LATE PLEISTOCENE–HOLOCENE HISTORY: HUNTINGTON RIVER AND MILLER BROOK VALLEYS, NORTHERN VERMONT

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INTRODUCTION

The areas visited on this field trip are within the Huntington River valley, draining the western slopes of the Green Mountains immediately south of the Winooski River, and the Miller Brook valley, a much smaller, east-flowing drainage basin north of the Winooski River (Fig. 1). Our objectives are to present the results of recently completed and ongoing research at the University of Vermont centered on better understanding the Late Pleistocene and Holocene history of these valleys. Parts of the material presented in this article appear in University of Vermont theses by Zehfuss (1996), Whalen (1997), Church (1997), and Bryan (1995). A comprehensive summary of regional Holocene findings appears in Bierman and others (1997) and a progress report on work in the Miller Brook valley was published by Loso and others (1997).

In the following paper we first outline the Late Pleistocene history of the Miller Brook valley inferred from our current work in the context of earlier studies of the valley. Central to this section is the reinterpretation of glacial landforms previously identified as moraines. In particular, we outline the evidence for an ice contact environment in the valley at the time most of the surficial materials were deposited. We next present a summary of the glacial lake history and later fluvial history of parts of north-central Vermont derived from recent surveying. We follow this with a review of information gleaned from numerous alluvial fans, built on both lacustrine and fluvial terraces, whose history spans the entire Holocene. We present detailed maps, logs of trenches, and ^{14}C dates as the primary data from which we base our interpretations.

The field sites described in the following text are found on the "Huntington" and "Bolton Mountain" 7.5' U.S.G.S. Quadrangle maps. Parts of these maps are reproduced as part of this field guide. Most of the field stops described herein occur on private property and permission needs to be secured before venturing onto these field sites. Contacts are listed in the Road Log.

ICE-CONTACT ENVIRONMENT: MILLER BROOK VALLEY

Stephen F. Wright

Introduction

The Miller Brook Valley, Stowe, Vermont, is a generally ESE-draining valley extending from a low point along the crest of the Green Mountains (Nebraska Notch, Elev. 576 m, 1890 ft) to its confluence with the Little River (Elev. 184 m, 605 ft), (Figs. 1 and 2). The bedrock geology of the area is described by Christman and Secor (1961) although more recent and detailed mapping has been completed and will be incorporated into the new State Geologic map. Rocks along the Miller Brook valley consist of medium grade schists belonging to both the Underhill and Hazens Notch formations. The dominant foliation in these rocks (S_2) strikes N–S and dips moderately to steeply east. Resistant rock units within these formations "V" downstream and control the orientation of tributary brooks to Miller Brook as well as the orientation of Miller Brook itself upstream of Lake Mansfield (Fig. 3). The ESE trend of the Miller Brook valley, and many other river and stream valleys in the Green Mountains, is probably controlled by similarly oriented zones of joints or brittle strike-slip faults, traces of which are readily visible on aerial photographs (see Christman and Secor, 1961, for compilations of brittle structures in the area).

Beginning at Nebraska Notch, Miller Brook flows through three steep-sided, bowl-shaped segments of the valley (labeled "1, 2, and 3" on Fig. 3). Lake Mansfield occupies the lowest of these flat-bottomed, steep sided valley segments and is artificially dammed. A large alluvial fan protrudes into the lake from the north. The stream feeding this fan is currently incised into the fan. Below Lake Mansfield in the area mapped, Miller Brook lies entirely within surficial materials, stepping down through progressively lower lacustrine and fluvial terraces until entering the Little River just upstream from the Waterbury Reservoir. Downstream from the Lake Mansfield dam, the valley contains several distinct ridges lying within or adjacent to fluvial landforms and older lacustrine terraces and standing with up to 30 m of relief. The origin of these ridges and the surrounding sediments is the subject of this paper.

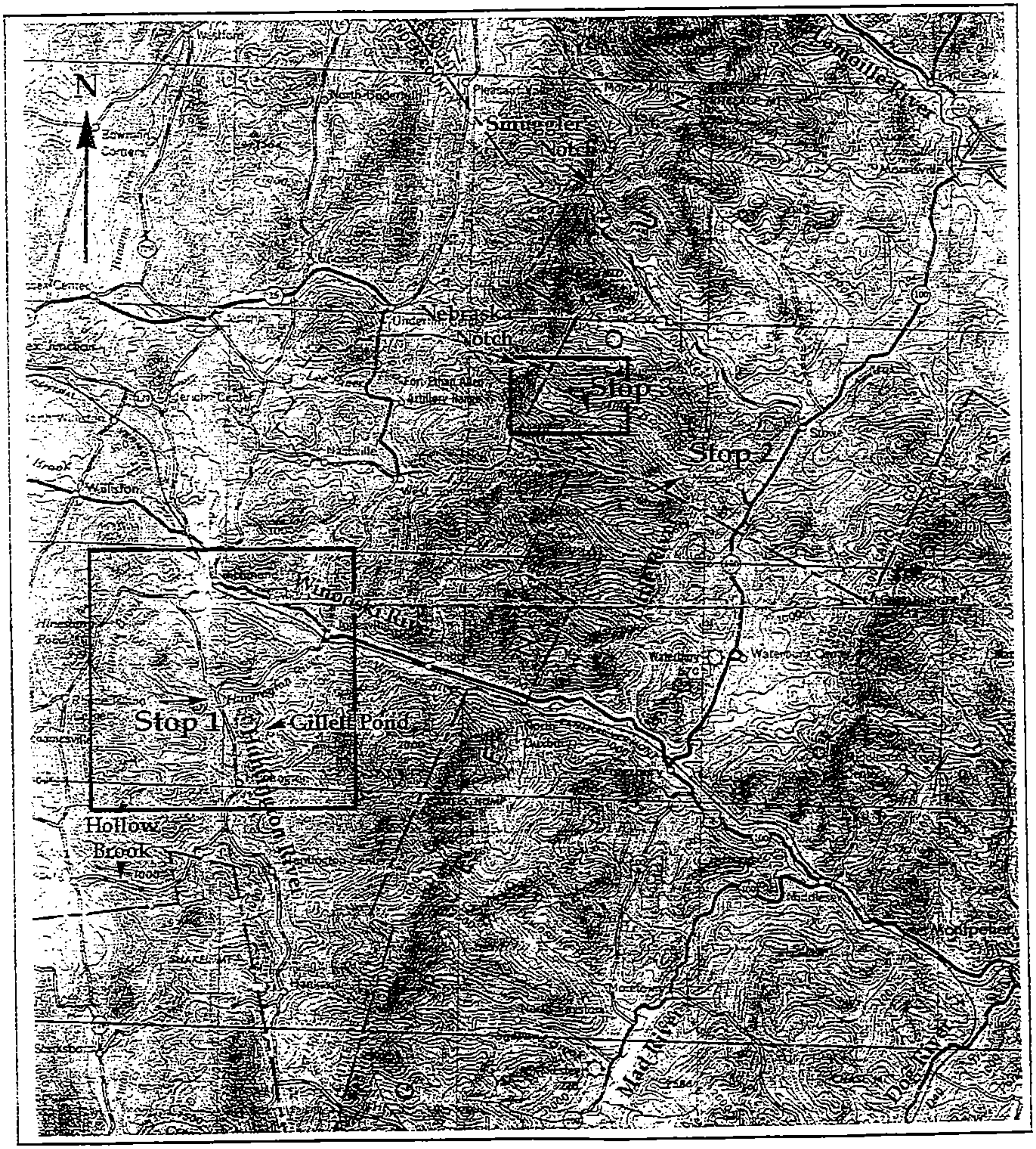

Figure 1: Shaded relief map of north-central Vermont showing the location of field stops discussed in this guide. Drainage basins discussed in the text are indicated on the map. Ice flow direction was generally to the SSE, across the N–S trending ridge of the Green Mountains based on striae preserved along the Green Mountain Ridge (Stewart and MacClintock, 1970). Note that Interstate 89 is not shown traversing through the Winooski Valley on this map. Grid outlines 10 km squares. Upper box outlines Fig. 3 and lower box outlines Fig. 12.

Wagner (1970) first identified several ridges of surficial material in the Miller Brook valley and interpreted these to be moraines produced by a tongue of ice retreating up the Miller Brook Valley. He further conjectured that the Miller Brook moraine (and other moraines he identified in northern Vermont) were not produced by the waning Laurentide ice sheet, but by independent alpine glaciers that occupied the valley subsequent to ice-sheet retreat. Wagner's paper stimulated considerable discussion, mostly centered on whether or not the ridges were produced by a waning tongue of the Laurentide ice sheet or by a local glacier (Stewart, 1971; MacClintock, 1971; Wagner, 1971; Ackerly, 1989; Waitt and Davis, 1988) and raised again the question of whether or not alpine glaciers existed in New England following retreat of the Laurentide ice sheet (e.g. Goldthwait, 1916; see review by Waitt and Davis, 1988). Wagner's hypothesis is reevaluated below, using newly constructed maps and soil pit data. At least a portion of the area visited on this field trip was examined on an earlier NEIGC field trip led by Wagner (1972).

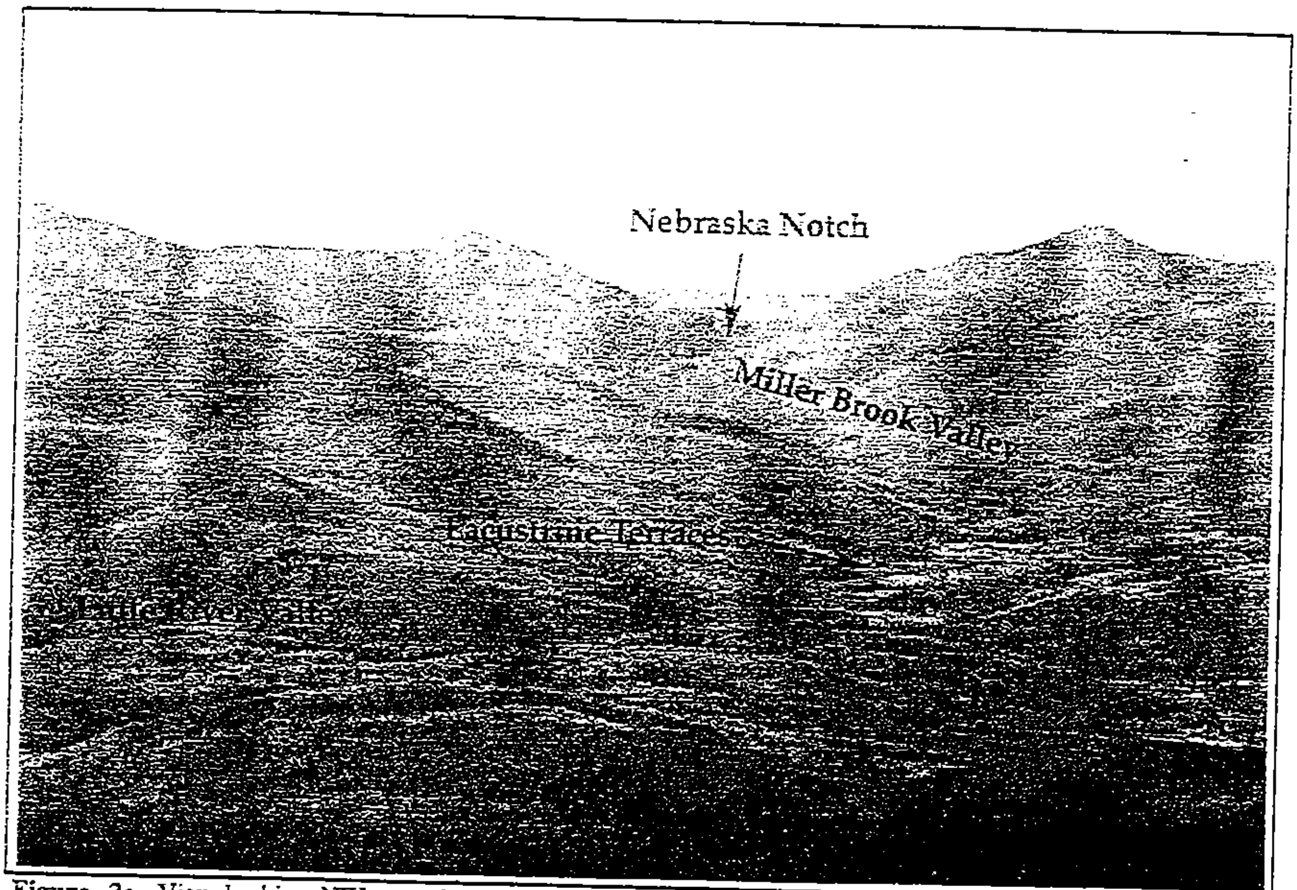

Figure 2: View looking NW towards the Miller Brook valley and Nebraska Notch (elevation 576 m, 1890 ft) from Hunger Mountain. Nebraska Notch is the lowest pass through the mountains between the Lamoille River Valley to the north and the Winooski River Valley to the south. Dewey Mountain (elev. 1024 m, 3360 ft) lies to the north of the Notch and Mount Clark to the south (elev. 902 m, 2960 ft). Small open meadows along the lower part of the Miller Brook valley are on a flight of terraces ranging from 256 to 198 m (840 to 650 ft) corresponding to Lakes Mansfield I and II and the Quaker Springs stage of Lake Vermont.

Detailed Mapping

Interpreting landforms in the Miller Brook Valley has always been confounded by the lack of adequate maps. The ridges that Wagner (1970) identified as moraines are crudely located on his map and his brief descriptions are insufficient to clearly locate their position or morphology. Only portions of the ridges appear on the U.S.G.S. topographic map (Bolton Mountain Quadrangle) and the position of Miller Brook and its principal tributary (unnamed) from the SW are incorrectly shown. During the Fall of 1995, the area immediately downstream of the Lake Mansfield dam was mapped at a scale of 1:2,500 by two students, M. Loso and H. Schwartz, using a Total Station. This map and preliminary descriptions and interpretations of soil pits constructed by P. Bierman's geomorphology class are presented in Loso and others (1997). The mapping area was continued downstream by the author in the fall of 1996, initially using tape and compass methods (1:2,000) with parts later surveyed for elevation

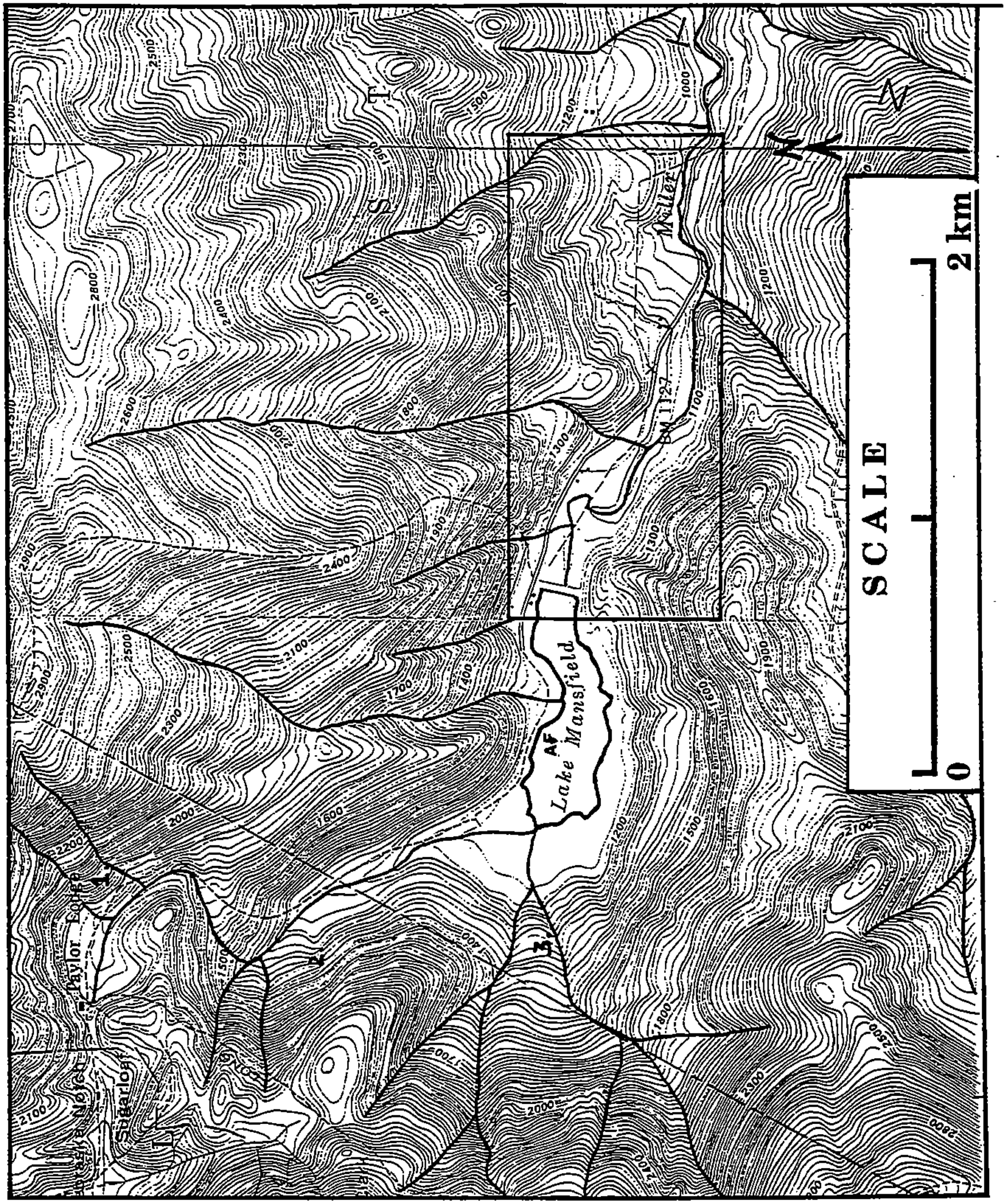

Figure 3: Portion of the Bolton Mountain 7.5' Quadrangle Map (20 ft contours) showing the Miller Brook Valley from its headwaters in Nebraska Notch . The head of the Miller Brook Valley contains three cirque-like landforms (bowl-shaped with steep sides and a gently sloped floor): **(1)** the valley immediately east of Taylor Lodge, **(2)** the NNW-trending portion of the valley NNW of Lake Mansfield, and **(3)** the portion of the valley occupied by Lake Mansfield. Box outlines detailed map of Surficial Landforms (Fig. 4). **AF** = Alluvial Fan

control using the Total Station. The map presented in this field guide is a compilation of these two maps set within an enlarged portion of the U.S.G.S. base map (Fig. 4). The new mapping uses 2 meter contours tied to a benchmark at 1127 ft, whereas the surrounding U.S.G.S. topographic map uses 20 ft contours.

Description of the Landforms

Ridges of surficial material in the Miller Brook valley extend from ~150 m west of the Lake Mansfield dam (not mapped on Fig. 4), across the entire mapped area (Fig. 4), and reconnaissance work indicates that they extend at least another kilometer down-valley. For clarity, individual ridges have been designated with letters, e.g. Ridge C, on Figure 4. The ridges generally follow sinuous pathways, both along the side and across the middle of the valley and are cut by both ephemeral streams and Miller Brook. In places they appear to bifurcate or to show cross-cutting relationships with one another (e.g. Ridges C and D, and Ridges F and G, Fig. 4). The ridges are both sharp-crested (Ridges A, B, the eastern end of C, E, F, and G) and rounded (most of Ridge C and Ridge D), applying terminology employed by Shreve (1985) and show relief ranging from 4 to in excess of 25 m above adjacent fluvial or lacustrine terraces. In general, the crest of Ridges A, B, and C gradually diminishes from 352 m just below the Lake Mansfield dam to 342 m NE of the Mill Pond dam. An exception to this is the abrupt 14 m rise (to 362 m) and fall along a 100 m reach SW of the Middle Pond (Fig. 4).

That the ridges are primary constructional landforms and not erosional remnants is evidenced by several observations: (1) Ridge A surrounds a small bog ("B" in Fig. 4, adjacent to Soil Pit T2H). Sperling and others (1989) retrieved a core from this bog and present a ^{14}C date of 9,280 $\pm$ 235 yBP (years before present) from sediment recovered between 2.75 and 2.85 m depth, implying that the bog has been separated from the valley bottom by the intervening ridge for over 9,000 ^{14}C years, within 3,000 ^{14}C years since ice retreat (Lin Li, 1996). (2) Soil pits adjacent to Ridges A (T3R), C, and D clearly show fine to medium grained sand onlapping the coarse sand, gravel, and rounded cobbles comprising the adjacent ridges, indicating that the ridges were partially buried by fluvial and lacustrine sediments after their formation (Fig. 5). (3) A small alluvial fan, fed by an ephemeral stream 100 m NW of the previously described bog, has partially buried Ridge A (Fig. 4). By inference to the active Holocene history of fans elsewhere in the region (see later sections of this paper) we suggest that this fan too has been actively depositing material against the ridge throughout the Holocene.

Ridges A, B, and C

The "classic" Lake Mansfield ridges, the ones Wagner (1970) describes as forming during a later phase of glaciation (his Phase II), are labeled Ridges A and B on Figure 4. Ridge A begins just beyond a broad area of hummocky relief including one well-defined, kettle-like closed depression where the trails intersect, south of Soil Pit RTP. This ridge, interpreted by Wagner (1970) to be a lateral moraine, parallels the south side of the valley. No correlative ridge exists along the north side of the valley. Approximately 600 m below the Lake Mansfield dam the ridge turns abruptly NE (Ridge B, Fig. 4) and crosses the valley where it is cut by Miller Brook. This is the segment interpreted to be an end moraine by Wagner (1970). Based on the map pattern shown in Figure 4, Ridge B does not curve up-valley to meet an unidentified lateral moraine along the north side of the valley, but instead strikes straight across the valley, turns slightly and continues down the middle of the valley (Ridge C; the road is built upon it) until it is cut again by Miller Brook, just east of the Mill Pond dam.

Ten soil pits were dug either along or adjacent to Ridges A and B (e.g. T2M, Fig. 4) as part of the study presented by Loso and others (1997). Several of the pits considered most important to this study were reopened and are reinterpreted here together with observations from new pits (e.g. C-2, Fig. 4). With few exceptions, most of the pits were excavated to approximately 1 m depth.

The near-surface materials comprising Ridges A, B, and C are quite similar to one another and texturally bear attributes of both till and fluvial sediments. Soil Pit C-2, along the crest of Ridge C (Fig. 4), exposes 0.5 m of poorly sorted, poorly to well rounded coarse sand, gravel, and cobble clasts in a fine sand matrix. These materials overlie clean gravel and coarse sand extending to the bottom of the pit (0.7 m). Soil Pit T1M, along the crest of Ridge B (Fig. 4), similarly contains a poorly sorted mixture of moderately to well rounded coarse sand, pebbles, and cobbles in a medium to fine sand matrix. A recent soil slip along the NE side of Ridge B (~5 m downstream from Soil Pit T1R,) reveals clean, moderately sorted and rounded, coarse sand and gravel just above water level that is overlain by at least 3 m of material similar to that exposed in Soil Pit T1M along the crest of the ridge. The gravels occurring in both Ridges B and C are clearly fluvial and the overlying material in both ridges contains abundant rounded clasts, also indicative of fluvial processes. Based on both their map pattern and the fluvial sediments within them, I interpret these ridges to be segments of an esker and not moraines. The poorly sorted veneer of sediment overlying the gravels has likely originated from the low discharge of the stream occupying the esker tunnel towards

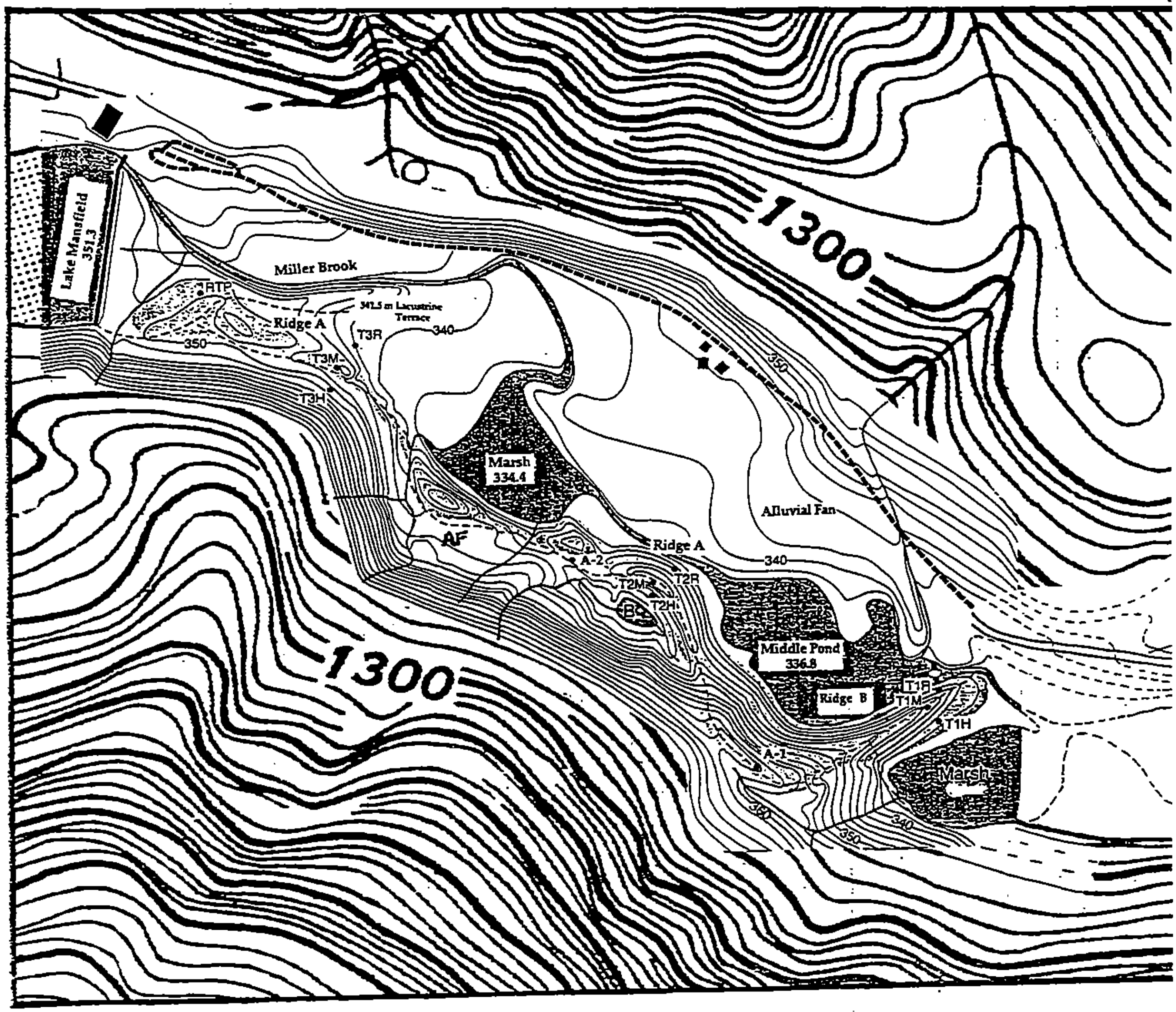

Figure 4: Detailed map of surficial landforms in the upper portion of the Miller Brook Valley (see Fig. 3 for exact location). Western half of map is by M. Loso and H. Schwartz (Loso et al., 1997) and uses 2 m contours. Eastern half of map is by S. Wright and that part surveyed also uses 2 m contours, dashed where inferred. Both maps are placed within an enlarged portion of the Bolton Mountain 7.5' Quadrangle map. Ridges are labeled with letters, e.g. Ridge A, and extend across the entire mapped area. AF = Alluvial Fan.

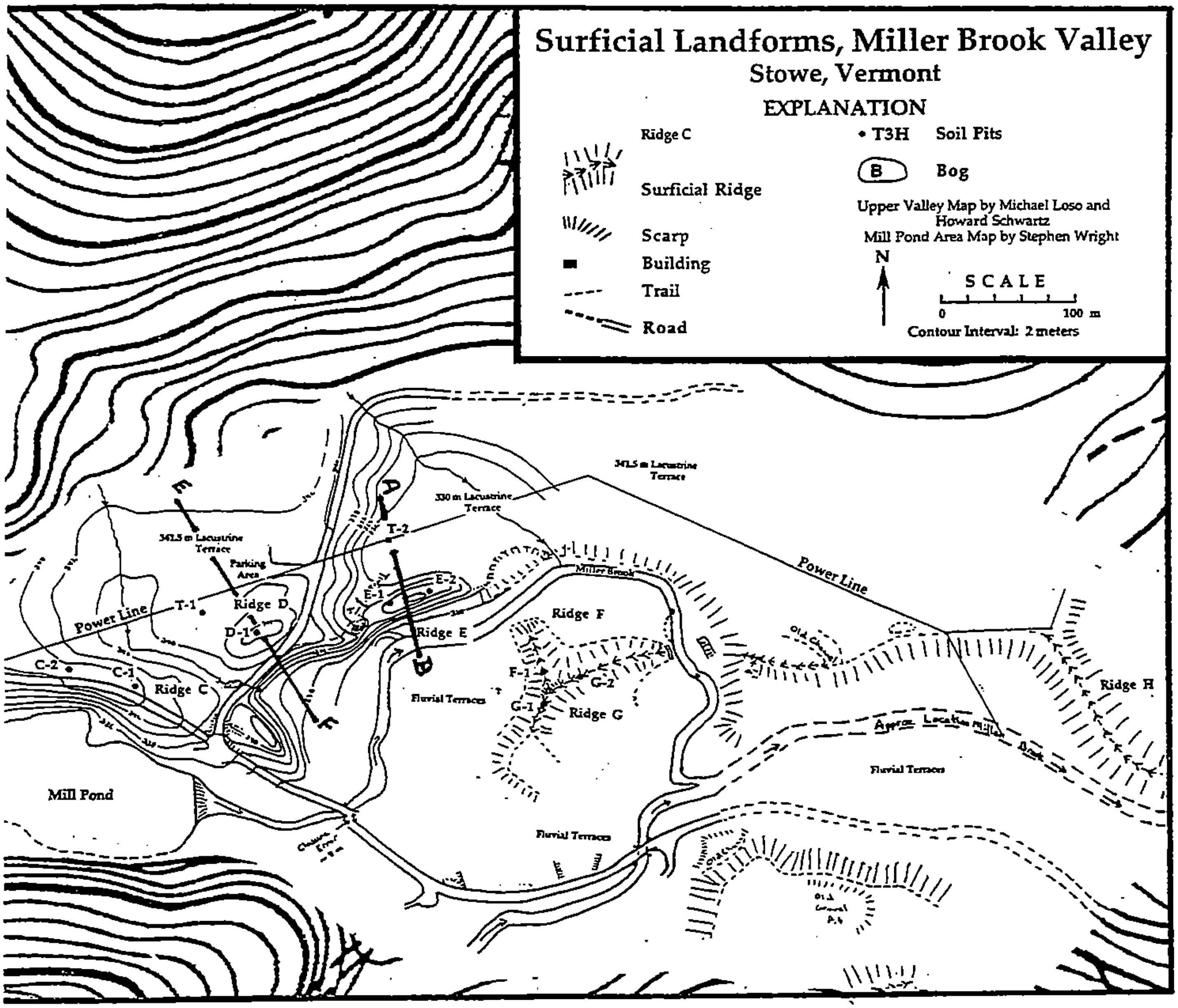

Figure 4: Continued from previous page.

the end of its history. The rounding of most clasts indicates at least some transport of the melt-out till. Soil pit C-1 on Ridge C (Fig. 4) contains coarse diamict including a few faceted, striated cobbles. It seems likely that this diamict melted out of the ice shortly before the ice tunnel was abandoned and the clasts never subjected to significant abrasion.

The transition from Ridge B to Ridge A is marked by an abrupt change in orientation from N60E to N45W, rapid ascent to the highest elevation of any of the mapped ridges (362 m, Fig. 4), and the presence of numerous large, mostly angular boulders, many exceeding 2 m in diameter. Large boulders are also common along segments of Ridge A opposite the "Marsh" (at 334.4 m elev.) and in the vicinity of Soil Pit T3M, but much less common along the segment opposite the Bog ("B" on Fig. 4). Boulders of similar size and frequency are rare along the other ridges shown on Figure 4, all of which occupy positions considerably removed from the sides of the valley. Soil Pits along the crest of Ridge A (A-1, T2M, and T3M) all display unsorted, unbedded coarse sand, gravel, cobbles, and boulders in a medium to fine sand matrix with minor silt (see grain size distribution curves in Loso et al., 1997). Pebbles and cobbles excavated in A-1 and reexcavated in T3M are nearly all moderately rounded (T2M was not reexcavated). Soil textures in these pits are similar to the soil pit (T1M) on the crest of Ridge B, except for the large, usually angular boulders mentioned earlier. These materials differ from the colluvium along the adjacent hillside in that most of the clasts larger than 1 mm are rounded as opposed to angular or subangular. In the top meter of Ridge A none of the pits revealed layers of clean, coarse sand and gravel similar to those observed in Ridges B and C and it is therefore more difficult to claim that fluvial processes are responsible for the deposition of these materials. Nevertheless, the abundant rounded clasts, paucity of silt and clay, and textural similarity to the surficial materials overlying fluvial gravels in Ridges B and C are at least consistent with their deposition in a subglacial stream flowing along the side of the valley. Given the mapped continuity of Ridge A with Ridges B and C, I similarly interpret Ridge A to be an up-valley segment of the same esker. The abundant large boulders in and on it were most likely derived from materials sliding down the adjacent hillside onto the ice surface and later being incorporated into the esker as the tunnel ceiling was melted by the subglacial stream.

Ridges D, E, F, G, and H

Similar to Ridge C, described in the previous section, Ridges D, E, F, G, and H all lie in the central portion of the Miller Brook valley, well away from the valley sides (Fig. 4). Ridge D is a rounded, elongate hill rising in low relief relative (maximum elevation 345.3 m) to the surrounding terrace at 340.5 m elevation. It is oriented approximately N60E and may be continuous with Ridge E. Ridge E is sharp-crested, rises to 338.4 m and shows sharp relief with the 330 m terrace to the north and the <324 m fluvial terraces to the south. Soil pits in these ridges (D-1, E-1, E-2; Fig. 4) all contain clean, well rounded gravel and cobbles in a coarse sand matrix. Bedding was observed in Pit E-1. The sediments in these ridges are clearly fluvial in origin and I therefore interpret Ridges D and E to be segments of an esker. Ridge C appears to cross-cut Ridge D, implying that the former is younger, but it is also possible that the esker bifurcated at this point (Fig. 4).

Ridges F and G are the most striking in the valley forming sharp crested ridges rising at least 25 m above the fluvial terraces that surround them (Fig. 4). Ridge F may be the continuation of Ridge E as it arches across Miller Brook. Ridge F is clearly cross-cut by Ridge G, which rises approximately 5 m above Ridge F at their intersection. Ridge G strikes N15E at its southern end, but swings almost due east where it is cut by Miller Brook. Ridge H on the opposite side of Miller Brook is the continuation of Ridge G, rising to the 341.5 terrace level, where it is completely buried, and then reappears at the eastern edge of the map where it has been excavated by stream erosion (Fig. 4). Soil pits in these ridges (F-1, G-1, G-2) all contain unsorted, moderately rounded cobbles and pebbles in a fine to coarse sand and gravel matrix. Large (up to 1.5 m), relatively unrounded boulders are also incorporated into the ridges. The texture of surficial materials in these pits is very similar to that in the near-surface parts of Ridges B and C (see earlier descriptions). None of the soil pits exceeded 1 m depth and none exposed any clean gravel similar to that observed at the surface in Ridges D and E. Based on the abundance of rounded clasts in these ridges and their sinuous, mid-valley form, I also interpret these ridges to be eskers. Furthermore, it is likely that the easternmost end of Ridge C once connected with the southern end of Ridge G and the intervening esker has been removed by Miller Brook. Ridges D, E, and F may document a former esker tunnel that was abandoned in favor of the tunnel occupied by the eastern end of Ridge C and the southern end of Ridge G.

Lacustrine Terraces

Two distinct terraces exist in the map area, the upper one at ~341.5 m (~1,120 ft) and the lower one at ~330 m (~1,082 ft). Elevations are taken from the middle of these terraces which show ±0.4 m of minor relief. Materials exposed in soil Pits T3R, A-2, T-1, and T-2, excavated in these terraces, are described here as well as materials exposed in recent road-cuts in the vicinity of the Mill Pond dam (Fig. 4). Two meters of well sorted and bedded fine sand and silt with two thin beds (2–3 cm) of coarse sand onlap the coarse sediments of Ridge A in Soil Pit T3R, located adjacent to Ridge A, on the 341.5 m terrace (0.4 m of colluvium overlie the terrace deposits, Loso et al., 1997). One of the coarse sand layers contains load casts down into the underlying silts. Bedding strikes to 331 and dips 29° NE, parallel to the slope of the buried ridge. Some of the bedding has slumped to the NE, down the slope of the buried ridge. Loso and others (1997) interpret these sediments to be lacustrine, deposited in a shallow area of a lake whose minimum elevation was 342 m. Soil Pit A-2, dug along Ridge A, also reveals medium to fine sand with isolated, matrix supported, moderately rounded pebbles and cobbles. This pit is at the same elevation as Pit T3R and these sediments are probably also lacustrine in origin and onlap Ridge A.

Two topographic profiles (A–B and E–F, Fig. 4) show the terraces adjacent to Ridges D and E and the materials exposed in nearby soil pits and auger holes (Fig. 5). Soil Pit T-1, located on the 341.5 m terrace 40 m west of Ridge D (Fig. 4), was extended to 3.7 m depth using a bucket auger. The upper 1.4 m consists of clean, moderately sorted and well rounded, medium to coarse sand and gravel. The remainder of the auger hole (1.4 to 3.7 m) exposed only fine sand with rare layers of medium to coarse sand and one isolated rounded pebble (Fig. 5). I interpret the fine sands to be lacustrine and the overlying coarse sand and gravel as being fluvial. If this interpretation is correct, the lake elevation in this area is marked by the transition from fine to coarse sand, 1.4 m below the terrace level, ~340.1 m (1,116 ft). Exposures in the vicinity of the road intersection opposite the Mill Pond dam show that the lacustrine sediments are extensively deformed where they are cut by faults and are slumped indicating that the lacustrine and later fluvial sediments in this area were deposited on top of pockets of dead ice. This implies that the lake formed synchronously with the final melting of glacial ice from the valley.

The lower 330 m terrace also appears to record both a lacustrine and fluvial activity. Soil Pit T-2 (along cross-section A–B) was excavated to 1.60 m where it bottomed in coarse rounded gravel and sand. These are overlain by 0.85 m of fine sand and silt which in turn is overlain by 0.75 m of rounded gravel and coarse sand (Figs. 4 and 5). The lake elevation here is interpreted to be at the contact between the fine sand/silt and gravel, or at ~329.2 m (1,080 ft).

The two terraces, corresponding to lake elevations of 340.1 and 329.2 m, may correlate with Lake Winooski, the outlet of which lay 4.0 km south of Williamstown, Vermont at an elevation of 279 m (Larsen, 1987b; see also review of regional glacial lakes later in this field guide). Projecting this threshold elevation N21.5W to the Miller Brook valley with an isostatic gradient of 0.9 m/km gives an elevation of 322.2 m, implying a water depth at the outlet of 7 m for the lower lake level and almost 18 m for the higher lake level, unless the outlet eroded from its current elevation.

Discussion

The direction of ice flow in this part of Vermont was generally from NNW to SSE, across the N–S trending ridge of the Green Mountains (Stewart and MacClintock, 1970; Christman and Secor, 1961; Larsen, 1987a; Ackerly and Larsen, 1987) as evidenced by grooves and striations preserved along the crest of the Green Mountains. Once the elevation of the ice surface dropped below the N–S ridge of the Green Mountains, continued SSE ice flow was funneled through, from north to south, the Lamoille River Valley (elev. 150 m, 490 ft), Smuggler's Notch (elev. 670 m, 2200 ft), Nebraska Notch (elev. 576 m, 1890 ft) and the Winooski River Valley (elev. 103 m, 340 ft), (Fig. 1). Cores taken from Sterling Pond (1.7 km east of Smuggler's Notch, elev. 915 m, 3,000 ft) indicate that the ice was below this elevation at least by 12,700 14 C years ago (Lin Li, 1996). Nebraska Notch is the lowest gap through the Green Mountains between the Lamoille River valley to the north and the Winooski River valley to the south. Therefore, the Miller Brook valley must have contained Laurentide ice well after ice had melted from the eastern flanks of the Green Mountains immediately to the north and south. Once the ice elevation dropped below the elevation of Nebraska Notch, ice supply to the Miller Brook valley was shut off and the ice in the valley stagnated soon thereafter. The esker documented in this report probably formed immediately before and during this stagnant ice stage. While not mapped in detail, reconnaissance work down-valley shows the esker continuing at least 2.6 km down-valley from the Lake Mansfield dam, the crest dropping in elevation from 352 m just below the Lake Mansfield dam to 299 m at its most eastern end. Ice-contact deformation of the lacustrine sediments underlying the 341.5 m terrace imply that that lake occupied the Miller Brook Valley during the final stages of stagnant ice melting. It is unclear whether or not this lake was ever continuous with Lake Winooski, although the lake producing the lower 330 m terrace is low enough to make its correlation with Lake Winooski likely.

Wagner's (1970) interpretation that the ridges described here are moraines stemmed from the following observations: (1) The head of Miller Brook occurs in a bowl-shaped valley, steep-sided and flat-bottomed, a shape typical of glacial cirques; (2) The ridge extending down-stream and along the south side of the valley from the Lake

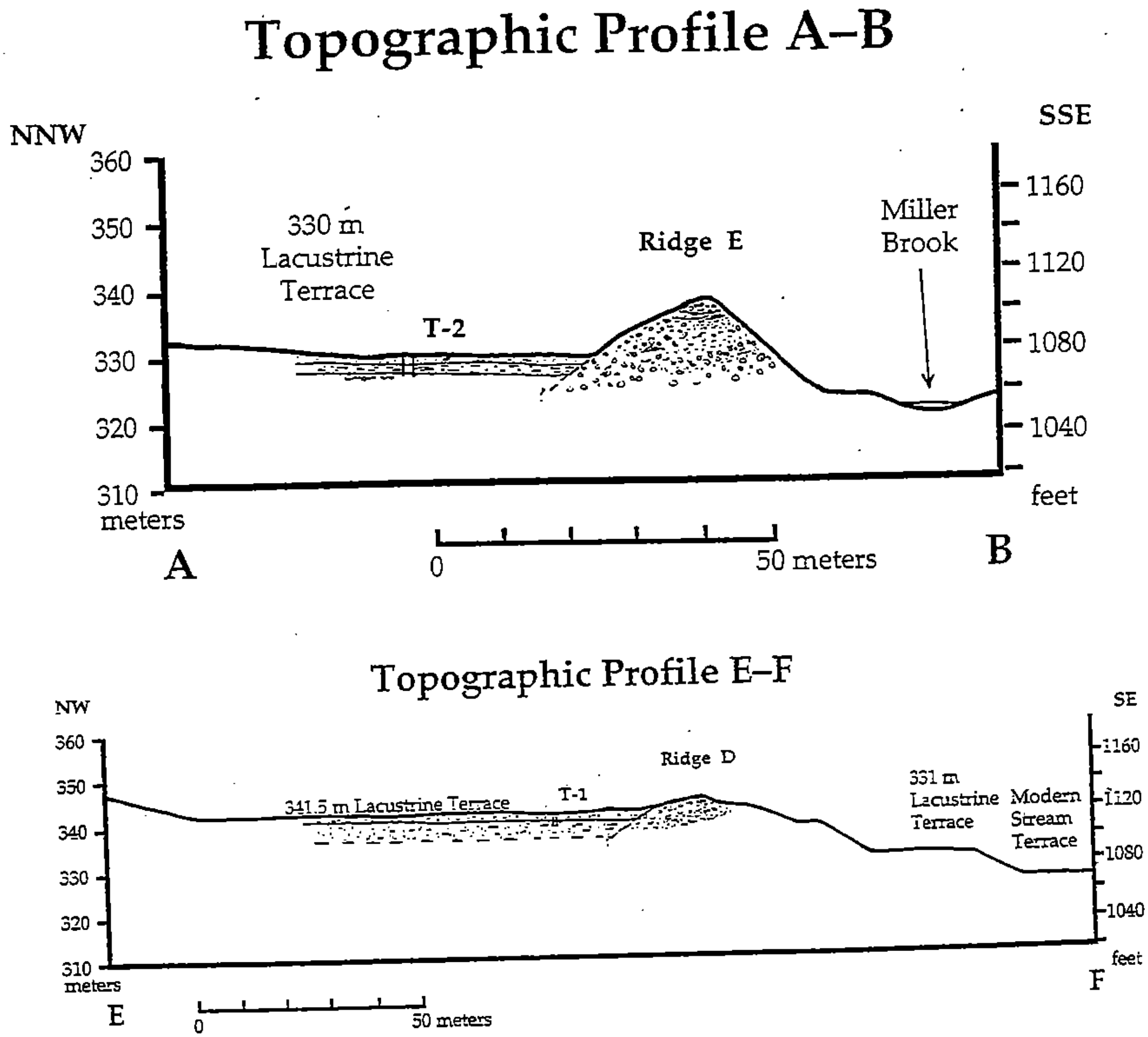

Figure 5: Unexaggerated topographic profiles across terraces and Ridges D and E northeast of the Mill Pond (Fig. 4). **Profile A–B** extends from the 330 m terrace, across **Ridge E**, to Miller Brook. Ridge E is composed of well sorted and bedded coarse sand and gravel. **Profile E–F** extends from the 341.5 m terrace across **Ridge D** to a terrace at 331 m and then down to alluvial terraces adjacent to Miller Brook. Ridge C consists of rounded and bedded gravel and cobbles, similar to Ridge E. Materials exposed in Ridges D and E are interpreted here to be of fluvial origin deposited in an esker tunnel. Soil pits near the border of Ridge D and the 341.5 m terrace show the terrace sands and gravels onlapping the much coarser cobble gravels contained in the Ridge. Soil Pit T-1 in the 341.5 m terrace exposes 1.4 m of medium to coarse sand and gravel that overlie at least 2.2 m of fine sand. Soil pit T-2 in the 330 m terrace exposes 75 cm of coarse sand and gravel overlying 85 cm of grey silt and fine sand, which in turn overlies coarse gravel. The upper sand and gravel in both terraces is interpreted to be fluvial in origin, whereas the underlying fine sand and silt lacustrine deposited in lakes at elevations of 340.1 and 329.2 m respectively.

Mansfield dam turns and crosses the valley in a manner similar to lateral and end moraines produced by alpine glaciers; and (3) A sloping terrace, extending from the end moraine down-valley to a delta was interpreted to be an outwash plain graded from the end moraine down to a pro-glacial lake. I concur with Wagner (1970) that the head of the Miller Brook valley is cirque-like, especially its uppermost reach (Fig. 3), despite arguments by Waitt (Waitt and Davis, 1988) to the contrary. While Loso and others (1997) have determined that the floor of the Miller Brook valley is too low to maintain a valley glacier after the retreat of the Laurentide ice sheet. Given our current understanding of climatic cycling during the Quaternary where gradual cooling over has been followed by rapid warming (e.g. Dansgaard et al., 1993), it is likely that the Miller Brook cirque, and others in New England, formed during the onset of these different glacial episodes, before being overridden by continental ice. Waitt and Davis (1988) have pointed out that alpine glacial landforms can be preserved, despite subsequent cover by continental ice. In this light, the bedrock landform, the cirque at the valley head, formed before the onset of continental glaciation, whereas the ridges of surficial material were formed as the ice sheet thinned and stagnated in the Miller Brook valley.

Conclusions

(1) Detailed mapping reveals that the ridges of surficial material occurring in the Miller Brook valley can be interpreted as a connected system of ridges lying both along the valley edge and valley center.

(2) Ridges B, C, D, and E all contain clean sand and gravel interpreted here to be of fluvial origin. Materials exposed in shallow holes in Ridges A, F, and G are poorly sorted, yet are dominated by relatively coarse rounded clasts. Based on both the map pattern and the fluvial materials exposed within them, I interpret all of these ridges to be eskers.

(3) The map pattern indicates that Ridges D, E, and F were once continuous and are cut by, and therefore younger than, Ridges C and G. It is also possible that the esker tunnel bifurcated and rejoined and that all of the ridges formed synchronously.

(4) Soil pits in the terrace sands commonly expose highly disrupted bedding indicative of collapse following ice melt-out. Closed depressions within and adjacent to Ridges A and B are also likely to be ice melt-out features—kettles. The eskers, kettles, and collapse structures all suggest sediment deposition in contact with glacial ice, most likely stagnant ice.

(5) Onlapping contact relationships of lake sediments over the materials in the Ridges indicate that a lake occupied the valley soon after ice retreat forming terraces at two different elevations. Lake elevations are interpreted to be at 340.1 and 329.2 m, based on the contact between lacustrine and fluvial sediments and may correlate with Lake Winooski.

(6) If Ridges A and B are indeed moraines (Wagner, 1970), they must post-date the eskers, because the eskers are at elevations very close to that of Ridges A and B, necessitating ice, probably stagnant ice, of at least that thickness. If they post-date the melt out of the Laurentide ice sheet, they must have been produced by either (1) a considerable thickening of the Laurentide ice on the West side of the Green Mountains, allowing an ice tongue to extend through the Nebraska Notch, or (2) the establishment of a small cirque glacier. Both require a considerable cooling of the regional climate which is not supported by paleotemperature estimates during the early Holocene (Loso et al., 1997).

(7) If the "cirque-like basins" at the head of the Miller Brook valley are indeed cirques, they most likely formed during the long periods of cooling prior to the advance of the Laurentide and earlier ice sheets.