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Sedimentology of Silurian Flysch, Ashland Synclinorium, Maine

Roy, David C.

TRIP C-5

SEDIMENTOLOGY OF SILURIAN FLYSCH, ASHLAND SYNCLINORIUM, MAINE

by

David C. Roy
Department of Geology and Geophysics
Boston College

The Silurian of the Ashland Synclinorium offers an opportunity to study turbidity current deposition in a sequence that may well represent continental margin sedimentation following the Taconian Orogeny (Roy, 1978). The uplift of pre-Silurian rocks to the west and northwest of the synclinorium produced emergent terrain with a narrow shelf environment and apparently steep eastward slopes into a basin in which sedimentation was uninterrupted. A 2600 meter (8500 feet) section of Silurian shale, graywacke, and conglomerate was deposited at the base of the slope and in the basin. Basinward from the former land area the deposits become generally finer-grained and more distal in turbidite characteristics. Upward in the Silurian section, similar changes reflect both reduction of land relief and progressive advance of marine conditions onto the detrital source area during the Silurian. These changes produced increasingly more distal conditions everywhere within the basin.

The stratigraphy of the Stockholm region is summarized in Figure 1 and is discussed by Roy and Mencher, (1976) and Roy, Trip B-6, this volume). On this trip we will focus on turbidite deposition within the Jemtland Formation (STOPS 2,4, and 6) which forms part of the upper half of the Silurian section. The lower and more proximal part of the section as seen in the Frenchville and New Sweden Formations will be seen at STOPS 3 and 7; the pre-Silurian stratigraphic setting (Madawaska Lake and Cary's Mills formations) will be examined in STOPS 1,3, and 5. The locations of all stops are given in this volume in Figure 2 of Roy, (Trip B-6).

Post-Taconian Submarine Erosion

We will visit an exposure of the Taconian angular unconformity between the Ordovician Madawaska Lake Formation and the Lower Silurian Frenchville Formation (STOP 3). The details of the exposure are given in the stop description below and the regional aspects of the Ordovician-Silurian transition are given elsewhere in this volume by Roy, (Trip B-6). It is concluded that at least the final pre-Frenchville erosion at this exposure was submarine and it is possible that all of the folding and erosion of the Madawaska Lake beds were accomplished below sea level.

Submarine unconformities with apparently substantial hiatuses in eugeosynclinal regions are not widely reported as such. Direct and indirect evidence of intraformational submarine erosion with short hiatuses are of course widely observed and reported in both shallow and deep-water sedimentary sections. In the present case the unconformity is angular and is a systemic interface that represents a non-trivial hiatus. The erosion is considered to have occurred on a post-Taconian submarine slope for four reasons:

1) To the west and northwest, Lower Silurian rocks are absent,

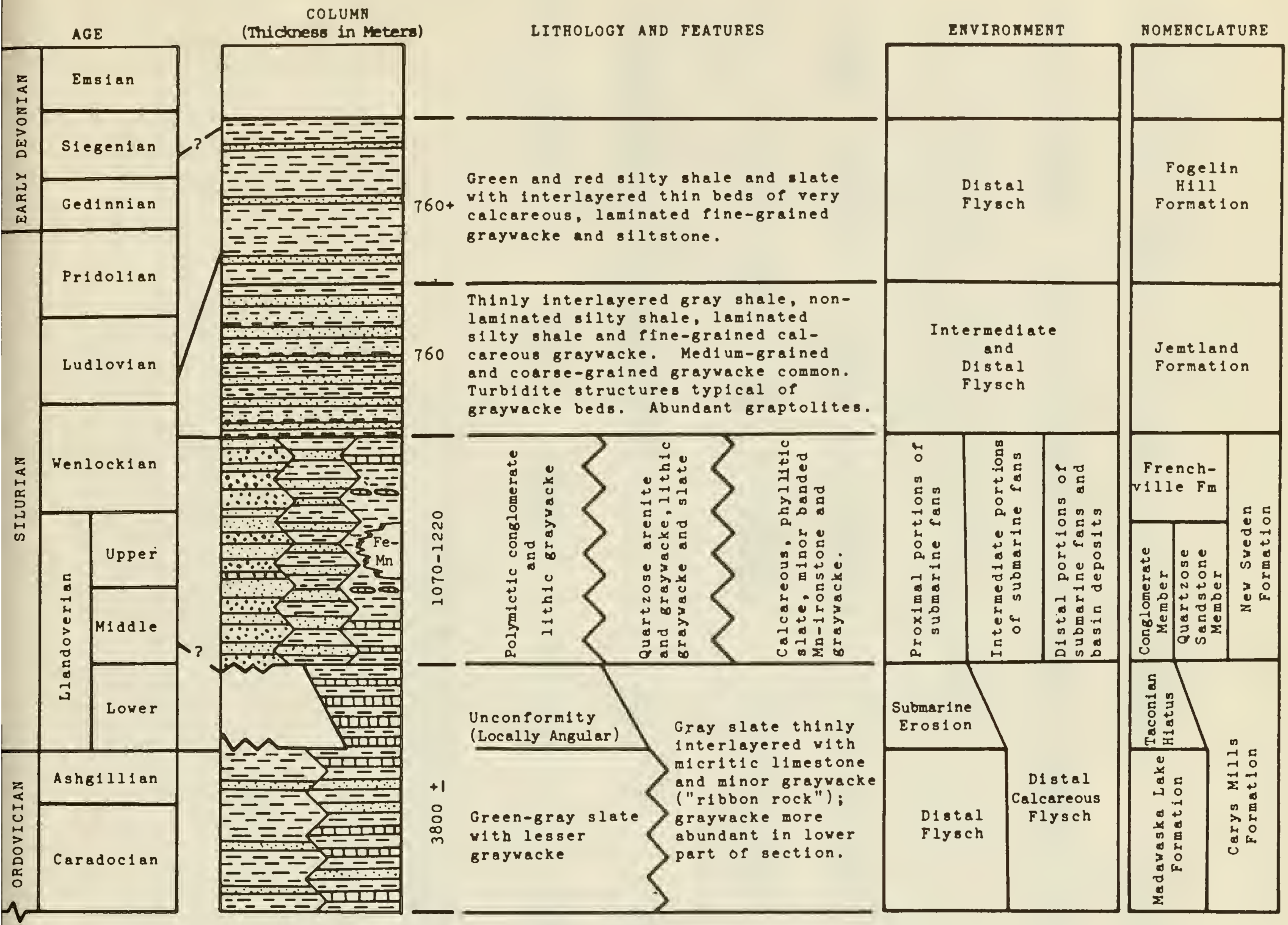

Figure 1: Stratigraphic section of the Stockholm-Jemtland area (from Roy and Mencher, 1976).

whereas above the unconformity and to the east a thick "deep-water" section representing almost the entire Silurian is present.

2) Paleocurrent measurements and provenance of sandstone beds in the Frenchville and Jemtland formations indicate downslope transport of detritus from the west and northwest.

3) Frenchville sandstone and conglomerate beds contain brachiopod assemblage composed of representatives of mixed depth communities (Roy, 1973; McKerrow and Ziegler, 1971).

4) At least the final erosion of the Madawaska Lake Formation produced large flute molds on the erosional surface which suggests differential scour of semiconsolidated mud by sediment-laden currents.

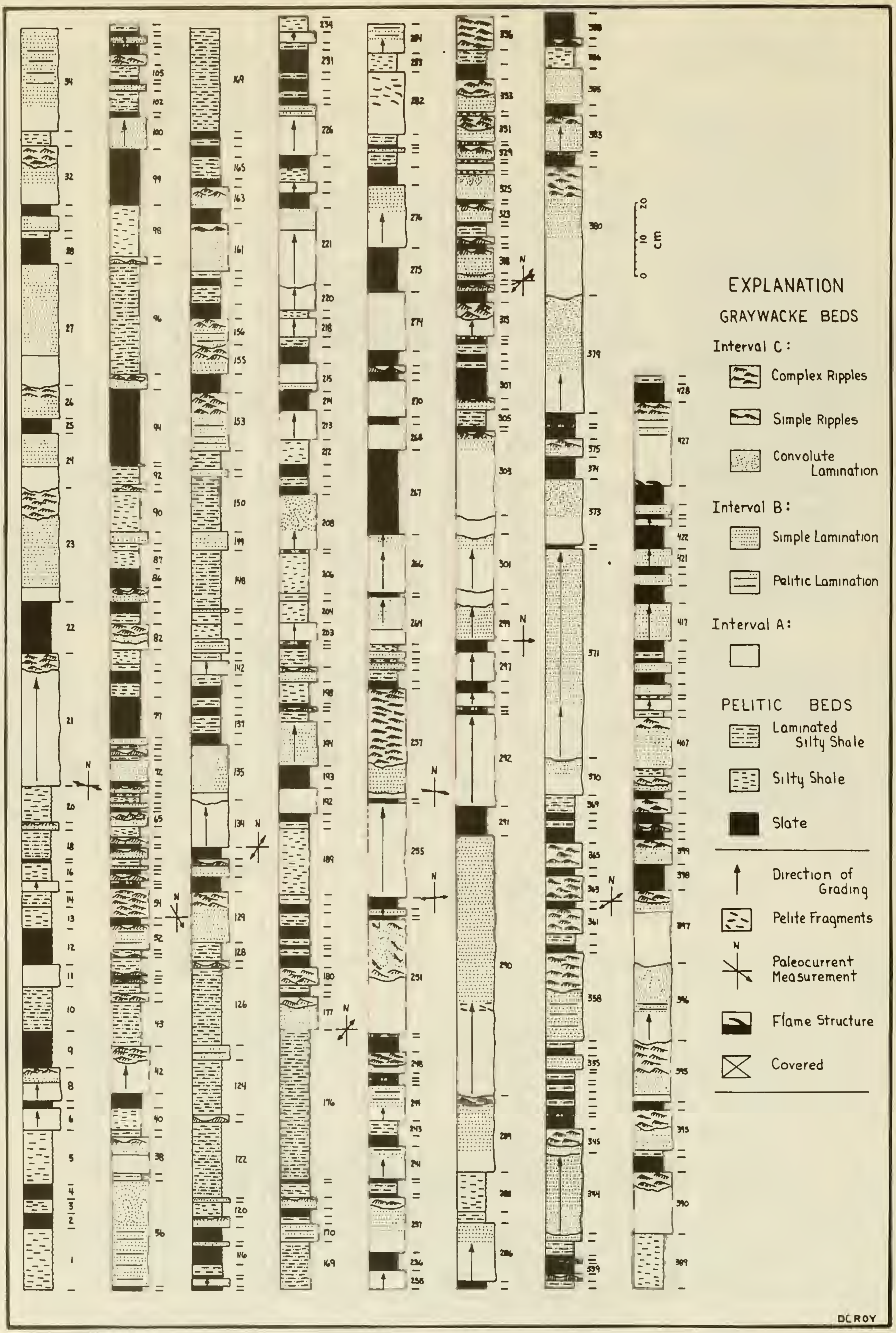

Figure 2; Lithologic and depositional description of the Jemtland section at STOP 4. This is section 2 in Figures 4 and 5.

Early Silurian Sedimentation

Following the Taconian uplift to the west, clastic debris was shed eastward into a broad basin. Along the western margin of the basin, at the position of the Ashland Synclinorium, a thick sequence of sandstone and conglomerate was deposited (Frenchville Formation) which gave way to more shale-and limestone-rich facies out in the basin (New Sweden and Spragueville formations). These Lower Silurian lithofacies are more easily examined in the Ashland-Presque Isle area and are described in more detail elsewhere in this quidebook (Roy, Trip B-6).

Where we are able to see the base of the Frenchville along the western margin the Ashland Synclinorium the formation rests unconformably on the Madawaska Lake Formation as just described in connection with the exposure at STOP 3. The more eastern lithofacies each rest conformably on the "ribbon rock" limestone of the Upper Member of the Carys Mills Formation. It is therefore inferred that the Taconian hiatus decrease eastward across the Ashland Synclinorium to essentially zero and that the Taconian uplift can be fairly well dated by the influx of mud that terminated the more cyclic "ribbon rock" deposition of the Carys Mills. The change from Carys Mills sedimentation to those of the New Sweden and Spragueville formations is pretty well dated as about graptolite zone 19 of the Early Silurian (Pavlides, 1968; Roy and Mencher, 1976). It is likely that the Aroostook-Matapedia Basin in which the Carys Mills was deposited became more shallow as a result of the Taconian uplift that raised land to the west (Roy, 1970a). Subsidence of the basin (and possibly also the western upland) during post-Taconian sedimetation is inferred from the great thickness of the Silurian section in the basin and the fining upward of the section.

Jemtland Sedimentation

The Jemtland Formation is a thin-bedded flysch composed of five principal rock-types and two minor rock-types. The major rock-types are:

1) Indistinctly laminated calcareous , platy, silty shale. This rock type contains the most abundant and best preserved graptolites.

2) Nonlaminated, calcareous, silty shale. This rock type usually shows an irregular bedding cleavage.

3) Dark-gray to black fine-grained thinly cleaved slate. Cleavage in this rock type is usually axial planar to the folds, or nearly so.

4) Light-gray, calcareous, micaceous, laminated and cross-laminated, quartzose, siltstone or fine-grained sandstone (graywacke).

5) Gray, medium-to coarse-grained, calcareous, feldspathic and lithic graywacke.

These rock types are interlayered on the scale of centimeters and tens of centimeters. It is common for lithic graywacke to grade upward into the micaceous quartzose graywacke in thicker graded beds. The minor rock types are tuff (STOPS 2 and 6) and micritic limestone.

All Jemtland exposures can be described lithologically in terms of the above rocks (usually just the major rock-types) and can be described sedimentologically in terms of a Bouma-type turbidite model. Roy (1970a, 1970b) has shown that the pelitic rock types (types 1,2, and 3 above) do not show any preferred ordering with respect to each other or the graywacke beds and hence must be treated separately in terms of sedimentation. The graywacke beds may be nicely described in terms of Bouma's (1962) A,B, and C intervals. A pelitic bed relates only indirectly to the turbidity current that deposited the underlying graywacke bed as discussed below.

Figure 2 shows a graphical description of the outcrop at STOP 4 (essentially the "type" Jemtland) in terms of Bouma's model as modified by Walker (1965, 1967). This exposure and that at STOP 2 are typical of the graywacke facies of the formation. Figure 3 shows two sections (similarly described) from the more eastern slate facies of the Jemtland; see Figure 9 for the locations of these two eastern sections. From all three of the sections the following generalizations are evident:

1. Amalgamated (composite) turbidites (Walker, 1965) are common in the graywacke facies.

2. Basal "A" intervals are much more common in the graywacke facies. North of the latitude of Washburn there is in fact a fairly regular eastward decrease in the proportion of graywacke beds that begin with basal "A" intervals as shown in Figure 4.

3. The transition from "A" to overlying "B" intervals is usually gradational whereas transitions from "B" intervals to "C" intervals almost always involve an erosional interface. The upward ordering of A,B, and C is statistically favored (Roy, 1970b).

4. Grading is common in "A" intervals and is present but less obvious in many "B" intervals. Graded "A" intervals were produced by deposition under conditions of very rapid fallout. Non-graded "A" intervals may be material transported by grain flows.

5. Both of the silty shale rock types are more abundant in the graywacke facies than the finer-grained dark slate. The dark slate increases in abundance basinward as shown in Figure 5.

6. The most common type of pelite to follow the graywacke beds is the type that is the most abundant in the particular section (Roy, 1970b).

In addition there are features that are not well displayed in the graphical sections of Figures 2 and 3 but are generally observed in outcrop:

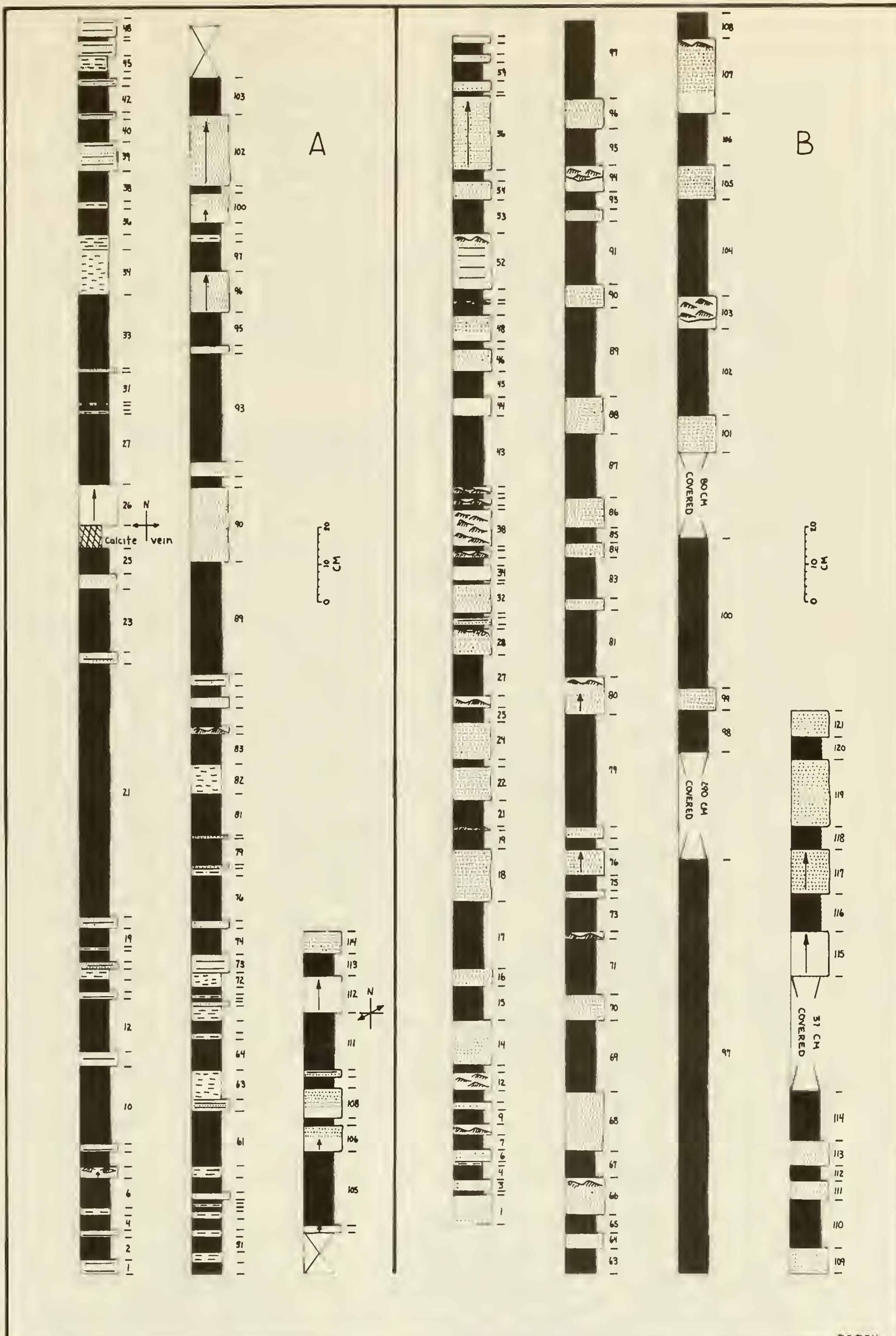

Figure 3: Lithologic and depostional descriptions of outcrops of the slate facies of the Jemtland Formation: A) Outcrop at section 4 of Figures 4 and 5; B) Outcrop at section 5 of Figures 4 and 5 (see also Figure 9).

7. Graywacke beds overlying either of the two types of silty shale described above generally have erosional sole features (flutes, tool marks, ridges and grooves, etc.) whereas soles of graywacke beds overlying the fine-grained pelite show load features (e.g. load casts, flame structures, etc.).

8. The clay/silt matrix of the graywacke beds appears to be primary. This conclusion is based on depositional segregation of the matrix in sedimentary structures and the sharp, little-altered boundaries of feldspar and rock fragments in many of the graywacke beds. Carbonate alteration is more common than clay alteration in the graywacke.

9. Bioturbation is very rare and delicate siltstone laminae within pelite beds are traceable laterally for great distances as is well shown at STOP 2.

10. Laminae within "B" intervals become thinner, more traceable, and more clay/silt rich upward. Pelite laminae are commonly seen in the upper parts of "B" intervals. Weisbrich (1977) and Robert Brown (unpublished data) have produced parallel laminated beds in flume experiments at plane-bed flow velocities in which laminae thickness and, to some extent, clay/silt incorperation are found to depend on the rate of bed aggradation. The experiments were run by allowing sand to fall-out at known rates through a recirculating slurry of fixed lutum (clay plus silt) content. As a rule rapid bed aggradation (high fall-out rate) produces indistinct and thick laminae whereas low bed aggradation (low fall-out rate) produces thin, well defined, and more laterally persistent laminae. Incorporation of lutum in the experimental deposits increases with decreasing bed aggradation rate with marked increases to a few percent at aggradation rates less than about .05 cm/min. So far, pure pelite laminae within experimentally produced laminated fine sand beds have not been formed and their presence in "B" intervals of Jemtland and other turbidites is still a mystery. Variations in laminae thickness and persistence within "B" intervals, however, appears to be useful in qualitatively assessing variations in bed aggradation rates during deposition of these turbidite intervals. The experimental aggradation rates used by Weisbrick and Brown to produced lamination comparable to that seen in the Jemtland ranged from .003 to .5 cm/min; thus the deposition time of "B" intervals of the Jemtland were possibly tens of minutes in duration.

11. Ripple lamination in "C" intervals typically represents climbing ripples with low angles of climb and thus indicate low values of the ratio of bed aggradation-to-ripple migration (Jopling and Walker, 1968; Scheible, 1979). This ratio is given by: Ar/Mr = tan Ac where Ar is the bed aggradation rate, Mr is the ripple migration rate and Ac is the angle of climb (Scheible, 1979). In fairly well developed climbing ripples, angles of climb of 5 - 10° (Ar/Mr of .1 to .2) appear necessary to permit clear discernment of climbing ripple cosets;

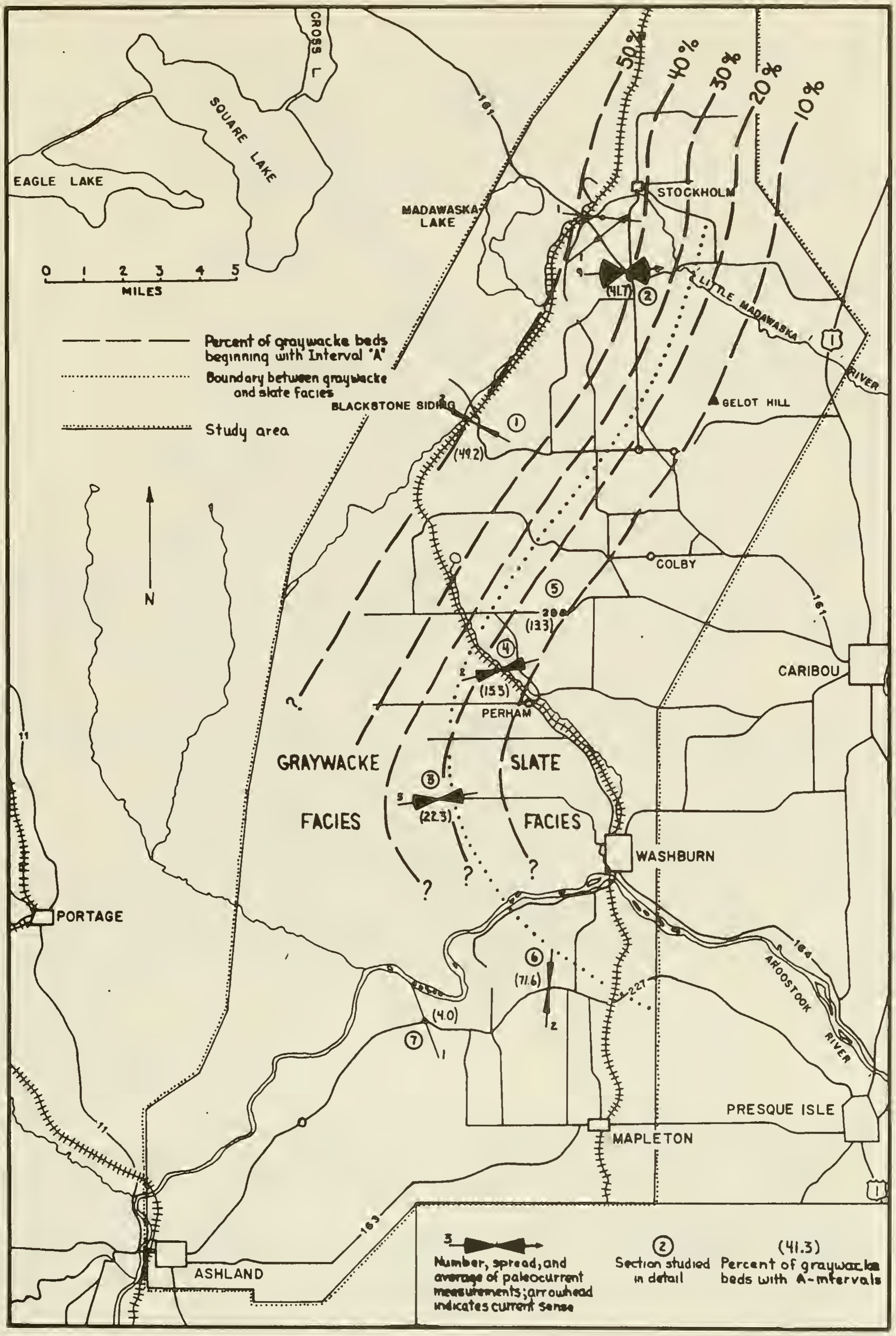

Figure 4: Variation in proportion of graywacke beds in the Jemtland Formation that have basal A-intervals.

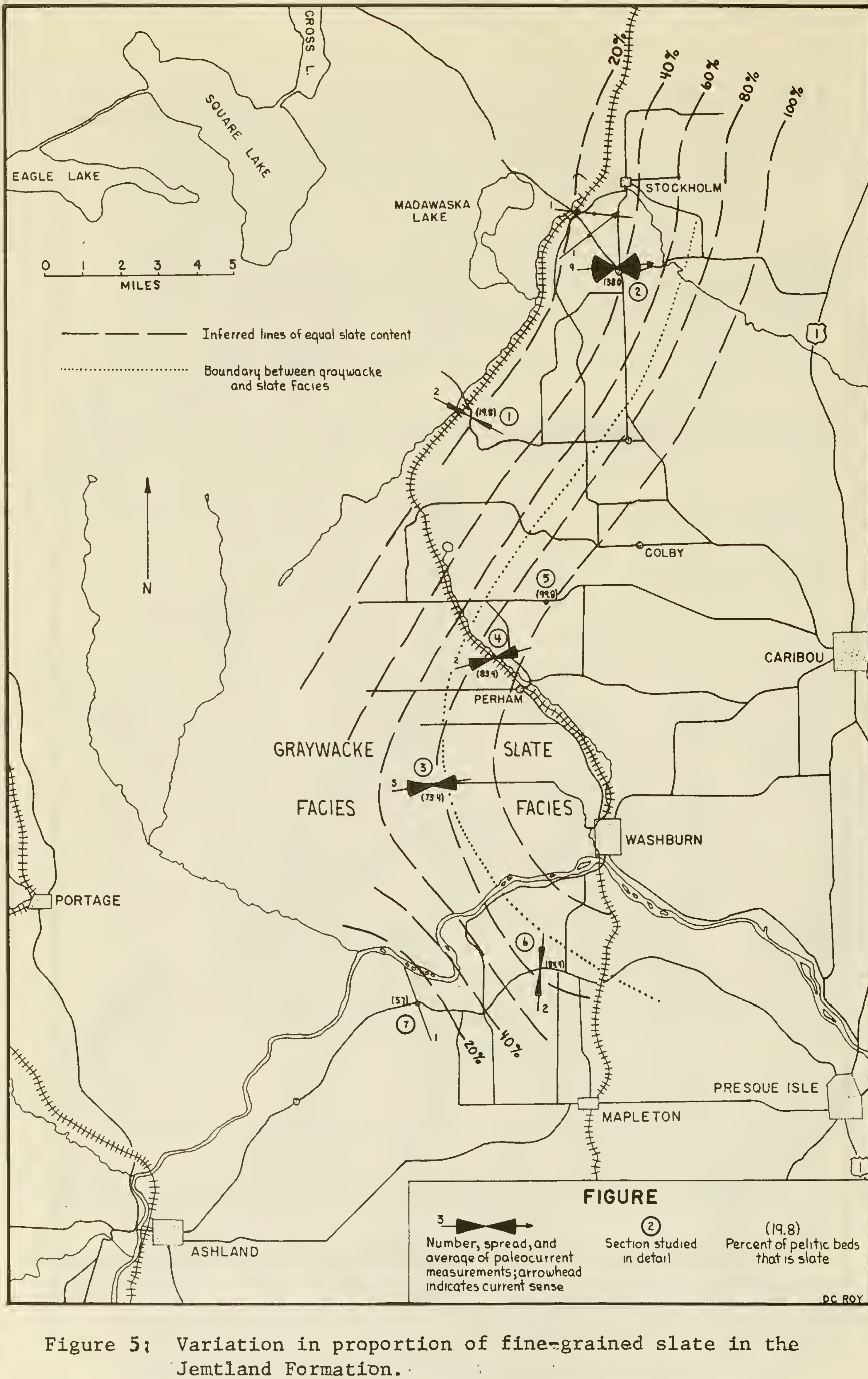

Figure 5: Variation in proportion of fine-grained slate in the Jemtland Formation.

somewhat higher angles of climb are probably necessary in more complicated natural cosets to clearly see the climbing character of the ripples. The generally low Ar/Mr ratios in Jemtland "C" intervals probably is the cause of the erosional surface at the base of most such intervals. Non-erosive transitions from "B" to "C" intervals would require high Ar/Mr ratios or nearly vertical angles of climb to prevent substrate erosion. Scheible's (1979) work suggests that as a practical matter realization of such high Ar/Mr ratios means that flow velocities may have to be below velocities for initiation of motion of the sand grains on a flat bed (to greatly reduce Mr) while appreciable sand of that grainsize is still available in the flow to fall-out. It has been shown that ripples are stable and can migrate at flow velocities less than that required to initiate ripples on a flat bed (Middleton and Southard, 1977). Such low flow velocities, however, may inhibit development of ripple bed forms from the precurser flat bed conditions at the close of "B" interval deposition. This is because the initiation of ripples on a flat-bed requires flow velocities on the order of the flat-bed initial motion velocity unless there is significant perturbation of the flat-bed (Middleton and Southard, 1977). It is also likely that the presence of fall-out from a turbidity current reduces the lower velocity limit of upper flat-bed stability to values well into the ripple stability field as established (for a given grainsize) under conventional non-aggradation experimental conditions. During turbidity current deposition, ripple development is probably suppressed both by fall-out and the continuing reduction of grainsize during sedimentation (Allen, 1970).

12. Pelite clasts are common in the coarser-grained graywacke beds. These, usually tabular, clasts may have maximum dimensions that are on the order of the thickness of the graywacke bed itself. Most of the pelite clasts are fragments of Jemtland shale added to the detritus by submarine erosion upslope from the position of deposition. It is common that the clasts are positioned within the graywacke bed at levels of 1/4 or 3/4 of the bed-thickness above the base of the bed. This same localization of pelite clasts is found in Frenchville turbidites and the present writer has no very good explantion for this tendency.

The above features suggest, or are at least consistent with, deposition of the graywacke beds from lutum-rich turbidity currents. The clay and silt of each turbidity current cloud probably remained in suspension for some time following sand deposition. Upward mixing of the warm shelf-water of the turbidity current after reaching the cold bottom water of the basin probably helped to maintain a fairly persistent near-bottom suspension cloud which was resupplied by subsequent turbidity currents. The unlaminated silty shale and the pelite of the fine=grained slate probably represent deposition from such more or less stagnant suspension clouds. The non-laminated silty shale would represent deposition from the near-source part of the cloud.

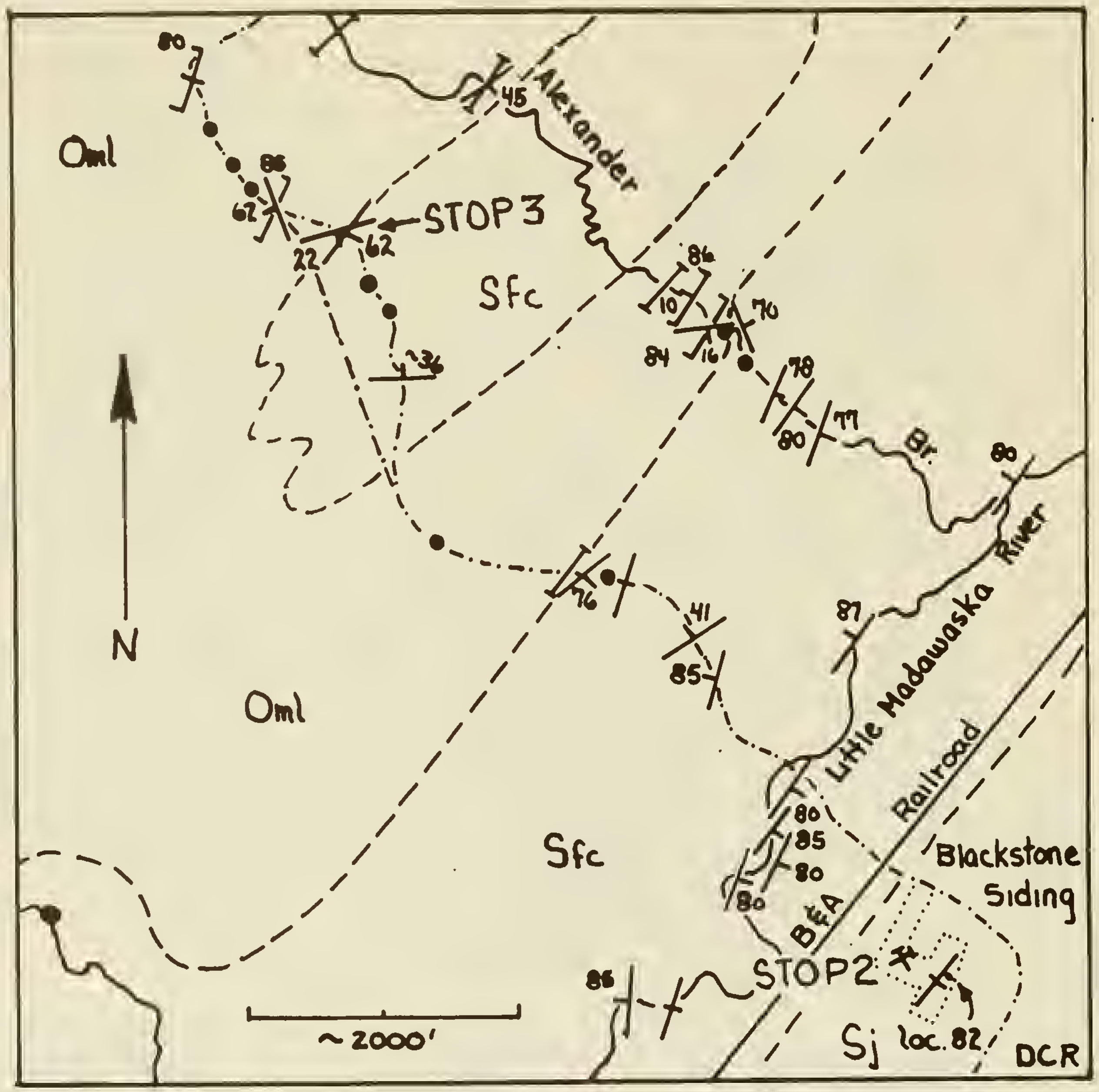

Figure 6: Geologic map of the Blackstone Siding area showing the locations of STOPS 2 and 3. Base from an uncorrected airphoto.

The laminated silty shale is more difficult to explain because the fabric of the shale and the common orientation of graptolites within it suggest current effects during deposition. It is possible that the laminated silty shale beds were deposited from the silt-rich phase of basinal suspension clouds that were moving in response to contour currents, residual turbidity currents, or other currents within the basin.

Post-Jemtland Sedimentation and the Close of the Silurian

Along the axis of the Stockholm Mountain Syncline (Roy, Trip B-6; Figure 2) the Jemtland Formation is overlain by the Fogelin Hill Formation which may span the Siluro-Devonian boundary (Roy and Mencher, 1976; Figure 1). The Fogelin Hill is conspicuous in its content of red and green slate and absence of the coarser-grain graywacke beds found in the Jemtland. The red and green slates suggest important changes in the geochemical environment of the basin following Jemtland deposition. The basin appears to have become more oxidizing and more distal with respect to detrital sources.

The Fogelin Hill Formation appears to span the time interval of the Salinic Disturbance for which there is good evidence both to the east (Presque Isle area) and to the west (Fish River Lake area). Rocks very similar to the Fogelin Hill are present in the Portage area to the west of the synclinorium where they contain Early Devonian graptolites and rest unconformably on Ordovician rocks (see Figure 2 of Roy, Trip B-6; Roy and Mencher, unpublished data). Crinoidal limestone is present as thin beds in both the Portage area and high in the Fogelin Hill section within the synclinorium. The Fogelin Hill Formation is interpreted by Roy, (this volume) to have been deposited in a residual basin of the synclinorium that survived but was restricted by the Salinic "uplifts" on both sides.

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Itinerary

Mileage	
	Assembly point is the parking lot of Keddy's Motor Inn. Starting time is 8:00 A.M. Head north on U.S.1 through Presque Isle. Mileage starts at the bridge over the Aroostook River north of town.
0	Bridge over Aroostook River. U.S.1 from here to Caribou passes through some of the best potato country in Aroostook County. The bedrock supporting the agriculture is composed of the Carys Mills and Spragueville formations.
7.75	Bear left off "new U.S.1" onto "old U.S.1" toward downtown Caribou.
11.05	Turn left onto Route 161 in Caribou just beyond the downtown shopping mall.
11.35	Turn left toward Main Street.
11.40	Turn right on Main Street which is also Route 161.
12.25	Bear right at junction with Route 228 and continue north on Route 161.
16.55	STOP 1. Park on shoulder of highway. Please be careful since the exposure is on the inside of a curve.

This is one of the best exposures of the Lower Member of the Carys Mills as I have mapped it in the Caribou Quadrangle. Graptolites from this exposure have been assigned by Pavlides and others (1961) to zone 13 of the Ordovician (Caradocian). The strata here are about 3500 feet (1200 meters) below the base of the Upper Member of the Carys Mills which is composed of the famed limestone "ribbon rock" (largely of earliest Silurian age) of the Aroostook-Matapedia Belt. Four main rock-types are present here: 1) gray, fine-grained, green-weathering, calcareous slate; 2) light-gray, medium-to-fine grained, micaceous, calcareous, graded, laminated/cross laminated quartzo-feldspathic graywacke; 3) light-gray, massive, micaceous, rusty-orange weathering, calcite-veined quartz graywacke in which sedimentary structures are rare; 4) dark-gray, pale-gray weathering, laminated micritic limestone. This pre-Taconian sequence is inferred to have been deposited in an oceanic basin receiving abundant terrigenous detritus from intraoceanic sources which may include volcanic islands to the west and a tectonic island arc in the present Miramichi Anticlinorium (Rast and Stringer, 1975). Terrigenous sources are inferred to wane in importance during deposition of the Upper Member of the Carys Mills were calcareous turbidites dominate the deposit.

Return to cars and continue north on Route 161.

19.15 Bear left at Y-intersection. Outcrops of the Late Early Silurian New Sweden Formation are on the left side of the highway. The "Caribou Station" of Boston College's seismic network is located a short distance straight ahead from this intersection (so much for geophysics on this trip).

20.00 Turn left (west) at the light in Sweden, Maine (Texaco Station).

22.65 Continue straight at the sharp right (north) turn in the paved road. We are entering a major active lumbering area and you are urged to watch out for large trucks; it is further recommeded that you let them have the right-of-way.

24.15 Turn right (north). Road becomes a bit narrower and rougher here (usually).

25.65 Turn left (south) onto the entrance road for the "Blackstone Siding quarry".

25.85 Park as best you can.

NOTE: We will spend about 1.5 hours in the Blackstone Siding area (Figure 6) examining STOPS 2 and 3. The outcrop at STOP 3 is small (!) and is best examined by small groups so it is suggested that cars go to it one or two at a time (following directions below) during our stay here. Those more interested in studying Jemtland turbidites may simply stay at STOP 2.

STOP 2. The Blackstone Siding quarry provides the best exposure of the Jemtland Formation in the region. It displays the most proximal phase of the formation and provides slightly weathered pavement surfaces that permit careful study of turbidite features. The strata strike about N35°E, are essentially vertical, and top to the southeast. No reversals of facing have been found. In the southeast corner of the pit are exposures of basal beds of the Aquagene Tuff Member of the formation which can be traced discontinuously to the northeast for a distance of about nine miles (14 km). Graptolites are ubiquitous in this quarry and some fine specimens are possible. The strata here are of Early Ludlovian age (graptolite zones 33-34 of the Silurian).

Return to cars and head out to the main road.

26.05 Main lumber road. Turn left (west).

26.15 Blackstone Siding (International Paper). In this vicinity we cross the Jemtland-Frenchville contact that is not observed here but is seen to be gradational in river exposures along strike to the northeast.

26.30 Little Madawaska River.

26.3 Road to right (north); stay on main road.

26.8 Turn right onto a segment of the old haul road that is now been bypassed.

27.3 STOP 3. In this small outcrop (some have called it an "incrop") the Taconian unconformity is exposed between the Madawaska Lake Formation (Ordovician) and the Frenchville Formation (Figure 6). The contact is interesting because it is angular, there are large flute casts on the sole of the basal sandstone bed of the Frenchville, and step-lineations on the sole of the sandstone preserve the intersection of Madawaska Lake bedding and the erosion surface. The relationships of these features are shown in Figure 7A. The flute casts are assymmetric with the steep slope of the flute located on the down-dip (pre-Frenchville) side of the flute and the "floor" of the flute mold was essentially parallel to the bedding in the underlying Madawaska Lake Formation (Figure 7B). Taken together, these features suggest Taconian folding (submarine?) of semiconsolidated Madawaska Lake beds followed by submarine erosion by a turbidity current and finally deposition of the pebbly lithic graywacke. The material of the graywacke bed may have been transported by grainflow or other mechanisms, arriving at the bottom position (canyon floor?) represented by the outcrop after the turbidity current had largely passed.

Return to cars and continue northwest along the old stretch of the lumber road.

27.40 Main road. Make sharp left to head back (eastward) on the main road.

27.5 As you go up the hill the Madawaska Lake-Frenchville contact is again crossed (we are only a short distance along strike from STOP 3).

28.30 Little Madawaska River.

28.45 Blackstone Siding.

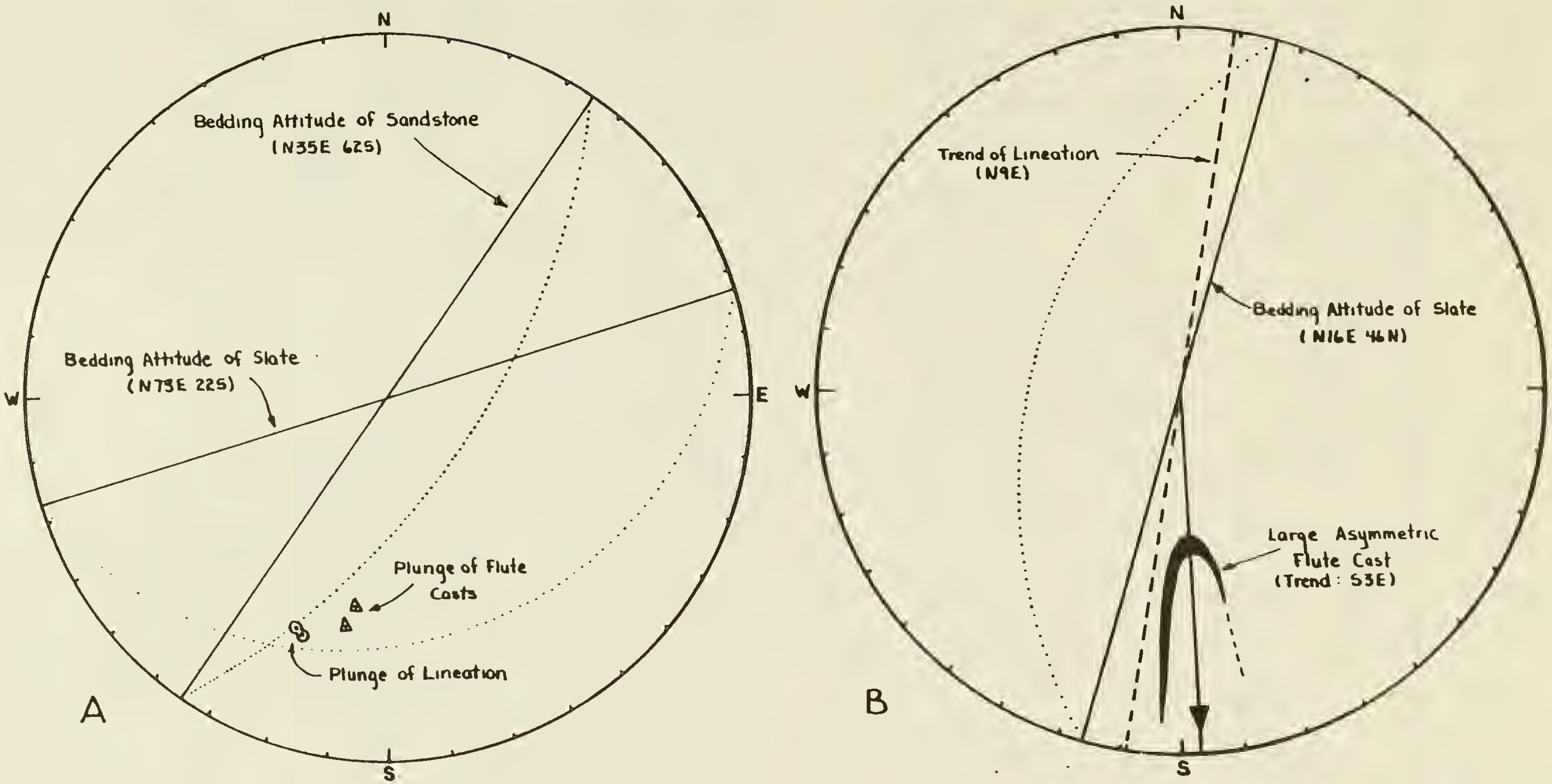

Figure 7: A- Present relationships of bedding step-lineation, and flute-cast plunge at STOP 3.
B- Pre-Frenchville orientations of Madawaska Lake bedding and flute casts showing the relationship of the cast assymmetry to bedding in the substrate.

28.55 Entrance to Blackstone Siding Quarry. Continue east.

30.05 Turn left (east).

31.55 Continue straight on paved road.

34.20 Intersection with Route 161 (Texico Station). Turn left (north).

38.80 STOP 4. Park as directed. The exposure is on the west side of Route 161 in a slight curve. Care must be exercised in both parking and crossing the highway. This will probably be a good place for a LUNCH STOP. A small store (if open on Sunday) in Jemtland (near the stop) may provide provisions.

This is the "type exposure" of the Jemtland Formation. The formation here is similar to that seen at STOP 2 but is more slate-rich (less silty shale) and is inferred to be slightly more distal. The outcrop is near the middle of the Jemtland and is on the southeastern flank of the Stockholm Mountain Syncline (see Figure 2 of Roy, Trip B-6, this volume). The proportion of graywacke (58 percent) is similar to that in the sequence at STOP 2. Figure 2 shows the details of the stratigraphic section here. Common sole features readily permit paleocurrent measurements which show a west-to-east flow of the turbidity currents (Figures 2,4, and 5).

Continue north on Route 161.

39.50 Approximately here we cross the axis of the Stockholm Mountain Syncline. Youngest unit is the poorly exposed Fogelin Hill Formation.

40.75 Little Madawaska River. Frenchville Formation is exposed in the river upstream from the bridge.

43.30 STOP 5. Park on the shoulder of the highway.

This is one of the better exposures of the Madawaska Lake Formation (Ordovician) in the "type area" of the formation. In this exposure the rocks are typical and consist of prodominant olive-green, fracture cleaved slate with lesser thin beds and laminae of calcareous quartzo-feldspathic siltstone or fine-grained sandstone. Here also are thin beds of rusty-weathering pyritiferous micritic limestone. One exposure here also shows red slate which is a minor but conspicuous rock type in the formation near the unconformity with the overlying Frenchville Formation in this area. The Madawaska Lake is the temporal equivalent of the Winterville Formation (volcanic rich) to the west. More westerly in the Madawaska Lake, lithic graywacke increases in abundance presumably reflecting proximity to volcanic islands.

Continue north on Route 161.

43.45 Turn around in the Rest Area and head south.

46.15 Little Madawaska River.

46.20 Turn left (east) on paved road.

47.70 Turn left (north) at Stockholm Post Office. Continue north across the Little Madawaska River and R.R. tracks, by the store, and up the hill.

48.60 Entrance to Stockholm Town Dump on left. Enter and drive to refuse area and park. Town permission is required to enter this scenic area. Walk southwest along the strike of the lithic tuff horizon that is more or less exposed in the dump.

STOP 6. Aquagene Tuff Member (provisional name) of the Jemtland Formation. An almost complete section of the tuff sequence is available in these brush covered exposures and is depicted in Figure 8. The member (here 63 feet thick) is stratigraphically in the middle of the formation on the northwest flank of the Stockholm Mountain Syncline as shown in Figure 2 of Roy, (Trip B-6, this volume). The member is thinner and more discontinuous on the southeast flank of the fold. Fossil localities stratigraphically below, above, and within the member in the immediate vicinity date the tuff as Ludlovian of the Late Silurian. Four broad tuffaceous rock types comprise this section. Type I tuff, the most abundant, is light gray-green, chalk-white weathering, and variably lithic. In section devitrified shards and pumice fragments are clearly visible. Plagioclase, quartz, and chlorite are dominant mineral phases. Lithic tuff, designated as Type II, is composed of sand-to pebble-size fragments of intermediate and mafic volcanic rocks, plagioclase, quartz, myrmekitic quartz-feldspar, and detrital carbonate (including fossil fragments) set in a matrix of devitrified shards and pumice fragments. Type II tuff usually transitions upward into Type I in apparently graded sedimentation units. Type III tuff is a chlorite-rich rock that differs from Type I primarily in the presence of large chlorite "patches" that are flattened parallel to a bedding parting. Upward gradation from Type I to Type III tuff is observed in three beds (Figure 8). Type IV tuff is fine-grained, light gray-green in color, cherty in appearance, and occurs in thin beds less than 6 inches thick that commonly show faint lamination. This type forms a 7-foot interval in the middle of the section. In thin section tuff of Type IV shows devitrified shards and pumice fragments in a dominant matrix of microcrystalline quartz-chlorite-plagioclase. The sequence of tuff here is thought to have been deposited in deep water and probably consists largely of resedimented tuffaceous material. The ash was most likely derived from the west where contemporaneous volcanic rocks interlayered with shallow-water sediments are present.

Return to cars and return to main road.

48.9 Main road at entrance to the dump. Turn right.

49.8 Intersection at the Stockholm Post Office. Turn right (west).

51.3 Intersection with Route 161. Turn left (south).

53.2 Outcrop of STOP 4 on the right.

57.8 Intersection at light (Texaco Station). Continue south.

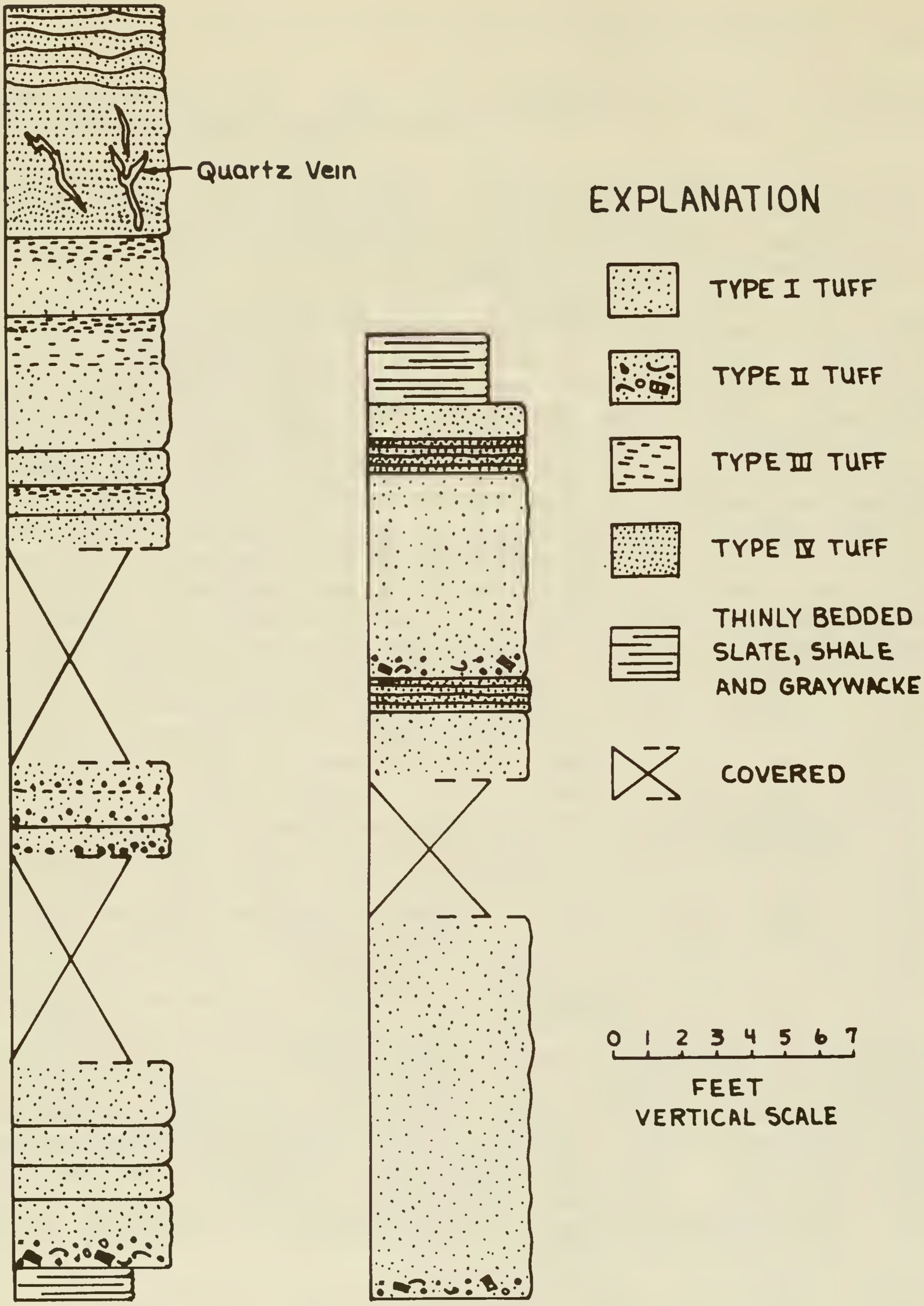

Figure 8: Stratigraphic section of the Aquagene Tuff Member of the Jemtland Formation at STOP 6. The types of tuff are described in the stop description.

60.4 Turn right (southwest) onto gravel road.

61.05 Turn right (west) onto paved road.

62.25 Railroad crossing in Colby.

63.3 Turn a hard left (southeast) onto gravel road at "T" intersection.

64.4 Turn right (west) onto paved road (Route 228).

65.35 Turn left (south) onto gravel road.

67.75 Turn right (west) onto paved road.

69.15 Junction with Route 228 in Perham. Turn left (south).

69.35 Main intersection in Perham. Turn left (southeast) and park in church parking lot (if vacant).

STOP 7. In the village of Perham there are at least three mappable horizons of manganiferous ironstone within the New Sweden Formation. These horizons and others in the Perham area are shown in Figure 9. Here the ironstone is interlayered with gray, calcareous, finely cleaved, laminated, phyllitic slate with lesser micritic limestone beds. Facing here is to the southeast. The ironstone is thinly laminated and generally quite calcareous. The details of laminae mineralogy have not been determined as yet, but hematite-rich (including specularite), carbonate-rich, and manganese-rich varieties seem most prominant. The manganese-rich laminae are reported to contain predominantly Braunite ($3Mn_2O_3 \cdot MnSiO_3$) by Pavlides (1962); Braunite is also found in small ovoid masses as well as in laminae. The origin of the laminated ironstones is not well understood. They appear to be primary sedimentary deposits which have been altered by diagenesis and low-grade metamorphism. They occur at various stratigraphic levels within the New Sweden and are rarely more than a few feet thick and a few hundred feet in strike-dimension. They are commonly interrupted by "barren" slate intervals. The New Sweden is a deep-water formation, approximately 4000 feet thick, that is distal to the turbidite-rich phases of the Frenchville Formation. The iron and manganese have a logical source in the volcanic rocks of the Ordovician Winterville Formation which formed the large emergent terrain (Taconia) a "short" distance to the west. I rather suspect that the laminated ironstones are explicable in terms of turbidity current transport of shallow, warm, shelf water (plus sediment), with the iron and manganese in both particulate and soluble forms, into a deep-water basin. The details await a better understanding of the laminae mineralogy and trace-element chemistry.

The road log ends with STOP 7. Participants may return to Presque Isle by continuing south on Route 228 to Washburn and taking Route 164 to Presque Isle. Route 164 intersects U.S.1 just north of Presque Isle. Presque Isle is about 18 miles from here. Those wishing to go to Caribou simply return to the intersection at mileage 69.15 and turn right (east); you will pass through Carson and join Route 164 in Jacobs and thence to Caribou. Caribou is about 12 miles from here.

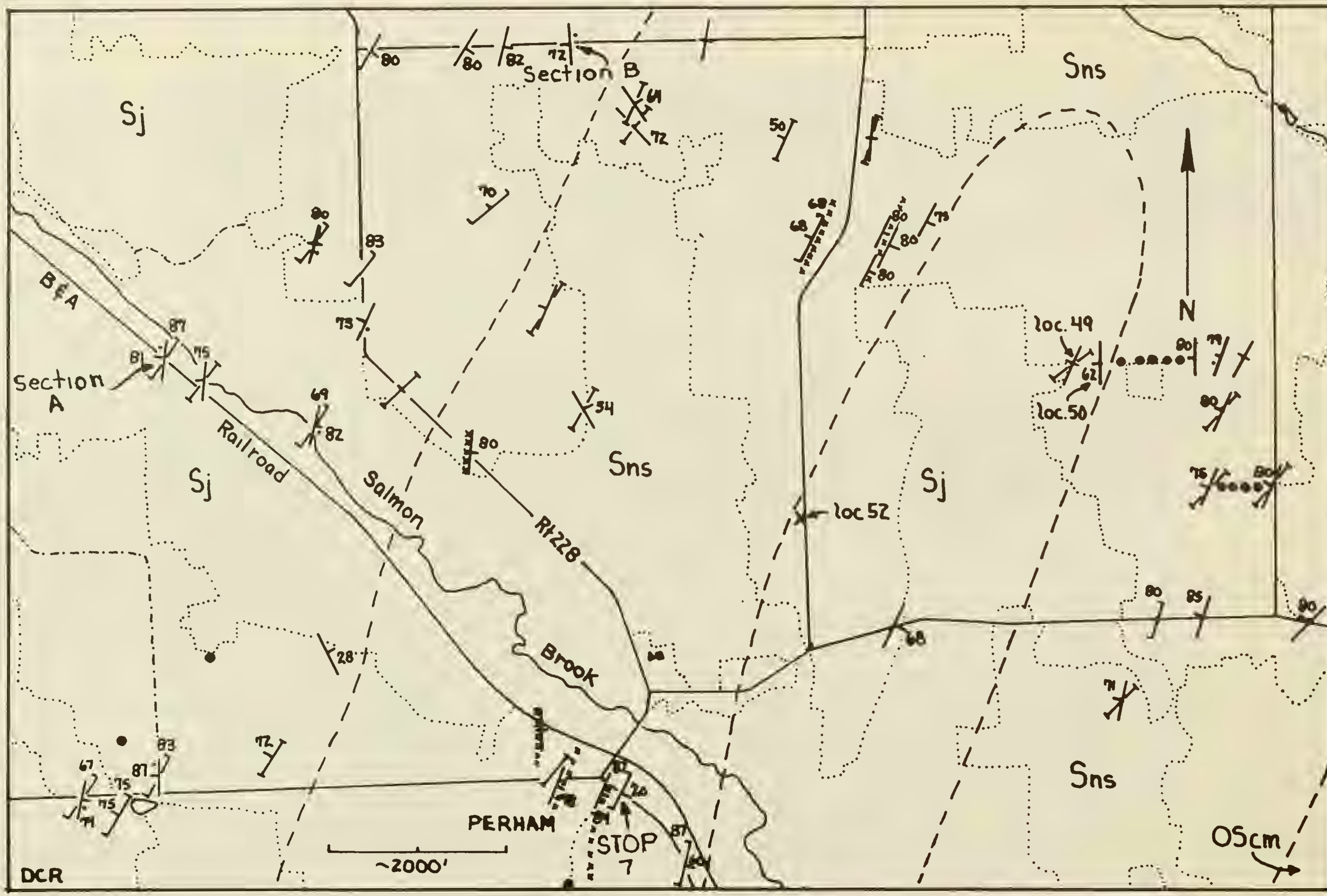

Figure 9: Geologic map of the Perham area showing the locations of STOP 7 and sections A and B of Figure 3. Lines of x's indicate traces of manganiferous horizons; dotted lines show outlines of cleared areas. Base is an uncorrected airphoto.