EVIDENCE AGAINST THE ALLOCHTHONOUS NATURE OF THE STANBRIDGE NAPPE AT HIGHGATE GORGE, NORTHWESTERN VERMONT

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INTRODUCTION

This trip features the spectacular exposure of upper Cambrian and Lower Ordovician carbonate shelf and shelf edge strata and overlying limestone breccias and calcareous shales in the Highgate Falls Gorge, at Highgate Center, northwestern Vermont. Here, a continuously exposed, *conformable* sequence of sandy dolomitic breccias of the Gorge Formation and shaly limestones and limestone breccias of the Highgate Formation are overlain by partly black slates and minor micrites of the Morses Line Formation. This contrasts with the conclusions reached by workers in southern Quebec, where this sequence is inferred to contain a major tectonic (thrust) boundary between overlying allochthonous slaty limestone, calcareous slate, and argillite (Highgate and Morses Line Formations) and underlying dolomite and dolomite breccia of the Laurentian shelf sequence (the Milton Dolomite in Quebec, which is in part equivalent to the Gorge Formation of Vermont). We shall examine the relationship of these rocks in the gorge and at selected stops to the north (Rock River and Choiniére Farm), near the International Border.

Also, beautifully exposed in the gorge, is the Highgate Falls Thrust, an out-of-sequence thrust fault that is likely part of the larger Champlain Thrust system, and which emplaces upper Cambrian dolomite breccias of the Gorge Formation over lower to mid-Ordovician black slates of the Morses Lines Formation. Diachronously evolved en echelon fractures sets (many showing various stages of rotation) and associated minor thrusts are well-displayed throughout the slates beneath the Highgate Falls Thrust.

Walking in the gorge can be treacherous and difficult both on the boulder field in the channel and the outcrop; both may be very slippery if wet. Care should be observed, and adequate footwear is advised.

We include additional stops at the Swanton Limestone Quarry, the “Beam”, and Lessor’s Quarry. The Swanton quarry exposes of the top surface of the lower block (Iberville Formation) of the Highgate Springs Thrust, part of the Champlain Thrust fault system. The latter two stops have been designated as “Rolfe Stanley Memorial Outcrops” by the University of Vermont and beautifully display foreland deformation features in parautochthonous Laurentian shelf rocks (NO HAMMERS FOR THESE TWO STOPS, PLEASE)

THE STANBRIDGE NAPPE OF SOUTHERN QUEBEC

Adjacent to the International Border, in southern Quebec (Figure 1), the east-dipping Ordovician-aged Stanbridge Nappe has previously been interpreted to be an allochthonous group of carbonates and argillaceous slates derived from the Laurentian continental rise, which was detached and thrust over the upper Cambrian Milton Dolomite, part of the imbricated, parauthochthonous Laurentian shelf, along a major, structural boundary (St. Julien and Hubert, 1975; Charbonneau, 1980; Globensky, 1981). Although it is not exposed, the western boundary of the Stanbridge Complex comprises the southernmost section of Logan’s Line in Quebec.

The Stanbridge Nappe is the southernmost of the Quebec Allochthons, part of the larger belt of allochthons that extend discontinuously from Newfoundland, across to the Gaspé and southwards to just across the International Border in northwestern Vermont; The allochthons reappear in west-central Vermont and continue southwards as the Taconic Allochthons. They are generally composed of far-traveled low-grade metamorphosed deep-marine mud-rocks and clastics originally deposited on the Laurentian continental lower slope and rise, and thrust westward, up and over the Laurentian shelf. The two belts are separated by parauthochthonous carbonate and siliciclastic rocks deposited on the Laurentian shelf and upper slope, that was subsequently imbricated during the Taconic Orogeny (e.g. the Champlain Thrust). While these parauthochthonous rocks have undergone transport along thrust faults, they are still in structural contact with related rocks deposited in a similar setting (e.g. the continental shelf), This contrasts with the allochthons that have seen significant transport from an original lower slope and rise setting and are now structurally emplaced against shelf rocks. Many of the Quebec allochthons are floored by flysch and contain olistostromal units, and all are structurally emplaced on top of younger rocks.

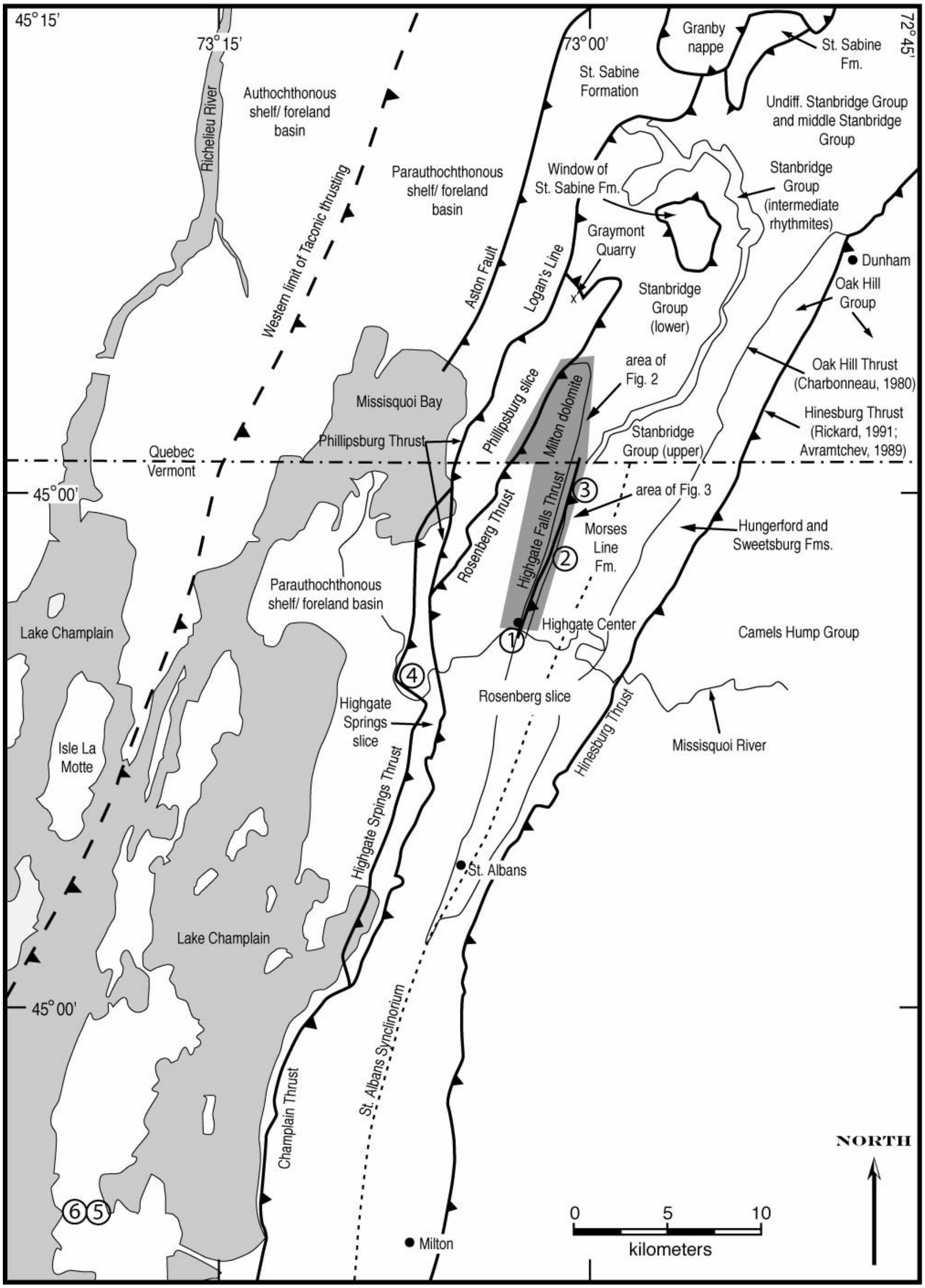


Figure 1. Regional map of significant structures and lithologic units in northwestern Vermont and southern Quebec. Based in part on Doll et al. (1961), Fisher (1968), Charbonneau (1980), Globensky (1981), and Avramtchev (1989).

The Stanbridge Nappe is composed of the dominantly argillaceous Stanbridge Complex of Charbonneau (1980; Figure 1; Figure 2). The complex is divided into three sequences: 1) the lower sequence, composed of bedded slaty limestone and limestone conglomerates, overlain by thick sequences of bedded calcareous slate with sparse individual limestone beds and ribbon limestone bed sequences (usually not more than a few meters thick); 2) an intermediate rhythmite unit, composed of thinly laminated siltstone-argillite-mudstone beds; and 3) an upper sequence of calcareous slate, slaty limestones and calcareous conglomerates. The entire complex is an internally coherent package that structurally overlies massive dolomites, chert-bearing and sandy dolomites, and dolomitic conglomerates of the Milton Dolomite along an unnamed (and unobserved) thrust fault. The Milton Dolomite (a term abandoned south of the International Border) is the northern extension of the Dunham Dolomite, and Saxe Brook and Gorge formations of northwestern Vermont, and is part of the imbricated carbonate-siliciclastic shelf sequence. The inferred structural relationship between the slaty Stanbridge Complex and underlying non-slate-bearing shelf carbonates is first reported in St. Julien and Hubert (1975) who include the bedded limestones of the lower sequence of the Stanbridge Complex as part of the transported Stanbridge Nappe. Significantly, the Stanbridge Complex does not contain flysch or olistostromes, and structurally overlies older, or approximately coeval rocks of the Rosenberg and Phillipsburg slices (Figure 1).

CORRELATIVE ROCKS IN NORTHWESTERN VERMONT

In Vermont, the lower slaty limestones and overlying calcareous slates of the lower unit of the Stanbridge Nappe are correlated with the Highgate and Morses Line Formations, respectively (Figure 4; Charbonneau, 1980; Globensky, 1981; Schoonmaker, 2005). The intermediate rhythmite and upper sequence correlate with higher sections of the Morses Line Formation above the Corliss Conglomerate, an internal member of the Morses Line Formation. Underlying the Highgate Formation are a series of massive dolomites, sandy dolomites, and dolomite breccias, including the Dunham, Saxe Brook, and Gorge Formations (in ascending order), all part of the Rosenberg Slice of Clark (1934) and equivalent to the Milton Dolomite in Quebec (Figure 3). These dolomitic units beneath the Highgate Formation have long been assigned to the imbricated shelf sequence (e.g. Stanley and Ratcliffe, 1985).

Previous workers in Vermont are divided on the presence of a major structural boundary in this section. Mehrtens and Dorsey (1987), and Schoonmaker and Kidd (2007) have interpreted the contacts between the Gorge and Highgate and Highgate and Morses Line Formation to be conformable, and it is similarly shown on the Centennial Map of Doll et al. (1961). Shaw (1958) and Pingree (1982) placed a thrust fault at the contact between the Highgate Formation and Morses Line Slates, while Haschke (1994) placed a normal fault at that same position. However, all these workers concluded that that bedded limestones and limestone breccias of the Highgate Formation were deposited on top of the dolomites and dolomitic breccias of the Gorge Formation. This contrasts with the interpretation in Quebec where the base of the bedded limestones and limestone breccias (Highgate Formation) is interpreted to be in thrust fault contact with the underlying dolomites and dolomitic breccias of the Milton Dolomite (Gorge Formation).

We will observe the contact relationships between the dolomitic units of the Gorge Formation and overlying bedded limestones and limestone breccias of the Highgate Formation (stop 1a), as well as the overlying partly calcareous slates, previously referred to as the Highgate Slate (e.g. Keith, 1923), but which we reclassify as the lower part of the Morses Line Formation. These are beautifully exposed in the Highgate Falls Gorge (Stop 1b; Figures 3 and 5). We will also observe rocks lithologically similar to those seen in the gorge that are present to the north-northeast, well east of the strike of the westernmost Stanbridge rocks in Quebec (Stops 2 and 3). The relationships we will observe show that the Highgate and Morse Line formations are internally conformable (with the exception of minor thrusts, and the younger, out-of-sequence Highgate Falls Thrust) and depositionally overlie the shelf-derived dolomitic Gorge Formation. Also, we will visit the Swanton Limestone Quarry in Swanton (Stop 4), where large sections of the hanging wall to the Highgate Springs Thrust (part of the Champlain Thrust system) have been removed, spectacularly exposing the fault and the top, slickensided surface of the underlying Iberville Shale.

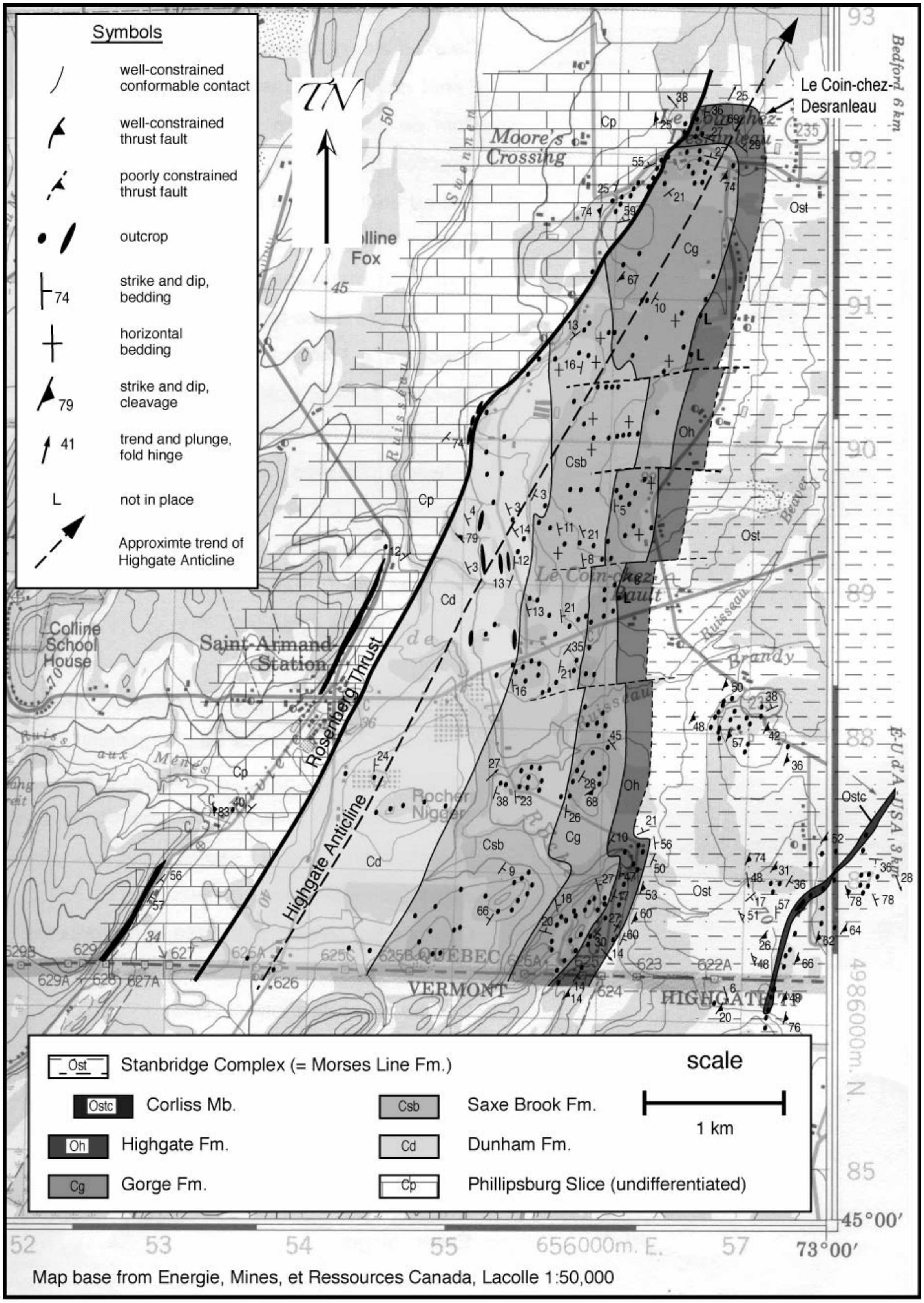


Figure 2. Geologic map, St. Armand Station area, southern Quebec.

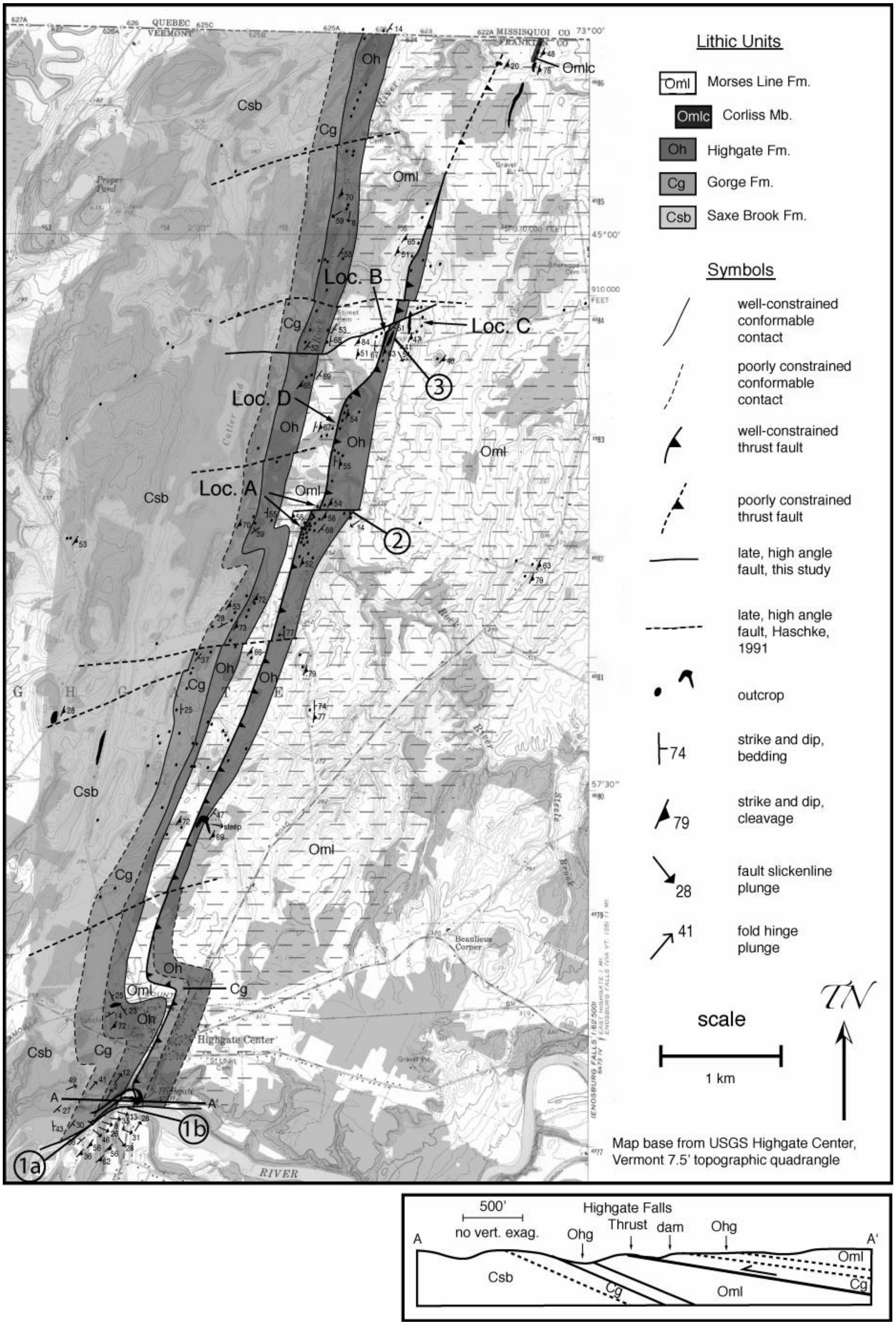
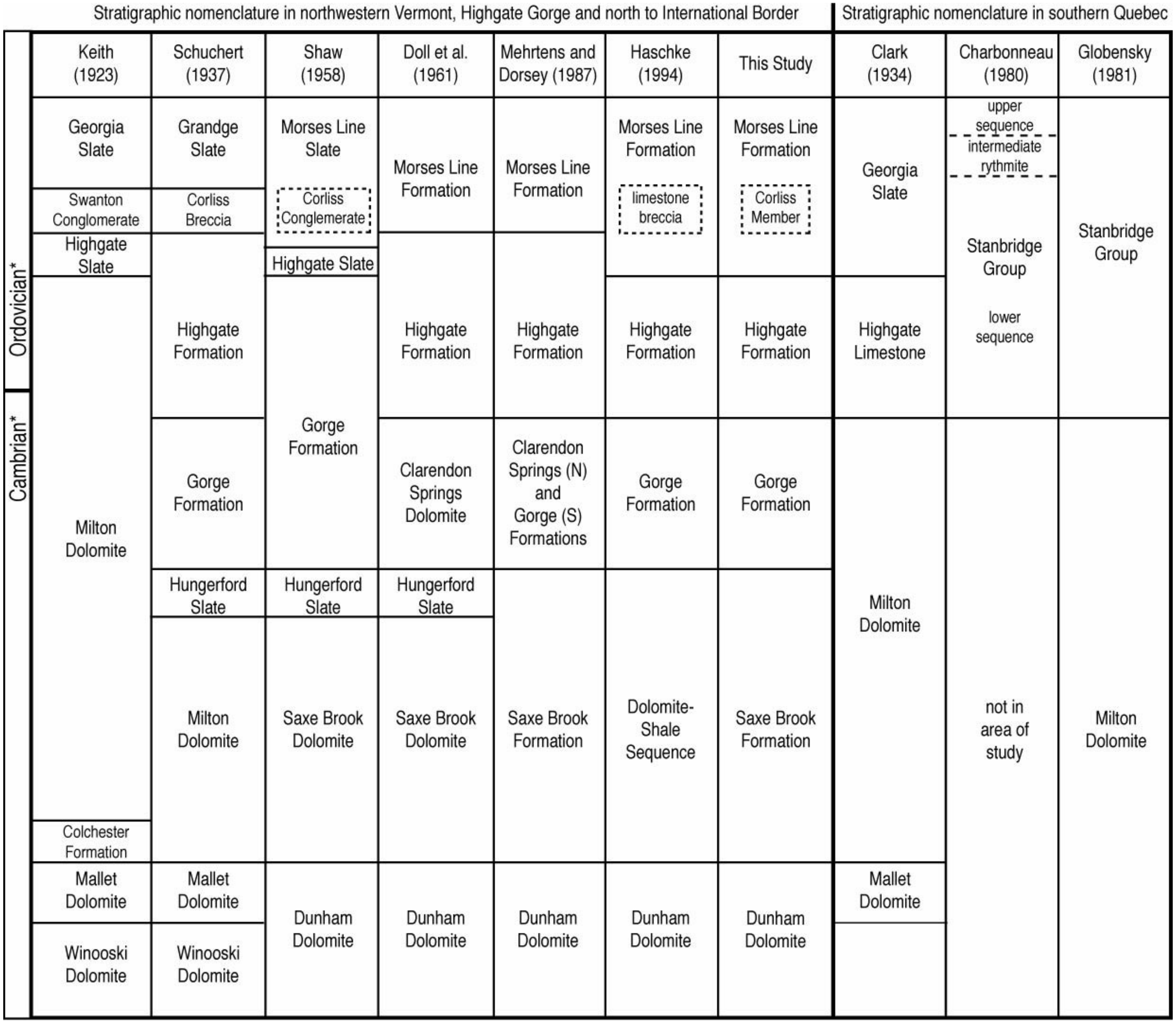


Figure 3. Geologic map, Highgate Center area, Vermont.



	Stratigraphic nomenclature in northwestern Vermont, Highgate Gorge and north to International Border							Stratigraphic nomenclature in southern Quebec		
	Keith (1923)	Schuchert (1937)	Shaw (1958)	Doll et al. (1961)	Mehrtens and Dorsey (1987)	Haschke (1994)	This Study	Clark (1934)	Charbonneau (1980)	Globensky (1981)
Ordovician*	Georgia Slate	Grandge Slate	Morses Line Slate	Morses Line Formation	Morses Line Formation	Morses Line Formation	Morses Line Formation	Georgia Slate	upper sequence intermediate rythmite	Stanbridge Group
	Swanton Conglomerate	Corliss Breccia	Corliss Conglomerate			limestone breccia	Corliss Member		Stanbridge Group lower sequence	
	Highgate Slate	Highgate Formation	Highgate Slate	Highgate Formation	Highgate Formation					
	Milton Dolomite		Gorge Formation			Highgate Formation	Highgate Formation	Highgate Limestone		
Cambrian*										
		Gorge Formation		Clarendon Springs Dolomite	Clarendon Springs (N) and Gorge (S) Formations	Gorge Formation	Gorge Formation	Milton Dolomite	not in area of study	Milton Dolomite
		Hungerford Slate	Hungerford Slate	Hungerford Slate	Saxe Brook Formation	Dolomite-Shale Sequence	Saxe Brook Formation			
		Milton Dolomite	Saxe Brook Dolomite	Saxe Brook Dolomite						
	Colchester Formation									
	Mallet Dolomite	Mallet Dolomite	Dunham Dolomite	Dunham Dolomite	Dunham Dolomite	Dunham Dolomite	Dunham Dolomite	Mallet Dolomite		
	Winooski Dolomite	Winooski Dolomite								

Figure 4. Lithostratigraphic correlation chart of the Cambrian through Middle Ordovician formations of the Rosenberg slice. *Cambrian-Ordovician boundary located after Landing (1983) as it applies to our study and does not necessarily represent placement of this boundary by other workers.

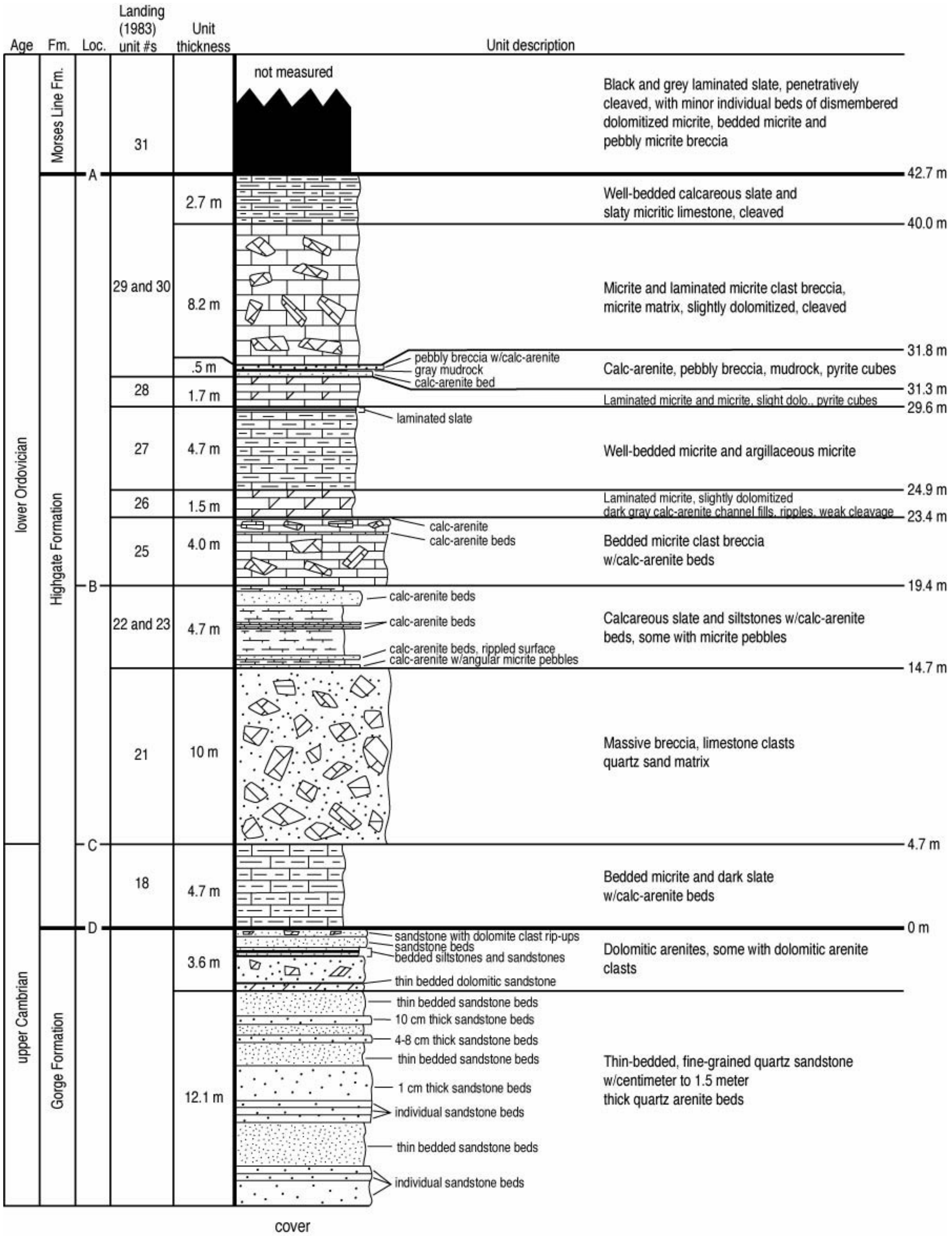


Figure 5. Measured detailed lithostratigraphy of part of the continuously exposed section on the north shore of the Mississquoi River gorge at Highgate Center. Cambrian-Ordovician boundary from Landing (1983).

STOP 1: HIGHGATE FALLS GORGE

(Stop 1a: N 44.93372º Lat., W 73.05165º Long.; Stop 1b: N 44.93540º Lat., W 73.04866º Long.; NAD 83)

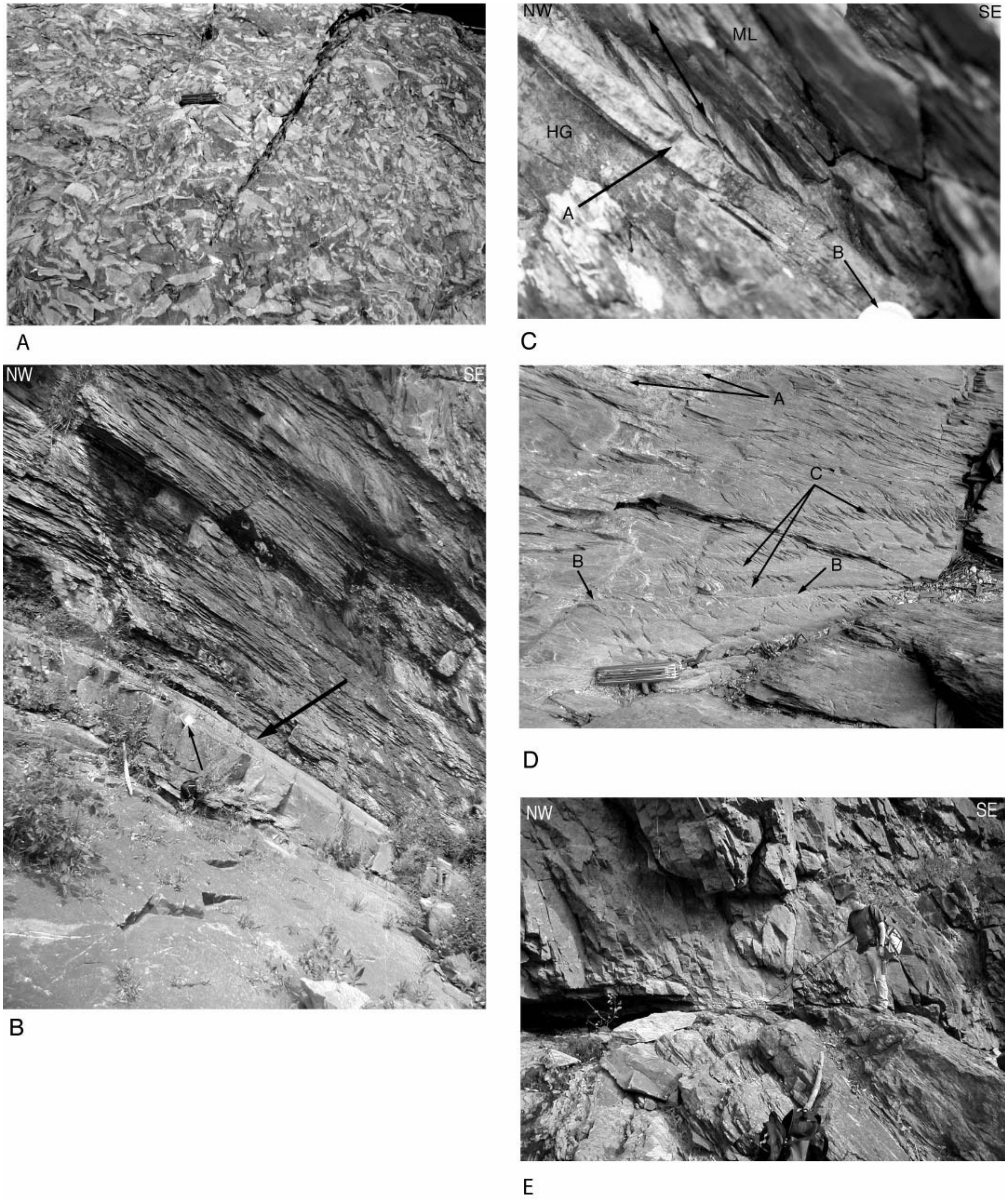
The east-west oriented Highgate Falls Gorge on the Mississquoi River continuously exposes a cross-section (Figure 3) of upper Cambrian to lower Ordovician rocks that include the upper section of the Gorge Formation (dolomitic arenites and quartz sandstones), the entire Highgate Formation (a variable unit containing bedded micrite, limestone clast breccias, calcareous slate, and argillaceous micrite), and the lower part of the Morses Line Formation (argillaceous slates with dolomitized micrite beds, bedded micrite, and limestone breccias;). The Highgate Falls Thrust repeats part of this section near the upper part of the gorge.

Because the Mississquoi River laps against the walls in part of the gorge, the gorge is cut into lower and upper sections with different access points. The lower gorge (stop 1a) displays the contact between the Gorge and Highgate Formations and is accessed by proceeding west along the canoe portage on the north bank from the trailhead on VT Rte. 207. Follow canoe portage signs, descend to the riverbank, and walk upstream to the outcrop starting at a point slightly downstream from the turbine building of the Highgate Center Hydroelectric Plant on the far bank. Here, the depositional contact the Gorge Formation and the overlying Highgate Formation can be observed (Figure 5, Loc. D). The contact is readily identifiable in the gorge by the abrupt change from thick-bedded dolomitic arenites of the Gorge Formation below, to thinner bedded argillaceous micrites and limestone breccias of the Highgate Formation above (Figure 6b). In Quebec, this contact is inferred to be a major fault boundary between the autochthonous shelf platform rocks (Milton Dolomite) and allochthonous, deep marine rocks (Stanbridge Complex).

To access the bulk of the upper part of the Highgate Formation (stop 1b), its contact with the overlying Morses Line Formation, and the Highgate Falls Thrust, return to VT Rte. 207. From there, cross the highway and proceed on foot east along a well-defined path (a continuation of the canoe portage) through the woods until about 50’ short of a small parking area next to the footbridge over the Highgate Falls Dam. Within sight of the parking area a small, poorly defined side footpath descends through the trees into the gorge. **CARE SHOULD BE EXERCISED DESCENDING TO THE GORGE AND ON THE ROCKS IN THE GORGE, ESPECIALLY WHEN THE ROCKS ARE WET.** Once in the gorge, the Highgate Falls Thrust is clearly visible in the north wall, approximately 200’ downstream from the point where the path descends (Figure 6e). A dolomite clast breccia with dolomitic matrix of the Gorge Formation is thrust over dark slates and a bedded argillaceous micrite and carbonate breccia interval within the Morse Line slates along a shallowly east-dipping surface characterized by phyllonitic fault zone cleavage; beds and cleavage in the lower block are bent in the direction of transport of the upper block.

To the west and slightly downstream from the VT Rte. 207 bridge, the contact between calcareous slates of the uppermost Highgate Formation are overlain by black slates of the Morses Line Formation (Loc. A, Figure 5). The contact on the north bank is mesoscopically folded and marked by a minor thrust fault containing a slickenlined and stepped calcite vein on the north limb (Figure 6c). On the south bank, the south limb is an observable depositional contact. Landing (1983) interpreted the micrite clast breccia (unit 29, Figure 5) that occurs beneath the calcareous slate as a tectonic breccia and the base of the black slates as an unnamed thrust. In contrast, Haschke (1994) suggested the slickensided surface on the north limb was a detachment that cut out a major thrust between the Highgate and Morses Line Formations, following relationships described by Hayman and Kidd (2002) for the northern part of the Taconic Allochthon. The observable conformable contact relationships on the south bank in the Highgate Falls Gorge do not support either of these hypotheses. Further, minor thrust faults observed in the Morse Line slates (Figure 6d) and cleavage can also be seen in the Highgate Formation limestones, suggesting that a significant structural boundary is not present within this section, which contrasts to the Quebec and Taconic allochthons where deformation and cleavage deformation occurred prior to final emplacement (Rowley and Kidd, 1981; St. Julien, 1977; Lebel and Kirkwood, 1998).

Figure 6. Field photos are all from the north bank of the Missisquoi River in the gorge at Highgate Center. A) The sedimentary breccia identified as “fault breccia” by Schuchert (1937). Pocketknife is 9 cm long. B) Large arrow indicates contact between the lowest beds of the Highgate Formation, above, and the uppermost sandstone bed of the Gorge Formation, below (Loc. D, Figure 5). Small arrow points to 15 cm tall notebook. C) Minor, locally impersistent thrust fault at contact between Highgate and Morses Line Formations. Arrow (A) = calcite slickenfiber vein, approximately 1 cm thick. Arrow (B) = dime for scale, only partially visible. Large bi-directional arrow indicates cleavage orientation. D) Minor thrust faults and en echelon fractures in Morses Line Formation. Arrow (A) points to deformed fault, slip surface parallels ground surface in photo. Arrows (B) indicate relatively undeformed planar thrust that cuts oblique to ground surface. Both faults are surrounded by extension fractures (arrows C). Pocketknife is 9 cm long. E) Highgate Falls thrust exposed in the Missisquoi River Gorge. Geologist (A.S.) points to slip surface. Upper block moved to the west (left in photo). Photo courtesy of Marjorie Gale.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Within the Morses Line Formation, dismembered dolomitized micrite beds can be observed, wrapped by the regional cleavage. Some of these beds are cut by small pre-cleavage faults with a normal sense of displacement. These normal faults are interpreted to be from passive continental margin downslope slumping. Similar dolomite beds in slate will be observed at stop 3, well east of the strike of these beds, where they form part of the upper block of the Highgate Falls thrust (Figure 3).

Landing's (1983) contact between the Gorge and Highgate Formations can be observed at Loc. B (Figure 5). Very similar argillaceous limestones and limestone breccias are present both below and above this level. We prefer to define this contact at the lower horizon (Loc. D; Figure 5), which separates dolomitic sandstones below (Gorge Formation) from the argillaceous limestones and limestone breccias above (Highgate Formation), as a much more readily identifiable contact in the field and likely representing a significant change in depositional environment from sand-dominated carbonate deposition to shale-dominated carbonate deposition. Regardless of the placement of the Gorge-Highgate contact (Loc. D vs. Loc. B) within the Highgate Falls Gorge, no major structural boundary is observed in this section, up to the position of the out-of sequence Highgate Falls Thrust.

STOP 2: UPPER BLOCK OF HIGHGATE FALLS THRUST, HIGHGATE FORMATION

(N 44.97881° Lat., W 73.02570° Long.; NAD 83)

This stop exposes broken beds of micrite breccia next to the road, and bedded argillaceous micrite in the Rock River beneath the small bridge here, both of the Highgate Formation. A photogenic asymmetrical fold may be seen if the water level is low. Although we will not venture across, the entire ridge directly to the west is composed of bedded micrite and massive micrite sedimentary breccia. At its base on the western side of the ridge, there are local fault zone breccia and mostly obscured contacts with black slates (some containing dismembered dolomitized micrite beds similar to those seen in the Highgate Falls Gorge) are present and this represents the northern extension of the Highgate Falls Thrust (Loc. A, Figure 3). However, the limestone breccias of the Highgate Formation make up the upper block here, indicating that the thrust climbs up-section north of the gorge, likely along lateral ramp(s). The small, flat-floored valley west of the ridge is underlain by the Morses Line slates, and the more resistant Highgate carbonates appear as a series of north-south ridges on the west side of this small valley.

STOP 3: CHOINIERE FARM

(N 44.99238° Lat., W 73.02034° Long.; NAD 83)

Here two small, north-south oriented ridges are present. Underlying the eastern ridge, well-cleaved argillaceous slates of the Morses Line Formation are exposed. Dismembered dolomitized micrite that is lithologically similar to micrites in the Highgate Falls Gorge can be found at the northern end of the ridge. The ridge to the west is underlain by bedded argillaceous micrite similar to the Highgate Formation suggesting a depositional contact exists in the saddle between the two ridges.

At the base of the western flank of the western ridge, steeply dipping phyllonitic slates and dismembered dolomitized micrite beds are exposed. To access these exposures proceed around the northern part of the ridge, crossing the fence and proceed south along the base of the cliff (Loc. B, Figure 3). We interpret this to be along, or near, the Highgate Falls Thrust, which here emplaces Highgate Formation carbonates over the Morses Line slates that make up the valley west of the ridge. Further north, these ridges die out into flat-lying fields near the International Border, where a final exposure of faulted rocks occurs entirely within Morse Line slates (Figure 7). This demonstrates an episodic decrease in stratigraphic throw between the upper and lower blocks of the Highgate Falls Thrust, probably along lateral ramps, from the Highgate Falls Gorge north to the International Border. At the International Border, slates of the Morse Line Formation make up both the upper and lower blocks, and this indicates that no significant tectonic boundary exists within the section that includes the dolomitic Gorge Formation up through the lower part of the Morses Line Formation (to near the level of the Corliss Conglomerate and Intermediate Rhythmites of the Stanbridge Complex).

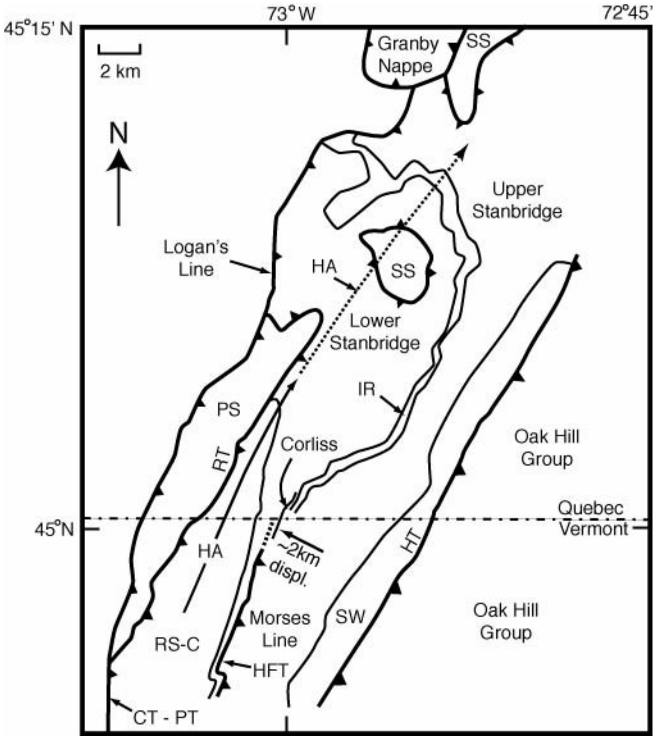

Fig. 7. Generalized geology and structure of southern Quebec and northwestern Vermont. CT-PT = Champlain/Phillipsburg Thrust. HA = Highgate Anticline. HFT = Highgate Falls Thrust. HT = Hinesburg Thrust. IR = Intermediate Rhythmite unit of the Stanbridge Group. PS = Phillipsburg Slice. RS-C = Carbonates of the Rosenberg Slice (up to the top of the Highgate Formation). RT = Rosenberg Thrust. SS = Saint Sabine windows. SW = Sweetsburg, Dunham, and Cheshire Formations east of the Hinesburg Thrust. Adapted from Doll et al. (1961); Charbonneau (1980); Globensky (1981); Avramtchev (1989).

STOP 4: SWANTON LIMESTONE QUARRY

(N 44.90706º Lat., W 73.11090º Long.; NAD 83)

The Swanton Limestone Quarry has exposed large sections of the Highgate Springs Thrust, part of the Champlain Thrust fault system. Here, light gray, bedded limestone of the Beldens Formation is thrust over black Iberville Shale. Both cross-sectional views and the top surface of the lower block (top of shale) are exposed. The fault zone is expressed as mylonitic marble in the Beldens Formation and highly foliated and veined shale in the Iberville Formation. Slivers of dark gray mylonitized marble are also intercalated in the shale. The top surface of the Iberville Formation is decorated with slickensided and stepped calcite veins; earlier thrust-sense slickenlines are dominantly to the WNW, but locally developed late slickenlines can occur in orientations highly oblique to this, and with both normal and thrust sense.

STOP 5: THE “BEAM”, A ROLFE STANLEY MEMORIAL OUTCROP

(N 44.65130º Lat., W 73.31649º Long.; NAD 83)

The “Beam” is one of two Rolfe Stanley Memorial Outcrops visited on this trip. Over the years, many thousands of introductory geology students, as well as undergraduate and graduate students in Rolfe’s structural geology courses have visited these sites. Both beautifully expose important features of foreland deformation, including thrust faulting, fault duplexes, fault bend folds, en echelon fractures and rotation, and pressure solution cleavage. Detailed descriptions and interpretation of these outcrops can be found in Stanley (1988).

The “Beam” occurs in the Cumberland Head Formation, and is a ~1 foot thick micrite bed between calcareous shale, and is bounded by bedding parallel thrust faults that display slickensided and stepped calcite veins and fault zone cleavage (Figure 8). The micrite bed is relatively uncleaved while the surrounding shale displays a strong, steeply east-dipping spaced cleavage, similar to that seen throughout the region, containing clay selvedges. The fault zone cleavage dips more shallowly to the east. Near the fault zone, the spaced cleavage in the shale is rotated towards parallelism with the fault zone cleavage indicating westward transport along the thrust faults. This is consistent with fiber orientation and slickenside fracture steps developed within veins in the fault zones.

Several ramps have been cut through the micrite bed, merging with the bounding bedding-parallel faults, creating several horsts. Ramp faults show progressive development from initial slight buckle folding, en echelon fracture formation along the west-dipping limb, and subsequent rotation and failure through the trace of the fractures. Some fractures show diachronous development where older fractures are rotated and cut by younger, unrotated ones. Fracture arrays dominantly dip to the east (west-climbing), parallel and are cut by ramps, but a few dip to the west (east-climbing) and are not cut by through-going faults. Several reasons for this can be envisaged, and may be discussed at the outcrop.

Deformation in the "Beam" contrasts with that in the surrounding calcareous shale. The "Beam" has shortened through rigid body displacement along thrust faults with little cleavage development within it, and minor folding over the ramps (~13%), while shortening in the shale is accommodated by pressure solution development (~11-16%), with some minor bedding parallel faults present in the shale. Stanley (1988) interpreted the development of ramp faults to be time transgressive, from east to west across the outcrop. This diachronous shortening in the "Beam" was accompanied by a similar progressive cleavage development from east to west in the surrounding shale (Figure 9).

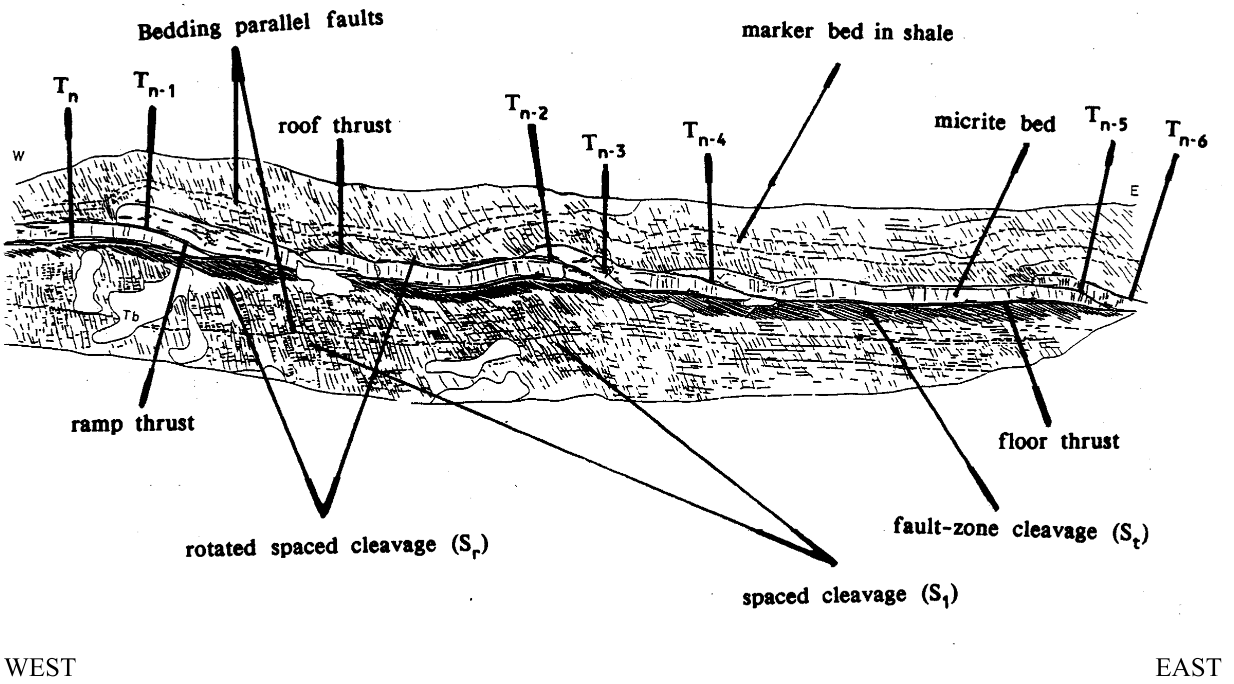

Figure 8. The "Beam" (facing north). Duplex-faulted micrite bed surrounded by calcareous, cleaved shale. Modified from Stanley (1988). Ramp thrusts evolved from east to west, based on cross-cutting fabrics in ramp, roof, and floor thrusts.

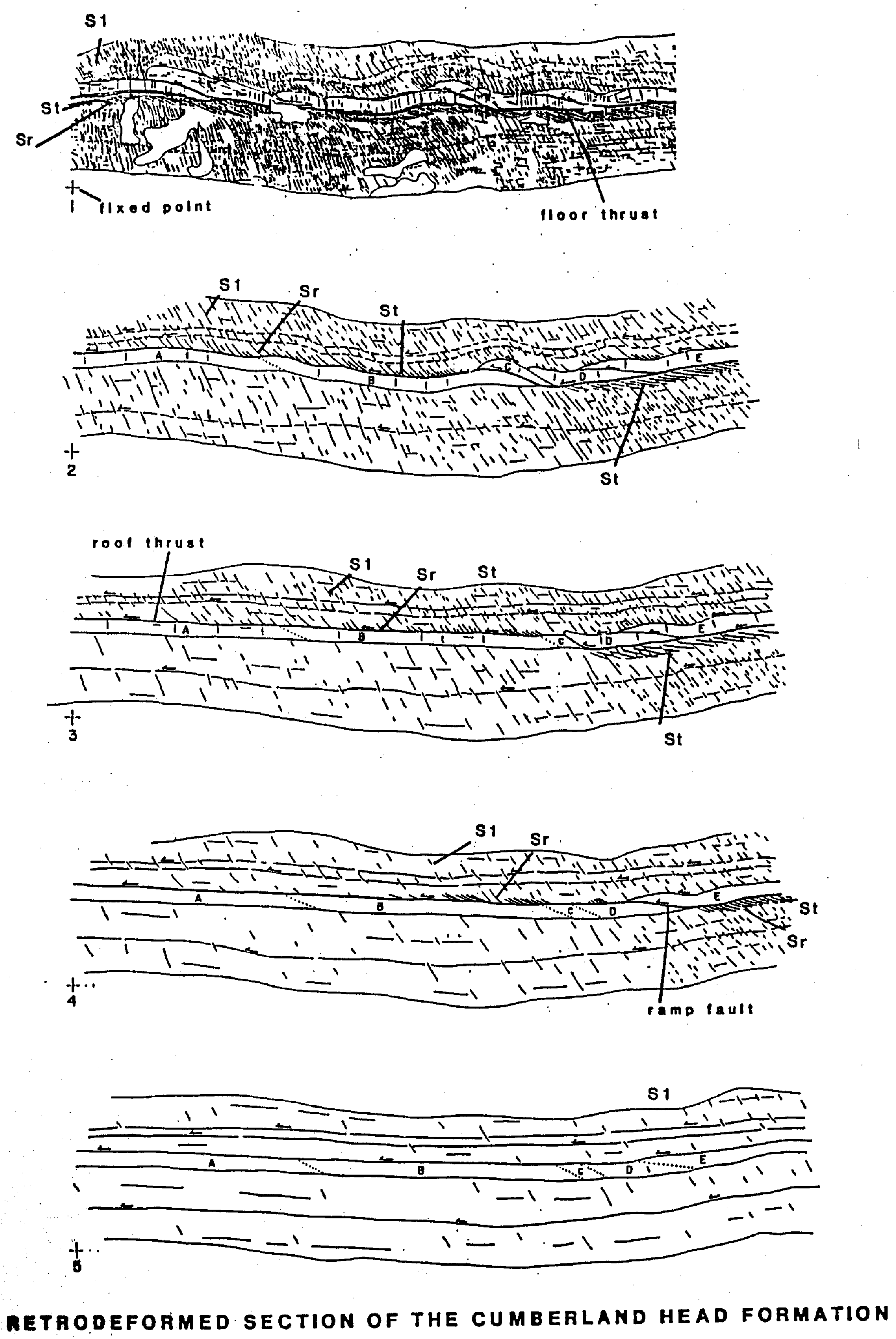

Figure 9. Retrodeformation of the beam. Progressive pulling back of ramp thrust occurs from west to east accompanied by progressive decrease in cleavage development. From Stanley (1988).

STOP 6: LESSOR'S QUARRY, A ROLFE STANLEY MEMORIAL OUTCROP

(N 44.64938° Lat., W 73.32899° Long.; NAD 83)

Lessor's Quarry exposes several bedding parallel faults in the Glens Falls Limestone. Here, the north wall displays several interesting features (Figure 10). A large bedding-parallel thrust truncates a synclinally folded, earlier thrust. The folding of the earlier thrust is thought (Stanley, 1988) to be the result of an unseen ramp beneath the quarry; e.g. a fault bend fold similar to those seen in the roof thrusts at the "Beam". Since the younger through-going thrust cuts the earlier folded thrust, the younger thrust must be an out-of-sequence fault.

Also related to the younger out-of-sequence fault is the orientation of bedding in the block above the thrust. In the eastern part of the wall, bedding parallels the thrust, while in the middle parts of the north wall, bedding is truncated by the thrust. Then, in the western part of the wall, bedding returns to a parallel position (Figure 10). This suggests that the currently flat thrust in the middle of the wall, initially developed as a ramp, cutting bedding in the upper block. This part of the upper block was then transported off the ramp and onto a nearby flat section of fault, resulting in counterclockwise rotation of the upper block in this section. Note also, the spaced pressure solution cleavage in the upper block is rotated in a counterclockwise manner in the middle part of the wall, over the "ramp" section. Because the cleavage was rotated during movement, it must have evolved subsequent to cleavage development, consistent with its interpretation as an out-of-sequence fault (recall that the Highgate Falls Thrust also rotates cleavage).

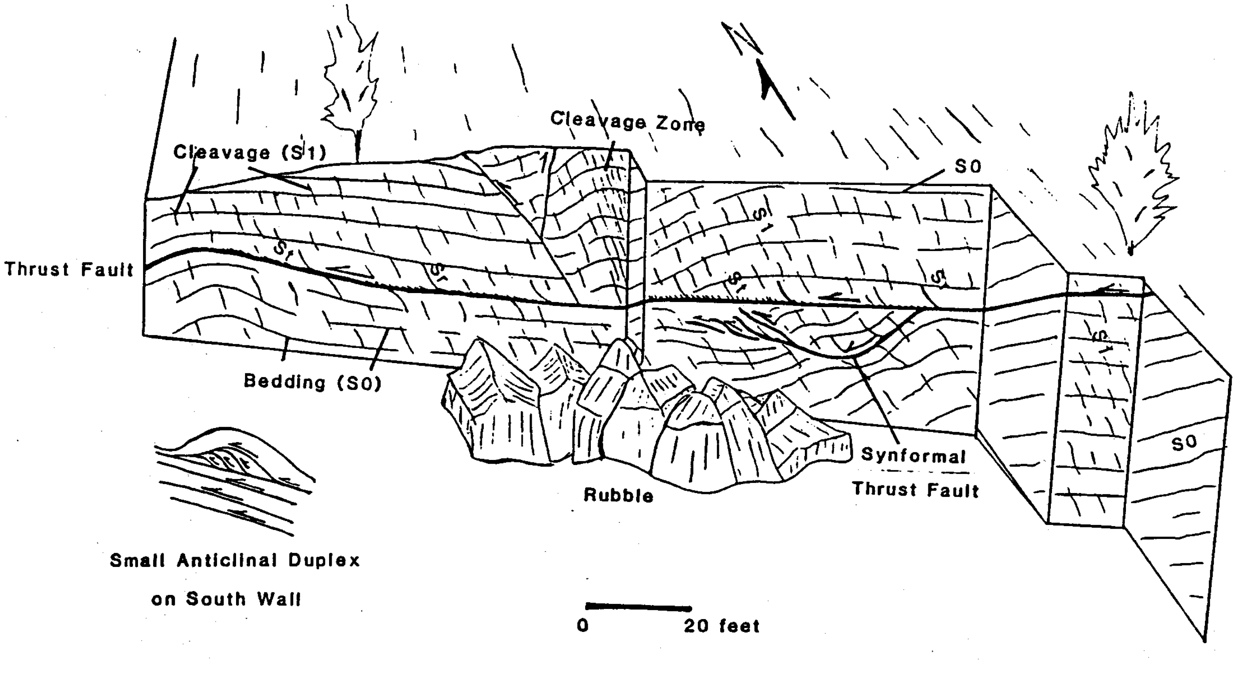

Figure 10. Lessor's Quarry, north wall. From Stanley (1988).

REFERENCES

Charbonneau, J-M., 1980, Region de Sutton: Ministere de L'Energie et des Ressources DPV-681, 89 p., 1 pl.

Globensky, Y., et al., 1993, Lexique Stratigraphique Canadien, Région des Appalaches, des Basses Terres du Saint Laurent et des îles de la Madeleine: Ministere de l'Energie et des Ressources du Quebec, DV 91-23, 327 p

Haschke, M. R., 1994, The Champlain thrust fault system in northwestern Vermont—structure and lithology of the Taconic foreland sequence in the Highgate Center quadrangle [Unpublished M.Sc. thesis]: State University of New York at Albany, Albany, New York, 124 p., 3 pl.

Hayman, N. M., and Kidd, W. S. F., 2002, Reactivation of prethrusting, synconvergence normal faults as ramps within the Ordovician Champlain–Taconic thrust system: Geological Society of America Bulletin, v. 114, p. 476-489.

Landing, E., 1983, Highgate Gorge: Upper Cambrian and Lower Ordovician continental slope deposition and biostratigraphy, northwestern Vermont: Journal of Paleontology, v. 57, p. 1149-1187.

Lebel, D., and Kirkwood, D., 1998, Nappes and mélanges in the Quebec-Bellechasse area: Their regional tectonic and stratigraphic significance in the Humber zone: Geological Association of Canada/Mineralogical Association of Canada, Fieldtrip Guidebook, 64 p.

Mehrtens, C. J., and Dorsey, R. J., 1987, Stratigraphy and bedrock geology of the northwestern portion of the St. Albans quadrangle and the adjacent Highgate Center quadrangle, Vermont: Vermont Geological Survey Special Bulletin No. 9, 28 p., 2 pl.

Rowley, D. B., and Kidd, W. S. F., 1981, Stratigraphic relationships and detrital composition of the medial Ordovician flysch of western New England: Implications for the tectonic evolution of the Taconic orogeny: Journal of Geology, v. 89, p. 199-218.

Schoonmaker, A., 2005, Convergent and collisional tectonics in parts of Oregon, Maine, and the Vermont–Quebec border: [unpublished Ph.D. dissertation], University at Albany, State University of New York, Albany, New York, 218 p., 7 pl.

Shaw, A. B., 1958, Stratigraphy and structure of the St. Albans area, northwestern Vermont: Bulletin of the Geological Society of America, v. 69, p. 519-568, 1 pl.

St.-Julien, P., 1977, Geology of the Quebec City area, Guidebook for Geologic excursions A-4 and B-3: New England Intercollegiate Conference, Quebec City, p. A4-1—A4-32.

St.-Julien, P., and Hubert, C., 1975, Evolution of the Taconian orogen in the Quebec Appalachians: American Journal of Science, v. 275-A, p. 337-362.

Schoonmaker, A., and Kidd, W.S.F., 2007, A reappraisal of the allochthonous nature of the Rosenberg slice and Stanbridge Group of southern Quebec and northwestern Vermont, Canadian Journal of Earth Sciences, v. 44, p. 155-169.

Stanley, R.S., 1988, Foreland deformation as seen in western Vermont, Field Trip Guidebook, New York State Geological Association, 60th Annual Meeting, p. 45-78.

Stanley, R.S., and Ratcliffe, N.M. 1985, Tectonic synthesis of the Taconian Orogeny in western New England, Geological Society of America Bulletin, v. 96, p. 1227-1250.

ROAD LOG

Assembly Point – on Park Street, along the east side of Highgate Falls village park, adjacent to VT Rte 207, 0.1 mile north from intersection with Brousseau Road and 0.3 mi south of bridge on VT Rte. 207 over Highgate Gorge. Trip participants will first consolidate vehicles, and BEFORE STARTING AT STOP 1 (and for stops 1-3) leave surplus vehicles at Park & Ride lot on north side of VT Rte 78 just east of intersection with VT Rte 207. Those subsequently following this log in small groups can use the parking lot at the north end of the VT Rte 207 bridge over Highgate Gorge.

Time: 8:00 am, Friday, September 25th, 2009.

Miles	Increment	Directions
0.0	0.0	From intersection of Park Street with VT 207, going north.
0.2	0.2	Cross bridge over Highgate Gorge; at north end of the bridge turn left into parking area. Walk west down the track about 300 yards and turn off it south down the canoe portage trail to the river bank; walk east along the bank (watch for poison ivy here) about 100 yards to the start of the outcrop for STOP 1a.
--	--	Return to parking area. Walk (WATCH FOR FAST TRAFFIC) across to east side of Rte 207, and follow track through the woods along the north side of the gorge for about 250 yards. Find trail down to outcrop of STOP 1b in the gorge (ROCKS MAY BE SLIPPERY WHEN WET); this starts about 50 feet in from the end of the track (which comes to the east side of the old, now pedestrian, bridge over the dam – there is a good overall view of the outcrop from the bridge).
--	--	Return to track, and to the parking area at Rte 207.
0.45	0.25	Turn left from parking area, go north to intersection with VT Route 78; turn right.
0.7	0.25	Go east on VT Rte 78; in Highgate Center turn half left onto Gore Rd, VT Rte 207.
2.2	1.5	Go north on Rte 207 to intersection with Tarte Road; turn half left onto Tarte Road.
3.75	1.55	Go north on Tarte Road to small bridge over Rock River at sharp right hand bend; park on left just before the turn; STOP 2 in low roadcut on west side of road, and in river on both sides of the bridge (assuming water level is low).
4.75	1.0	Continue north on Tarte Road to sharp right hand bend; park off road on west side just before driveway; ASK PERMISSION at blue house or at the farmhouse (Blue Roof Farm) after the bend. Walk along the driveway and farm track beyond for about 100 yards; then walk due west across the pasture for another 100 yards to the east side of the outcrop of STOP 3.
--	--	Walk back to vehicles the same way you came in.
7.8	3.05	Turn around, go south to intersection of Tarte Road with Rte 207, and to intersection with Rte 78 in Highgate Center; turn right onto Rte 78.
11.45	3.65	Go west on Rte 78. Mileage is at Interstate 89 bridge (ramps to I-89 exit)
12.25	0.8	In Swanton, turn left onto York Street (if you miss this not very well-marked side street, just continue another 0.1 mile and turn left at the T intersection with Grand Street, and pick up the log passing the end of York St.)
12.4	0.15	Go south on York St; at intersection with Grand Street (US Route 7) turn left.
12.6	0.2	From Grand Street, turn right on to Jewett Street.
12.8	0.2	Entrance to Shelburne Limestone Corporation's Swanton Quarry and Quarry Office. STOP 4. Visits to the quarry MUST BE ARRANGED WELL IN ADVANCE; all visits MUST BE ESCORTED; HARD HATS REQUIRED.
13.0	0.2	Return up Jewett Street to intersection with US 7, Grand Street; turn right.
19.0	6.0	Go south on Rte 7 to traffic light at intersection with VT Rte. 207; turn left.
19.2	0.2	Turn right onto I-89 South entrance ramp
38.8	19.6	Take exit ramp for US Rte 2 West
39.0	0.2	At end of ramp, turn right onto US Rte 2 West.
48.2	9.2	Park OFF THE MAIN ROAD (!) at McBride Lane, a small side road on the right (east). STOP 5 - “The Beam” of Rolfe Stanley, in low road cut on north side of McBride Lane. NO HAMMERS PLEASE.
48.3	0.1	When traffic permits, turn out and continue north on Rte 2, prepared to make a left turn onto Sunset View Road.
49.9	0.6	Turn left onto track; this turn is just before the high voltage power lines cross the road.

50.0 0.1 Park in small gravel area on left; STOP 6 – Lessor's Quarry - NO HAMMERS PLEASE.

End of field trip.

To go to or return to Lyndon State College, backtrack to I-89; go south and east on I-89 to Montpelier; take Rte 2 to St. Johnsbury; take I-91 north to Lyndonville. (about 100 miles)

To get to Ferry to Cumberland Head/Plattsburgh NY – from Lessor's Quarry, return to Sunset View Road, turn left, go 0.7 miles to T intersection; turn right onto West Shore Road; go 2.0 miles to intersection with VT Rte 314 Ferry Road; turn part left and go north 0.7 miles on Ferry Road; turn left into Grand Isle Ferry Terminal.

or, return to US Route 2, and follow it north to Rouses Point bridge and I-87. (note that as of writing in August 2009, the Crown Point/Ticonderoga bridge to NY is under repair and reduced to one lane only; expect delays).

For southern destinations, follow I-89 to US route 7 at Burlington, Vermont, to Rte 22A in Vergennes, to US Rte 4 at Fair Haven, to NY Rte 149 in Fort Ann, to I-87 at Lake George.