RETHINKING GRENVILLE-AGE DEFORMATION - DUCTILE SHEAR IN GRANITIC GNEISSES OF THE LOWLANDS

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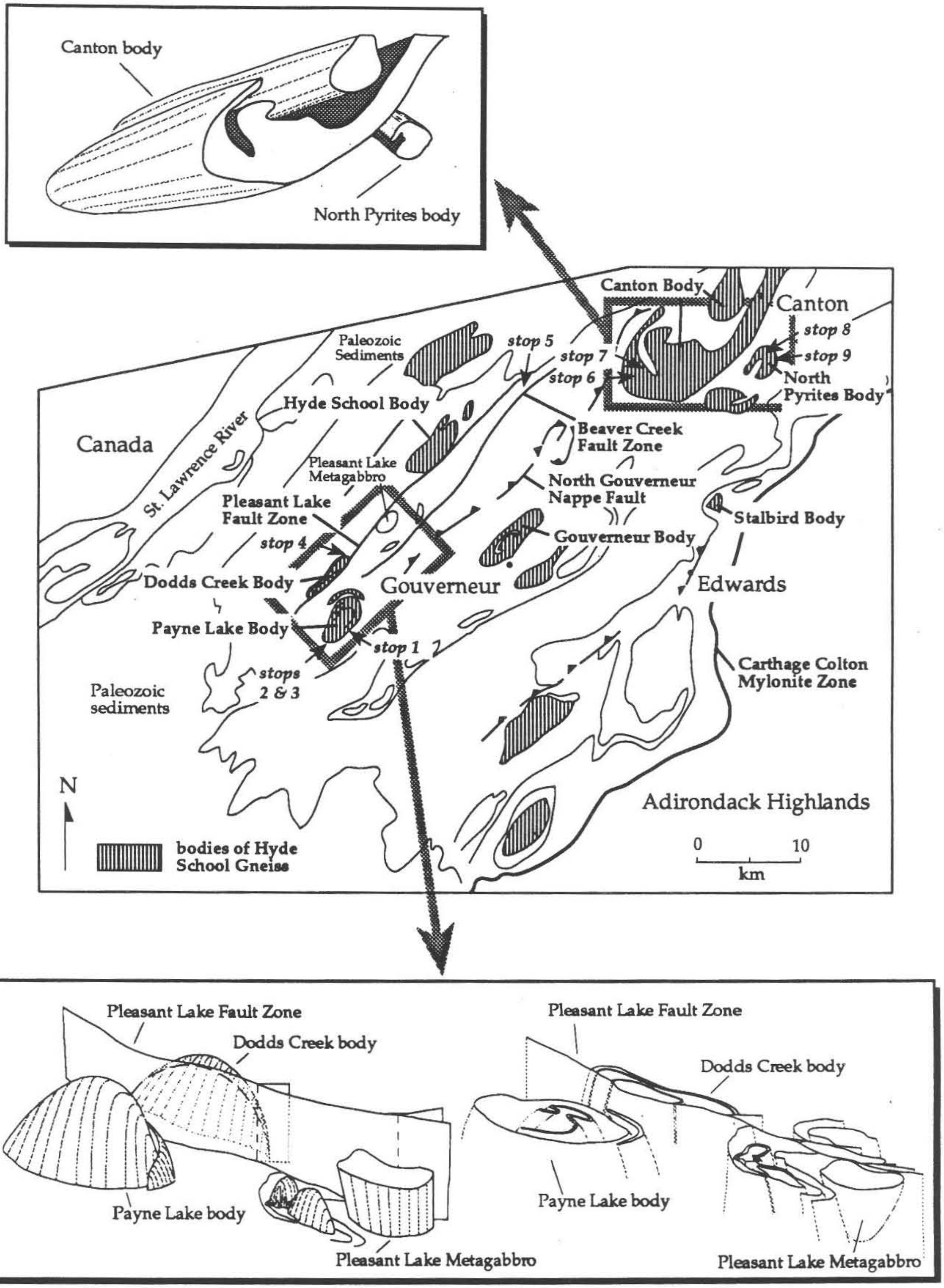
INTRODUCTION

Grenville-age metamorphic rocks exposed in New York State are customarily divided into two regions, the Northwest Lowlands and the Adirondack Highlands (figure 1). The Lowlands are dominated by upper amphibolite to lower granulite facies metasedimentary lithologies; the Highlands are dominated by lower granulite to granulite facies metaigneous units. The Highlands-Lowlands Boundary lies along the Carthage-Colton Mylonite Zone, a major shear zone that juxtaposes the two terranes and exhibits evidence of a complex motion history. The youngest motion along the Carthage-Colton Zone has recently been dated at approximately 1098 Ma by Mezger *et al.* (1992).

Despite the dominance of metasedimentary lithologies in the Lowlands, a number of metaigneous units have figured prominently in various models for the structural history of the Lowlands. Chief among these are the 14 large bodies of leucogranitic gneiss collectively referred to in the recent literature as the Hyde School Gneiss, after exposures in the Hyde School body (Carl *et al.*, 1990, Whitney *et al.*, 1989; McLelland *et al.*, 1992) (figure 1). The Hyde School Gneiss bodies are complex domical structures scattered throughout the Lowlands. U/Pb zircon geochronology indicates that protoliths for the Hyde School Gneiss in a majority of these bodies formed *ca.* 1225-1230 Ma (McLelland *et al.*, 1992).

Traditional views portray the structural evolution of Proterozoic rocks in the Northwest Lowlands as a series of folding events at scales ranging from microscopic to regional as part of a series of contractional orogenic events stretching from Texas to Labrador over a time period from some time between 1300 and 1200 Ma to about 1050 Ma. These models attribute complex patterns in the distribution of lithologic units to the interference of fold wave forms of different ages and orientations. Shearing, when recognized at all, has been


Canton body
North Pyrites body
Canton Body
Canton
stop 8
stop 9
North Pyrites Body
stop 5
stop 7
stop 6
Paleozoic Sediments
Hyde School Body
Canada
St. Lawrence River
Pleasant Lake Metagabbro
Pleasant Lake Fault Zone
Beaver Creek Fault Zone
North Gouverneur Nappe Fault
Gouverneur Body
Stalbird Body
stop 4
Dodds Creek Body
Gouverneur
Edwards
Payne Lake Body
stop 1
stops 2 & 3
Paleozoic sediments
Carthage Colton Mylonite Zone
Adirondack Highlands
N
bodies of Hyde School Gneiss
0
10
km
Pleasant Lake Fault Zone
Dodds Creek body
Payne Lake body
Pleasant Lake Metagabbro
Pleasant Lake Fault Zone
Dodds Creek body
Payne Lake body
Pleasant Lake Metagabbro

relegated to discreet and narrow zones and has not been previously thought of as a major kinematic element in evolution of Lowlands structures.

Over the past several years, I have evolved a very different view of deformation in the Lowlands, one in which regional ductile shear played a major role, and have argued that models for the formation of structures in the Lowlands must be consistent with the manner in which microscopic through macroscopic structures evolve when rocks undergo deformation involving a large component of ductile shear. Evidence for the importance of regional ductile shear has come from examining several bodies of Hyde School Gneiss, as well as a series of younger granitic gneisses in the Lowlands. The introductory paper for this field trip will first compare published models for the evolution of Lowlands structures, then briefly outline an alternative model consistent with structural features of the Hyde School Gneiss, and finally explore the evidence compelling us to think seriously about regional shear.

TWO DIFFERENT MODELS FOR THE EVOLUTION OF MAJOR STRUCTURES IN THE LOWLANDS

The Cross-Folding Model

Many workers over the years have proposed similar models for the evolution of structures in the Lowlands (*e.g.*, Brown, 1989; Foose and Carl, 1977; Whitney *et al.*, 1989; Wiener *et al.*, 1984). Each of these models portrays successive episodes of folding as responsible for reorientation of foliations and lineations. In particular, these models suggest that the quasi-circular, ovoidal, and hook-shaped outcrop patterns of the Hyde School Gneiss (map, figure 1) were formed by repeated co-axial isoclinal folding (producing Ramsay Type III refolds) followed by cross-folding (producing Type I refolds in earlier complex structures). The model is illustrated nicely in 3 dimensions in a figure published by Foose and Carl (1977) portraying a set of F_1 isoclines refolded co-

Figure 1 (previous page). Generalized geologic map of the Northwest Lowlands showing bodies of the Hyde School Gneiss (map modified from Carl *et al.*, 1990). 3-dimensional reconstruction at the top of the page shows the subsurface geometry of the westsouthwest plunging Canton sheath fold and the northwest plunging North Pyrites sheath fold as viewed obliquely from the south. The 3-dimensional reconstructions at the bottom of the page show subsurface and above-ground geometries of the Payne Lake and Dodds Creek sheath folds and several other adjacent sheath-shaped structures as viewed looking obliquely down to the southwest.

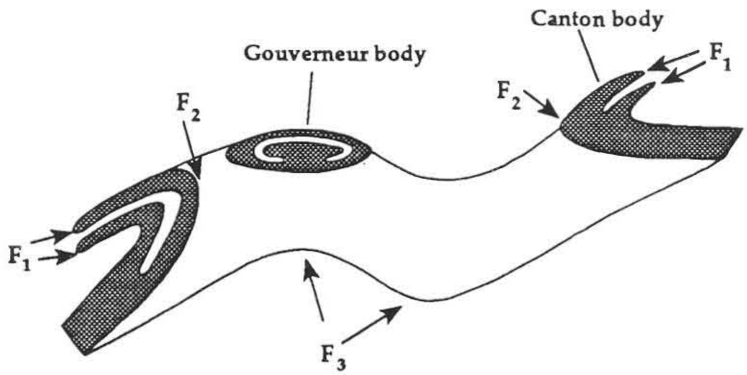


Figure 2. Outcrop patterns and subsurface geometry of the Canton and Gouverneur bodies according to the widely-published cross-folding model for deformation of the Lowlands (from Foose and Carl, 1977).

axially by northeast-trending F_2 isoclines and cross-folded into domes and basins by northwest-trending F_3 folds (figure 2). In this model, what can be visualized as the humps of a Loch Ness Monster breach the surface in the domical culminations of the Hyde School Gneiss bodies of the Lowlands.

While other models suggest three generations of early northeast-trending folds instead of two, all view deformation across the Lowlands as having proceeded largely by folding and re-folding. Shear, when recognized at all, is portrayed as occurring along discreet shear zones such as the North Gouverneur Nappe Fault (Brown, 1989), the "tectonic slides" in the southeastern Lowlands, and other very localized structures. Only Heyn's work (1990) brings large-scale ductile shear into evolution of a major zone in the Lowlands, the Carthage Colton Mylonite Zone that separates the Lowlands from the Highlands.

The Sheath Fold Model

Work by Tewksbury and co-workers (1991, 1992, 1993, in review, and in progress) has shown that shear fabrics are extensively developed, both in the Hyde School Gneiss and in younger granitic gneisses of the Beaver Creek Region. We have argued that the refolding/cross folding model can explain the *geometries* of the Hyde School Gneiss bodies, but that it cannot successfully explain the extensive development of shear fabrics in the Hyde School Gneiss and in other granitic rocks in the Lowlands. Furthermore, we have argued that

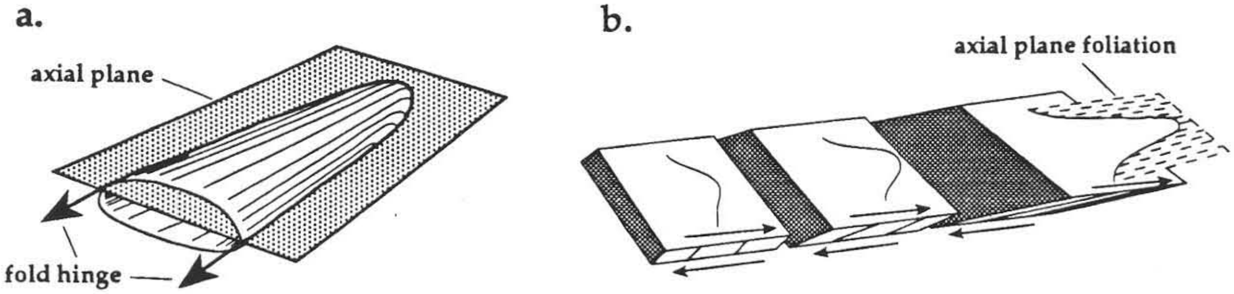


Figure 3. a) The anatomy of a sheath fold, showing the re-curved nature of the fold hinge; b) progressive development of a sheath fold during simple shear by passive amplification of an irregularity that extends across the shear planes (modified from Malavielle, 1987).

any model for the development of large-scale structures in the Lowlands must be consistent with the way that structures evolve when rocks undergo deformation involving a large component of ductile shear at a regional scale.

We have proposed that both the geometries and fabrics of the Hyde School Gneiss are more consistent with the development of sheath folds than with refolding followed by cross folding. A sheath fold is a fold shaped like a sword sheath or the hand of a mitten. Rather than having a straight hinge, as a cylindrical fold does, a sheath fold has a highly recurved hinge (figure 3a). A simple sheath fold has a circular to ovoidal cross section, and map areas dominated by sheath folds show many closed outcrop traces. Sheath fold development does not require folding and orthogonal cross-folding in order to create recurved hinges and ovoidal outcrop patterns. Rather, sheath folds are commonly thought to develop progressively in environments of simple shear by passive amplification of irregularities that extend upward across shear planes (Cobbold and Quinquis, 1980) (figure 3b). A structural irregularity (*e.g.*, a local culmination in an older fold hinge), a bolus of magma, or any other type of irregularity can be streaked out into a long finger by progressive simple shear. The higher the shear strain, the more elongate the sheath. Remarkably complex patterns can be produced by clustered irregularities (Skjernaa, 1989).

Our model contends that the Hyde School Gneiss bodies are sheath folds, produced in an environment of regional ductile shear. Furthermore, we have established the importance of ductile shear in rocks in the Lowlands other than the Hyde School Gneiss. Our model eliminates the D_4 cross folding of many previous authors (*e.g.*, Wiener *et al.*, 1984) (D_3 of Brown, 1989) and suggests instead that circular outcrop patterns and highly recurved hinges developed by sheath folding during their D_2 (or Brown's D_1). Such a model was proposed in passing by Whitney *et al.* (1989), but they cited no supporting evidence. Our work over the last several years provides strong evidence in support of a sheath fold model, and the following sections briefly outline that evidence.

EVIDENCE FOR REGIONAL DUCTILE SHEAR AND THE DEVELOPMENT OF SHEATH FOLDS

Circular or ovoidal outcrop patterns can be produced by dome-and-basin refolds resulting from two successive folding episodes of different orientations. Alternatively, circular or ovoidal outcrop patterns can be produced by sheath folds resulting from one episode of deformation dominated by ductile shear. Distinguishing between the two possibilities requires an understanding of both the 3-dimensional geometry of the structures and the related microfabrics.

Our model is based on evidence collected during detailed studies of fabrics and structures in the Hyde School Gneiss of the Payne Lake and Dodds Creek bodies, during reconnaissance work in several different granitic bodies in the Beaver Creek Region, and during work currently in progress on the Canton, North Pyrites, and Stalbird bodies of the Hyde School Gneiss (HSG) (figure 1).

Geometries of Macroscopic and Mesoscopic Structures

The first piece of evidence in favor of a sheath fold model for the formation of bodies of the HSG is that the ones we have studied are sheath-shaped. In the Payne Lake body, both the mass of HSG and the main regional foliation define an elongate domical structure with subvertical margins (figure 1). The Dodds Creek body was undoubtedly similar in geometry but was truncated nearly down the middle by slip along the late, brittle Pleasant Lake Fault Zone. It is now a steep-sided half dome. Interlayers of metasediment within both bodies mimic the sheath shape of the outer contacts and reveal a complex double "tip" in the sheath shape of the Payne Lake body (figure 1).

While both the Payne Lake and Dodds Creek bodies are nearly vertical sheaths, the Canton, North Pyrites, and Stalbird bodies have shapes consistent with interpretation as shallowly-plunging sheaths. Figure 1 shows the geometry of the complex, westsouthwest-plunging Canton body and the simpler northwest-plunging North Pyrites body. Reconnaissance work on the Stalbird body has revealed intriguing closed foliation patterns within the body itself, suggesting that the Stalbird body may consist of a series of "glove fingers".

If the HSG bodies did, indeed, form as sheath folds, one might expect to find evidence for other sheath-shaped structures in nearby areas in rocks other than the Hyde School Gneiss. Such structures do exist immediately north of the Payne Lake body and east of the Pleasant Lake Fault Zone in an area mapped by Lewis (1969). Here, upward closing sheath-shaped structures occur in metasedimentary gneisses and marbles, and a downward closing sheath-shaped structure occurs in the Pleasant Lake Metagabbro. Figure 1 shows how similar in geometry these structures are to the Payne Lake and Dodds Creek bodies.

One might also hope to find mesoscopic sheath folds in the region. Rare mesoscopic sheath folds in metasediments south of the Payne Lake body (stop 3) have long axes parallel to the Payne Lake sheath axis and provide additional evidence for the presence of macroscopic sheath folds. Rare mesoscopic sheath folds also exist in metasediments adjacent to mylonitized granitic gneiss above what Brown (1989) has termed the North Gouverneur Nappe Fault.

Microfabrics in the Hyde School Gneiss

One of the primary results of our work has been the discovery that what has been referred to for many years as "the main regional foliation" has the characteristics of a ductile shear fabric in many portions of the Hyde School Gneiss in all of the bodies we have examined. Features include porphyroclasts with core-and-mantle structure and asymmetric tails (sigma grains and rare delta grains), abundant matrix material consisting of dynamically-recrystallized grains, quartz ribbons (some many centimeters long), rare mica fish, and rare grain shape preferred orientation in quartz.

A second important result of our work is that the Hyde School Gneiss shows evidence of multiple shear fabrics. In the Payne Lake and Dodds Creek bodies, one shear fabric (the main regional foliation S_m) wraps around the margins of the bodies and defines the shapes of the sheaths (figures 1 and 4a). A second shear fabric (S_{d2}) lies parallel to the axial planes of the sheaths (figure 4b). This younger fabric lies parallel to S_m on the sheath fold limbs and cuts discordantly across both the main foliation and the margins of the body at the northeastern and southeastern hinge regions and in the cores of the bodies. Both S_m and S_{d1} in the Payne Lake body show east side up sense of shear. In the Dodds Creek body, S_m shows clear east side up sense of shear. Sparse data on S_{d1} in the

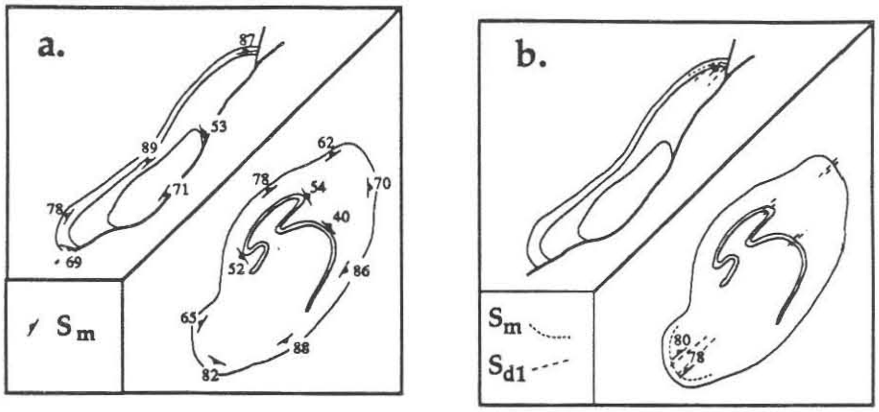
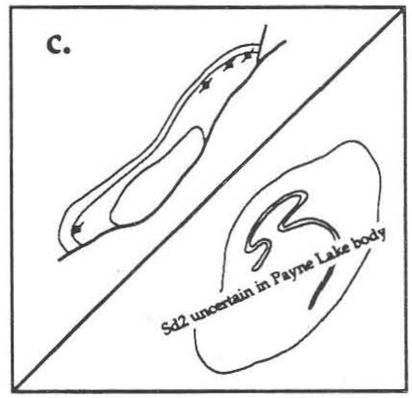


Figure 4. Attitudes of foliations in the Dodds Creek (upper left) and Payne Lake (lower right) bodies. 2a) Attitudes of the main shear fabric, S_m. 2b) Attitudes of the main shear fabric, S_m, and the older discordant shear fabric, S_{d1}. 2c) Attitudes of the younger discordant shear fabric (S_{d2}) from discreet ductile shear zones in the Dodds Creek body.



Dodds Creek body suggest east side up sense of shear as well, but data are too limited for us to confidently confirm the shear sense. Preliminary work in the Canton and North Pyrites bodies suggest that S_m and S_{d1} are clearly present at least in the North Pyrites body as well, with similar concordant and discordant relationships to the body as a whole.

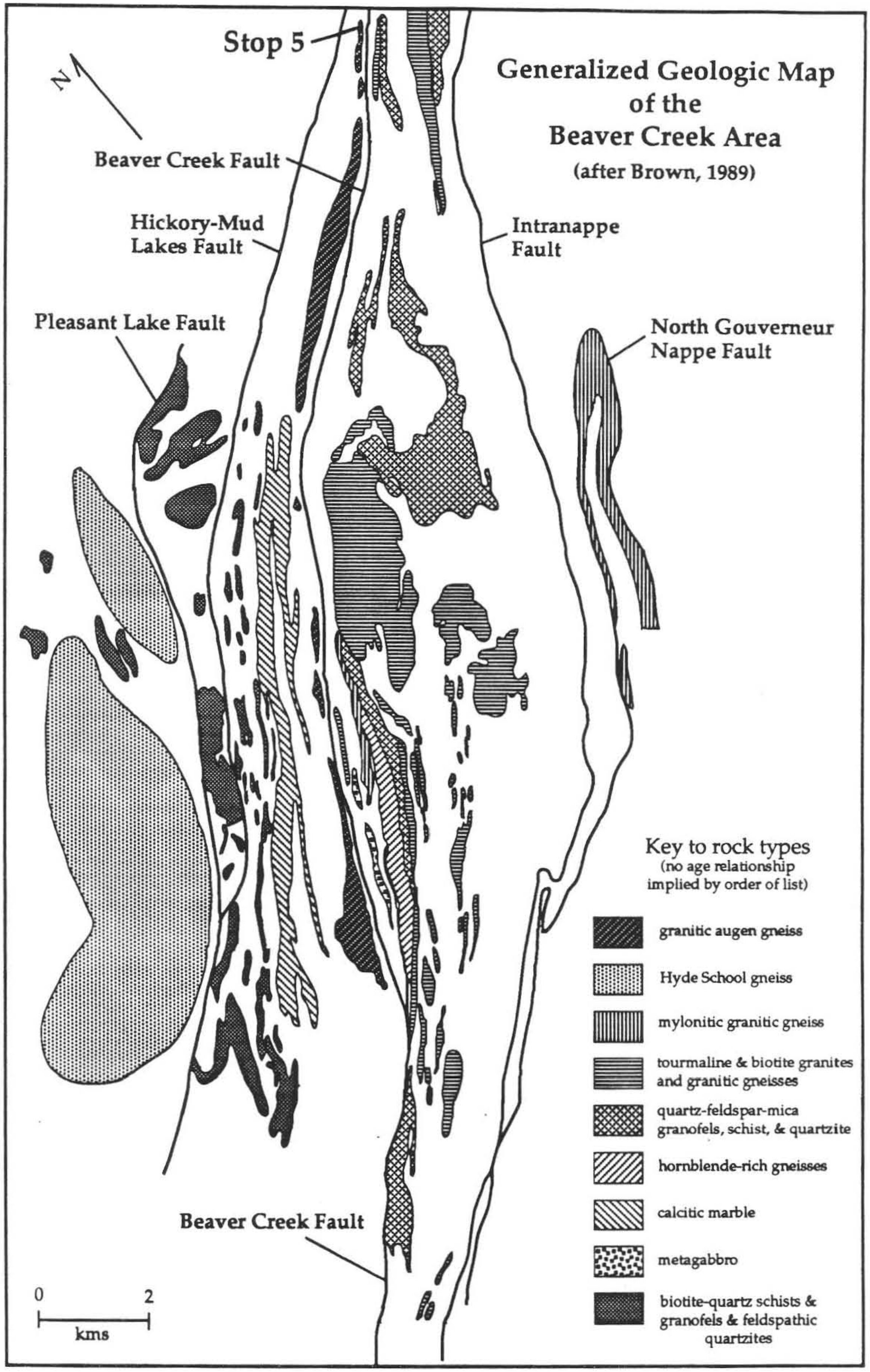
We have argued that the S_m and S_{d1} shear fabrics developed progressively in an environment of regional ductile shear (Tewksbury *et al.*, 1991; Tewksbury and Kirby, 1992). We have proposed early development of the main regional foliation in a deep, subhorizontal regional shear zone in an an environment of plate collision. As shearing continued, irregularities within the shear zone (formed by intrusion of granitic magmas that eventually became the Hyde School Gneiss??) amplified into sheath folds. The early shear fabric (S_m) and related lineations were reoriented as sheath folds grew, and a younger shear fabric (S_{d1}) developed parallel to the axial surfaces of the developing sheaths and with the same sense of shear as S_m. This discordant fabric formed parallel to S_m along the limbs of the sheaths but cut across S_m at the hinge regions.

Shear Fabrics in Other Rocks in the Lowlands

If the Hyde School Gneiss bodies were shaped by regional ductile shear, it stands to reason that one might also expect to find evidence for ductile shear in rocks other than the Hyde School Gneiss. We examined granitic gneisses and metasedimentary rocks immediately east and west of the Beaver Creek Fault Zone and immediately beneath the North Gouverneur Nappe Fault, including the following map units shown in figure 5: granitic augen gneiss, mylonitic granitic gneiss, tourmaline and biotite granites and granitic gneisses, calcitic marble, and quartz-feldspar-mica granofels, schist and quartzite. We chose to extend our investigation into the Beaver Creek region for several reasons. First, Brown (1989) reported both well-lineated granitic gneisses and mylonitic granitic gneisses in several portions of the region. Second, outcrop patterns of metasedimentary units lying in the area immediately west of the Beaver Creek Fault are attenuated in comparison to outcrop patterns of identical units farther northwest (figure 5). We suspected that shear along a major zone parallel to the Beaver Creek Fault Zone might have been responsible for the "shredded" character of the units. Third, east of the Beaver Creek Fault Zone, outcrop patterns of granitic gneisses and metasediments form a large sigmoid, with a smaller sigmoid containing mylonitic granitic gneisses "riding piggyback" to the west (figure 5). These sigmoids bear a striking similarity in morphology to the sigma grains seen in thin sections of ductily sheared rocks. We suspected that asymmetry of attenuated units in the "tails" might reflect major dextral shear in the region.

We made four important discoveries in the Beaver Creek region. First, the "main regional foliation" in many portions of the granitic gneisses is a well-lineated, strongly annealed fabric showing considerable evidence for ductile shear. This suggests that an early event of shear across the entire Beaver Creek region was responsible for creating the "main regional foliation", a conclusion consistent with similar findings in the Payne Lake and Dodds Creek bodies.

Second, while the general importance of early regional shear appears to be clear, the correlations between shear directions in the Payne Lake/Dodds Creek region and those in the Beaver Creek region are not. Stretching lineations and structural geometries in the Payne Lake/Dodds Creek region suggest dominantly vertical, east-side-up shear. Shear directions in the Beaver Creek region are more variable but are clearly not dominantly vertical. In fact, shallowly- to moderately-plunging shear directions are the rule, even where the main foliation dips steeply. Highly variable stretching lineation


Generalized Geologic Map
of the
Beaver Creek Area
(after Brown, 1989)
Stop 5
N
Beaver Creek Fault
Hickory-Mud Lakes Fault
Pleasant Lake Fault
Intranappe Fault
North Gouverneur Nappe Fault
Beaver Creek Fault
0
2
kms
Key to rock types
(no age relationship implied by order of list)
granitic augen gneiss
Hyde School gneiss
mylonitic granitic gneiss
tourmaline & biotite granites and granitic gneisses
quartz-feldspar-mica granofels, schist, & quartzite
hornblende-rich gneisses
calcitic marble
metagabbro
biotite-quartz schists & granofels & feldspathic quartzites

orientations in the Beaver Creek region suggest re-orientation of both shear fabrics and stretching lineations by subsequent deformation. Such a conclusion is supported by our observation that, while foliation and lineation orientation varies with position within the "sigmoid" east of the Beaver Creek Fault, no correlation appears to exist between fabric development and position in the sigmoid. This suggests that whatever produced the sigmoid occurred after development of the main regional foliation and was not accompanied by a pervasive fabric-forming event. We suggest that early, intense, pervasive regional shear may have been followed in the Beaver Creek region by more "compartmentalized" shear, with localized, complex folding between zones of high shear strain, producing multiple shear fabrics in some rocks, but not in others. The asymmetry of the sigmoid and the pattern of re-orientation of lineations suggests that the region may have been dominated by late dextral shear across wide, steeply-dipping, northeast-striking zones.

Third, Brown (1989) used the geometries of folds to suggest that the North Gouverneur Nappe was emplaced by southeast-directed transport. Our study of kinematic indicators in granitic gneisses beneath the North Gouverneur Nappe Fault and megacrystic hornblende gneisses above the Fault indicates northwest-directed transport.

Fourth, metasediments in the Beaver Creek Region show remarkably poor preservation of ductile shear fabrics. Strongly-lineated and sheared granitic gneisses lie within centimeters of featureless metasediments. We believe that, while substantial annealing in the granitic gneisses eliminated much of the fine-grained, dynamically-recrystallized material, quartz ribbons and porphyroclasts survived. Many of the metasedimentary lithologies did not have appropriate mineralogies to develop quartz ribbons and asymmetric porphyroclasts, and annealing completely wiped out whatever ductile shear features were produced in the rocks. Rare lineated quartzites, quartz-clot marbles, and megacrystic igneous interlayers are the only lithologies we found that preserve shear fabrics. This has implications for studying regional shear in the Lowlands and suggests that the absence of shear fabrics in metasedimentary rocks does not necessarily imply the absence of ductile shear.

Figure 5 (previous page). Generalized geologic map of the Beaver Creek Region (after Brown, 1989).

Evidence for Protracted Shear and Changes in Shear Sense

All of the granitic gneisses we have examined have shown evidence of multiple shear fabrics suggesting protracted ductile shear. Most of the regions we examine also showed complexities in both shear sense and character of deformation. In both the Dodds Creek and Beaver Creek areas, late ductile shear had a sense of slip opposite to that of earlier ductile shear, and, in the Dodds Creek body, late ductile shear occurred along discreet zones rather than pervasively throughout the body. In addition, all of the regions show a progression from ductile to brittle shear conditions. Limited evidence from cataclasites in the Dodds Creek body adjacent to the Pleasant Lake Fault Zone suggest that late brittle faulting may have involved a large component of strike slip. Late reversals in shear sense, compartmentalized shear, and the transition from ductile to brittle conditions may all be part of a complex system of extensional unroofing of the Lowlands region, a process that has also been suggested by a number of people for evolution of the Carthage Colton Mylonite Zone.

The most important implication of complex shear fabrics in the Lowlands is that ductile shear was an important regional aspect of Lowlands deformation and is not something to be viewed as limited in importance either spatially or temporally. Models for evolution of both major and minor structures must be consistent with this observation, and we believe that a sheath fold origin for the bodies of Hyde School Gneiss, as well as other quasi-circular structures in the Lowlands, is the most reasonable one.

MAJOR QUESTIONS FOR THE LOWLANDS AS A WHOLE

The sheath fold model raises a number of interesting questions for the Lowlands as a whole. First, quartz ribbon lineations and the orientations of long axes of possible sheath folds vary considerably across the Lowlands. Both are vertical at Dodds Creek and Payne Lake. Lineations plunge shallowly westsouthwest in the Canton body and shallowly northwest in the North Pyrites body. Stretching lineations plunge north, northwest, and northeast in granitic gneisses of the Beaver Creek region. Why the variation? We also do not yet know the pattern of shear sense across the entire region.

There is also the question of timing of shear. U/Pb zircon geochronology indicates that the Hyde School Gneiss has an average age of 1225-1230 Ma

(McLelland *et al.*, 1992). Granitic gneisses from the Beaver Creek region are part of a younger series of granitic rocks intruded between 1150 and 1170 Ma. The oldest fabric in each is a shear fabric. Is it the *same* shear fabric? If it is, shearing clearly must postdate intrusion of the younger granites, long after formation of the Hyde School Gneiss protolith. On the other hand, both Tewksbury (1992) and McLelland (in press) have postulated that the Hyde School Gneiss was intruded into a major regional shear zone, providing a nice irregularity to be amplified into large sheath folds and localizing major shear by melt-enhanced deformation. If this were true, then the two main shear fabrics (S_m and S_{d1}) in the Hyde School Gneiss must have formed before the Beaver Creek gneisses were intruded. This means, of course, that the oldest shear fabric in the Beaver Creek gneisses formed by a later shearing event in the Lowlands, complicating still further the picture of regional shear.

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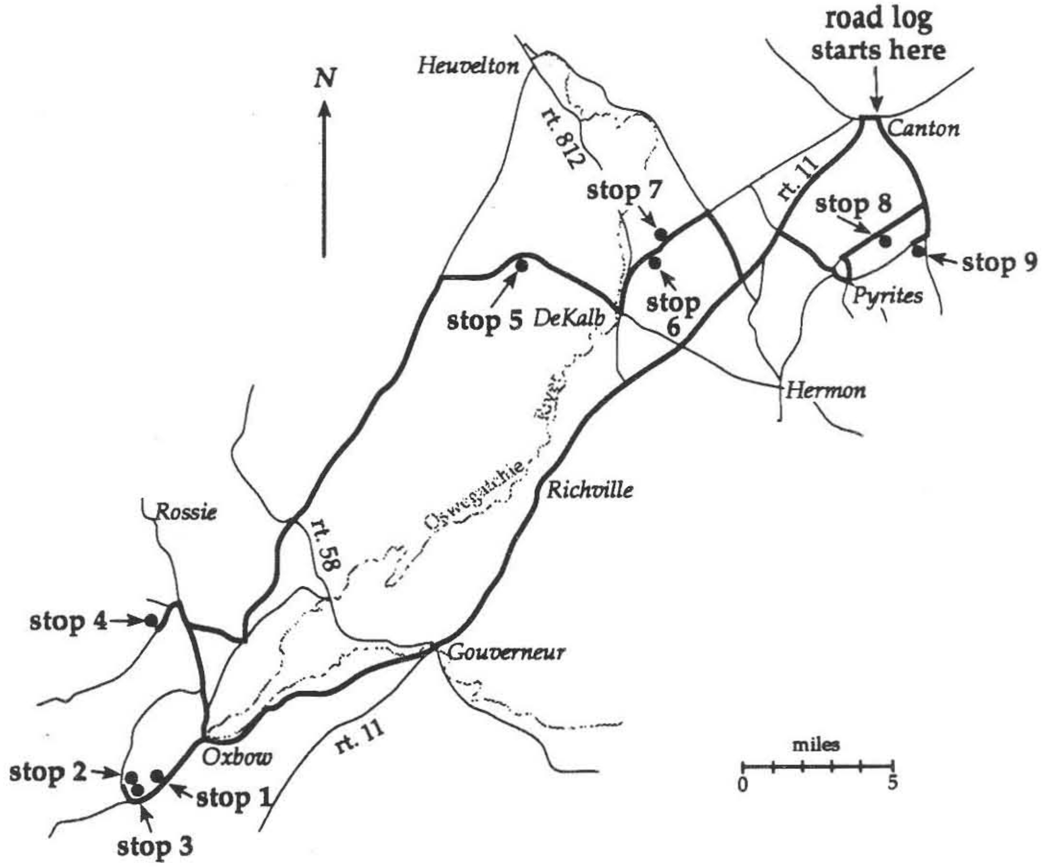

Figure 6. Route map for the field trip, with heavy lines indicating the route of the trip. The trip begins and ends in Canton.

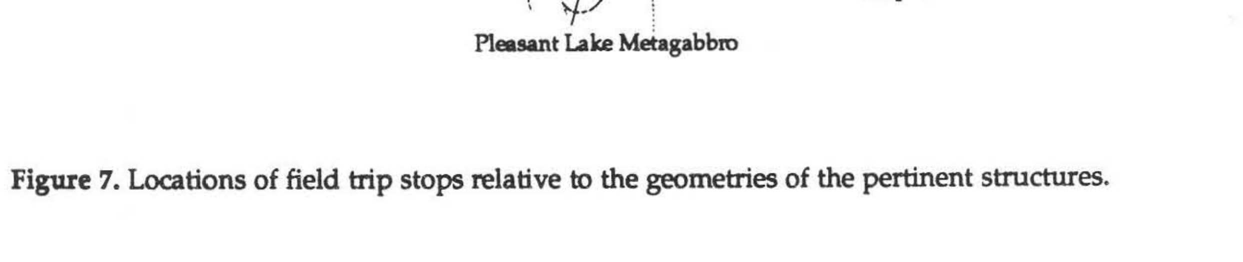

Figure 7. Locations of field trip stops relative to the geometries of the pertinent structures.

ROAD LOG FOR RETHINKING GRENVILLE-AGE DEFORMATION

A map view of the following road log appears in figure 6. The locations of stops relative to the geometries of pertinent structures in the Lowlands appear in figures 1 and 7.

cumulative mileage	miles from last point	route description
0.0	0.0	Begin at traffic light in downtown Canton at the intersection of Park Street and Main Street. Proceed west on route 11 (Main Street).
0.3	0.3	Turn left at traffic light, following route 11.
1.0	0.7	Hyde School Gneiss of Canton body on the left.
4.3	3.3	The famed Snake Roadcut. The marbles exhibit complex fold patterns, some of which may be sheath folds.
8.4	4.1	Dekalb Junction. Continue straight ahead on route 11.
24.2	15.8	Downtown Gouverneur at intersection of routes 58 and 11. Continue straight ahead on route 11.
24.5	0.3	Turn right onto Johnstown Street.
30.6	6.1	Hamlet of Wegatchie.
33.0	2.4	Hamlet of Oxbow.
33.2	0.2	Turn left onto Jefferson County route 22.
34.7	1.5	Payne Lake Fishing Access Site, where there are good views of cliffs of Hyde School Gneiss on the eastern margin of the Payne Lake body. Fields east of the Payne Lake body are largely underlain by marble.
35.6	0.9	**STOP 1.** Park at the gate on the west side of the road, and walk west along the State access at the edge of the field to the outcrops of Hyde School Gneiss (HSG) visible from the road.

STOP 1: Main foliation (S_m) in the Hyde School Gneiss along the eastern limb of the Payne Lake body (figure 7). The contact is not exposed but lies between non-resistent metasediments and resistant HSG at the west edge of the field. The best exposures lie along a very small stream bed in the first set of outcrops immediately south of the fishing access path. The stop description begins in the stream bed at the first set of HSG outcrops.

The HSG at this stop is a lineated and well-foliated pink leucogneiss with interlayered amphibolite. The main foliation (S_m) is subvertical and strikes parallel to the margin of the body, and the lineation (L_m) plunges steeply in the main foliation plane. Because the outcrops are dominantly quasi-horizontal glacially polished surfaces, the lineation is difficult to see. One of the only vertical foliation surfaces exposed at this stop lies in the stream bed, where it is clear that the lineation is a very nice quartz ribbon lineation.

Thin sections show that the main foliation is a well-developed shear fabric displaying sigma grains with core and mantle texture, quartz ribbons ramping from shear plane to shear plane, and dynamically-recrystallized grains. The fabric is well-recovered and shows polygranular quartz ribbons, no grain shape preferred orientation of fine quartz grains, and generally straight grain boundaries. Sense of shear is east side up.

The HSG contains abundant coarse-grained granite and pegmatite, and it is clear at outcrops such as this one that granitic liquids were present throughout the shearing history of the HSG. Some pegmatites are thoroughly sheared, streaked out parallel to S_m as bumpy chains of coarse K-feldspar porphyroclasts in the main foliation plane. Other coarse granitic phases are discordant and show no fabric at all. A particularly nice example of an intermediate state occurs on the flat part of the outcrop above the lineated surface along the stream bed. Here, coarse-grained granite is clearly discordant to the main foliation but is itself weakly foliated.

While much of the HSG in the Payne Lake body is devoid of amphibolite, localities such as this one at the margin of the body typically contain abundant interlayers of amphibolite. Amphibolite interlayers lie parallel to the main foliation, and have been sheared out and streaked out parallel to the foliation. It cannot be overemphasized that the current relationship between amphibolite and leucogneiss is structural.

Amphibolite layers are discontinuous along strike and are commonly segmented. Some of the layer terminations are clearly isoclinal fold hinges. A fine example of such a fold occurs in the stream bed immediately east of the large patch of junipers separating the stream bed from the higher outcrops extending to the south. Here, a biotitic amphibolite layer has been folded into an isoclinal fold with the main foliation lying parallel to the axial plane.

Outcrops stretching to the south show other important features of the interlayered amphibolites. As in many of the other bodies of the HSG, amphibolite layers are divided into blocky segments separated by medium- to coarse-grained granite. The granite separating the blocks is typically unfoliated or less well-foliated than the adjacent leucogneiss. A number of amphibolite interlayers in this large exposure show fold terminations, and many of the fold sets are not simple trains of isoclinal folds. While none are unequivocally sheath folds, many have outcrop patterns that could reflect sheath folding.

35.6	0.0	Continue southwest on Jefferson County route 22.
36.6	1.0	Turn right onto New Connecticut Road. Ask permission to visit stops 2 and 3 at the Raymon Farm on the corner of New Connecticut Road and County Route 22. Resistant rocks of the Hyde School Gneiss form a prominent knobby, wooded rise across the fields to the north of New Connecticut Road. The southern contact of the Payne Lake body with surrounding metasediments lies approximately at the break in slope below the wooded rise.
36.8	0.2	Newly excavated roadcut of serpentinized marbles.
37.2	0.4	**STOP 2.** This property is farmed by the Raymon family at the corner of New Connecticut Road and County Route 22; ask permission before visiting this locality. Park along the road, and walk north across the field. Follow the farm track that rises from the field diagonally up across the contact at the break in slope marking the transition to more resistant HSG. Proceed to the top of the rise immediately west of the farm track. The stop description begins in the HSG outcrops at the top of the rise.

STOP 2: Discordant foliation (S_{d1}) in the Hyde School Gneiss along the southern end of the Payne Lake body (figure 7).

Figure 7 shows clearly that this locality lies at the southern end of the Payne Lake body, where the main foliation (S_m) in the HSG, as well as the compositional layering and the contact between HSG and surrounding units, swings around the end of the body. At this locality, S_m and the contact dip very steeply south and strike approximately N35W.

The most prominent feature in the dark pink leucogneiss at the top of the rise is a well-developed, steeply-plunging quartz ribbon lineation that is well-exposed on quasi-vertical surfaces. Close examination of the outcrop shows a striking thing. The lineation is associated with a weak, sub-vertical foliation striking approximately N55E, parallel to the *length* of the Payne Lake body, *not* parallel to the margin of the body. The main foliation (S_m) is difficult to locate in this exposure, where the lineated fabric is well-developed and where there is no compositional layering in the HSG. Interlayered amphibolite *is* exposed to the northwest below the crest of the rise, and the orientation of the foliated amphibolite makes it very clear that the prominent lineated fabric is discordant to both the main foliation (S_m) and the compositional layering. We have named the well-lineated, discordant fabric S_{d1} (the subscript "1" derives from the fact that we find a second discordant fabric of slightly different character but similar orientation in the Dodds Creek body, as described in the log for stop 4).

Thin sections show that S_{d1}, like S_m, is a well-developed shear fabric displaying sigma grains with core and mantle structure, quartz ribbons ramping from shear plane to shear plane, and dynamically-recrystallized grains. The fabric is well-recovered and shows polygranular quartz ribbons, no grain shape preferred orientation of fine quartz grains, and generally straight grain boundaries. Sense of shear is east side up. S_{d1} is a distributed shear fabric but is not equally well-developed at all localities around the southern margin of the Payne Lake body. In some areas of outcrop, the most prominent fabric in the rock is the well-lineated S_{d1} fabric; in other areas, the most prominent fabric is S_m.

In summary, the Payne Lake body exhibits two distinct shear fabrics, one parallel to the margins of the body (S_m) and one parallel to the long dimension of the body (S_{d1}). Along the eastern and western limbs of the body, the two fabrics are parallel to one another and are consequently particularly well-developed, especially along the eastern margin (e.g., at the previous stop). We have interpreted S_m to have been the earlier fabric developed in a sub-horizontal regional shear zone. As sheath folds grew, S_m was folded into very large folds with highly recurved hinges. Figure 1 shows the geometry of the Payne Lake sheath. S_{d1} developed with a shear sense consistent with earlier shear directions as a younger shear fabric parallel to the axial plane of the growing sheath. Along the limbs of the sheath, S_{d1} lies parallel to S_m (figure 4b); in the hinge region at the north and south ends of the body, S_{d1} is discordant to S_m.

37.2	0.0	Continue west on New Connecticut Road.
37.3	0.1	Turn around in driveway, and go back east on New Connecticut Road.
37.5	0.2	**STOP 3.** This property is owned by the Raymon family at the corner of New Connecticut Road and County Route 22; ask permission before visiting this locality. Park along the road, and walk north across the field. The contact between the Payne Lake body and adjacent units lies at the prominent break in slope at the edge of the wooded area. This stop description covers exposures of units adjacent to the Payne Lake body in outcrops on the low shoulder north of the field but south of the Payne Lake body itself. The stop description begins in the cluster of outcrops at the top of the rise.

STOP 3: Sheath folds and late dike with mylonitic fabric in units adjacent to the Hyde School Gneiss (figure 7).

A variety of metasediments, including feldspathic quartzites, marbles, and garnet-sillimanite gneiss, are interlayered with leucogneiss in these outcrops. The contact here between HSG and surrounding metasediments gives every appearance of being gradational.

Compositional layering and the main foliation (S_m) in these units dip steeply and strike approximately N80W, parallel to the margin of the Payne Lake body. In the flat outcrops at the top of the rise, garnet-sillimanite gneiss exhibits both eye-shaped folds several centimeters across and refolded isoclinal folds. We interpret the eye-shaped folds as sheath folds. Sheath fold long axes and isoclinal fold hinges plunge steeply in the foliation plane, parallel to quartz ribbon stretching lineations in adjacent HSG. The presence of mesoscopic sheath folds provides additional supporting evidence for interpretation of the Payne Lake body as a large sheath fold.

Refolds in isoclinal intrafolial folds and tight to open folds in S_m also occur in this outcrop. A moderately well-developed foliation is locally developed parallel to the axial planes of these folds. The folds plunge steeply, and the axial plane foliation is subvertical and strikes approximately N50E, subparallel to S_{d1} and to the long dimension of the Payne Lake body.

Walk east to the last major set of outcrops before the ground drops away to the farm in the distance to the southeast. A sub-vertical dike approximately 15cm thick and striking N60E cuts interlayered metasediment and leucogneiss. The dike displays a prominent mylonitic fabric that is best developed within the dike itself but that does occur in the country rock on either side of the dike. The mylonitic fabric is subvertical and strikes approximately N50E, subparallel to the long dimension of the Payne Lake body and at a high angle to S_m in the outcrop.

Thin sections of the mylonitic fabric of the dike show sigma grains with core and mantle structure, quartz ribbons, and dynamically-recrystallized grains. The fabric in this dike is the least-recovered of the fabrics at Payne Lake. Serrated grain boundaries are common, and some grain shape preferred orientation of fine quartz is present. Some later cataclasis is also evident. Orientations of outcrop surfaces makes it impossible to locate the stretching direction of quartz ribbons in the field. Multiple sections, however, show that quartz elongation is best developed in vertically-oriented sections, suggesting a steep stretching lineation. Shear sense is east side up, consistent with shear sense on both S_m and S_{d1}. Based upon shear sense and orientation, the argument could be made that this fabric, and the axial planar fabric in the sheath fold outcrop, are likely S_{d1} fabrics. The fact that the mylonitic dike fabric is relatively poorly-recovered suggests that it represents a late phase in development of S_{d1}.

The features at this stop have two implications. First, shear in the Payne Lake body apparently had a long history, developing from a major shear zone with regional shear fabrics (S_m) to sheath folds with axial planar shear fabrics (S_{d1}) to late, discreet zones of shear with poorly-recovered mylonitic fabrics (late phase S_{d1} or S_{d2}). Second, intrusion of granitic liquids persisted until the latest phases of shear, and some were clearly important in localizing melt-enhanced shear. This raises the question of the importance of melt-enhanced deformation in the overall development of the Payne Lake sheath fold.

37.5	0.0	Continue east on New Connecticut Road.
37.6	0.1	Newly excavated roadcut of strongly lineated metasediments.
37.9	0.3	Turn left onto Jefferson County route 22.
41.2	3.3	T-intersection. Turn left onto Jefferson County route 25.

42.1	0.9	Turn left toward Rossie on St. Lawrence County route 3. Good views of the northern end of the Payne Lake body to the southwest.
46.0	3.9	Bridge over the Indian River. The river channel follows the Pleasant Lake Fault Zone (PLFZ), a major late brittle structure (figure 1). Slip along the PLFZ has removed half of the Dodds Creek body, leaving the body with a steep-sided, half-dome shape. Cataclasis along the PLFZ significantly reduced the resistance of gneisses along the fault. Swamp and floodplain cover the entire width of the fault zone, and rocks within the fault zone itself are not exposed anywhere along the Indian River. Mylonites in the Lowlands, on the other hand, are *not* typically more weakly resistant than unmylonitized lithologies.
46.2	0.2	Turn left onto Lead Mine Road.
46.7	0.5	Turn left onto River Road.
46.9	0.2	Good view of the north end of the Dodds Creek body "at 2:00". The contact between the HSG of the Dodds Creek body and the weakly resistant metasedimentary lithologies underlying adjacent fields lies at the base of the knobby exposures of pink leucogneiss.
47.3	0.4	**STOP 4.** This property is owned by Mr. Edmon Phalen in the farm next door; please ask permission to visit this locality. Park along the road, and walk to the outcrops on the knoll west of the road.

STOP 4: Main fabric (S_m) and discordant foliation (S_{d2}) in the Hyde School Gneiss along the northern end of the Dodds Creek body (figure 7).

The HSG at this stop near the margin of the Dodds Creek body is a pink, medium- to fine-grained leucogneiss with abundant interlayers of amphibolite. Flat outcrops on the north side of the knoll near the barnyard have abundant interlayers of quartzite several centimeters thick. While both the Dodds Creek and Payne Lake bodies have been previously mapped as consisting entirely of leucogneiss and interlayered amphibolite, we have established that both bodies, in fact, contain significant metasedimentary interlayers. The Dodds Creek body contains both thin interlayers of metasediment, as at this stop, and two wide swaths of interlayered marble, quartzite, and garnet-sillimanite gneiss (the concentric half-rings in figure 1). The Payne Lake body also contains a prominent metasedimentary interlayer with a peculiar "ear" shape (also shown in figure 1).

The HSG at this stop is well-foliated parallel to compositional layering, and thin sections from outcrops at the top of the knoll show that this main foliation (S_m) is a shear fabric, as it is at Payne Lake. Fabrics display sigma grains with core and mantle structure, quartz ribbons ramping from shear plane to shear plane, and dynamically-recrystallized grains. The fabric is well-recovered and shows polygranular quartz ribbons, no grain shape preferred orientation of fine quartz grains, and generally straight grain boundaries.

S_m at this stop is sub-vertical and strikes N95E, parallel to the margins of the Dodds Creek body. Stretching lineations plunge moderately steeply in the S_m foliation plane. At the southern margin of the Dodds Creek body, quartz ribbon lineations have a somewhat more variable orientation, consistent with reorientation during development of a large sheath fold in S_m. Along the margins of the body, quartz ribbon lineations plunge steeply. Sense of shear along the margins is east side up, as it is at Payne Lake.

A number of prominent discreet ductile shear zones several centimeters thick occur in the HSG at this stop and elsewhere in the Dodds Creek body. These zones are sub-vertical and strike N40E, approximately parallel to the long dimension of the Dodds Creek body. At the north and south margins of the Dodds Creek body, the mylonitic fabric of these zones is clearly distinct from the main shear fabric (S_m), because it is discordant to S_m. As at Payne Lake, the two fabrics can be difficult to distinguish from one another where they are quasi-parallel along the long margins of the Dodds Creek body.

There are four significant differences between the main foliation (S_m) and the younger discordant mylonitic fabric. First, S_m is a distributed shear fabric, moderately well-developed to well-developed over zones 10's to 100's of meters wide. The discordant fabric, one the other hand, is distinctly domainal, occurring in ductile shear zones several centimeters thick. Second, the discordant fabric is clearly a mylonitic fabric in outcrop; the taffy-like appearance stems from abundant quartz ribbons and dynamically-recrystallized grains. Despite the fact that S_m is not as clearly mylonitic in outcrop, thin sections show unequivocal shear fabrics. In fact, when one is hunting for foliations in lichen-covered outcrops without amphibolites in the Dodds Creek body, it is very easy to latch onto the discordant fabric as the main fabric, because it is so easy to see. One must be careful to look for *both* fabrics. Third, the discordant fabric is only poorly-recovered. Serrated grain boundaries are common, and pronounced undulose extinction and grain shape preferred orientation of fine quartz are present. Fourth, and most interesting, the sense of shear in this discordant fabric is *opposite* from shear both on the main foliation (S_m) in the Payne Lake and Dodds Creek bodies and on the discordant fabric (S_{d1}) in the Payne Lake body. Every sample we examined from the discreet ductile shear zones shown west side up and slightly oblique sense of shear. We named this fabric S_{d2}, presuming from its un-recovered character and opposite shear sense that it is younger than S_{d1} at Payne Lake. Figure 4c shows the geometry of S_{d2} in the Dodds Creek body.

As at Payne Lake, melt-enhanced deformation seems to have been important in late shearing at Dodds Creek. Several of the ductile shear zones at this stop are developed in what appear to be granitic dikes injected across S_m roughly parallel to S_{d2}.

We have found only limited evidence at Dodds Creek for an older pervasive discordant fabric (S_{d1}) similar to the one discovered in the Payne Lake body. At this stop, HSG exposed on the sloping outcrop surface below the phone pole shows a very weak pervasive fabric discordant to S_m and roughly parallel to the long dimension of the Dodds Creek body. Exposures along the Indian River immediately adjacent to a spur of the Pleasant Lake Fault Zone at the northern end of the Dodds Creek body show fabrics of similar orientation related to folds much like those at stop 3 in the Payne Lake body. Thin sections show that these are weakly-developed shear fabrics.

The HSG at this stop and at many places in the Dodds Creek body is laced with fracture swarms oriented approximately parallel to the Pleasant Lake Fault Zone. Thin sections show nice cataclastic textures. It is important to note that, while intensity of cataclasis does increase with proximity to the Pleasant Lake Fault Zone, intensity of ductile shear fabric development does *not*.

Evidence from the Dodds Creek body reveals an even more protracted history of ductile shear than that suggested by work in the Payne Lake body. Fabrics in the Dodds Creek body are consistent with development of S_m in a regional subhorizontal shear zone. Sheath fold development followed, with production of weak axial planar fabric (S_{d1}). Shear sense reversed, and discreet ductile shear zones developed but did not have time to recover before they were affected by cataclasis. Shear sense reversal and progression to brittle deformation is consistent with late extensional unroofing in the Lowlands.

47.3	0.0	Continue south on River Road.
47.4	0.1	Turn around in the partly paved road on the left. Proceed back north on River Road.
47.6	0.2	Good views of the Pleasant Lake Fault Zone to the right of the road, with rocks east of the PLFZ underlying the wooded rise beyond the river.
48.0	0.4	T-intersection. Turn right onto Lead Mine Road.
48.5	0.5	T-intersection. Turn right onto St. Lawrence County route 3.
48.7	0.2	Bridge over the Indian River (again).
49.3	0.6	Turn left onto Scotch Settlement Road.
51.2	1.9	T-intersection. Turn left onto Old State Road (St. Lawrence County route 10).
55.9	4.7	Intersection with route 58. Continue straight on Old State Road (St. Lawrence County route 10).
65.7	14.5	Turn right onto Mayhew Road.
68.3	2.6	Farm for permission for STOP 5.
68.9	0.6	**STOP 5.** Park on the right hand side of the road. This property is owned by the Amish farm on the north side of the road and back about 0.6 miles; please ask permission to visit this locality. Walk into the field to the south of the road to the crest of rounded knobs of granitic gneiss about 1600′ from the road, bypassing the wooded knoll approximately 1050′ from the road.

STOP 5: Shear fabrics in biotitic augen gneiss and surrounding metasedimentary lithologies immediately west of the Beaver Creek Fault Zone (figures 1 and 5).

Figure 5 shows a condensed and generalized geologic map of the Beaver Creek region based on an excellent and detailed map by Brown (1989). Several aspects are pertinent to this stop. First, granitic gneisses of two different ages appear in the region. The *ca.* 1225-1230 Ma Hyde School Gneiss is exposed in two bodies, the larger Hyde School body and the smaller Hickory Lake body. The other granitic gneisses in the region are younger than the HSG, having been intruded *ca.* 1150-1170 Ma. Second, while controversy rages over whether the HSG was originally plutonic or volcanic, no one disputes the plutonic origin of the younger granitic gneisses in the Beaver Creek region. Third, the region is divided into a number of elongate zones by northeast-striking faults, including the Hickory-Mud Lakes Fault, the Beaver Creek Fault and the Pleasant Lake Fault (the northern extension of the fault that cuts off the Dodds Creek body, as described at stop 4). Fourth, outcrop patterns of both metasedimentary and metaplutonic units lying immediately west of the Beaver Creek Fault Zone (BCFZ) are attenuated and elongated NE-SW, while similar units have larger, more irregular outcrop patterns farther northwest, suggesting the possibility of major ductile shear in the zone west of the BCFZ. Fifth, both the granitic gneisses and the metasedimentary units immediately west of the Beaver Creek Fault Zone are well foliated and display the "main regional foliation". This stop will give us a chance to study the character of the main regional foliation in several lithologies other than the Hyde School Gneiss.

At this stop, we will examine the most northerly of a series of seven elongate granitic gneiss bodies lying immediately west of the Beaver Creek Fault Zone (figure 5). This granitic gneiss is not only different in age from the HSG but also different in character, being a pink to grayish-pink, coarse-grained biotite-quartz-oligoclase-microcline gneiss with distinctive microcline augen.

These gneisses are spectacularly lineated – quartz ribbons lie like pieces of linguini on the steeply-dipping foliation surfaces exposed on the knoll. The lineations are best viewed on the sub-vertical faces of the east side of the knoll. Lineations plunge approximately 25, 40E.

The foliation carrying the lineation is the main regional foliation and shows characteristics that indicate formation by ductile shear. In thin section, the foliation shows clear fabric asymmetry in sigma grains and ramping quartz ribbons. Relatively coarse grain size in porphyroclast tails suggests a period of annealing following development of the main shear fabric. By contrast, the early shear fabric in the HSG of the Payne Lake and Dodds Creek bodies is recovered but not well-annealed. Shear sense in the Beaver Creek granitic gneisses shows consistent sinistral strike slip with a small component of east side down motion along subvertical planes striking approximately N40E. The fact that the gneiss bodies are elongate parallel to the main shear fabric in the rocks suggests that the individual bodies may have been intruded into a developing shear zone. Several of the bodies farther southwest (figure 5) that show only poorly-developed shear fabrics may have been intruded either relatively late or into zones that did not experience as much subsequent shear strain.

As in the Payne Lake and Dodds Creek bodies of the Hyde School Gneiss, the granitic gneisses west of the Beaver Creek Fault Zone show evidence in thin section of additional shear fabrics younger than the shear fabric of the main regional foliation. Some samples show a younger well-recovered but unannealed shear fabric. This fabric displays classic core and mantle structure around sigma porphyroclasts, polygranular quartz ribbons, and grain size reduction. This younger fabric appears to lie parallel to the main foliation. Shear sense consistently shows a component of sinistral strike slip.

Some thin sections show a third shear fabric, this one an unrecovered fabric. This fabric is characterized by quartz grain shape preferred orientation, biotite fish, and rare feldspar sigma grains. Sense of shear is opposite that shown by earlier phases and has a component of dextral, rather than sinistral, strike slip.

Interestingly enough, the dextral shear sense observed on this youngest shear fabric is, in fact, the sense of shear that one might infer from the geometry of the sigmoid east of the Beaver Creek Fault Zone (figure 5), and it is also the same as the sense of shear that we have suggested for the Pleasant Lake Fault Zone where it truncates the Dodds Creek body farther southwest. Late formation of the sigmoid is consistent with the results of our reconnaissance work in the sigmoid, which suggest that formation of the sigmoid postdates development of the main foliation and lineation in that region.

Multiple shear fabrics suggest a protracted history of ductile shear, much as we observed in the Payne Lake/Dodds Creek region. Changes in shear direction also suggest a complicated kinematic picture.

Walk 240′ southwest from the crest of the knoll. While the contact itself between granitic gneiss and surrounding metasediments is not exposed, outcrops of metasediment lie very close to granitic gneiss on the east side of the knoll. As you walk southwest, examine the character of the foliation in the marbles. The foliation in the marbles and calc-silicate gneisses is defined primarily by compositional layering and lies parallel to the prominent lineated foliation in the augen gneiss. One of the striking aspects of these rocks is that spectacularly lineated granitic gneisses with well-developed shear fabrics lie within centimeters of metasedimentary lithologies that show absolutely no microfabric evidence of ductile shear.

The only fabric asymmetry that we noted in the metasediments occurs in the outcrop of marble 240′ southwest of the knoll where we first examined the granitic gneiss. This rock is a marble with quartz lozenges several millimeters to centimeters in size floating in a sea of coarse, equant calcite grains. While the calcite aggregate preserves absolutely no record of the shear that produced the spectacular lineations in the adjacent granitic gneisses, many of the quartz lozenges have a distinctly asymmetric shape. The lozenges are sigmoidal in shape and ramp from one foliation plane to another. Shear sense is left lateral with a small component of down-to-the-east motion. This sense of slip is consistent with that observed for the earliest microfabrics in the granitic gneiss.

Well-lineated rocks with good kinematic indicators appear to occur primarily in the granitic gneisses of the region. The metasediments we examined here and elsewhere in the Beaver Creek region preserve essentially no kinematic indicators, even in locations within centimeters of highly-sheared granitic gneiss. Several factors may be involved. If melt-enhanced deformation was important during shear, the granitic material may have concentrated the shear, leaving adjacent metasediments with comparatively low shear strains. Second, quartzofeldspathic aggregates are ideal for preserving the kinds of kinematic indicators associated with ductile shear. Marble-bearing metasediments may, in fact, have accumulated as much shear strain as adjacent granitic gneisses, but shear fabrics may have annealed completely in the metasediments. Regardless of the cause, the effect is an important one to note and suggests that trying to sort out the history of regional shear in the Lowlands by examining the metasedimentary lithologies may well be an exercise in frustration.

In summary, the "main regional foliation" is clearly a shear fabric in both the well-foliated and lineated granitic gneisses we observed in the Beaver Creek Region and in the Hyde School Gneiss of the Payne Lake and Dodds Creek bodies, despite the fact that the Hyde School Gneiss is considerably older. Granitic gneisses of both ages also show conspicuous evidence for protracted ductile shear with complex shear histories. All of the evidence points toward the importance of ductile shear across the Lowlands over a protracted period of time in development of both major and minor structures.

Walk approximately 200′ toward Beaver Creek to small, rounded outcrops of

gray to white marble. You are standing right at the edge of the Beaver Creek Fault Zone, which is very much like the Pleasant Lake Fault Zone that we saw at stop 5 – no outcrop and lots of creek and swamp. Close examination of the marbles in these outcrops reveals little in the way of fault zone features, despite proximity to the Beaver Creek Fault Zone. The lack of major cataclastic features in outcrops immediately adjacent to the Beaver Creek Fault Zone is also reminiscent of the Pleasant Lake Fault Zone.

68.9	0.0	Continue southeast on Mayhew Road.
69.1	0.2	Cross Beaver Creek and the Beaver Creek Fault Zone. The lack of outcrop in the weakly-resistant cataclastic rocks of this late fault zone is similar to that along the Pleasant Lake Fault Zone.
72.5	3.4	Cross the Oswegatchie River.
72.6	0.1	Hamlet of DeKalb. Turn left onto route 812.
73.7	1.1	Hamlet of Coopers Falls.
73.9	0.2	Turn right onto Old Canton Road.
74.0	0.1	Crossing the "Race Track". This low area of fields and swamps sweeping in a broad arc marks the weakly resistant metasedimentary rocks bordering the more resistant Hyde School Gneiss of the Canton body. The road climbs out of the Race Track onto HSG, which crops out in abundant rounded knobs.
74.7	0.7	**STOP 6.** Low pink outcrop on the east side of the road.

STOP 6: Lineated Hyde School Gneiss of the Canton body (figure 7).

If time permits, we will stop briefly to examine well-lineated Hyde School Gneiss of the Canton body at this locality.

HSG in the Canton body is lithologically similar to that in the Payne Lake and Dodds Creek bodies, but the orientations of lineations are conspicuously different. Lineations in the Payne Lake and Dodds Creek bodies plunge very steeply, consistent with the vertical orientations of the sheaths. Lineations in the Canton body, on the other hand, plunge moderately to shallowly throughout much of the body. Lineations at this locality plunge approximately 25, S60W, an orientation consistent with the overall shallow plunge of the complex Canton body finger.

Some publications have portrayed the Canton body as a southsouthwest plunging structure, e.g., Foose's "Loch Ness Monster" model that interprets the Canton body and the Gouverneur body as two eroded "humps" connected in the subsurface (figure 2). Orientations of both foliations and lineations in the Canton body, however, suggest that a shallowly westsouthwest-plunging overturned structure is a better interpretation (figure 1). Preliminary data from our on-going work on the Canton body show shear fabrics similar to those in the Payne Lake and Dodds Creek bodies, and we would argue that a shallowly westsouthwest-plunging sheath fold is a better interpretation for the large-scale structure of the Canton body. Preliminary thin section analysis on samples collected during summer 1993 suggests that shear sense in much of the Canton body is top side down to the west.

Work in progress shows fabrics in this part of the Canton body to be more like those in the Beaver Creek region than those in either the Payne Lake body or Dodds Creek body. Fabric asymmetry is present in ramping quartz ribbons and relict sigma grains with coarse asymmetric tails, but fabrics are strongly annealed, as they are in granitic gneisses of the Beaver Creek region. Fine, dynamically recrystallized grains, so common in the Payne Lake and Dodds Creek bodies, are rare in the Canton body.

74.7	0.0	Continue straight ahead on Old Canton Road.
75.7	1.0	**STOP 7.** Outcrops in the field to the west of the road. Ask permission at the Theron Stacey farm (west side of the road, first farm to the north across the creek). Park on the side of the road, and walk through the gate. Walk a short distance into the field along the farm track, and then proceed approximately 135' south to the first knoll.

STOP 7: Hyde School Gneiss of the Canton body and garnet-sillimanite gneiss in adjacent metasediments (figure 7).

This locality lies along the southern edge of a narrow, curved inlier of metasedimentary rock that gives the Canton body its famous "double fish hook" appearance. The inlier dips shallowly southwest beneath the westsouthwest to west-plunging tip of the Canton body (figures 1 and 7).

At this stop, we will examine the garnet-sillimanite gneiss that commonly (but not ubiquitously) occurs at or near the margins of the Hyde School Gneiss bodies. Similar garnet-sillimanite gneiss borders inliers of metasedimentary rock within both the Payne Lake and Dodds Creek bodies.

The small outcrop approximately 135' south of the farm track displays well-lineated porphyroblastic garnet-sillimanite gneiss. Lineations plunge approximately 25, S75W, parallel to quartz ribbon lineations in adjacent mylonitic HSG.

Walk 40' farther south to a small knoll consisting of HSG south of the contact. This outcrop nicely displays a characteristic feature of well-lineated and sheared HSG. Many outcrops of HSG are better lineated than they are foliated, and the appearance of the HSG varies considerably with the orientation of the outcrop surface. Surfaces oriented parallel or nearly parallel to the stretching lineation typically appear streaky and "well foliated". Surfaces oriented perpendicular or nearly perpendicular to the stretching lineation typically appear "poorly foliated" or even massive. This results, of course, from the fact that much of the "foliated" appearance arises from the lineation. Some exposures of HSG are essentially L-tectonites (lineation but no foliation, like a bundle of pencils); in such exposures, the foliation is impossible to locate on surfaces oriented perpendicular to the lineation. Understanding the variation in appearance with orientation can be very useful in outcrops where glacial erosion has sculpted rounded knobs and where there are no foliation surfaces to examine for stretching lineation orientation. Studying the outcrop for the "streakiest" surfaces can give a clue to the approximate stretching direction.

This locality exhibits other interesting features that we will not have time to examine during this trip. Roughly 800' northwest along strike from the knoll where we examined the HSG, dip slopes on the main foliation (S_m) have prominent southwest-plunging corrugations 0.5-1.0m in wavelength. Examination of west-facing outcrop surfaces reveals that these corrugations are erosional features marking the intersection of slightly less resistent HSG with slight more resistent shear zones 1-2cm thick. The shear zones dip steeply west at a high angle to S_m. The shear zones have a prominent mylonitic fabric and a component of down-to-the-west slip. As in the Payne Lake, Dodds Creek, and Beaver Creek gneisses, younger shear fabrics such as these attest to prolonged and complex ductile shear in the Lowlands.

75.7	0.0	Continue northeast on the Old Canton Road.
75.8	0.1	Crossing the Little Race Track. The stream valley marks

		the location of a weakly resistant, curved "finger" of metasedimentary rock that gives the Canton body its well-known double fish hook map pattern (figure 1).
77.3	1.5	Turn right onto Forest House Road.
79.8	2.5	Turn left onto route 11.
81.8	2.0	Turn right onto the Eddy-Pyrites Road.
84.2	2.4	Turn right onto route 47. The following convoluted route description results from the fact that the route 21 bridge over the Grass River was closed when this road log was written. When the bridge re-opens, turn *left* onto route 47, instead of right. Cross the Grass River, and take the first left. That will bring you to mileage 86.0 below. If, on the other hand, you simply must see bustling downtown Pyrites, carry on and follow the road log as written.
84.6	0.4	Turn left onto North Woods Road.
85.0	0.4	Turn left.
85.1	0.1	Bridge across the Grass River.
85.2	0.1	Village of Pyrites. Turn left.
86.0	0.8	Continue straight ahead.
86.9	0.9	First outcrops of Hyde School Gneiss in the North Pyrites body.
87.4	0.5	**STOP 8.** Low outcrops on the right side of the road.

STOP 8: Spectacularly lineated Hyde School Gneiss of the North Pyrites body (figure 7).

This outcrop displays fabulously lineated Hyde School Gneiss near the northern margin of the North Pyrites body. Quartz ribbons in this outcrop are many centimeters long and plunge shallowly northwest (approximately 10, N60W). The foliation carrying the lineation dips shallowly north (N89W, 18NE).

The power pole at the east end of the outcrop is rip-rapped with locally-derived lineated HSG containing mafic tongues highly elongate parallel to the stretching lineation. The origin of these tongues is not clear at this outcrop. In a spectacular series of outcrops in the yard and gardens of the house across the road and to the west, however, features clearly show that the mafic material occurred originally in layers and has since been isoclinally folded and disrupted by shear. The tongues may very well have sheath-shaped geometries, although this is difficult to prove in these glacially-polished outcrops. We will not visit this locality during the field trip, because the gardens could easily be trampled. The owners, the French's, have been kind enough to give individuals permission to view the outcrops and could be approached for permission if a group is very small.

Unlike the annealed fabrics in rocks of the Canton body, fabrics in many samples from the North Pyrites body are recovered but not annealed. In addition, fabrics in some samples from the North Pyrites body are spectacularly *un-recovered* and display highly strained porphyrclasts and serrated grain boundaries, suggesting, once again, a complex and protracted shear history in the Lowlands.

87.4	0.0	Continue east.
89.4	2.0	Turn right onto St. Lawrence County route 25.
90.4	1.0	Turn right onto Pink School House Road.
91.0	0.6	**STOP 9.** Outcrops to the south of the road between the road and the woods.

STOP 9: Discordant shear fabric in the Hyde School Gneiss along the eastern margin of the North Pyrites body (figure 7).

This exposure of lineated and foliated Hyde School Gneiss lies along the eastern margin of the North Pyrites body. Unlike the HSG at stop 8, the HSG at this locality displays well-developed compositional layering oriented approximately N20W, 70SW. The prominent lineation in the outcrop does not, however, lie in the plane of the compositional layering. Rather, the lineation is carried in a foliation that dips shallowly northwest, discordant to the compositional layering. This discordant foliation has the same kinds of distinctive asymmetric structures characteristic of shear fabrics that can be seen in the HSG of the Payne Lake, Dodds Creek, and Canton bodies, and we have termed this discordant foliation S_d. The lineation at this locality plunges approximately 20, N50W.

The orientations of S_d and the associated lineation L_d vary somewhat across the North Pyrites body, but L_d generally plunges shallowly NW. Shear sense determined from preliminary examination of thin sections appears to be top side down to the northwest.

Based on both the shape of the North Pyrites body and on the presence of prominent shear fabrics, we tentatively suggest that the North Pyrites body is a sheath fold plunging shallowly northwest (figure 1). We would interpret the lineated foliation, S_d, in much the same way as we have interpreted the discordant foliation in the Payne Lake body, as an axial plane foliation that developed parallel to the sheath fold axial surface as the sheath fold grew in a major shear zone. Where the earlier fabric, S_m, lies at a high angle to the axial plane of the sheath, as it does at this locality, S_d is clearly discordant to S_m and to compositional layering.

91.0	0.0	Turn around, and go back east on Pink School House Road.
91.6	0.6	Turn left onto St. Lawrence County route 25.
93.8	2.2	Join St. Lawrence County route 27.
95.0	1.2	Bridge across the Little River.
95.3	0.3	St. Lawrence University campus.
96.0	0.7	Intersection of Park and Main Streets, downtown Canton.