CLEAVAGE IN THE COSSAYUNA AREA, as seen at the outcrop

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ABSTRACT

This trip crosses the Taconic allochthonous sheets in Washington County, N.Y., eastward on Saturday and westward on Sunday. The purpose is to look at various structures visible at outcrop and with a hand lens and to consider how much of the deformation can be attributed to dissolution. I believe that much rock has moved through solution, but many features seen at outcrop are not easily interpreted. At the west edge of the klippe rocks, the underlying carbonates are remarkably undeformed, and the Taconic Sequence, though folded and cleaved, does not show obviously massive rock loss. Eastward the situation becomes more complicated, and at the easternmost stop, extension fibers have formed in fanning "cleavage." I hope those taking the trip will share their observations and thoughts at the outcrop so that we all learn.

INTRODUCTION

The Cossayuna quadrangle lies in Washington County, N.Y., along the western edge of coherent thrust sheets of Cambrian to Middle Ordovician shales known collectively as the Taconic Sequence. The Shushan quadrangle is southeast of the Cossayuna quadrangle, and about a mile farther east carbonates re-emerge from beneath the Taconic slices. The age, succession, and allochthony of these rocks have been discussed elsewhere (Platt, 1962; Zen, 1964; Cady, 1968; Rodgers, 1971; among many) as have discussions of their environment of deposition (Rodgers, 1968; Platt, 1969). NEIGC has run numerous field trips through various parts of these complexly deformed rocks, including the 1976 meeting, so no discussion of regional relations is presented for this trip. Figure 1 shows the location of the area visited on this trip, and indicates the general structure from my Ph.D. thesis and some later work. All the mapping in the Taconics seems to me to owe much to T.N. Dale's comprehensive work (1899).

Dale was especially involved with the slate in eastern New York and Vermont and elsewhere (Dale and others, 1914), for all through the Nineteenth Century the rock was of substantial economic importance. Even though the rock no longer provides the main roofing material, and annual production has declined for decades, study of its origin has increased recently. Just since the reviews of Siddans (1972) and Wood (1974), there has been a flood of data indicating that selective dissolution has produced cleavage of many types in many kinds of rock. A summary of some of the data is presented in the Atlas of Rock Cleavage (Bayly and others, 1977).

Solution along stylolites is not new, nor is the interpretation that they form in anisotropic stress fields. Durney (1978) gives a review of theories about pressure solution, and Stockdale (1922) gives a review of the occurrence of stylolites in limestone. Apparently Sorby and Heim recognized the dissolution origin of pitted pebbles a century ago. Excellent photos of quartz grains penetrating chert grains are in the article by Sloss and Feray (1948), thus showing selective solubility; the succession of solubilities of several minerals is indicated by Trurnit (1969). That stylolites and cleavage are at least in part caused by the same process was suggested by Plessman (1964) and Nickelsen (1972) among others, and has been supported by Alvarez and others, (1976; 1978).

That pressure solution results in cleavage is a fairly new idea. Quite a few other proposed causes have been recorded in the literature on slate. Some of the best evidence against these alternatives has been published since my cleavage conference, so a few remarks on the newer papers follow. Early in this century Leith (1905) suggested that slaty cleavage could form by flattening while fracture cleavage could form by shear strain. White (1949) showed this to be erroneous, for "slip cleavage" grades into schistosity in eastern Vermont. That cleavage surfaces should be 45° from maximum compression as fostered by Becker (1896) was refuted by Goguel (1945) and recently by Groshong (1975a). That major rotation of platy minerals is most important in slate fabric has been weighed by Beutner (1978) and found wanting. Intracrystalline deformation has been considered important by many, including Deelman (1976) who rejects pressure solution as a substantial factor even in diagenesis. Yet crushing is notable for its absence in many natural specimens from terranes with widely different amounts of strain (Marlow and Etheridge, 1977; Engelder and Engelder, 1977; Gray, 1978). Clearly some mechanical reorientation occurs as individual grains are dissolved away (Means and Williams, 1974) or as they grow into pores (Etheridge and others, 1974). Maxwell's (1962) suggestion that slaty cleavage could form in wet mud was widely accepted for a time but now seems less satisfactory (Geiser, 1975; Maltman, 1977).

While emphasizing the importance of pressure solution in deformation of rocks generally, recent literature has attempted to evaluate what are conditions under which it accounts for less than other kinds of distortion. For example, Kerrich and Allison (1978) indicated that cataclasis is dominant at low confining pressure and temperature, pressure solution at intermediate temperature, and dislocation creep at high temperature. Of course, such a qualitative scale will be shifted up and down for different minerals and for various other conditions; Kerrich and others (1977a) say the transition from grain-surface diffusion to intracrystalline creep occurs near 450°C for small grains of quartz and near 300°C for small crystals of calcite. Mitra (1977) suggests that pressure solution is linear Newtonian while dislocation creep obeys a power law and that the latter becomes dominant as the strain rate increases. McClay's review (1977) shows that at low stress pressure solution is orders of magnitude faster than intracrystalline creep and surface diffusion in quartz and still at least ten times faster in calcite. In fact, most discussion of dissolution and diffusion have dealt with calcite and quartz; more data on rates of deformation by dissolution, diffusion, and dislocation movement for other minerals would be useful. It is clear that selective dissolution of certain minerals can change the bulk rock chemistry (Kerrich and others, 1977b; Mitra, 1979).

In summary, dissolution of selected mineral grains and along selected surfaces of those grains is increasingly recognized as a major factor in rock deformation in the upper crust generally (Groshong, 1975b), and in the formation of rock cleavage especially. The properties of minerals in various deformation modes have been studied extensively. That different minerals behave very differently is well known, but only recently has it been recognized that this diversity of behavior could be mostly due to orders-of-magnitude differences in solubility and rates of dissolution rather than to solid deformation. Distinguishing these from each other can be difficult; Williams (1972) notes the difficulty of distinguishing detrital from authigenic mica. At higher grades early pressure solution effects may be lost in later recrystallization (Stephens and others, 1979).

While this review has been cursory, I hope it will stimulate discussion at the outcrops.

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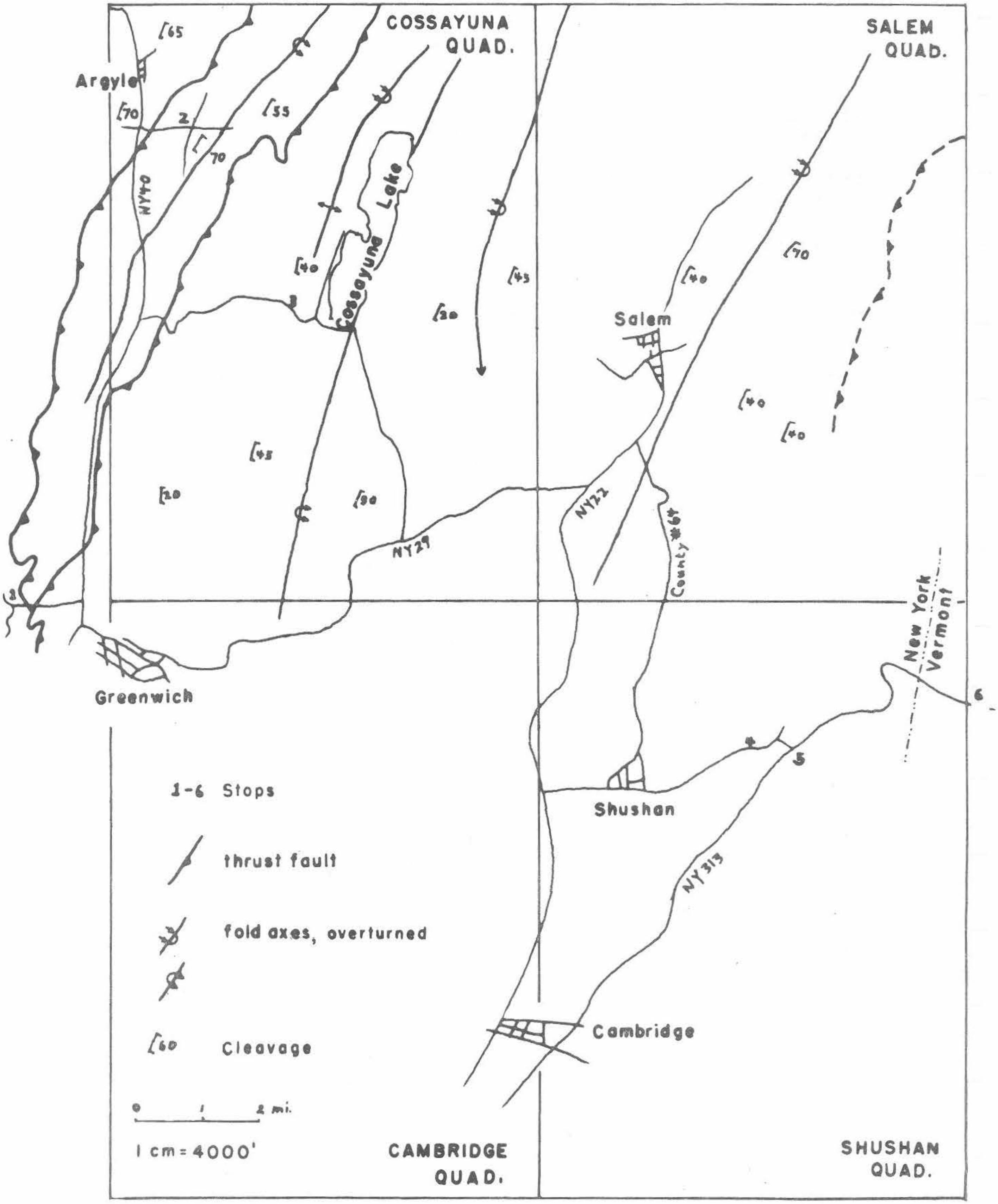


Fig. 1. Location of stops 1 through 6 and generalized structural map of the Cossayuna area and vicinity.

DESCRIPTION OF STOPS

STOP #1. Bald Mountain, near Middle Falls, N.Y.

Re-enter the bus 1 hour after getting out.

Enter the quarry on the west side and walk around the southwest side of the hill along the old road. The quarry existed to produce lime, and some evidence of kilns remain. The geologic relations at Bald Mountain have been examined by scores of geologists for over a century. Published mapping by Ruedemann (Cushing and Ruedemann, 1914) shows Lower Or~~o~~dovician limestone overlain by a thrust plate of Lower Cambrian shale. In fact, a screen of Middle Ordovician shale intervenes between, and the best explanation of the geology in this vicinity is that the carbonate floats as a tectonic fish in the Ordovician shale which is overlain by the thrust plate of Taconic rocks. Our interest in the locality is that we can see shale with pebbles of carbonate, and we can see some dissolution features adjacent to some of the carbonate. One point to note is how LITTLE deformation there is in the Ordovician carbonate, even in small pieces, in contrast to the cleaved shale.

STOP #2. One mile southeast of Argyle, northwest quadrant of road intersection. Re-enter the bus after no more than an hour.

Some small folds in these Lower Cambrian carbonate, silt, and shale beds can be seen in the southwest part of the corner field. The chevron folds do not show much cleavage, but other parts of the pasture do. Dale (1899) found trilobites in both the pebbles and the matrix, but the conglomeratic look to the carbonate beds is probably due to insoluble residue concentrated along dissolution surfaces. The main point of this stop is to examine the styles of deformation in this more or less carbonate-rich part of the Taconic Sequence.

STOP #3. 1000' west of the south end of Cossayuna Lake.

Re-enter the bus in one hour.

At the road cut it is easy to see conglomerate of carbonate pebbles in shale and some beds of limestone in shale. Walk up to the outcrops of this rock on the slope north of the road cut. In several places the glacially scraped rock shows solution features in the carbonate. Seeing this requires getting down on hands and knees and using a hand lens in many cases; hence if it is raining, we will abandon this stop. One aspect of the solution of these rocks is that many solution features do not continue very far in the rock; they are approximately parallel to tight fold axes in the area. How much change in thickness of beds around tight folds, particularly in area of "similar folds, is due to removal of rock? In nearly isoclinal folds, it is possible to show that dissolution could cause virtually all of it.

LUNCH. Re-enter the bus in 59 minutes.

STOP #4. BM564, 1 mile northwest along County 61 from NYRoute 313, 3/4 mile due north of Eagleville, Shushan quad. Bus pull off on south. Re-enter bus after 30 minutes.

Folds in Lower Cambrian Mettawee and West Castleton Formations. This small outcrop is rich in deformation features. Chevron folds and kinks. Microboudins. "Slip" both ways on vertical cleavage. It is not clear to me how slip both ways could occur on parallel cleavage surfaces; hence I conclude that during folding a substantial part of the rock went into solution, and the plane along which material was removed only appears to be a line of slip. Years ago, Donath (1961) showed that slip occurs along surfaces of mechanical anisotropy; here we can infer that the cleavage we see was not a place of particular anisotropy before or during the early stages of its formation. Flattening by selective dissolution seems a better way to me. But where does the material go? What is the reservoir rock for this source rock?

STOP #5. Intersection of NYRoute 313 and County 61, 2 1/4 mi. due east of Shushan, northern Shushan quad.
Re-enter bus after about an hour and a half.
Quite a variety of wonderful things are visible at this roadcut. I suggest that you walk east along the outcrop before you get down to the details. The paucity of veins at previous outcrops is in sharp contrast to this spot. I doubt it is merely a matter of metamorphic grade, though this rock is obviously more metamorphosed than the first stops. These rocks are folded and veined (calcite before quartz?) but the cleavage is not particularly impressive. Nevertheless, small crenulations show concentrations of micaceous minerals along limbs quite like the drawings of Gray (1979, Fig.3), and I infer, as he does, that solution of quartz is a major factor in the wrinkling. A thin section of sandstone from this outcrop shows extensively twinned calcite vein material, some sutured sand grain boundaries, and very little but nevertheless some dark submicroscopic material in strings along some grain boundaries and in sutured grain contacts. In one vein it appears that the calcite twin lamellae are bent. In the thin section, only two sand grains other than quartz were found, so this particular section was not

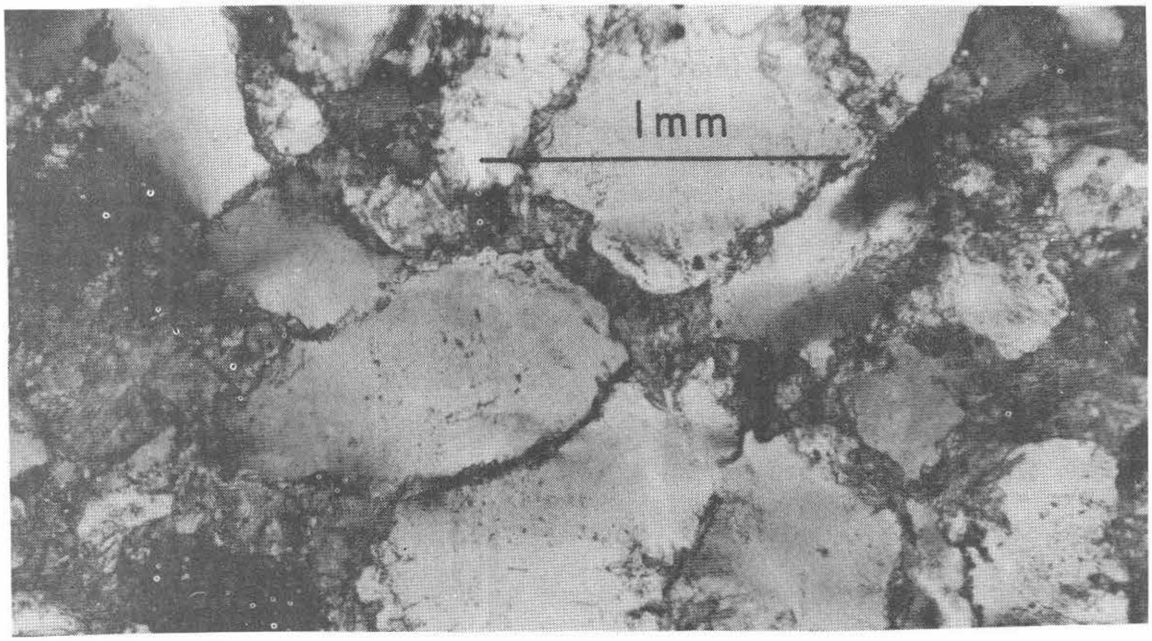


Fig. 2. Photomicrograph of clean quartz sandstone from stop #5. Note grain contacts. In the western part of the Taconic Sequence, similar rocks have frosted and very well rounded grains. As one may infer the same diagenesis for the similar rocks, the difference in grain contacts now is related to deformation and metamorphism.

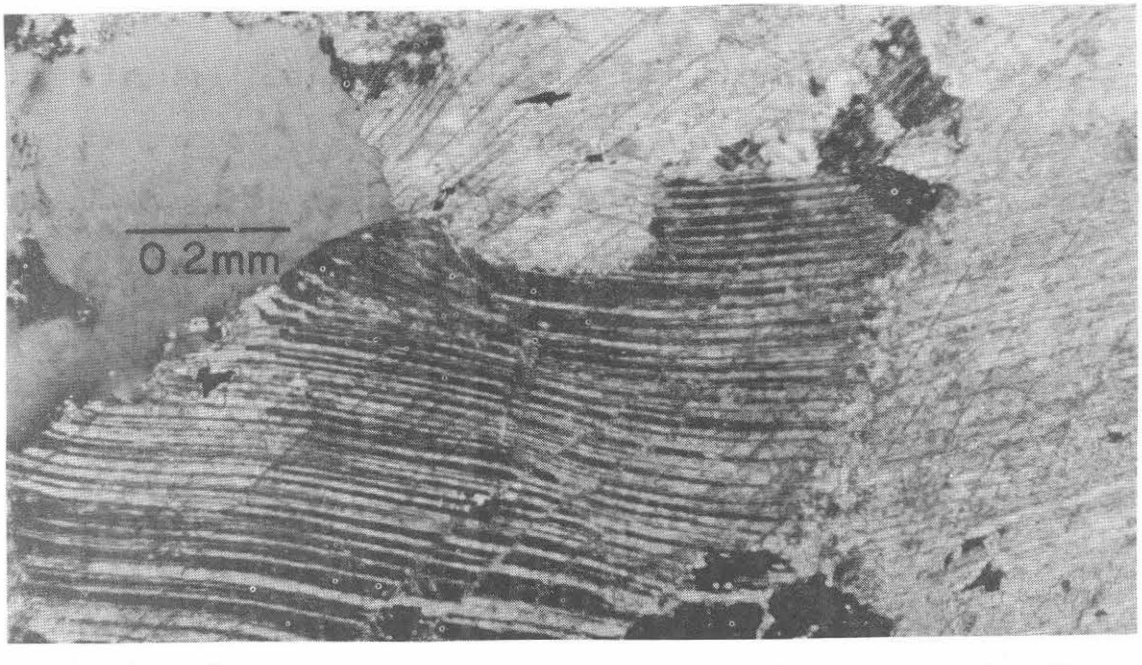


Fig. 3. Photomicrograph of clean quartz sandstone from stop #5. Curved and offset twin lamellae in calcite vein. Clearly the deformation has not been simple, for some quartz veins seem to cut calcite veins.

ideal rock to see mica beards, etc., as shown by Means (1975, Fig. 1).

STOP #6. Across from 1852 covered bridge over Battenkill in Vermont 2.4 miles east of N.Y.-Vt. border and 4.4 miles east of stop 5. Re-enter bus after 1 hour.

These carbonates are so-to-speak out from under the east side of the Taconic rocks we have been looking at between here and Bald Mountain (stop 1). As we have moved east and southeast across the Taconic Sequence, the metamorphism has increased, as was clear at the last stop. How does this affect the carbonates? Things to look at here include the following:

a. Crinoid stems in coarse beds. Although the crinoid is dead, the ossicle is in good condition.

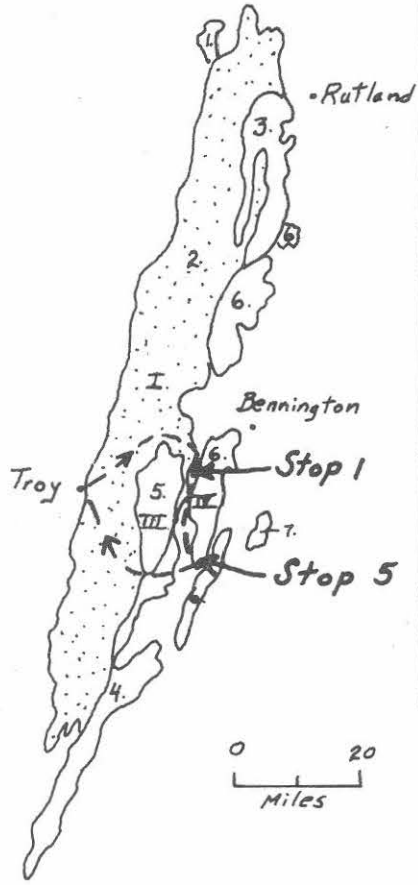
b. Some calcite layers look schistose. Are these beds?

c. The difference in ductility between different layers is apparent.

d. Where are the stylolites in these strongly deformed rocks? Or are there just no insoluble residues?

e. Near the west end of the outcrop folded layers have fanning "cleavage" but the feature that is fanning has calcite fibers.

f. Some curved veins have fibers. Did the fibers survive folding, or did the fibers form after the folding of the veins, or did the veins from with their present curvature? This would seem to imply that the fibers are related to something different from compressional dissolution cleavage fanning the fold.



Thrust sheets of the central Taconic region - This report (in order of relative age of emplacement, oldest at bottom)	Zen's (1967) thrust slices
	7. Greylock slice
IV Berlin Mountain sheet	6. Dorset Mountain slice
III Rensselaer Plateau sheet	5. Rensselaer Plateau slice
II Butternut Hill slices (too small to plot)	4. Chatham slice
	3. Bird Mountain slice
I. Giddings Brook sheet	2. Giddings Brook slice
	1. Sunset Lake slice

Figure 1. Field trip route, and thrust sheets of the Taconic allochthon.