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# The Northwest Boundary Fault of the Boundary Mountain Anticlinorium

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by

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## Introduction

The Northwest Boundary Fault (NWBF) has been mapped in detail from north of Little Turner Pond in the Attean 15' quadrangle southwestward to the Maine/Quebec border, a distance of 12 miles (Figure 1). This work was done during a four week period in 1978 and, due to the very limited access and time, mapping was generally confined to within one half mile of the fault. Work was supported by the Maine Geological Survey and the Nuclear Regulatory Commission.

## Geologic Setting

One of the prominent and apparently unique tectonic terranes in New England is the Chain Lakes massif of Boone and others (1970) which cores the NE-SW trending Boundary Mountain Anticlinorium (Albee, 1961). Some rocks within the massif have been dated by Naylor and others (1973) at 1.5 b.y. The northeastern end of the massif was intruded in the Upper Middle Ordovician by the Attean Quartz Monzonite (Albee and Boudette, 1972), and these two units constitute the pre-Upper Silurian rocks along the southeast side of the NWBF. The post-Upper Silurian rocks on the northwest side of the NWBF include slivers of Upper Silurian limestone and Lower Devonian phyllitic slates of the Seboomook Formation. Within the fault zone, a wide variety of breccias have been observed.

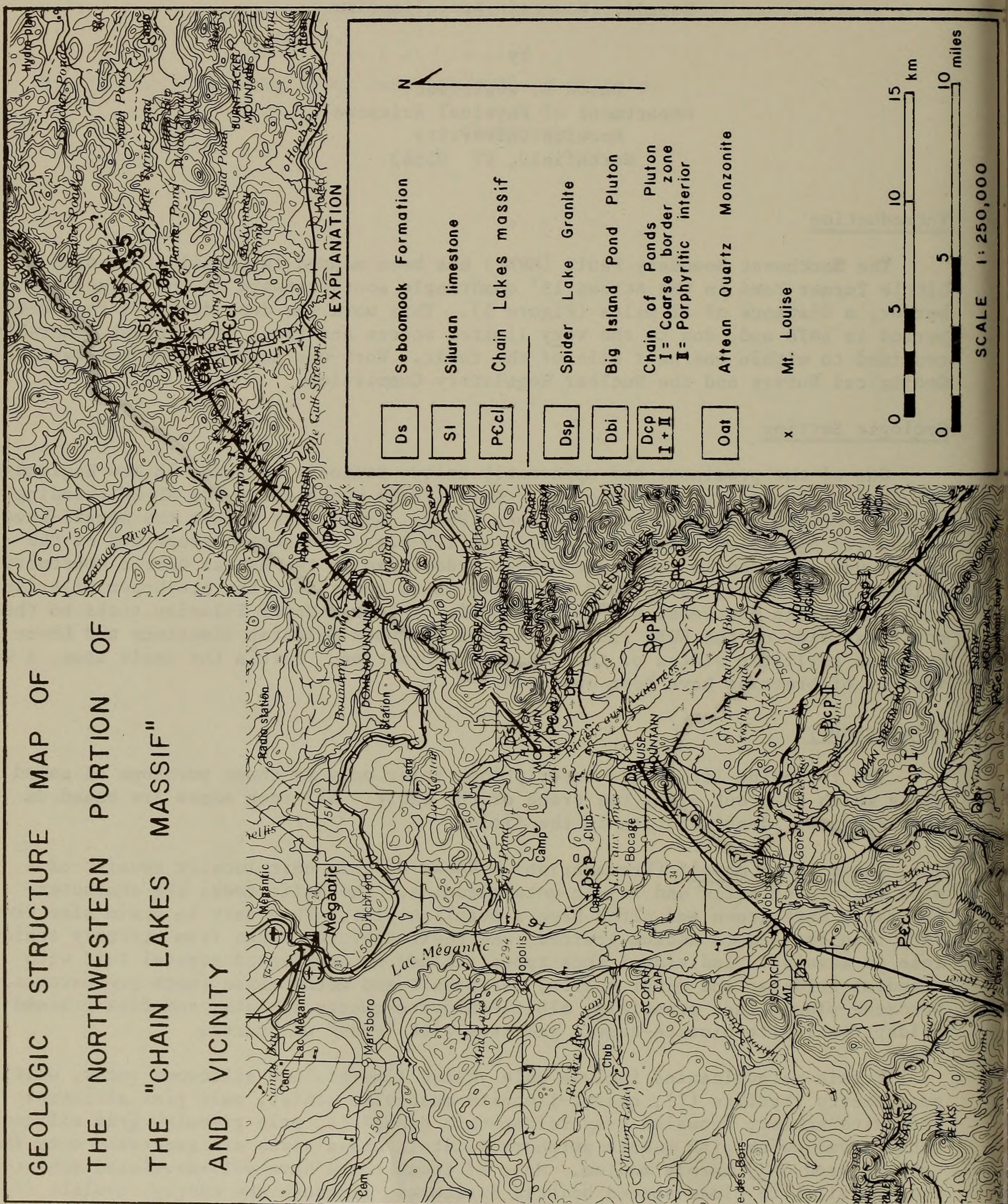
## Stratigraphy

The following lithologic descriptions refer only to those portions of named units which crop out along the trace of the fault. All rock names are based on hand specimen identification in the field.

Chain Lakes massif (Precambrian) - Rocks of this unit locally consist of a wide variety of mafic and felsic metavolcanics. The mafic rocks are characteristically dark green and often have a purplish tint. They vary in grain size from very fine grained to medium grained, and their textures range from strongly schistose to massive. Individual rock types include metamorphosed crystal tuff with euhedral feldspar and minor quartz, metabasalt and metadiabase (both greenstones), pyroxene-plagioclase granofels, albite-chlorite-quartz schists, and fine-grained feldspar-chlorite-biotite-quartz gneisses with "eyes" of quartz.

Felsic metavolcanics include pale yellow fine-grained siliceous rocks, whitish gray cherty rhyolite (?), quartz-limonite-muscovite schist, pale pink siliceous muscovite schist, brownish gray feldspathic granofels, pale greenish gray siliceous schist, yellowish pink quartz-porphory latite. Grain sizes are generally very fine to fine, and only rarely medium. Most of these rocks have well-developed schistocity parallel to close-spaced brittle fractures, although the cherty rhyolite (?) is massive. As a general rule, the felsic rocks are located between the mafic rocks and the NWBF.

Figure 1


GEOLOGIC STRUCTURE MAP OF
THE NORTHWESTERN PORTION OF
THE "CHAIN LAKES MASSIF"
AND VICINITY
EXPLANATION
N
Ds Seboomook Formation
Sl Silurian limestone
P€cl Chain Lakes massif
Dsp Spider Lake Granite
Dbi Big Island Pond Pluton
Dcp I + II Chain of Ponds Pluton
I = Coarse border zone
II = Porphyritic interior
Oat Attean Quartz Monzonite
x Mt. Louise
0 5 10 15 km
0 5 10 miles
SCALE 1:250,000

Attean Quartz Monzonite (Upper Middle Ordovician) - The Attean Quartz Monzonite occurs along the southern side of the contact in the Attean and Skinner Northeast Quadrangles, and in most of the Skinner Quadrangle. It is an extensively mylonitized, two-feldspar granite in most locations, commonly porphyritic with varying amounts of recognizable potassium feldspar phenocrysts. The percentage of quartz appears to range from as low as 20% up to 35%, but mylonitization makes these estimates difficult.

The texture of this unit varies with proximity to the contact, becoming finer grained to the northwest where the extent of mylonitization is greater. The rocks commonly contain oriented chlorite, producing a foliation and a pale green color on fresh surfaces. Outcrops in the Attean Quadrangle were observed to contain secondary calcite as well as chlorite. The weathered surfaces of the Attean Quartz Monzonite are typically whitish gray to strongly pink with increased extent of shearing and recrystallization.

Metalimestone (Upper Silurian) - As noted by Albee and Boudette (1972), thin slivers of Silurian limestone are found in the Attean Quadrangle along the contact between the pre-Upper Silurian rocks and the Devonian slates. One such sliver is well exposed in the Skinner Northeast Quadrangle east of East Branch Gulf Stream (Stop 2). The rocks are exposed over a distance of 610 m with a map width ranging from 61 m at the west end to 92 m at the east end of the outcrop belt (see Figure 2).

These limestones are typically gray on fresh surfaces, weathering to brown. The most common texture of the limestone is massive, but exposures of thinly laminated (1 mm) limestone were also observed. One outcrop exhibited a swirled texture of very fine-grained gray limestone and brownish weathering coarser limestone with disseminated black angular fragments. Mylonitized breccias of limestone and Attean Quartz Monzonite occur along the southern margin and within the outcrop belt.

West of the limestone sliver discussed above, two occurrences of limestone were observed. The first is in East Branch Gulf Stream where large angular boulders of pale purple, laminated limestone occur, the lamination being seen as discontinous layers of very fine-grained and medium-grained (1-2 mm) limestone. Square and circular particles can be seen in the coarser layers with the circular fragments having darker cores. These particles are thought to be crinoid stem fragments. The only other limestone occurrence in the map area is in the Skinner Quadrangle, between the Devonian slate and the Attean Quartz Monzonite, at the crest of the first major hill west of West Branch Gulf Stream. The limestone at this locality is fine grained and has a brownish gray color, appearing to be very similar to the major sliver described above.

Seboomook Formation (Lower Devonian) - Dark gray phyllitic slates are exposed on the northern side of nearly the entire extent of the contact between the pre- and post-Upper Silurian rocks. In those areas where Silurian limestones constitute the boundary, the Devonian slates are exposed immediately to the north of the limestone.

In the Skinner Northeast Quadrangle, in the eastern portion of the map area, slates are typically laminated on a scale of 1 to 2 mm with black metapelite beds and dark gray metasiltstone beds nearly parallel to a phyllitic slaty cleavage. Discontinuous 1 cm thick lenses of metasandstone occur commonly in places but rarely in most localities. Locally bedding can be observed dipping gently to the NW.

Dark gray phyllitic slates are common in the western portion of the map area, but they are rarely laminated. The grain size of these rocks is generally somewhat coarser (metasiltstone) than is that of the slates to the east, and phyllitic texture commonly is absent. The color of these rocks varies from black to gray, and weathered surfaces typically are brown and rusty.

Breccias (age unknown) - A wide variety of breccias are exposed in various locations along the length of the contact between pre- and post-Upper Silurian rocks, as well as in rocks immediately adjacent to that contact. In the eastern portion of the map area, near the Silurian limestone sliver, breccias of limestone-in-Attean Quartz Monzonite matrix, Attean Quartz Monzonite-in-limestone matrix, limestone-in-Devonian slate (schistose) matrix, and Devonian slate-in-limestone matrix have been observed. Clast sizes commonly reach 10 cm in their long dimension and rarely reach 20 cm. These breccias have angular, elongated clasts showing internal deformation, contained in a schistose matrix. The breccias generally are found at the lithologic contacts, but one limestone-in-black schist breccia occurs within the limestone outcrop belt.

A breccia containing clasts of Attean Quartz Monzonite, limestone, and black schist is exposed on the west shore of Gulf Stream at the contact. This rock is intensely sheared with a well-developed schistose texture and a dark green color.

Near the western outcrop limit of the Attean Quartz Monzonite, two exposures of breccia occur on opposite sides of an unnamed stream west of Gulf Stream. Both of these breccias consist of very angular, white cherty volcanic(?) fragments up to 10 cm in length contained in a granitic matrix. Abundant coarse quartz is present in the matrix along with small angular fragments of the banded cherty volcanic(?) rock. The western exposure of this breccia is approximately 30 m south of typical Devonian slate.

Farther to the west, near the west side of Little Gulf Stream, a breccia of angular white, cherty volcanic(?) fragments in a fine-grained, felsic schistose matrix is exposed. This breccia is very similar to rocks at another exposure located farther to the west, north of the summit of Clear Pond Mountain in the Boundary Pond Quadrangle.

All of the breccias share the characteristics of having clasts elongated parallel to the regional fracture foliation (N20-40$^{o}$E, 55-80$^{o}$W) and having extensive phyllosilicate mineralization on their sheared surfaces. These surfaces are commonly lineated, but no movement directions were obtained.

## Structural Geology

Features in pre-Upper Silurian rocks - Well-developed, closely-spaced intersecting brittle fractures with superimposed joint sets are the dominant structural features in the pre-Upper Silurian rocks. No faults or folds were mapped within the units of this group, but the lack of planar features would make the recognition of such features unlikely. Strongly mylonitized Attean Quartz Monzonite occurs in topographic depressions which parallel the NWBF, suggesting that faults within those rocks trend parallel to their northwestern contact.

The orientations of the closely-spaced brittle fractures show a consistent trend at a shallow angle to the northern boundary of these rocks. Strikes of these fractures are typically N20-40E, and dips vary from 60 to 85W. These fractures generally occur in sets that intersect at angles of 10 to 20 degrees or in a single set, producing in each case a pervasive fracture foliation. The spacing between fractures is generally less than 1 cm. Several fine-grained rock types in both the mafic and felsic metavolcanic group commonly have a schistocity that parallels or replaces the fracture foliation. Both the fracture foliation and the schistocity tend to increase in their degree of development as one approaches the NWBF. Fracture foliation is commonly very well developed in the Attean Quartz Monzonite where it is associated with observable mylonitization. Both quartz and feldspar generally exhibit the results of a mechanical reduction in grain size.

Many outcrops exhibit slickensides and mineral lineations on the steeply dipping fracture foliation surfaces. The direction of movement is almost directly down dip (normal), that is N side down, in nearly all cases. Occasionally lineations occur plunging at an angle less than the dip of the fracture surface, and very rarely slickensides indicate high angle reverse motion.

Joints in the pre-Upper Silurian rocks are generally well-developed, nearly vertical sets. They are typically planar and smooth, and their spacing is variable but usually consistent at the outcrop scale (1 cm. to 2 m.). Most joints are devoid of mineralization, but quartz-filled joints are locally abundant. This is particularly true at closest proximities to the NWBF. Rarely, quartz veins roughly parallel to the joint sets account for as much as 40% of an outcrop by volume.

Features in post-Upper Silurian rocks - The dominant structural feature in the Upper Silurian and Lower Devonian rocks is a well-developed slaty cleavage, commonly exhibiting a phyllitic sheen. Where bedding is observable, the cleavage is generally parallel or nearly parallel to the bedding. The shallow angles of intersection produce a nearly horizontal lineation on the cleavage surfaces which usually dip at a slightly steeper angle. A second cleavage is occasionally observed, generally associated with kink folds. The sense of rotation on these kinks is consistently down dip either to the northwest or southeast. A well-developed slaty cleavage occurs in some outcrops of the Upper Silurian limestone trending parallel to the regional strike and dipping moderately to steeply to the northwest. Many outcrops of the limestone are massive and have poor cleavage.

Joints in the post-Upper Silurian rocks are well developed, planar and smooth, and generally occur as one or two sets at high angles to the cleavage. The occurrence of quartz in these joints is most common near the NWBF.

The Northwest Boundary Fault - The topography of the mapped section of the NWBF is characterized by north and northwesterly trending stream valleys which cut across the strike of the fault. Hills between the valleys have an irregular topography with ridges and gullies parallel to the NWBF. Between each pair of adjacent streams the contact between pre- and post-Upper Silurian rocks can be mapped in detail, and the orientation of each segment of the NWBF is tightly controlled. Adjacent segments of the fault may be offset as much as 750 feet and the strike of the fault may change as much as 25 degrees from one segment to the next. Crossing faults located in the stream valleys are thought to account for these offsets and changes in orientation.

Small-scale structural features in the rocks adjacent to the NWBF may reflect a wide variety of motions during the complex deformation of those rocks. Boone (1981) has recently reviewed the results of a field conference held during the summer of 1980 and attended by G.M. Boone, E.L. Boudette, M. Bronston, S. Serra and this author. Boone's earlier work had led him to the conclusion that the NWBF represents a thrust dipping to the northwest. Boudette's work led him to postulate a thrust from southeast to northwest. My work suggested that the NWBF represents a normal fault, north side down. The conference showed that clear evidence was available on the outcrop scale for all three models, which led Bronston and Serra to propose a fourth model to accommodate all the evidence.

They suggested that a right-lateral strike-slip master fault with an irregular surface would generate synthetic and antithetic shears as well as both normal and thrust surfaces, each accompanied by folds with appropriate rotation sense. If one wants to account for individual features at scattered outcrops along the length of the fault zone, this model is very attractive, but it seems to fail to account for the sharp changes in orientation of segments of the fault and for their offsets. This author suggests that the dominant movement on the NWBF during the deformation of the post-Upper Silurian section may well have been right-lateral, producing many of the disparate small-scale structures, but that the most recent movement (post regional deformation) was normal faulting on that existing fault surface, producing the existing map pattern.

In the Attean quadrangle, Upper Silurian conglomerates contain clasts of the Attean Quartz Monzonite and Chain Lakes lithologies (Albee and Boudette, 1972). This tells us that this core of the Boundary Mountain Anticlinorium was rising relative to the basin to the northwest which was sinking to accept sediments to form the post-Upper Silurian section. During the deformation of the post-Upper Silurian section (the Acadian Orogeny), northwest-southeast compression tightly folded the sedimentary rocks and perhaps thrust them up onto the basement complex to the southeast. Perhaps this contact had a relatively steep angle and a strike-slip component to its motion, but neither a reverse fault or an unconformity would account for offsets in the contact or abrupt changes in orientation of the contact.

The model preferred by this author is one involving post-Acadian uplift of the granitic massif (just like the post-Taconic uplift), with a moderately high-angle normal fault developing along the northwestern border of the massif. Different rates of uplift along the length of the NWBF would produce tear or hinge faults, allowing segments of the fault to rise at faster or slower rates than neighboring segments. Segments of the NWBF which rose faster would be offset to the northwest. Segments where one end rose faster than the other end would have a different strike than adjoining segments. This style of faulting could account for the mapped pattern of the NWBF.

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## ROAD LOG

Field work for this trip was done during a four week period in the summer of 1978 while active woods operations were underway. Since that time, timber cutting has ceased and the access road to the region has not been maintained. In June of 1983 the area was revisited for the purpose of preparing this trip log and the author was startled by the extent to which spring rains had damaged the roads. Bridges were washed out and erosion gullies across the road were numerous. It is hoped that by the time of this scheduled trip that the road will be in significantly better condition. Particularly bad washouts are parenthetically noted in the trip log.

The assembly point is in the northern part of the town of Jackman on the west side of Route 201 at the parking lot of Dolly's Food Store (IGA) and the Jackman Post Office.

| Mileage | |
|---|---|
| 0.0 | Turn left onto Route 201 heading north. |
| 4.4 | Turn left on a paper company haul road known as both the Crocker Pond Road and the Holeb Road. |
| 6.0 | Cross Brady Brook. |
| 8.1 | (Careful - washout.) |
| 9.5 | Cross West Branch Sandy Stream. (If the bridge is still out, cross the shallows on the downstream side.) |
| 11.2 | Cross stream. |
| 11.7 | (Careful - washout.) |
| 12.0 | (Careful - washout.) |
| 12.4 | (Careful - washout.) |
| 14.4 | (Careful - washout.) |
| 15.0 | Mud Pond is on the south side. |
| 16.5 | Junction with the road to Turner Pond. Turn right (north). |
| 17.8 | Excellent spring on the right side. |
| 18.1 | Bear left at the fork. |
| 18.3 | Park along the side of the road. |

Stop 1. Exposures of the Attean Quartz Monzonite occur in and to the west of the road. The rocks are porphoritic with sub- to euhedral potassium feldspar phenocrysts generally 1 cm. in diameter. The alteration of biotite to chlorite has produced a weak northeasterly trending schistocity. Numerous nearly vertical mineralized

fractures have prominent orientations near N2E and N44W. Two similarly mineralized shear zones trend N40E and N80W. These rocks are the least deformed example of the Attean Quartz Monzonite which will be seen on the trip, and they are also furthest from the Northwest Boundary Fault (1 mile).

Continue driving north along the road.

19.0 Continue past the entry road on the right which goes into the west end of Turner Pond.

19.35 Park along the road. There is an old grown-over woods road on the north side which starts into the woods on a bearing S80W. This road bends all around, roughly following a brook northwesterl for 305 paces (1600 feet). At that point, an old road forks off S75W to the left. Take that fork for 142 paces (750 feet) where a well established game trail bears off N60W. Follow the game trail roughly parallel to the slope for 54 paces (285 feet). Continue to contour parallel the slope for 108 paces (570 feet) heading generally N70W. Then head N60W for 30 paces (155 feet) dropping from open maple forest down into a flat. Now follow the contour S65W for 70 paces (370 feet). This brings you to the east end of a gully system made by the Northwest Boundary Fault. (If you should get lost, simply head WNW uphill. If the rocks are sheared Attean Quartz Monzonite, keep bending north. If they are brown weathering limestone, you are in the fault zone. If they are black phyllites, you've gone too far north so bend southerly.)

Stop 2. Three principle lithologies are exposed along the linear topographic depression which trends S54W over the crest of the hil for a distance of just under 2,000 feet. Ths southeast side of the depression is flanked by strongly mylonitized Attean Quartz Monzonite. Within the depression are numerous outcrops of limestone with deformation varying from strong to unobservable. The northwestern side of the depression is made up of slaty and phylli rocks of the Seboomook Formation. Figure 2 shows the distribution of mapped outcrops but represents only a modest percentage of the total number of exposures.

The sheared rocks of the Attean Quartz Monzonite have a strong fracture foliation which typically trends more northerly (N25-40E) than does the northwestern contact of this unit. This relationshi is persistent for 10 miles along strike to the southwest, independent of whether the rocks are part of the Attean Quartz Monzonite or part of the Chain Lake massif further to the southwest (see Figure 3). The easternmost outcrop shown in Figure 2 is the first outcrop to be examined. Intensely sheared Attean Quartz Monzonite exhibits fractures trending N33E,74W which have chattery surfaces indicating normal movement. Shear fractures measured at the east end of the outcrop trend N40E,55W. The intersection of these less steeply dipping fractures may produce the chattery character of the more steeply dipping fractures, negating the possibility of interpretation of the sense of motion. A point for discussion.

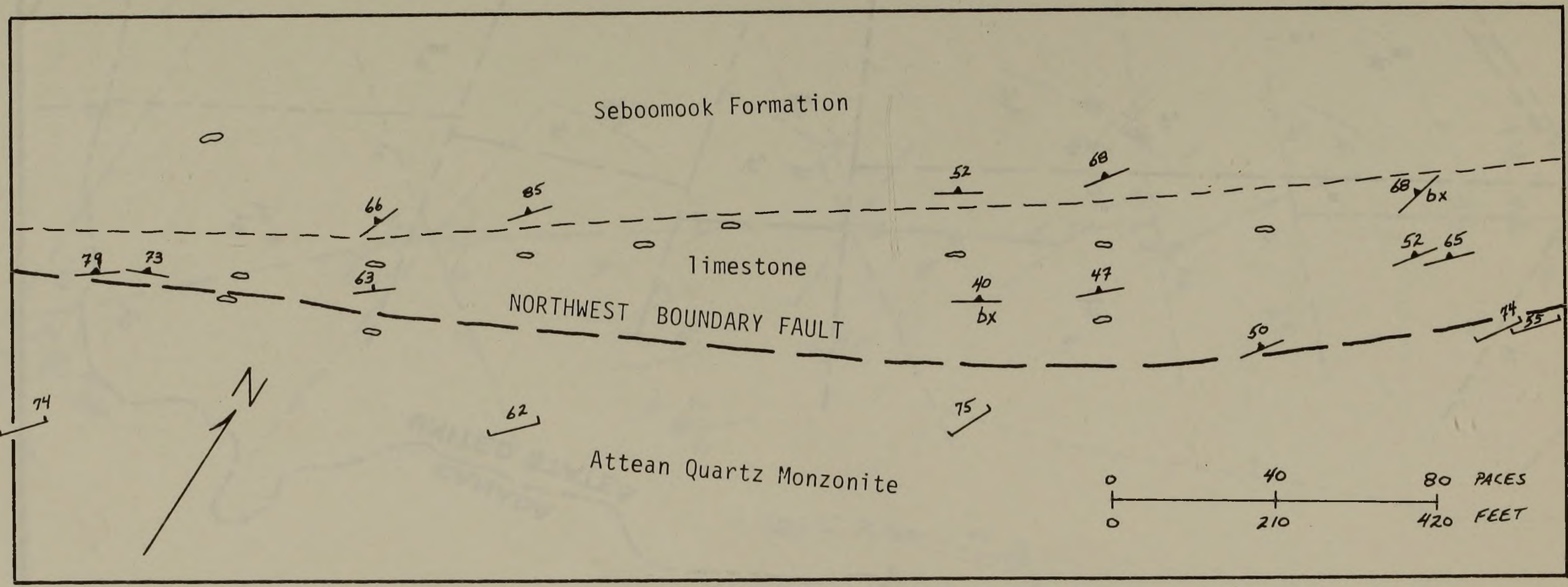



Figure 2. Detailed map of a sliver of Upper Silurian limestone located on the crest of the hill east of East Branch Gulf Stream in the Skinner NE 7½-minute quadrangle

Figure 3A

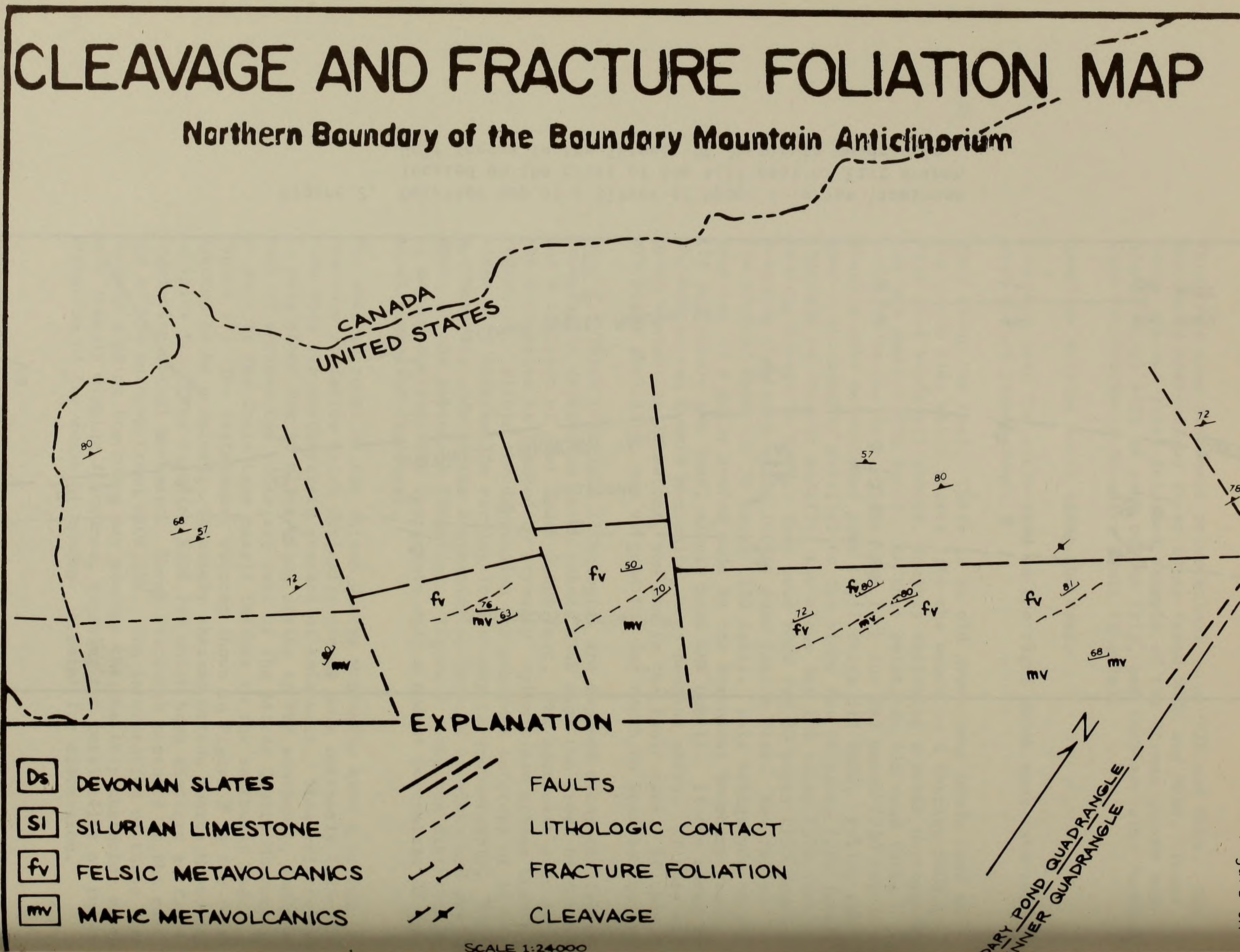
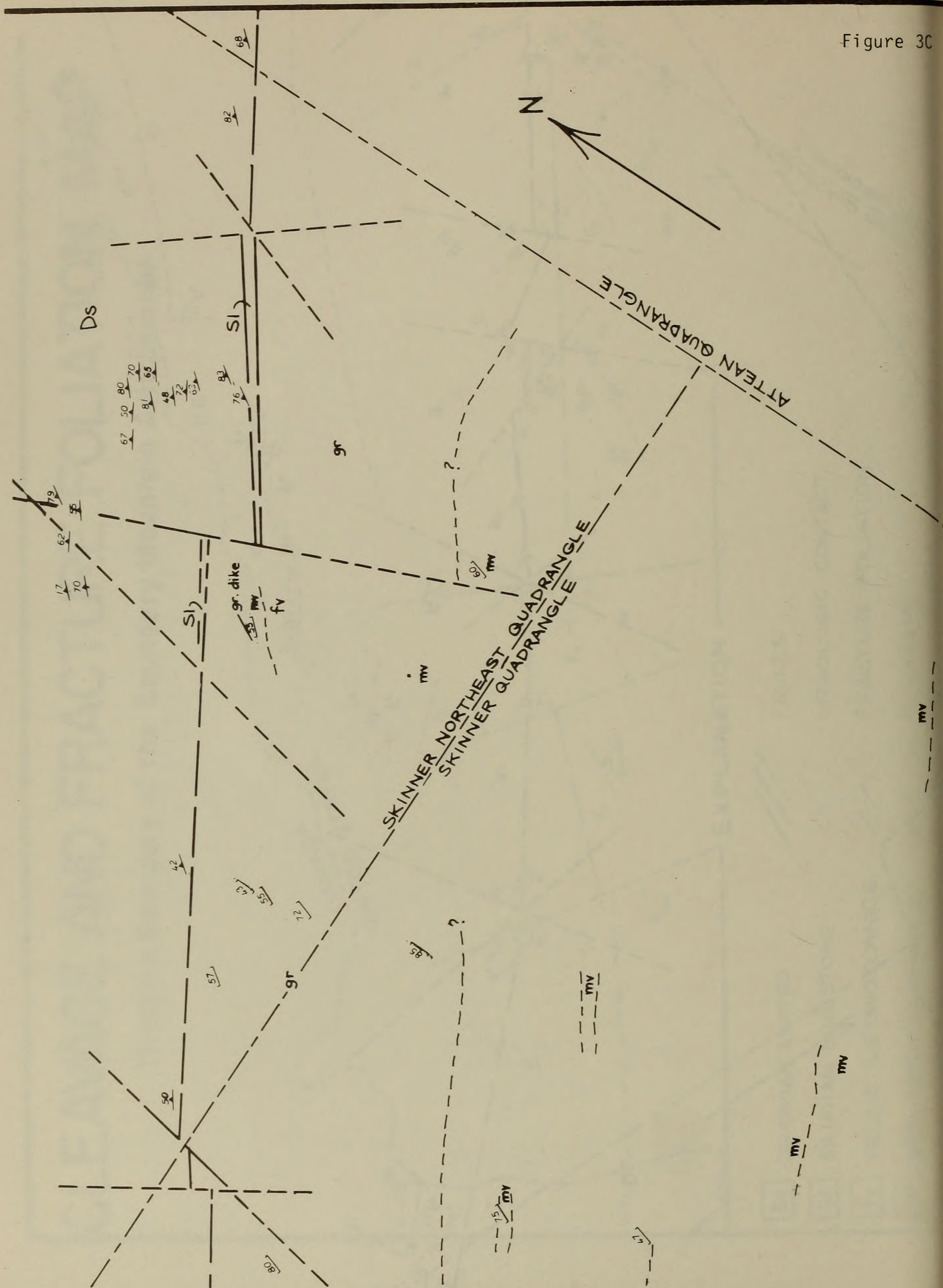

CLEAVAGE AND FRACTURE FOLIATION MAP
Northern Boundary of the Boundary Mountain Anticlinorium
CANADA
UNITED STATES
EXPLANATION
Ds DEVONIAN SLATES
SI SILURIAN LIMESTONE
fv FELSIC METAVOLCANICS
mv MAFIC METAVOLCANICS
FAULTS
LITHOLOGIC CONTACT
FRACTURE FOLIATION
CLEAVAGE
SCALE 1:24000
N
...ARY POND QUADRANGLE
...NNER QUADRANGLE

Figure 3B

Figure 3C


N
ATTEAN QUADRANGLE
SKINNER NORTHEAST QUADRANGLE
SKINNER QUADRANGLE
Ds
Sl
gr
gr. dike
mv
fv

A traverse heading S60W down the contact zone with side traverses periodically will provide an opportunity to see the detailed lithologic and structural characteristics of the exposures. The number of outcrops visited will be determined by the size and energy of the group. Particular interest is in the origin of the brecciated rocks within the limestone belt. The following have been observed: 1) clasts of mylonitized Attean in a strongly foliated limestone matrix, 2) clasts of limestone in mylonitized Attean, 3) angular limestone fragments in a micaceous matrix, and 4) angular to sub-rounded clasts of Chain Lakes granofels (P€), mylonitized Attean (O) and limestone (S) along with calc-silicate rocks and various granitic rocks, all in a strongly foliated quartzo-feldspathic matrix. It is this final breccia which constitutes the westernmost end of the outcrop belt and is the principle gathering point for this stop.

The polymictic breccia described as 4) above is easily located as a major cliff several meters high and 60 meters long, dropping down to the southeast. A cross-sectional view at the west end of the outcrop suggests a preferred orientation of N52E,79N for the clasts.

If the Attean Quartz Monzonite and Chain Lake massif were exposed during the Silurian and yielded pebbles and cobbles to form a conglomerate, then the limestone fragments in this breccia must be accounted for. Deposition followed by uplift of some limestone could have occurred, providing a source for these clasts. Presumably, the depositional surface would have been close to horizontal or dipping gently to the north (away from the source), but it now dips steeply. An unconformity of conglomerate on crystalline basement could be folded into a steeply dipping orientation, but 100 meters to the south the Attean Quartz Monzonite shows no evidence of deformation whereas 50 meters to the south the rocks of this unit are chloritized and well foliated (N40E,74W). Off to the north, bedding in the Seboomook dips 25NW, and locally bedding in the limestone dips 30-50NW. It is the author's interpretation that the breccia here is both a depositional (correlative with the Foxes Camp conglomerate of Albee and Boudette, 1972) and a fault breccia (representing the normal movement (NW down) on the Northwest Boundary Fault).

Return to the vehicles by following the fault NE and picking up the traverse which brought you in.

Continue in the same direction (northeast) on the gravel road.

20.3 Bear left at the fork.

20.9 Cross the brook.

21.0 Park along the side of the road.

Stop 3. Outcrops along the roadside (east side) are sheared Attean Quartz Monzonite which is strongly chloritized giving the rock a pale green color on fresh surfaces. This chlorite and recrystallized sheared feldspars produce a weak foliation oriented N58E,65N. Three pervasive brittle fracture sets can be seen. The early two are oriented N17E,55W and N63E,60N, and the last set to develop is oriented N42E,72N. Finally, one slickensided fracture cleavage surface has been seen here oriented N37E,41N with stepped chlorite and quartz showing normal movement ( N side down).

Continue N on the gravel road.

21.3 Park along the roadside to examine outcrops in and on the east side of the road.

Stop 4. Outcrops of Seboomook Formation show an extremely complex pattern of smale-scale deformation features. Early cleavage is parallel to lithologic layers which may or may not represent bedding. (Elsewhere in this formation false bedding is common as a result of transposition of finer-grained material along steeply dipping cleavage.) The trend of this early cleavage is N48E,80N, quite compatible with the regional cleavage patterns in this formation. Folds typically have amplitudes nearly equal wavelengths, and only rarely can a sense of "handedness" be observed. Fold axes have a variety of orientations; measurements include 44,N75W for a right-handed, chevron-type fold, 30,N45W for open antiforms and synforms, and 16,N33E for a set of waves which are truncated by a N37E,75N fault surface. The continuation of this fold set has not been located. Our fold set has steeply plunging axes (83,N3E) and shows clear chevron drag structure with a right-lateral sense of motion (long limbs N48E,78N). It can not be shown that these folds are related to the most recent movement on the Northwest Boundary Fault.

Turn around and proceed south.

21.45 Optional stop. Park along the road and walk N50E for 340 paces (1800 feet) to the crest of the hill.

Stop 5. Outcrops to the northwest are Seboomook Formation with well-developed slaty cleavage trending N33-63E, 45-65NW. A second cleavage can be seen oriented N18E,79W as axial planes to small open folds whose axes trend 71,N0E. Outcrops on the southeast side are mylonitized Attean Quartz Monzonite with well-developed fracture cleavage N25-47E, 54-70NW. The contact between these two units is tightly confined (see Figure 4) and strikes N50E based on detailed mapping along strike. The fracture cleavage in rocks near the contact commonly strikes more northerly than does the contact. This same relationship was seen at the second stop and remains poorly understood. Veins of quartz are more abundant in outcrops of both formations near the contact than they are further away.

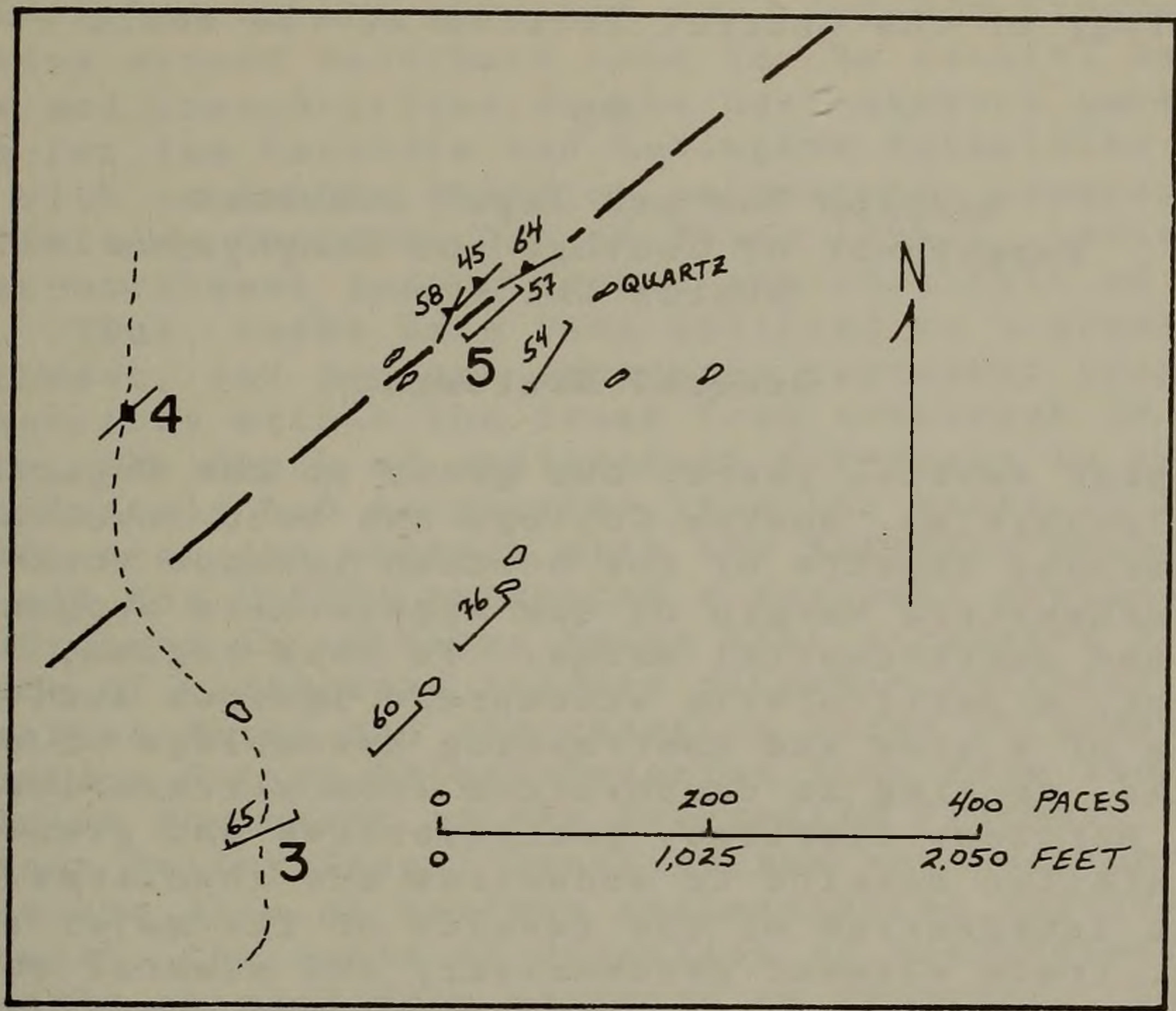



Figure 4. Detailed map of the localities of Stops 3, 4 and 5 northwest of Little Turner Pond in the Attean 15-minute quadrangle

Return to vehicles and retrace your route back to the Holeb Road.

26.1 Junction with the Holeb Road. Turn left and return to Route 201.

38.2 Junction with Route 201. (Excellent roadcuts can be seen on Route 201 to the north if time permits.)

End of trip.