maine

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THE NORUMBEGA FAULT ZONE BETWEEN BATH AND FREEDOM, MAINE

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INTRODUCTION

The purpose of this trip is to examine the characteristics of several shear zones which display predominantly cataclastic textures and which collectively comprise the Norumbega Fault Zone (see Fig. 1). These structures cut two distinct lithic sequences which were earlier juxtaposed by faulting. They are the polydeformed and metamorphosed Siluro-Devonian flysch sequence of the Kearsarge-Central Maine (or Merrimack) Synclinorium and the rocks of the Coastal Lithotectonic Block (Osberg, et al., 1985) which in the area of immediate concern on this trip include the Casco Bay Group of Bodine (1965) and Hussey (1985). The contact between the two is a west dipping pre-metamorphic thrust. The location of a strong west dipping seismic reflector (Stewart, et al. 1986) coincides with that of the mapped thrust.

The trip will also examine lithologies representative of both of the above-named sequences and consider aspects of their deformational and metamorphic histories. Figure 1 is based upon field mapping conducted by the author during the last seven years with the support of the Maine Geological Survey.

Stratigraphy

The Cushing and Cape Elizabeth Formations of the Casco Bay Group outcrop primarily, but not exclusively, east of the Norumbega Fault Zone in southwestern Maine. The Cushing Formation is a predominantly metavolcanic sequence which includes quartzo-feldspathic gneisses, which are interpreted to represent felsic metavolcanics, as well as amphibolites and hornblende bearing biotite granofels which represent intermediate to mafic meta-volcanics. Metasedimentary rocks are intercalated with these lithologies. They include thin marble and calc-silicate units, rusty weathering sulfidic and graphitic schists, and metapelite. The Cushing Formation is unconformably overlain by the Cape Elizabeth Formation which includes psammitic to occasionally pelitic metasedimentary rocks. Bedding style and relict sedimentary structures, notably graded bedding, point to turbidity current deposition of the sediments of the Cape Elizabeth Formation. The persistence along strike of certain lithologies stratigraphically immediately below the Cape Elizabeth and the complete absence of basal conglomerates indicate that the unconformable relationship is a subtle - and doubtless local - one. The Cape Elizabeth and Cushing Formations appear to have shared a common deformational and metamorphic history.

structure sections:

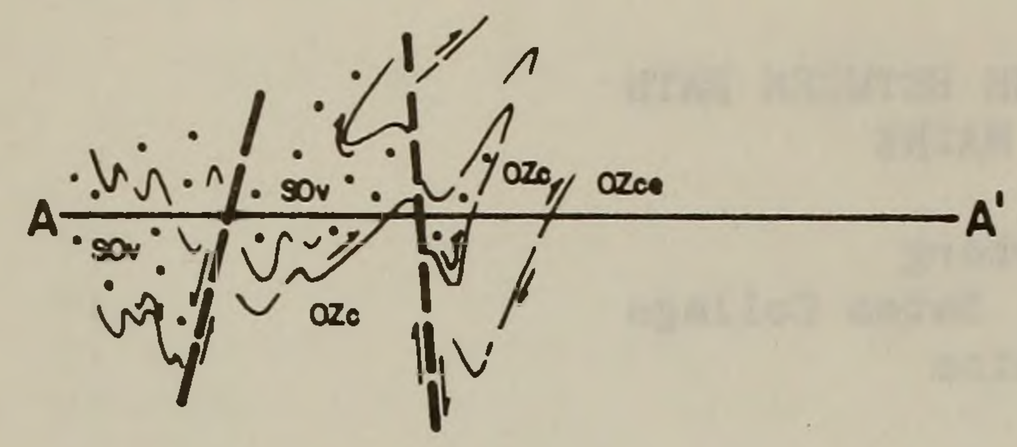


Figure 1. Geologic map of a portion of the Norumbega Fault Zone, southwestern Maine

Explanation

intrusive rocks –

Dg — granite and granodiorite

Dqd — quartz diorite

stratigraphic units –

SOv — VASSALBORO FORMATION
calcareous metasandstone and metasiltstone (calc-silicate granofels and biotite schist)

OZce — CAPE ELIZABETH FORMATION
quartz-biotite-muscovite schist and quartzite

OZc — CUSHING FORMATION
felsic and mafic metavolcanics with associated volcaniclastic metasediments

symbols –

lithologic contact

trace of older fold axis

trace of younger fold axis ...with direction of plunge and dip of limbs if known

trace of pre-metamorphic fault, teeth on upper plate

trace of post-metamorphic fault

AA' — structure section

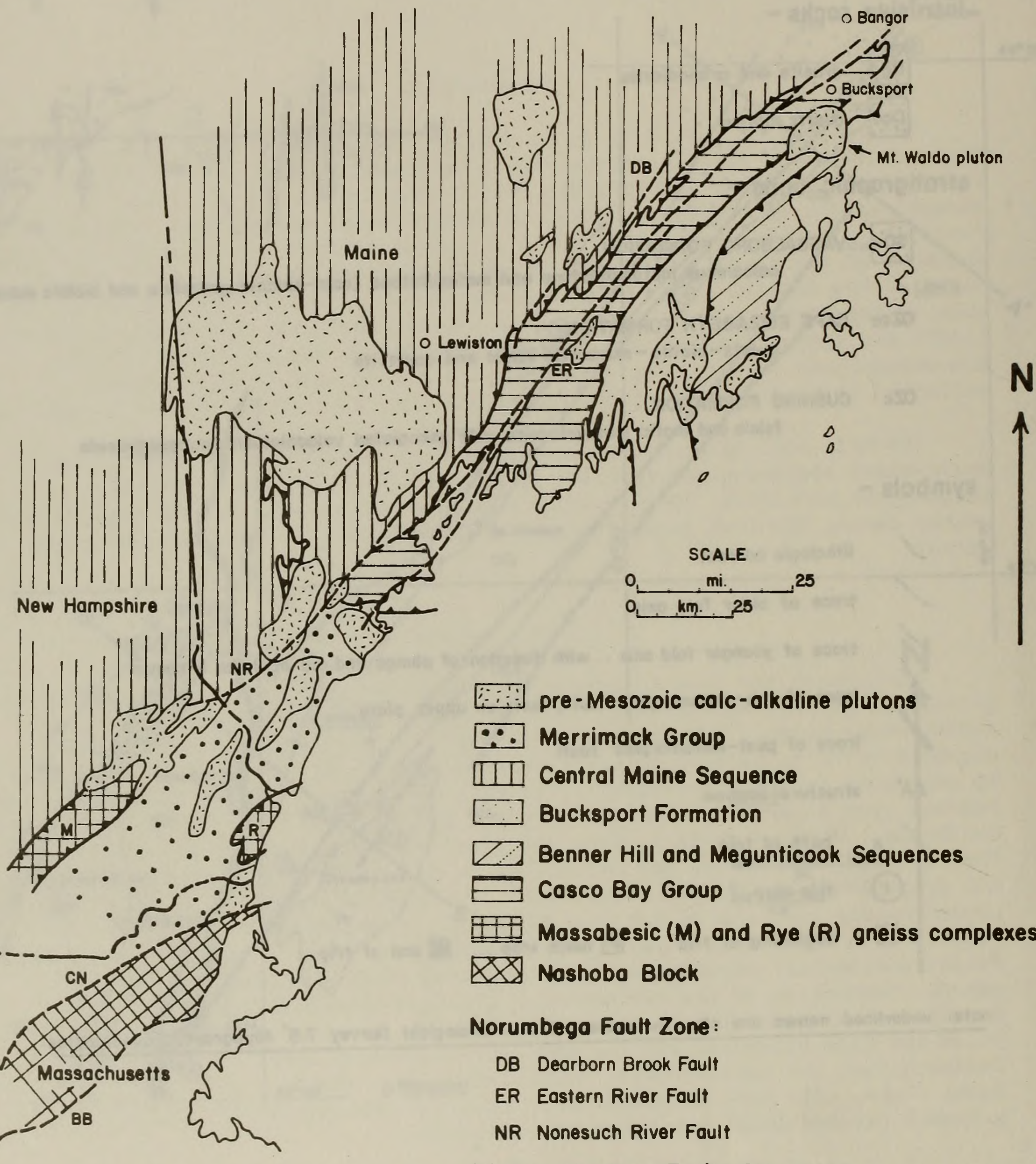
path of trip

① — trip stop

☐ beginning of trip .... ◪ lunch stop .... ■ end of trip

note: underlined names are also the names of U.S. Geological Survey 7.5' topographic quadrangles

Figure 2. Generalized geologic map of southwestern Maine and adjacent areas (modified from Hussey, 1985)



Faults everywhere separate the Central Maine and Casco Bay sequences. The former are, on the basis of graptolite fauna, of Silurian age and hence are considerably younger than the rocks of the Cushing and Cape Elizabeth Formations for which Rb-Sr ages of 481+/-40 m.a. and 485+/-30 m.a. have been obtained by Brookins (Brookins and Hussey, 1978).

Regional Relationships

The relationship between the Central Maine and Casco Bay sequences as discussed above is analogous in many respects to the relationship between the Merrimack Synclinorium rocks of eastern Massachusetts and the rocks of the Nashoba Block. The fault which separates them is also a west dipping structure, the Clinton-Newbury Fault (see Fig. 2). The Nashoba and Marlboro Formations of the Nashoba Block are predominantly metasedimentary and metavolcanic respectively. As such they may be lithotectonic correlatives of the Cape Elizabeth and Cushing Formations.

The lack of Acadian aged plutons and the lack of a thermal imprint on various zircon fractions from geochronologically studied Nashoba Block rocks has led others (see, for example, Zartman and Naylor, 1984; Hepburn and Munn, 1984) to conclude that the Nashoba Block represents a terrain accreted to North America after the Acadian Orogeny and perhaps as late as the Alleghenian Orogeny.

This cannot be true for that portion of the Coastal Lithotectonic Block being considered here. As shown in Figure 1 fold structures in the Cushing and Cape Elizabeth are truncated by the thrust contact and subsequently re-folded along with the thrust by folds which are northeast-southwest trending upright isoclinal folds of Acadian age. The thrust contact in Maine is therefore a pre-metamorphic fault while the Clinton-Newbury Fault is clearly a post-metamorphic structure. This difference does not negate the lithotectonic correlation noted above; but rather may illustrate the process of "diachronous welding" (Zen, 1983, p. 75).

The Nashoba Block in eastern Massachusetts is separated by the Bloody Bluff Fault from the more easterly Dedham-Milford terrane (Zen, et al, 1983) the latter having lithologic and geochronologic characteristics that suggest it is of Avalonian affinity (Hermes and Zartman, 1985). In an analogous way the region underlain by the Casco Bay Group, as well as the Passagassawakeag gneiss to the northeast, may be separated from more easterly terranes (Avalonia) by a major thrust fault in Maine (see Osberg, et al., 1985 and Fig. 2). Of interest to the question of when these Avalonian (?) terrains were accreted to North America is the fact that the fault which bounds them on the west is cut by the Mount Waldo pluton north of Penobscot Bay. The Mount Waldo has a Rb-Sr whole rock age of 390+/-10 m.a. (Brookins, 1974). A K/Ar age of 325 m.a. on biotite from the pluton was obtained by Zartman, et al. (1970). These data are consistent with the whole rock and $^{40}Ar/^{39}Ar$ mineral ages obtained by Dallmeyer and VanBreeman (1981) on three peraluminous, and presumably anatectic, granitoids which intrude the Central

Maine Sequence in the Augusta area. This consistency suggests that the postemplacement cooling histories of Acadian plutons was similar regardless of whether they intruded metasediments of Siluro-Devonian age or rocks of unknown Proterozoic Z to Ordovician age. It further suggests that the different terrains were assembled in their present configuration prior to pluton emplacement.

Norumbega Fault Zone

After the Acadian juxtaposition of rocks of the Central Maine Sequence with those of the Casco Bay Group the area was affected by the development in pre- and post-Carboniferous time of numerous shear zones displaying textures suggestive of both brittle and ductile faulting. Collectively these structures comprise the Norumbega Fault Zone. The zone bears a name first introduced by Stewart and Wones (1974, p. 230) and applied to a 3-400 m. wide zone of deformation trending N 55 E. The fault named by them in the Bucksport Quadrangle separates chlorite grade metasiltstones of the Vassalboro Formation on the northwest from sillimanite and higher grade quartz-feldspar-biotite gneisses of the Passagassawakeag gneiss (Bickel, 1971) to the southeast. The fault zone is well exposed along Route 15 between Brewer and Bucksport, where locally the texture of the Passagassawakeag has been completely destroyed. The rock is a dark ultramylonite with flinty, angular break (see Stewart and Wones, 1974, Stop #3).

Several named shear zones will be examined during this trip. Various criteria have been used to determine the sense of motion along these structures. For example, the Dearborn Brook Fault, named by Pankiwskyj (1976), follows a pronounced linear topographic low for approximately 17.5 miles. Northeast of the Village of Palermo (see Figure 1) it offsets the extrapolated Buchan type metamorphic isograds of Acadian age defined by Osberg (1971). Minor structures believed to be related to displacement along the fault indicate oblique slip that is, right-lateral, east side up, displacement. As discussed by Newberg (1985), if the orientation of the isogradic surfaces were quantitatively known displacement along the structure could be calculated. In any case displacement on the order of several hundred feet seems reasonable.

The Eastern River Fault (Newberg, 1983), whose trace passes through the Village of Dresden Mills (see Figure 1) is another linear structure within the Norumbega Fault Zone. The Cape Elizabeth Formation over an approximately 0.5 mile wide zone adjacent to the fault displays a prominent S-C mylonitic fabric. Interpretation of the microstructures in this zone indicate right lateral displacement. Offset of the Cushing/Cape Elizabeth contact as mapped in the field is consistent also with east side down displacement. The latter may be the effect of earlier ductile faulting or the effect of later brittle faulting which post-dated the emplacement of the Blinn Hill granodiorite (Newberg, 1986 and see Stop #6).

In a study of the textures associated with zones of high shear strain in several of the Acadian granitic plutons exposed east of Penobscot Bay Johnson and Wones (1984) concluded that motion was right lateral, southeast side up. This is consistent with apparent offset along the Dearborn Brook Fault but not with apparent offset along the Eastern River Fault.

Conclusions

On the basis of the relationships discussed above the following conclusions are offered:

1. The Casco Bay Group and Central Maine Sequence rocks are most likely part of the same lithospheric plate terrain ("Craton X" of Zen, 1983) but are separated by a major, pre-Acadian, west-dipping decollement.

2. The Norumbega Fault Zone includes a number of discrete shear zones having different movement histories. In general data suggest post-Acadian, pre-Carboniferous ductile faulting with right lateral strike slip displacement. This was followed by brittle faulting with dominantly dip-slip displacement.

3. From the point of view of the development of the Northern Appalachians in New England and the Canadian Maritimes cumulative displacement along the Zone is not significant and it is not a likely major terrain boundary.

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ITINERARY

ASSEMBLY POINT: Knox Corner ... the intersection of Routes 137 and 220 approximately 1.5 miles east of the Village of Freedom.

Mileage

0.0 intersection of Routes 137 and 220 ... proceed west on Route 137

1.0 entering Town of Freedom

1.3 bridge over Sandy Stream; cross bridge and turn right

2.1 STOP 1: outcrop of Vassalboro Formation on the east side of the road.... The rock exposed here is a strongly foliated, well sorted, calcareous metasandstone consisting of rounded 0.05-0.1 mm. grains of quartz with minor feldspar cemented by calcite. The foliation is defined by thin (>0.5 mm.) zones of biotite which show strong preferred orientation. The biotite contains abundant zircon in scattered 0.01-0.04 mm. grains. Minor detrital tourmaline and opaque minerals are present in the mica-rich intervals.

The Vassalboro here, and elsewhere in the Palermo quadrangle to the southwest shows an unusual structural feature called "asymmetric foliation boudinage" by Platt and Vissers (1980, p. 399). While ductile shortening occurred perpendicular to the foliation rigid body rotation of shear fractures and the adjacent foliation resulted in the "sausage-like" texture seen here (see Fig. 3).

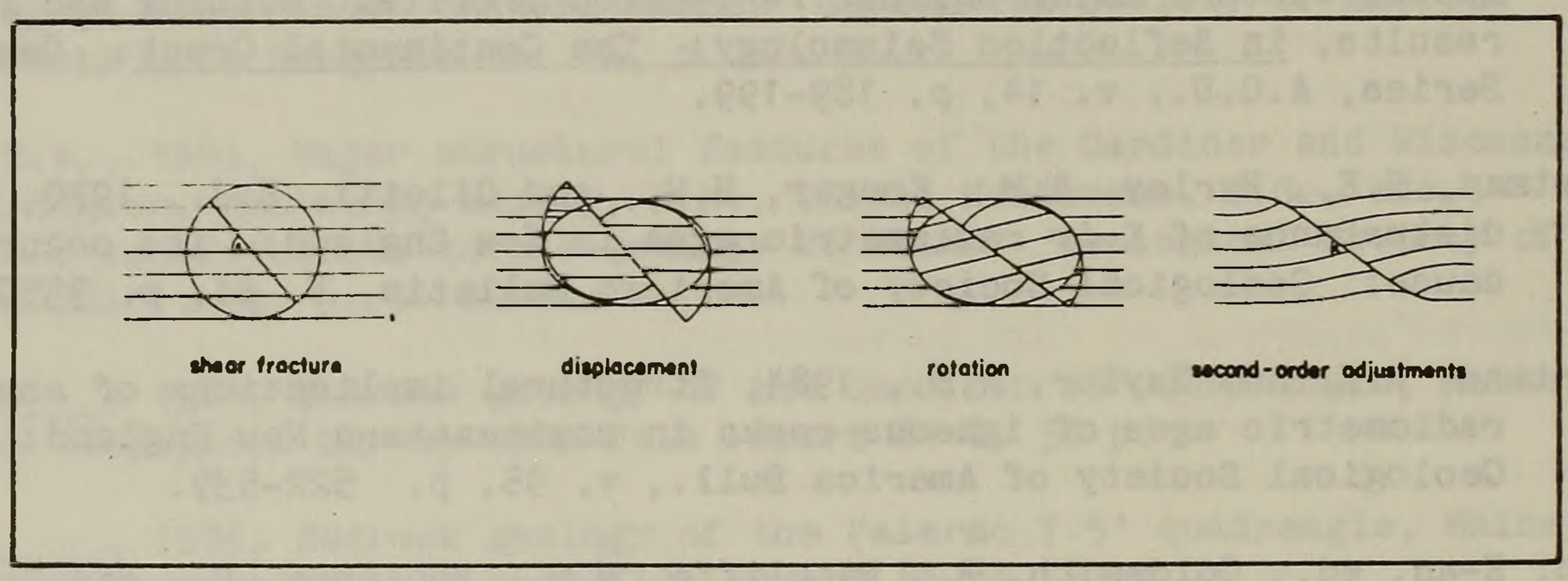

Figure 3. Progressive changes in the development of asymmetric foliation boudinage...after Platt and Vissers, 1980, p. 399.

Fluids present during deformation were responsible for the pseudomorphous replacement of biotite by chlorite + muscovite and for the precipitation of quartz in space generated by offset along the shear surfaces.

The deformation is clearly post-metamorphic and presumably related to high angle faulting along a late structure in the Norumbega Fault Zone.

turn around and return to Freedom Village

3.0 turn right (west) on Route 137

4.7 turn left onto dirt road

5.4 cross Winslow Brook.... The brook flows northeast into Sandy Pond along the inferred west dipping pre-metamorphic thrust which is the contact here between the Vassalboro Formation, exposed to the northwest, and the metasedimentary rocks of the older Cushing Formation, exposed to the southeast.

6.0 dirt road to the right, bear left

6.1 STOP 2: outcrops just southwest of the road along a small stream of a distinctive metapelite.... This lithology was informally referred to as the Sandy Pond Member of the Cushing Formation by Pankiwskyj (1976) who first mapped it. However, because of close spatial association with felsic metavolcanics belonging to the Nehumkeag Pond Member (informal name) of the Cushing Formation it seems preferable to include it with that member despite the distinctly different lithic character.

Thin sections of the metapelite evidence an earlier kyanite + staurolite Barrovian type metamorphism which may be pre-Acadian (C.V. Guidotti, pers. com.). The kyanite is now largely resorbed and the staurolite pseudomorphed by pinitized cordierite. The cordierite together with sillimanite, which occurs as fibrolite as well as large porphyroblasts, appear to have formed during later Buchan type metamorphism. The latter is related to the Acadian metamorphism of the Augusta-Waterville area (Osberg, 1974).

Where sillimanite porphyroblasts are abundant in the rock they stand on the weathered surfaces as resistant knots that are cut by a later cleavage. The resulting outcrop texture has lead to this lithology being dubbed "chip schist." Cordierite is pinitized particularly in proximity to post-Acadian faults.

turn around and return to Route 137

7.6 intersection with Route 137, turn left

7.6 Route 137 bears right, continue straight ahead (southwest)

11.1 Hutchins Corner (The Quebec-Western Maine Seismic Reflection line was run from Albion to Hutchins Corner and then continued to the southeast.) ...continue southwest

12.4 An approximately 10' thick limestone in the Vassalboro Formation was quarried on the left (east) side of the road presumably for agricultural purposes (?). Despite being very thin this unit is well exposed further southwest in the Palermo 7.5' quadrangle.

13.3 low outcrops of Vassalboro Formation on both sides of the road ... The same unusual boudinage seen at stop #1 may also be seen here.

14.9 STOP 3: outcrops on the east side of the Palermo (Freedom) Road of buff weathering biotite granofels (felsic metavolcanics) of the Nehumkeag Pond Member of the Cushing Formation. (This stop is the same as stop #11 of Pankiwskyj, 1978.) The thrust contact - Hackmatack Pond Fault - with the Vassalboro Formation is located approximately 300' to the west. In the field to the east scattered outcrops reflect the nature of other lithologies within the Nehumkeag Pond Member. The trace of the Palermo School Fault is located three or four hundred feet to the east. The fault is a late high angle fault with rusty weathering calc-silicate granofels of the Vassalboro Formation on its east, or downthrown, side.

17.9 outcrops of calc-silicate granofels and biotite schist of the Vassalboro Formation. These rocks are in the sillimanite zone ... in marked contrast to the very low metamorphic grade of the same lithology at stop #1 to the northeast.

18.7 intersection with old Route 3, turn left

19.6 Route 3, turn left.... The trace of the Hackmatack Pond thrust fault is inferred to pass through this intersection. To the west are units of the Vassalboro and Waterville formations of the Central Maine Sequence; to the east are exposed various lithologies of the Cushing and Cape Elizabeth formations of the Casco Bay Group.

19.9 STOP 4: The rusty weathering outcrop on the north side of the road marks the trace of the Palermo School Fault which here lies within the Cushing Formation. Thin septa of pseudotachylite are present often with chloritized and slickensided contacts. East of the fault the rock is a biotite granofels with lenses of garnet-plagioclase+/-calcite and garnet-diopside-calcite. To the west the rock is a very rusty weathering pelitic schist with pods and lenses of sheared pegmatite. Slickensides in composition surfaces oriented N60°E and dipping 60° NW rake 80° SW and indicate NW side up displacement along the structure.

turn around and proceed northwest along Route 3

21.5 Tobey's General Store

23.3 Dirigo Corner, turn left and proceed south towards Weeks Mills

23.9 outcrops of Vassalboro Formation: calcareous metasiltstone and metasandstone

26.4 STOP 5: rusty weathering sulfidic and graphitic unit within the Vassalboro Formation exposed on the east side of the road.... This outcrop is interpreted to lie along the trace of the Dearborn Brook Fault, another high angle brittle structure belonging to the Norumbega Fault Zone.

27.2 Village of Weeks Mills, turn right and proceed southwesterly

27.3 bear left

29.2 intersection with Route 32 at North Windsor, turn left (south)

34.3 intersection with Route 17 at South Windsor

note ... The trip may be continued from this point by crossing Route 17 and driving directly to STOP 6 which is located in the East Pittston 7.5' Quadrangle. The Weeks Mills, Togus Pond, and East Pittston 7.5' quadrangles would be useful, if not essential, in doing this. Hence, the log is discontinued here. Participants will travel via Routes 17, and 226 to the intersection of I-95 and Route 9-126 (just south of the Maine Turnpike) for lunch ... turn right and proceed west on Route 17.

(47.8)

0.0 parking lot on the north side of Route 9-126 opposite the truck stop and immediately west of I-95

0.7 large outcrop on the left side of the road. This is an exposure of the Mt. Ararat Member of the Cushing Formation mapped by Newberg (1984) as an inclusion (roof pendant?) within a small post-tectonic hornblende quartz diorite pluton. The exposure was also the subject of a previous NEIGC field trip (see stop #10 of Osberg, 1980)

2.1 cross Cobbosseecontee Stream, bear left and continue on Route 9-126

3.2 traffic light, turn left

3.5 traffic light, continue from right lane across bridge over the Kennebec River

3.7 traffic light at east end of bridge, turn right and continue south on Routes 27 and 126 through the Village of Randolph

5.0 turn left (east) on Route 194

5.3 small outcrop on the south side of the road of amphibolite within the Cushing Formation... This amphibolite has been traced to the southwest across the Kennebec River. It is approximately 200' thick and may represent a folded and metamorphosed mafic dike.

5.8 trace of the Dearborn Brook Fault (see Stop 5)

8.6 outcrop of the Nehumkeag Pond Member of the Cushing Formation... The rock here is a quartzofeldspathic gneiss with a discontinuous to weak foliation. This, and the other exposures of this unit are mica poor, massive and buff weathering with planar joint surfaces usually rust-stained. Often the gneiss contains scattered large garnets or irregular patches of garnet plus magnetite. The protolith is assumed to be a sequence of felsic pyroclastic rocks.

10.3 bridge over the Eastern River in East Pittston

10.5 bear left and continue on Route 194

10.9 turn right onto Nash Road

12.1 whaleback outcrop on left of amphibolite with minor calc-silicate granofels of the Cushing Formation

12.3 turn right and continue south along Blinn Hill Road... The road is located approximately 600 feet east of the unexposed contact between the Cushing and Cape Elizabeth formations.

13.6 STOP 7a: Palmer Brook, which flows west beneath the road here, exposes more or less continuous outcrop for approximately 3400'. We will walk the stream beginning by examining outcrops of garnet-muscovite-biotite schist and biotite granofels of the Cape Elizabeth Formation, located about 400' below the bridge. To the west (down stream) calc-silicate granofels of the Cushing Formation is exposed after an interval of 40' in which there is no exposure.

Amphibolite, a narrow (10-12') band of marble, and calc-silicate granofels predominate over the next half mile, which is, however, lithologically quite varied. Of particular interest are several rusty weathering sulfidic schist zones (cataclastically deformed and mineralized granofels i.e., shear zones?) and granite pegmatites, some of which show textures indication of ductile shear.

Approximately 400' west of the point where outcrop ceases in the stream there is an isolated exposure of buff weathering, finely laminated to foliated, granofels typical of the Nehumkeag Pond Member of the Cushing Formation.

continue walking west along tote road to discontinued portion of East Pittston Road (see Figure 4). From here we will return by car to the beginning of the traverse.

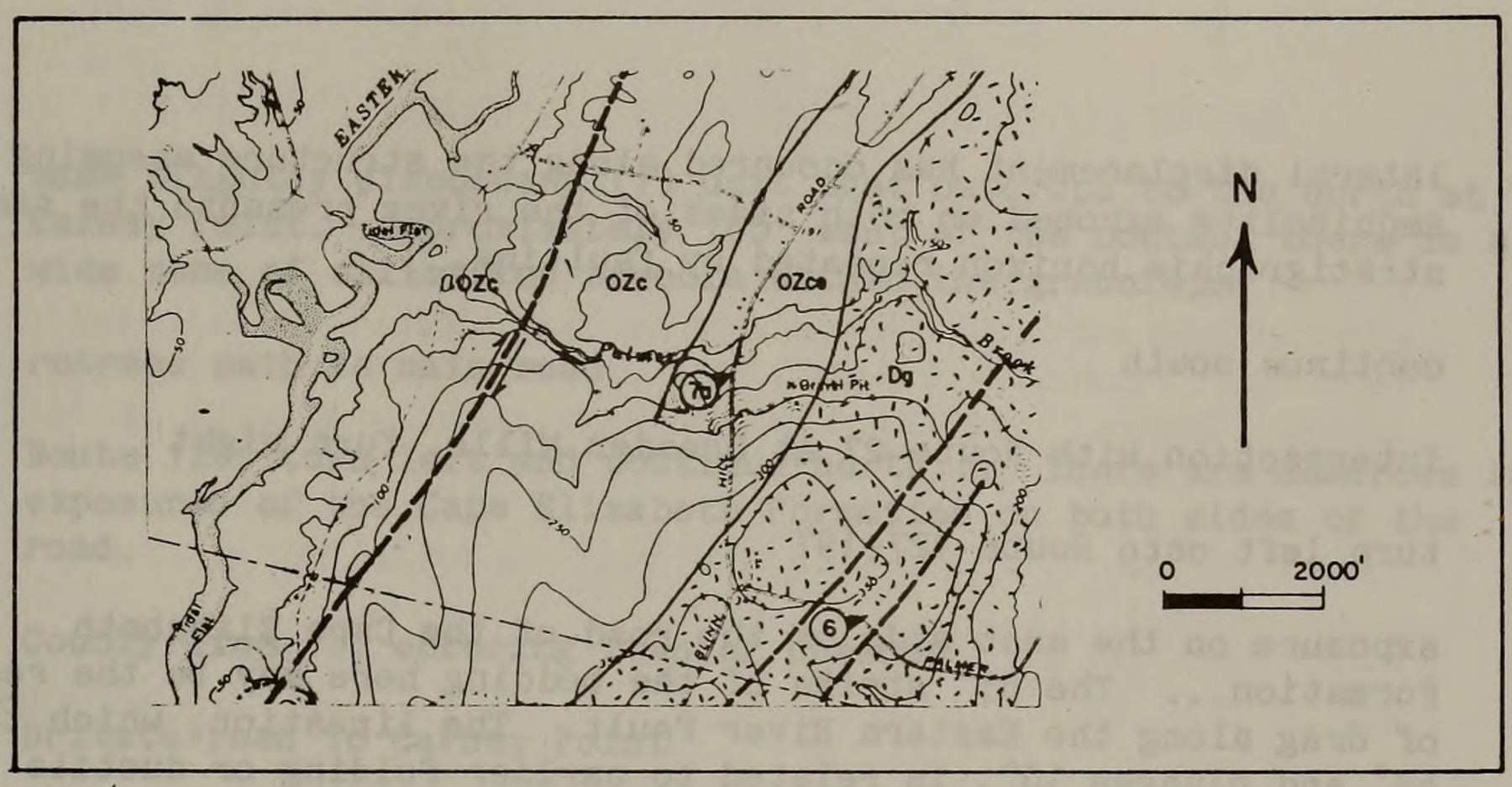

Figure 4. Location map showing stops 6 and 7a, E. Pittston 7.5' quadrangle

14.1 turn left onto Palmer Road

14.4 STOP 6: outcrops of Blinn Hill granodiorite on both sides of the road... A spur of the Eastern River Fault transects the pluton as shown in Figure 1. The texture seen here in outcrops north of the road is interpreted as cataclastic but relict areas of strain-free quartz seen in thin section suggest earlier ductile deformation of the granodiorite. Textures displayed by the numerous outcrops in this field are variable.

turn around and return to the Blinn Hill Road

14.8 turn left

15.1 crest of Blinn Hill, continue southwest

17.9 STOP 7: (The features of interest here are exposed best at low tide. Therefore the stop will be made only if the tide allows.) In the small stream flowing beneath the road and into the Eastern River just to the west there is almost continuous outcrop. Metapelite of the Cape Elizabeth Formation is in apparent conformable contact with biotite granofels of the Cushing Formation. Approximately 200' to the west a finely laminated biotite rich marble is exposed on both sides of the stream where it enters the Eastern River. These and other lithologies exposed here belong to the Wilson Cove member of the Cushing Formation (see Hussey, 1985, p. 8) As shown in Figure 1 the trace of the Eastern River Fault is located here. An indeterminate amount (perhaps as much as 24000') of apparent right

lateral displacement has occurred along the structure assuming an amphibolite exposed on both sides of the river presents the same stratigraphic horizon repeated by faulting.

continue south

18.0 intersection with Route 27 at Dresden Mills, turn right

18.1 turn left onto Route 127-197

18.7 exposure on the east side of the road of the Cape Elizabeth Formation... The 65° strike of the bedding here may be the result of drag along the Eastern River Fault. The lineation, which trends 65° and plunges 30°, is related to earlier folding or ductile faulting (?).

20.1 "Y" intersection, bear right on Route 197 and continue west

20.4 bridge over the Eastern River

21.4 exposure on the right (north) side of the road of rusty weathering granofels of the Nehumkeag Pond member of the Cushing Formation

21.6 intersection with Route 128, turn left

23.9 bridge over the Eastern River... The Cape Elizabeth Formation crops out below the bridge and to the right. The contact between the Cushing and Cape elizabeth Fromations in this area is buried beneath glacial drift, river silts, and the soils which yield Dresden's excellent potatoes.

26.7 Lincoln-Sagadahoc County line ... entering Town of Woolwich

27.7 small red house on the left, large white house on knoll on right ... turn right by a row of mailboxes onto a dirt road ... continue on road and park north of the first house ... walk west on woods road to shore at Twing Point

<u>STOP 8</u>: The contact between garnet-biotite-muscovite-quartz schist of the Cape Elizabeth Formation and buff weathering granofels (Nehumkeag Pond member of the Cushing Formation) is exposed here. Approximately 50' east of the contact there is a 200' thick section of amphibolite containing plagioclase, hornblende altered to chlorite with inclusions of relict pyroxene, and minor sphene, apatite, and magnetite. Narrow quartz "stripes" are seen in the outcrop in the amphibolite. In thin section these appear as cross-cutting, sub-parallel zones of strained quartz grains with mosaic texture and are interprerted as representing silica introduced along shear zones during faulting. The amphibolite is presumed to be the

same slightly discordant (?) unit that outcrops to the north at Carney Point. Approximately 100' west of the contact there is a 20' wide zone of silicified breccia within the granofels.

retrace path to main road

28.7 Route 128, turn left and continue north... There are numerous large exposures of the Cape Elizabeth Formation on both sides of the road.

29.7 County line ... entering Town of Dresden

30.2 private road to Carney Point

34.6 intersection of Route 197, turn left

35.2 bridge over the Kennebec River at Richmond

35.7 intersection of Routes 197 and 24, turn left

36.2 intersection in Richmond opposite Swan Island ... turn right on Route 197 and continue up the hill through the village

39.2 exposure on the right of the Mt. Ararat Member of the Cushing Formation. The unit is presumed to represent a sequence of metamorphosed intermediate to basic volcanics. Locally, as here, sillimanite bearing, rusty weathering pelitic volcaniclastic metasediments are interbedded with the flows (?). A late antiformal cross-fold with its axial surface dipping 30°NE and its axis oriented 320°, 20° may also be seen in this outcrop.

39.8 I-95 overpass ... park on the west side and walk south on the entrance ramp to I-95 southbound.

STOP 9: The large roadcut here is in the Mt. Ararat Member of the Cushing Formation. Texture and lithology are variable but the rocks are predominantly quartz-plagioclase-hornblende-biotite gneiss and hornblende-biotite granofels with compositional layering on a scale of 2 to 10 cms. The plagioclase averages An_{40}; occasional minor potash feldspar is present. Two samples collected a few feet from each other on the east side of I-95 at this location yielded the following modes:

apatite	2.0	1.1
hornblende	32.9	67.2
plagioclase	44.1	10.3
quartz	6.5	-
biotite	11.4	21.3
sphene	2.2	-
magnetite	0.9	0.1

There are a series of small folds here which have axial surfaces oriented 290°, 40°N. These are interpreted as being late folds. Chloritization and/or slickensiding of biotite rich composition surfaces may be due to layer parallel slip during folding. Pegmatite exposed here may be genetically related to the Sebago Pluton. The dikes can be seen cutting as well as folded by (?) these structures.

return to vehicles and continue west on Route 197

41.0 blinking light at Richmond Corner ... intersection of Routes 201 and 197

END OF TRIP