PROGLACIAL LAKE AND RIVER HISTORY IN THE WINOOSKI DRAINAGE BASIN

Timothy N. Whalen

Introduction

When the Hudson-Champlain lobe of the Laurentide ice sheet retreated from this mountainous region, proglacial lakes developed between the ice and the valley walls, leaving behind a scattered record of deltas and shorelines. As the lakes withdrew from the valleys, rivers began to incise the lake deposits. The subsequent fluvial activity in the Winooski Drainage Basin removed much of the glacial deposits and lowered the valley floors more than 40 m in the lower reaches. The purposes of this paper are 1) to provide an overview of the history of proglacial lakes occupying the Winooski River Valley and its tributaries, with special attention given to the Huntington Valley, 2) to identify when the transition occurred between lacustrine and fluvial processes in each of these valleys, and 3) to describe the mechanisms responsible for river incision in the Winooski Drainage Basin.

Deglacial History

The deglacial record of the Winooski Drainage Basin is one of northwestward ice retreat, ice lowering, and decreasing proglacial lake levels. Larsen (1972; 1987a & b) has previously described the sequence of proglacial lakes in the Winooski Drainage Basin and his five stage model (Table 1) is used as the basis for this discussion. Larsen specifically addressed the chronologies in the Mad, Dog, and Stevens Branch Valleys, but work in the Huntington River Valley (Wagner, 1972; Bryan, 1995) and in the Little River Valley (Merwin, 1908; Connally, 1972) also demonstrates that the history of proglacial lakes in these valleys can be placed within the context of Larsen's model. The following section focuses on the proglacial lake levels in the Huntington Valley and the reader is encouraged to review Larsen (1972; 1987a & b) for specifics concerning the other valleys in the Winooski Basin and Chapman (1937) for the Champlain Valley lake levels.

Table1: Winooski Drainage Basin Proglacial Lake Levels and Ice Positions

Stage	Winooski River	Huntington River	Little River	Mad River	Dog River	Stevens Branch
I	Ice Retreats to Valley Mouths	Lake Jerusalem to Southern Divide	Ice and Local Lakes	Lake Granville to Granville Gulf Divide	Roxbury Divide	Lake Williamstown to Williamstown Divide
II	Ice Retreats to Jonesville	Lake Huntington to Hollow Brook Divide	Lake Winooski above Divide	Lake Winooski to Warren	Lake Winooski to South Northfield	Lake Winooski to Divide
III	Ice Retreats to Richmond	Lake Huntington to Hollow Brook Divide	Lake Mansfield I to Divide	Lake Mansfield I to Moretown	Fluvial	Fluvial
IV	Ice Retreats to Green Mountain Front	Lake Mansfield II to Hollow Brook Divide	Lake Mansfield II to Stowe	Fluvial	Fluvial	Fluvial
V	Lake Coveville to Waterbury	Lake Coveville to Huntington	Lake Coveville to Moscow	Fluvial	Fluvial	Fluvial

Note: The lake positions are cited as the farthest upvalley location for stage and ice postions are cited as position at end of stage.

Stage I lakes were limited to single north-draining valleys because they were bordered to the north by the retreating ice. These lakes drained over southern spillways, located at different elevations, and into the Champlain (Huntington Valley) and Connecticut (Mad, Dog, and Stevens Branch Valleys) Basins. The Stage I spillway in the Huntington Valley is located at the southern divide at an elevation of 460 m (1510 ft), controlling a previously unnamed lake Stage I lake (Fig. 6). Following Larsen's (1972) criteria for naming Stage I lakes based on the nearest village, the name Lake Jerusalem is suggested. Evidence for Lake Jerusalem includes clay deposits found at 240 m (787 ft) south of Huntington Center (Bryan, 1995). During Stage II, the lakes east of the Huntington Valley coalesced, from southeast to northwest in a time-transgressive manner following the retreating ice, into Lake Winooski and utilized a 279 m (915 ft) spillway south of Williamstown, the lowest Stage I outlet. In the Huntington Valley during Stage II, the ice retreated past the Hollow Brook Valley, allowing Lake Jerusalem to empty into the Champlain Valley and to lower to the Lake Huntington level. Lake Huntington drained across a threshold presently located at 204 m (670 ft) in the Hollow Brook Valley, and its waters entered Lake Coveville in the Champlain Valley at the South Hinesburg delta.

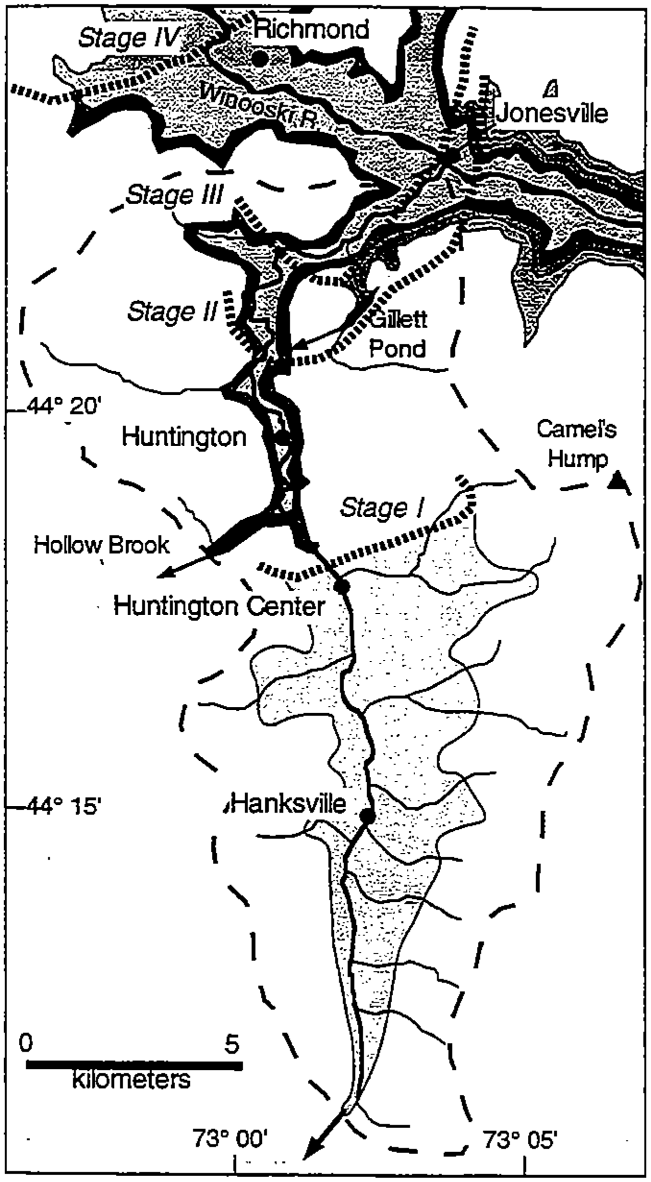


Figure 6: Map of proglacial lake extent and ice positions in the Huntington Valley. The lake levels are shown with the corresponding ice position at the end of each stage.

At the close of Stage II, the ice in the Winooski Valley had retreated to Jonesville, and Lake Huntington had expanded to fill the valley between the Hollow Brook spillway to the southwest and Gillett Pond to the northeast (Fig. 6). However, a tongue of ice remained in the lower Huntington Valley, and when the Gillett Pond spillway (229 m; 750 ft) was uncovered, Lake Winooski drained into the Huntington Valley. During Stage III, the Gillett Pond threshold controlled the level of Lake Mansfield I, and the Hollow Brook threshold continued to control the water level of Lake Huntington (Fig. 7). Stage IV commenced when the mouth of the Huntington Valley became ice free and the waters of Lake Mansfield I were able to drop to the level the Hollow Brook spillway, forming Lake Mansfield II. Once the ice retreated from the Green Mountain Front (Stage V), Lake Mansfield II lowered, Lake Coveville entered the Winooski Valley, and the present configuration of the Winooski River drainage was established.

Fluvial History

The river history in the valleys of the Winooski Basin began when the last proglacial lake shoaled and therefore commenced at different times in each valley. The upper reaches of the Mad River (south of Warren), for example, were clear of lake water during Stage I while the lowest reaches of the Little River remained submerged until the end of Stage V. However, a general valley evolution can be illustrated as in Figure 8, where the initial landscape over which the river flowed was most likely a glaciolacustrine fill terrace. This deposit is generally a coarsening upward sequence of rythmically bedded silts and clays grading into sands (some of which may be deltaic in origin and therefore exhibit foresets) and capped by fluvial deposits. These glaciolucustrine fill terraces have often been mapped as deltas on the basis of their morphology (broad, flat terraces), with little supporting sedimentological evidence (i.e., Wagner, 1972). Precise surveying demonstrates that the elevation of these surfaces decreases downstream in the Huntington River Valley (Whalen, 1997) whereas it should increase (due to glacio-isostatic rebound) if they were all built to a stable lake level. In fact the glaciolacustrine fill terraces are a composite of many depositional environments and record the transition from lacustrine to fluvial deposition.

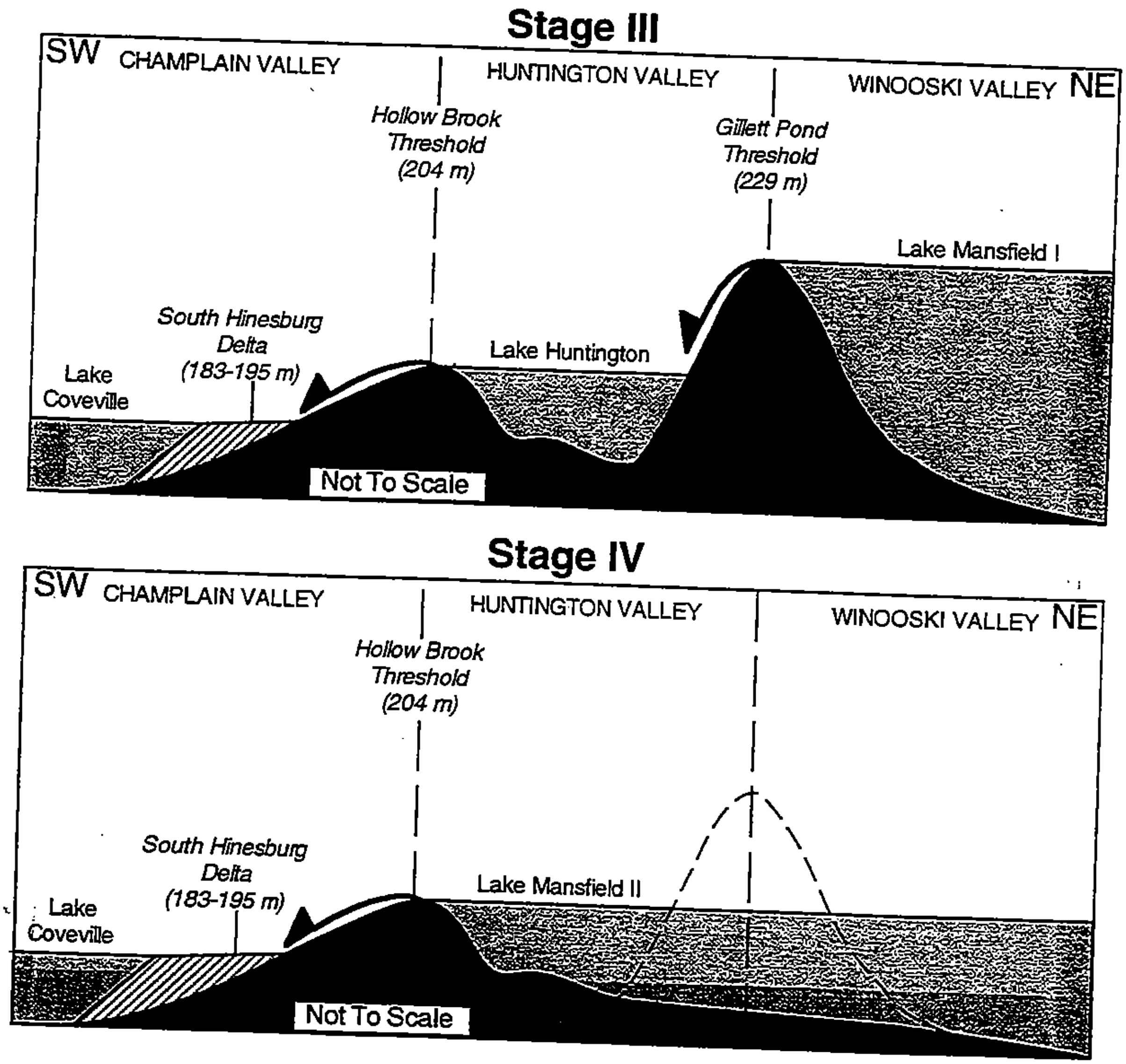


Figure 7: Schematic cross-section through the Huntington Valley during Stages III and IV. During both stages, Hollow Brook was a spillway into the Champlain Valley. During Stage III, when ice blocked the mouth of the Huntington Valley, Lake Mansfield I was forced to drain through the Gillett Pond Spillway. See Figure 6 for ice positions and lake extent.

Subsequent to the valley filling by the glaciolacustrine terrace, dramatic and episodic incision took place. Incision was a response to the proglacial lake base-level drops in the lower reaches of the Winooski Basin. The amount of incision of the glaciolacustrine fill terrace varied along a valley and depended on two factors: 1) the magnitude of base-level change and 2) the distance from the base-level change. Base-level changes continued as first the proglacial lakes, and later the Champlain Sea, in the Champlain Valley lowered to near the present level of Lake Champlain (i.e., Chapman, 1937). Each drop in water level initiated a wave of incision that propagated upstream until a bedrock knickpoint was encountered or until the incision diffused due to a decrease in stream power. Incision resulted in the cutting of the valley fill followed by a period of flood plain development at a lower level; therefore, fill-cut terraces were formed. If a knickpoint lay downstream, the base-level change could not propagate past it and no incision would occur upstream. Base-level changes no longer caused incision after the Upper Marine interval of the Champlain Sea because knickpoints developed along the lower reaches of the Winooski River below Essex.

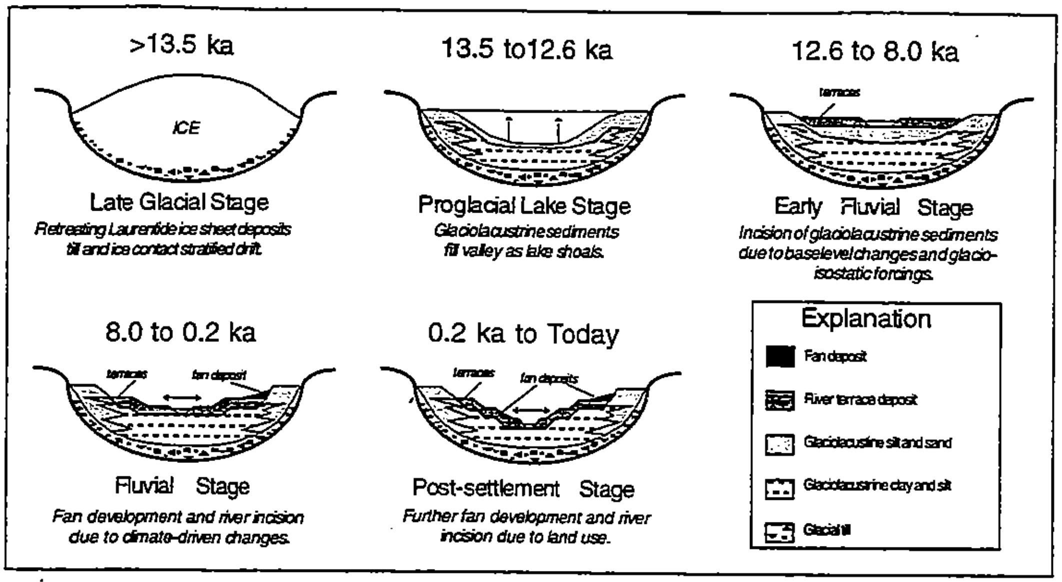


Figure 8: Schematic valley evolution for Winooski Drainage Basin. All ages are in ^{14}C years and are approximate. See text for discussion. Adapted from Church, 1997.

Subsequent to the base-level-driven incision, incision occurred as a response to climate changes and/or internal adjustments of the river system. Widespread climate changes occurred throughout the Holocene and appear to be correlative with periods of fan activity and terrace formation. The relief between terraces decreases after the period assigned to base-level changes which suggests that the mechanism that initiated incision was different. The morphology of the terrace surfaces also changes from a relatively flat feature to terraces dominated by ridges and swales.

Previous Studies of River Terraces in Vermont

One of the only studies of river chronologies in Vermont is that of Brakenridge et al. (1988) who excavated trenches on a point bar of the Missisquoi River, ~60 km north of here, in conjunction with an archeological study. They recovered many datable and identifiable wood fragments from the trenches and they recorded detailed stratigraphy of the terrace deposits. By plotting the channel elevation versus time, their results showed that incision had nearly ceased by 8000 ^{14}C yBP at which point lateral channel migration became the dominant process operating in the river. A period of incision coincides with the time of European settlement in the region (~150 years ago) and presumably the change in river behavior is associated with the clearing of the forests in the watershed for farming and timber.

Brakenridge and others (1988) attributed the decrease in the incision rate at 8000 ^{14}C yBP to be evidence that glacio-isostatic rebound had ended by that time, similar to a time frame proposed by Hutchinson et al. (1981) based on an "undeformed" or horizontal unconformity in the sediments of Lake George that was formed before 7000 ^{14}C yBP. Simple exponential decay models demonstrate that the rate of rebound generally would have decreased to immeasurable amounts during the early Holocene (Whalen, 1997), but episodic incision followed by terrace development continued during the Holocene in the Winooski Drainage Basin. Therefore, the rate of rebound can not in itself control incision, contrary to the suggestion of Brakenridge and others (1988), and other mechanisms must be considered.

Bedrock knickpoints are found in every river, including the Missisquoi below Brakenridge and others' site. Knickpoints stop incision initiated by base-level changes downstream and form local base levels by controlling the river elevation upstream. Even with continued glacio-isostatic uplift during the Holocene, the rate of incision would be dependent on the rate of knickpoint migration upstream. The migration of knickpoints upstream tend to push the fluvial system towards disequilibrium, and periodic internal adjustments, possibly initiated by large floods or widespread climate changes, are evident by the continued formation of terraces during the Holocene. The terrace chronologies in the Winooski Basin reflect a non-synchronous decrease in incision rate among valleys, suggesting that different knickpoints influenced individual valleys at different times.

Moultroup and Aldrich Farms

The flight of terraces at the Moultroup and Aldrich farms (Fig. 9) provides an excellent example of the differences between terraces formed by base level-driven incision and terraces formed by internal adjustments. Eight terraces are identified here and represent three stages of valley evolution, evident by both the relief between terraces and the stratigraphy of terrace deposits. The first stage of the valley evolution is the deposition of the glaciolacustrine fill terrace (T8). The second stage is dramatic incision followed by deposition of fill-cut terraces as a response to base level changes (T7-T6). The final stage is periodic incision related to internal adjustments of the fluvial system triggered by environmental changes (T5-T1).

Alluvial fans present on T5, T2, and T1 in this section of the Huntington Valley were dated by Church (1997) and Zehfuss (1996). The basal dates define the time of initial fan formation, but also provide lower limits to the time of terrace formation. The clustering of dates around distinct periods for fans built on a given terrace and the consistent relationship of younger fans built on lower terraces suggest that terrace formation is at least in part responsible for the timing of fan formation. In addition, limiting ages of the terrace deposits are reported by Whalen (1997) based on terraces correlated to dated base levels and direct dating of the terrace deposits (Tables 2 and 3).

Table 2: Huntington River Terrace and Basal Alluvial Fan Radiocarbon Ages

Terrace	Laboratory #	Material	Depth (m)	^{14}C Age	Calibrated Date (yr B.P.)	1 Sigma Range (yr B.P.)	2 Sigma Range (yr B.P.)
T1*	GX-21329	Wood	4.00	< 100	62-0	128-0	238-0
T2†	CAMS# 30358	Wood	3.60	1900±50	1830	1879-1751	1939-1710
T2*	CAMS# 22994	Wood	4.00	2500±60	2708-2402	2735-2363	2746-2352
T5†	CAMS# 30353	Charcoal	0.75	7790±60	8424	8541-8407	8565-8367
T5**	GX-20276	Wood	4.00	7835±105	8555	8713-8430	8981-8375
T5**	CAMS# 20963	Wood	1.30	8060±60	8981	8993-8764	9194-8662
T5**	CAMS# 20901	Wood	2.50	8530±100	9486	9531-9436	9819-9275
T6†	CAMS# 30347	Charcoal	0.49	8120±60	8991	9189-8980	9240-8736
T6†	CAMS# 30348	Charcoal	0.46	8230±60	9210	9362-900	9380-8988

Note: * Alluvial fan dated by Zehfuss, 1996. ** Alluvial fan dated by Bierman et al., 1997 and Church, 1997.

† Terrace dated by Whalen, 1997. Calibration using CALIB 3.0.3A (Stuvier and Reimer, 1993).

Two pieces of charcoal from the terrace deposits of T6 yielded dates of between 8100-8300 ^{14}C yBP and provide a minimum age for the formation of T6. However, the age of T6 is believed to be much older based on 1) the correlation of it to the Upper Marine of the Champlain Sea, 2)the ages of the fans built on T5, and 3) the age of the T5 deposits. A basal date obtained from wood below the Audubon fan on T5 is 8530 ± 100 ^{14}C yBP (CAMS# 20901) and another basal date from wood found 4.0 m below the Moultroup fan surface across the valley on T5 is 7835 ± 105 ^{14}C yBP (GX-20276). These dates agree well with the date of 7790 ± 60 ^{14}C yBP (CAMS# 30353) from a piece of charcoal recovered from 0.75 m below the T5 surface, suggesting that the T5 was formed by 8500 ^{14}C yBP and was active until at least 7800 ^{14}C yBP. Therefore, the charcoal recovered from T6 appears to been emplaced after the deposition of T6.

The date of 2500 ± 60 ^{14}C yBP (CAMS# 22994) from 4.0 m below Aldrich fan C surface on T2A places an upper limiting age on its formation. The younger alluvial fan, Aldrich B, with a basal age of 1900 ± 50 ^{14}C yBP (CAMS#30358) is located just downstream on T2B. The difference in ages between these adjacent fans points either to the migration of the river channel during this period or another difference in fan initiation. A piece of cloth, presumably a historical artifact, was recovered from the T1 deposits. The Aldrich A fan built on T1 is <100 ^{14}C yBP (GX-2139), consistent with interpreted age of the terrace deposits as historical.

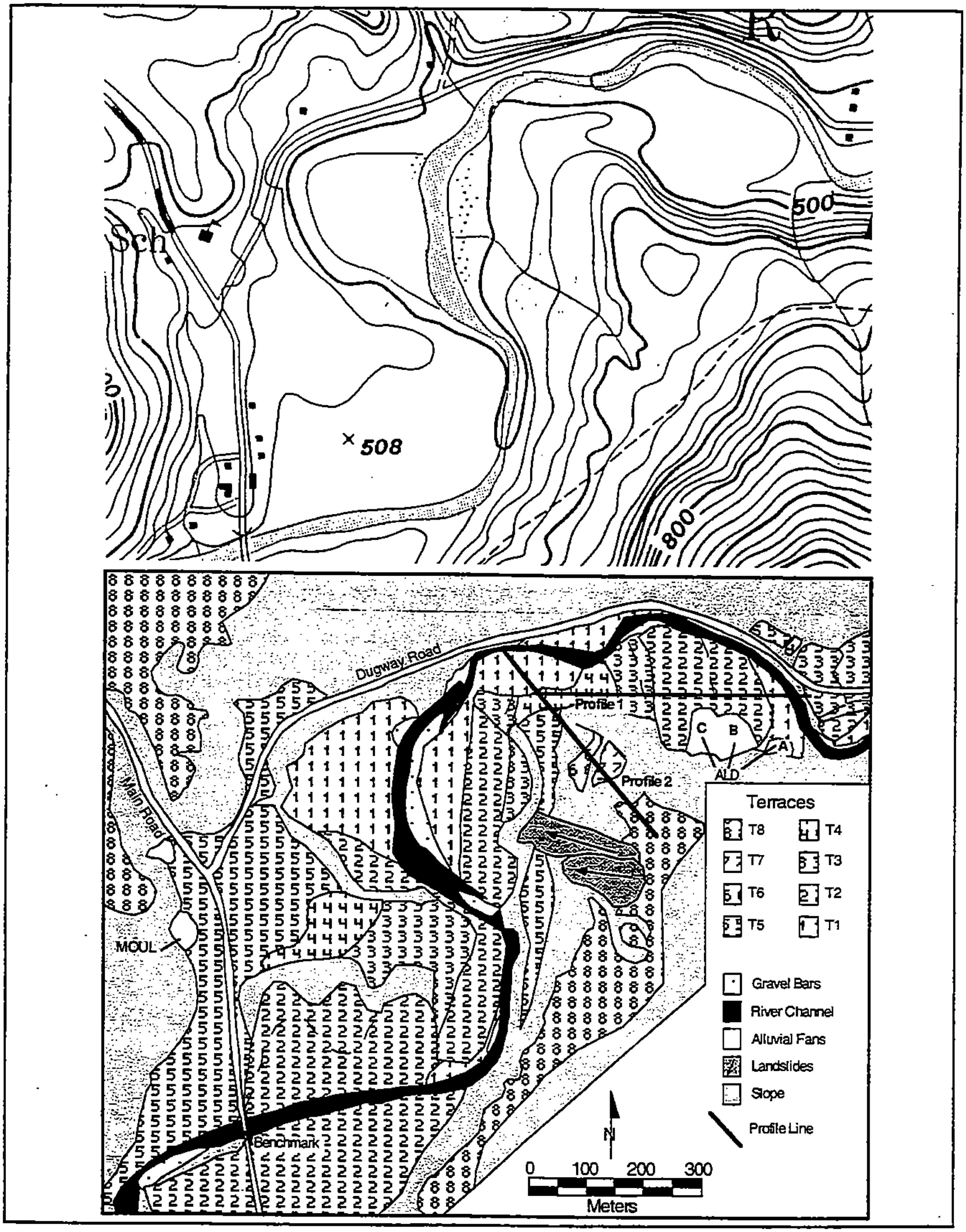


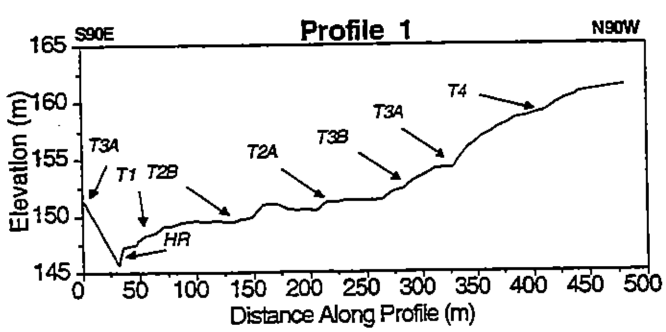
Figure 9: Topographic base map and same-scale map of geomorphic features at Stop 1. See Figures 13 and 15 for detail ed maps of fans and Figure 10 for profiles of terraces.

Table 3: Summary of Terrace Characteristics at Moultrop Farm

Terrace	Type	River System	Elevation (m)	Incision (m)	Age (^{14}C yBP)
T8	Fill Terrace	Meandering	190.98	-	12.8-12.6
T7	Fill-cut Terrace	Braided	180.44	10.54	12.6-11.7
T6	Fill-cut Terrace	Braided	176.25	4.19	11.7-10.8
T5	Fill-cut Terrace	Meandering	165.57	10.68	10.8-7.8
T4	Fill-cut Terrace	Meandering	162.50	3.07	7.8-6.0(?)
T3	Fill-cut Terrace	Meandering	158.90	3.60	6.0(?)-2.5
T2	Fill-cut Terrace	Meandering	155.47	3.43	2.5-0.2
T1	Fill-cut Terrace	Meandering	151.25	4.22	0.2-Today

Note: Ages based on correlations to dated baselevels in Champlain Valley and dated alluvial fan and terrace deposits (Table 2; Whalen, 1997).

Cross-valley profiles of the terraces clearly show that the magnitude of incision, represented by the relief between terraces, is larger for the highest terraces and decreases towards the river (Fig. 10). The magnitude of incision between both T8/T7 and T6/T5 is over 10 m and for all terraces below T5, less than 5 m of incision took place (Table 3). The obvious differences in relief between the upper (T8-T5) and the lower (T5-T1) terraces corresponds to the change in incision mechanisms and river behavior that is also visible in the terrace stratigraphy.



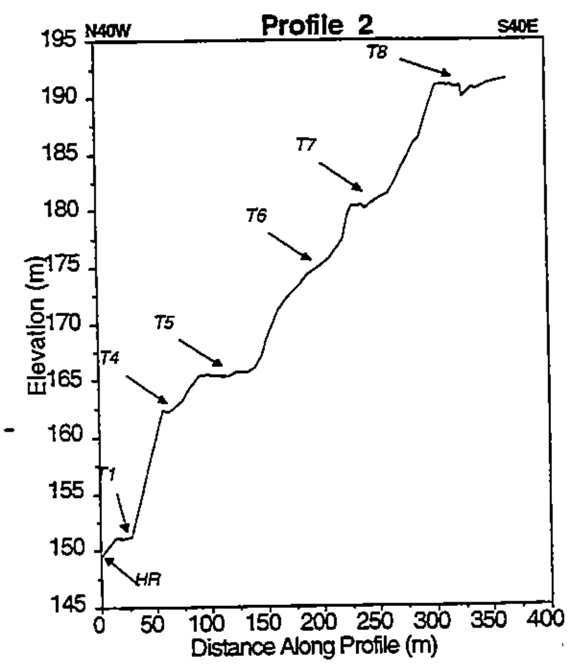


Figure 10: Cross-valley profiles of terraces at the Moultrop and Aldrich farms. Location of profiles is shown on Figure 9. Vertical exaggeration is 10X.

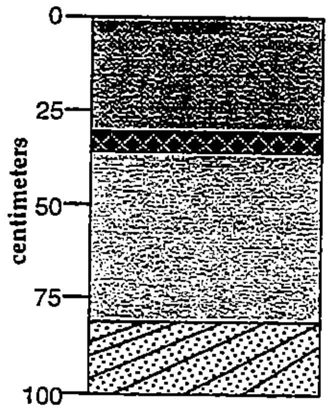
Backhoe trenches and shovel pits, opened on nearly every terrace here, revealed three different terrace stratigraphies (Fig. 11). Common to all terraces is the presence of a 25 cm plow zone capping the fluvial deposits. The plow zone represents the historical land use at this location as tilled fields before the present use as pasture land began about 35-40 years ago (pers. comm., Henry Moultroup). The upper meter of the glaciolacustrine fill terrace, T8, is composed of cross-bedded sand overlain by silty fine sand that suggests deposition by a meandering fluvial system. The stratigraphy of the pits and trenches from T7 and T6 (represented by the T6 log in Figure W5) is consistent with a braided fluvial system. Two fluvial units, channel deposits of imbricated pebbles and longitudinal bar deposits of pebbles and sand, overlie a diamicton interpreted to be glacial till, but overbank deposits are thin or absent on T7 and T6. The terraces deposits from T5 to T1 all show a similar stratigraphy, implying that the fluvial system behaved similarly to today's meandering river since the time of T5. The basal unit of imbricated gravels, deposited in the channel, is overlain by laterally accreted sand which is then capped by overbank deposits of silty fine sand.

The changes in terrace stratigraphy from T8 to T1 demonstrate that the Huntington River has evolved through time. T8 developed at the edge of the shoaling Lake Coveville and therefore probably represents a low gradient river, evident by the abundant fine-grained sediments and meandering-type deposits. However, in upvalley locations the glaciolacustrine terrace is capped with gravel-rich deposits that point towards deposition by a braided river; therefore the proximity to the lake appears to control the type of deposit. The fact that T7 and T6, composed of braided river deposits, formed farther from their respective base levels than T8 is consistent with this relationship. All three terraces developed at a time when incision due to base level changes and hillslope instability due to lack of vegetation would have delivered abundant sediment to the river. Initially, the postglacial landscape was out of equilibrium with prevailing conditions. Vegetation was sparse and due to the instability of the hillslopes, abundant sediment was transported to the river. As vegetation spread across the landscape and the hillslopes stabilized, the sediment supply decreased and equilibrated with the dominant processes, and the gradient of the river decreased as rebound lifted the mouth relative to the river. In addition, the decrease in incision after the initial period of rapid base level changes means that less sediment was eroded upvalley. Together, the changes in the type and amount of sediment supplied to the river led to the development of the fluvial system represented by T5-T1.

T5-T1 formed after the base level changes and glacio-isostatic rebound were substantially complete. The relief between the terraces is less than 5 m at this location, and sublevels are prevalent. Upstream of the Moultroup farm, these sublevels are indistinguishable; so the forcing which is responsible for them was diminished upstream. The proposed mechanism for the formation of these terraces is periodic incision as a response to knickpoint migration. Two kilometers downstream begins the Huntington Gorge. The last terrace to grade across the uppermost section of the gorge is T4. Therefore, the evolution of the gorge through the migration of the knickpoint upstream is a prime mechanism for causing the incision below T5.

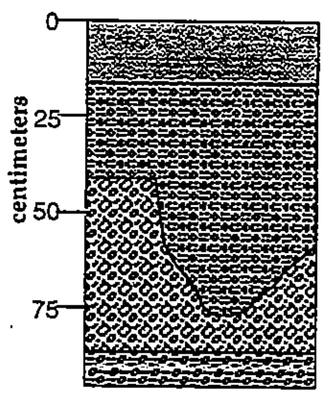
The terraces at the Moultroup and Aldrich farms provide one of the best examples of the different forms of fluvial terraces found in the Winooski basin. The terrace chronologies discussed here are consistent with those studied in the Little and Mad River valleys and may be applicable to other terraced valleys in Vermont.

T8



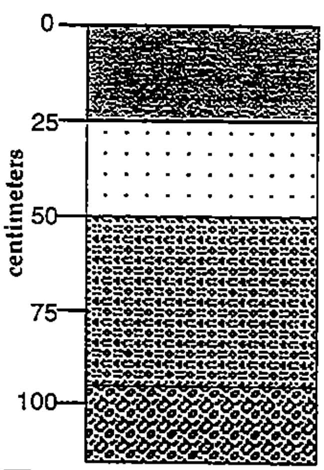
Unit	Sediment	Color	Interpretation
I	Fine Sand with Pebbles	Yellowish Brown 10YR 5/6	Plow Zone
II	Silty Fine Sand	Light Grey 10YR 7/1	Leached Overbank Deposits
III	Silty Fine Sand	Olive Yellow 2.5Y 6/6	Overbank Deposits
IV	Cross Bedded Coarse Sand	Olive Yellow 2.5Y 6/6	Point Bar Deposits

T6



Unit	Sediment	Color	Interpretation
I	Silty Sand with Pebbles	Olive Brown 2.5Y 4/4	Plow Zone
II	Pebbles in a Silty Sand Matrix	Yellowish Brown 10YR 5/8	Longitudinal Bar Deposits
III	Coarse Sand and Imbricated Pebbles	N/A	Channel Deposits
IV	Diamicton: Clayey Silt and Pebbles	Pale Olive 5Y 6/3	Glacial Till

T5



Unit	Sediment	Color	Interpretation
I	Fine Silty Sand with Pebbles	Light Olive Brown 2.5Y 5/4	Plow Zone
II	Silty Fine Sand	Olive 5Y 5/3	Overbank Deposits
III	Coarse Sand and Pebbles	Olive Grey 5Y 5/2	Point Bar Deposits
IV	Imbricated Gravels with Coarse Sand Matrix	N/A	Channel Deposits

Figure 11: Examples of sedimentological differences in the terrace deposits. These three shovels pits along Profile 1, illustrate the changes in river environment through time. See text for discussion.