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1999 TRIP

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PALEOPERIGLACIAL LANDSCAPES OF CENTRAL PENNSYLVANIA

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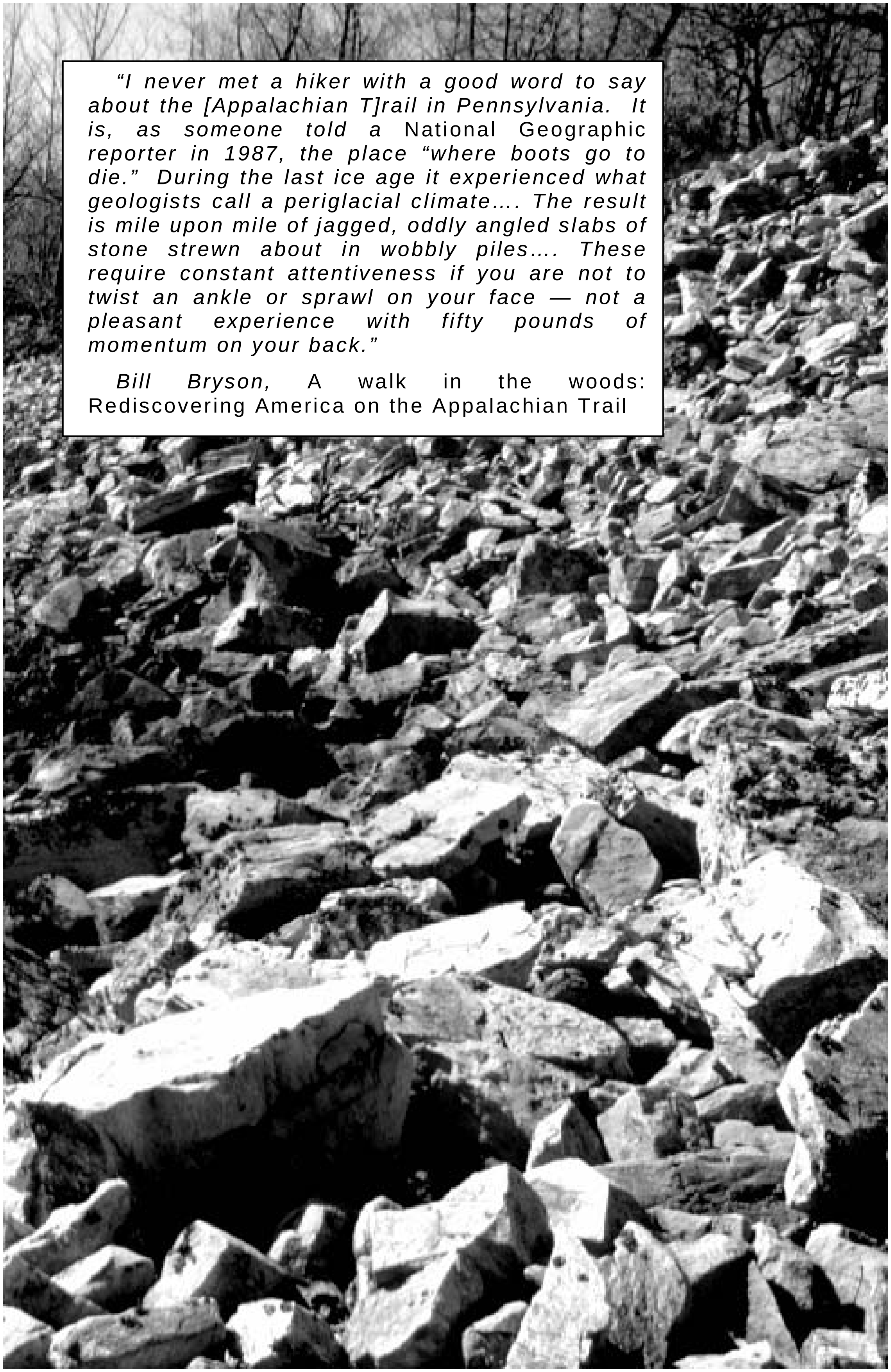
HOSTED BY BUCKNELL UNIVERSITY,
LEWISBURG, PENNSYLVANIA

"I never met a hiker with a good word to say about the [Appalachian T]rail in Pennsylvania. It is, as someone told a National Geographic *reporter in 1987, the place "where boots go to die." During the last ice age it experienced what geologists call a periglacial climate…. The result is mile upon mile of jagged, oddly angled slabs of stone strewn about in wobbly piles…. These require constant attentiveness if you are not to twist an ankle or sprawl on your face — not a pleasant experience with fifty pounds of momentum on your back."*

Bill Bryson, A walk in the woods: Rediscovering America on the Appalachian Trail



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I. INTRODUCTION

A. OVERVIEW

The purpose of the 1999 Friends of the Pleistocene field trip is to examine paleoperiglacial landforms in the Ridge and Valley of central Pennsylvania (Fig. PA). We will

- visit good examples of familiar periglacial features— sorted patterned ground, boulder fields, tors, debris fans and ancient fan fragments, dunes, loess, and shale chip colluvium;

- examine some periglacial features not previously seen on a FOP

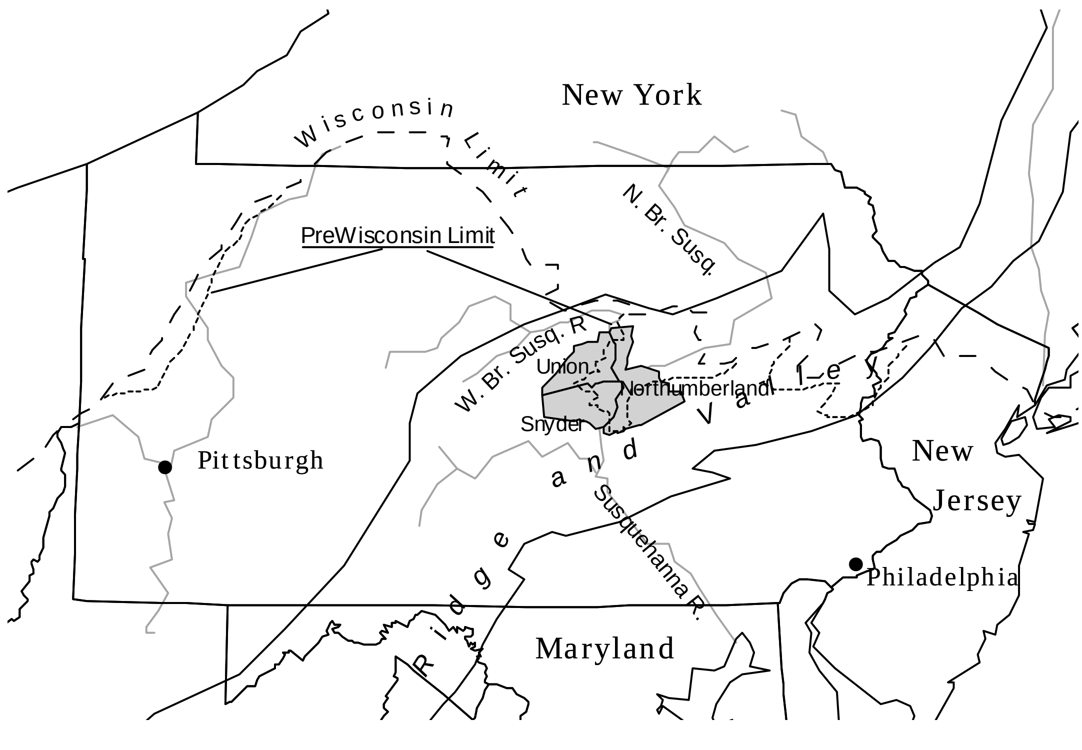

Figure 1 Field sites in three central Pennsylvania counties, with respect to political, physiographic, and glacial boundaries.

trip— ground ice scars, wind-transverse nivation welts, and related thermokarst? features; and

- review the relative positions of Pre-Wisconsinan till bodies, outwash surfaces, stream derangements, and terraces.

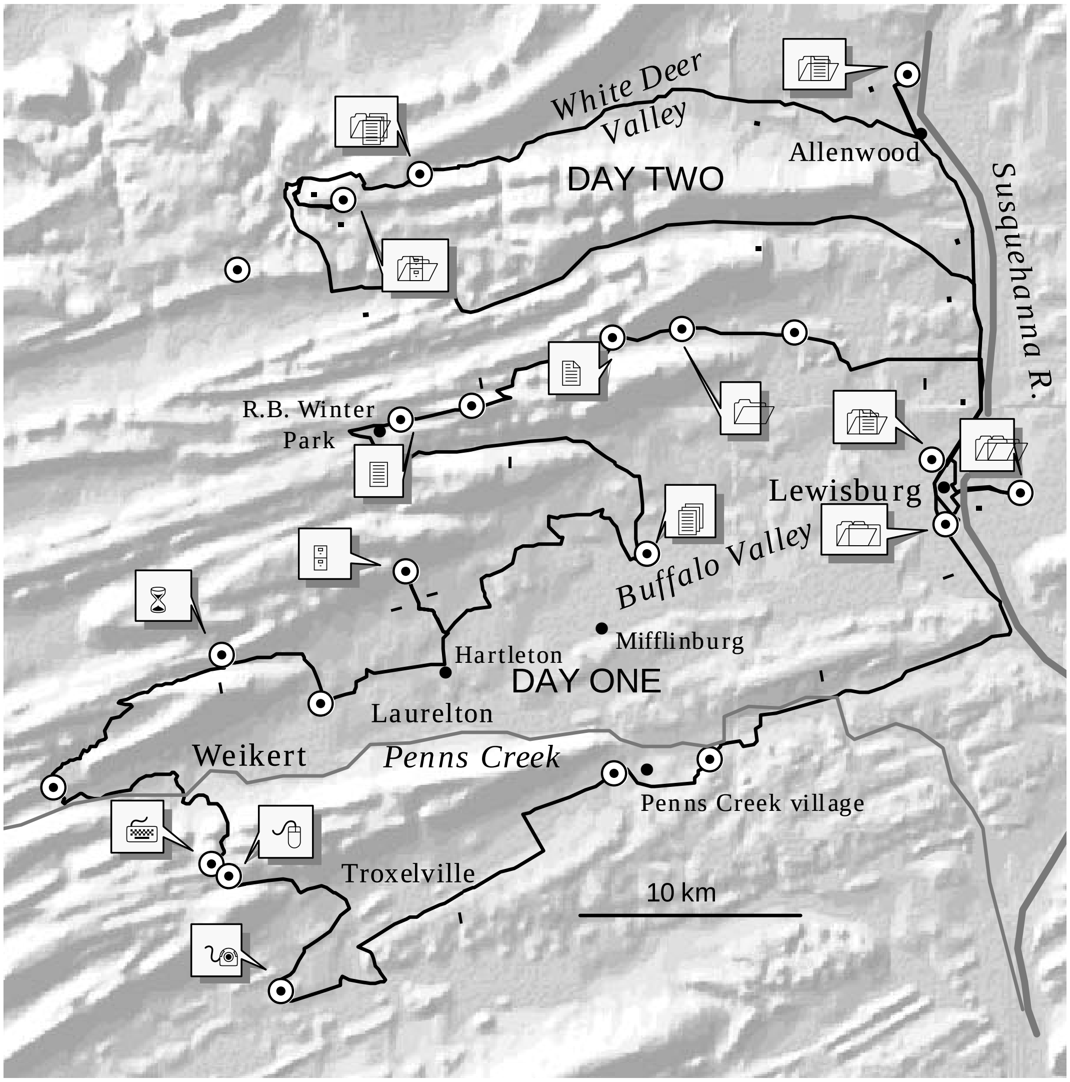

Figure 2: Route map … first & second days differentiated by arrow type.

These features have been mapped carefully enough that assertions can made about their temporal and spatial relationships; that is we can tentatively

- reconstruct large units of landscape back to late Wisconsinan times;
- understand the local circumstances — soil, drainage, slope, aspect — under which many different periglacial features developed, failed to develop, or were destroyed during deicing; and
- establish many pieces of relative chronology — showing which events must have preceded which other ones.

The trip will begin at Lewisburg, Pennsylvania — near the center of the state, the intersection of I-80 and the West Branch of the Susquehanna River. The trip, covering three Pennsylvania counties (Figure 2), will be entirely beyond the Wisconsinan limit, but repeatedly crossing the complex pre-Wisconsinan limits.

The first day's trip will travel west from the river into the high sandstone ridges to view the vigorously deformed slopes and upland valley floors. Then we'll go south into the broad lowlands to visit: high fan remnants, periglacially deformed pre-Wisconsinan moraine and outwash features, boulder colluvium and shale-chip colluvium of Wisconsinan and earlier age, and complex outwash and terrace surfaces. The briefer second day will follow the Susquehanna north, looking at aeolian sand and silt deposits, classic levels of Susquehanna terraces, and thick preWisconsinan tills including some punctured by karst.

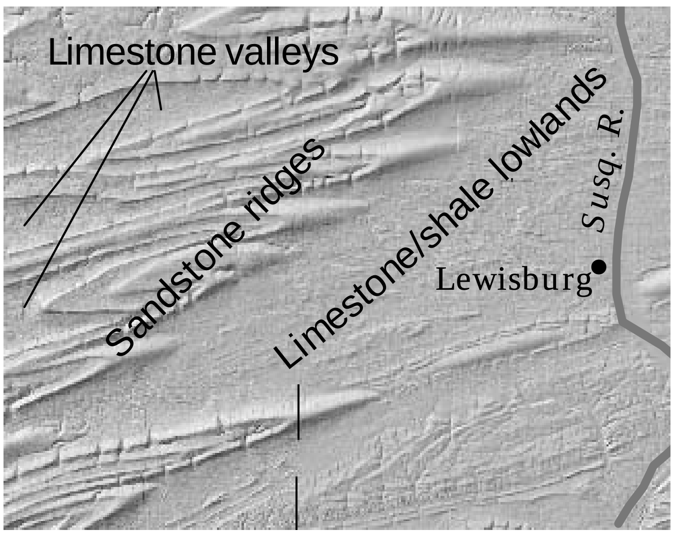

Figure 3: Landform regions of the central Susquehanna valley.

This guide book is a description of the landscape in central Pennsylvania, rather than a survey of periglacial process, and should be combined with a reference work on periglacial process (Washburn 1980, Williams and Smith 1989). I have permitted myself to be speculative in this guide, hoping to indue discussion and suggest different interpretations. If I were certain of everything I said, I'd've published it by now.

B. REGIONAL SITUATION

1. Ridge-and-Valley physiographic province.

Union and Snyder Counties lie wholly within the Ridge-and-Valley province of the northern central Appalachians. Compressive tectonic forces during the later Paleozoic folded a thick sedimentary section into broad folds. Extensive leveling sculpted the local topography in three broad forms, two of which we'll visit (Fig. LS).

a. Sections of thinly-bedded Devonian limestone and shale, as found around Lewisburg, folded with a shorter frequency, and weathered into narrower features. Characteristic transverse dimensions of the hills are measured in hundreds of meters, and relief is generally below 50 m.

b. Two great ridge-formers — Ordovician-age Bald Eagle Sandstone and Silurian-age Tuscarora orthoquartzite — folded into kilometers-wide anticlines and synclines, and weathered into highly-consistent linear ridges, up to 400 m in relief, and extending 10's of kilometers along strike. Various shales lie on each side of the ridge formers, creating narrow valleys. This mountainous landscape is typical of the mountainous regions west of Lewisburg. The ridge-formers are striking nearly E-W in this region, and plunge beneath the Devonian rocks within Union County, creating a complex of “cigar-shaped” anticlinal noses pointing eastward.

c. Further west than we will travel, thick Ordovician-age carbonates sections surface within breached anticlines and create the elongate, broad, low relief, fertile, limesone valleys typified by Nittany Valley around Penn State.

2. Drainage

In central Pennsylvania, the West Branch of the Susquehanna finds itself in the broad zone of weaker rocks limited by the “front” of plunging anticlines to the W, and by the plunging synclines — supported by the Pocono sandstone — of the anthracite valleys to the E.

Lesser drainage forms a general “lattice” pattern, with main streams following strike and tributaries approaching from either side. Several streams exhibit a significant indifference to the structure as they cut across ridges, however — most notably Penn Creek, but also Buffalo Creek at the Goosenecks above the town of Hartleton, and the upper reaches of Rapid and Laurel Runs that head in Penns Valley. These types of transverse drainage – as well as flat, concordant uplands — have, of course, suggested to W.M. Davis and his followers that the leveling history included an extensive erosional surface at or above present ridge crests. We will see some evidence of Pleistocene derangement of medium-sized drainage nearer the river.

3. Soils of central Pennsylvania

I will describe six soil associations, simplified from the Union County soil Atlas (Eckenrode, 1985). Parent material differences are the primary controls on the soil patterns, slope (including the influence of periglacial slope process) is secondary, and drainage is third.

a. *Limestone soils*. Well-drained, thick and fertile residual limestone (and calcareous shale) soils blanket lowland hills and plateaus. The soils vary by thickness and chert or shale content of the parent material. They are most common in the middle of Buffalo Valley (central Union County). Hagerstown and Edom are thick and fertile, Elliber and Opequin are thin and rocky.

b. *Shale soils*. Thinner soils, usually on steeper slopes with higher drainage density typify the lowland shale soils, especially the thin Klinesville on Bloomsburg redbeds (of which we'll see plenty), and its thicker sibling, Calvin.

c. *Glacial till soils*. PreWisconsinan Pleistocene deposits weather into characteristic rubified, clay-rich, bouldery soils of several very different drainage conditions. Well-drained Allenwood is a prime farmland soil upon flat land, poorly drained Shelmadine occurs in waterways, and Alvira is intermediate. The distinctive level of weathering of these soils is an important piece of evidence about climate history of this region.

d. *Terrace and floodplain soils*. These soils vary from the fine-grained, historic-era, undeveloped, poorly drained Holly that is common along smaller creeks, to the Basher, typical of lower river terraces, to the Monogahela and Wheeling on older terraces.

e. *Footslope sandstone soils*. The most common association in the county occurs on the moderately well drained colluvial lower slopes of the ridges. The soils are underlain by shale, but contain abundant boulders transported from upslope. The periglacial landforms of the first day of the trip are most frequently developed in the heavier and less-well drained Buchanan soils. The Laidig and Meckesville soils are found in the sandier, blockier material upslope from them.

f. *Mountain soils*. Rocky and well drained soils — and rubbly non-soils — are formed on steeper slopes and on mountain tops, atop sandstone bedrock. Hazleton, Ungers, and Dekalb vary by depth.

C. PERIGLACIAL AND GLACIAL LANDSCAPES

Many typical periglacial landforms and soil structures have been described in central Pennsylvania (Clark 1992, Clark. and Ciolkosz 1988). On this trip we will examine examples of many familiar periglacial soil and weathering landforms: boulder fields, sorted stone nets and stripes, unsorted patterned ground and ice wedge casts, shale chip colluvium, tors, as well as additional less-familiar ground ice and slope features. Stream, terrace, aeolian deposits, degraded till, and probable deperiglaciation features are widespread here as well, and will be featured on the trip.

1. Glaciation

A complex — and controversial — pattern of glacial advances is recorded in central Pennsylvania, as described in two previous *Friends* trips (Marchand, et al. 1978, Braun 1994). It is generally agreed that the latest Wisconsinan ice stopped about 50 km north of Lewisburg, and that preWisconsinan ice extended about 40 km south (Figure 1). The Wisconsinan deposits are fresh, sparse, and thin, the preWisconsinan materials are (as we will see) thick, widespread (but patchy), and heavily weathered. Although they have been conventionally mapped as Illinoisan (Berg 1980), no dating of older tills is possible except by pedogenic comparisons, stratigraphy, and paleomagnetism. Marchand differentiated six different advances, on the basis of stratigraphy and degree of weathering, that extended to the Juniata River 80 km W. Although his careful field work is admired, few accept all of Marchand's conclusions today and he can no longer defend himself. Braun (1994) demonstrated that preWisconsinan tills date from both before and after the most recent magnetic reversal (880 ka). He also showed that some apparent differences in pedological age are affected by parent material and he argued that the geometry of the elongate valley-filling ice bodies mapped by present pattern of remnant deposits, violates our understanding of glacial physics.

2. Climate

Much of the our inference about a Pleistocene permafrost climate in Pennsylvania is derived from periglacial landforms, and therefore presents a circular logic within this discussion. While many weathering and soil features are ambiguously created by deep annual freezing as well as permafrost, deep ground ice scars – as we'll see at Stop 3 – require an average annual temperature well below 0°. Paleobotanical evidence of tundra vegetation in Pennsylvania (Watts,1983) concurs with the geomorphic requirements of treelessness for the formation of sorted patterned ground and wind-transverse corrugations (nivational features controlled by snow dunes).

It is certainly to be expected that extreme cold climate would dominate in central Pennsylvania during glacial advances. High in elevation, far (half again as far as at present) from the ocean, and situated in a reentrant in the glacial boundary (which bends around this upland), central Pennsylvania should have been the coldest unglaciated part of the E US. But the number of periglacial episodes may greatly exceed our model of glacial advances, in part because the glacial record is so incomplete, and in part because dramatic climate deteriorations without glacial advance are recorded in deep sea cores.

As a midlatitude site, humidity, snowfall, seasonality, summer-melt-intensity, and deperiglaciation rate would have been very different here from those qualities now observed in the Arctic, and periglacial features may be distinct from contemporary models.

3. Periglaciation

Periglacial landforms are those created mostly or exclusively in a soil regime dominated by the annual and long-term growth and decay of ice. All periglacial landscapes show one or more of these processes, and evidence of each will be seen on this trip:

a. *Weathering* by freeze-thaw has produced abundant, angular, joint-bounded clasts. Unexploited fractures are rare on near-surface clasts, so annually-frozen rock is reduced to the characteristic dimensions of joints and bedding — from ca. 1m for the Tuscarora to <1 cm for shales. Little production of clay is expected under these conditions, and clay within Pleistocene colluvium is mostly recycled from a previous interglacial.

b. *Soil heaving* — especially differential heaving driven by downward-advancing freezing fronts — will mix the upper layers, heave rocks to the surface, and sort them in quasi-convective transport. Heaving should be effective within the active layer — the depth of annual melting in a permafrost soil. Most evidence — depth of sorted stripes, ice wedges, and perhaps a reduced "permafrost table" in some soils — suggests an active layer 1.0-1.5 m deep in the region. *Ice wedges* form as cold-driven contraction opens cracks in a frozen ground, permitting the annual inflow of water (or sand in the case of sand wedges) that jams the sides of the wedge apart during the next expansion.

c. *Slope processes* would be accelerated under these conditions, and relict hillslopes are "hyperstable" in that they are much flatter than a gradient over which present slope processes can transport material. *Creep*, of course, would be very active because of the greater depth of annual freezing and perhaps a longer freeze-thaw season on unforested lands. *Gellifluction* is a characteristic permafrost process, as excess water renders the active layer plastic; arctic hillslopes are sometimes active on angles as low as 3°. Observation suggests that south-facing hillslopes are lower in gradient than north-facing hillslopes, implying the periglacial slope processes were, on the average, "thaw-limited," and more active with a sunny aspect. Periglacial features are more common and better expressed on south-facing slopes. Cartometric analysis doesn't demonstrate a N-S valley asymmetry ... direct observation may be deceived by consistent and inevitable differences in sunlight and shadow.

d. *Nivation*, the suite of weathering, soil, and slope processes that are accelerated at the margin of persistent snow-pack, will serve to amplify any down-wind hollows in the landscape — snow accumulates, enlarges the hollow, and then accumulates more. Over an extended period, nivation is presumed to cut niches, then terraces, and then entire cryoplanation surfaces, on higher topography.

e. *Ground ice* grows within irregular permafrost, where ground water from a relatively warm area is brought near the surface in a colder area. In very cold conditions, the newly frozen water seals the water table, and an ice body is forced up by artesian pressure as a *pingo*; in Pennsylvania the big ground ice bodies are mineralogical *palsas*, forced up (within a discontinuous complex of ice and sediment) by cryostatic force. Both are sizable ice bodies with planar bases within the soil. Ground ice can also be formed as slope processes bury icings or other surface ice, or as frozen interstitial water in fine sediment.

f. *Streams* in a periglacial landscape might be predicted to be highly variable in discharge, to be steepened enough by the requirement of transporting the coarse material provided by mechanical weathering, and to aggrade themselves on their own icings. Most evidence about paleoperiglacial streams was quickly obliterated, of course.

g. Deperiglaciation — the alterations of the landscape by the melting of ice bodies and excess interstitial ice — is poorly understood, but certainly crucial to interpreting the relict landscape, since deperiglaciation has inevitably overprinted periglaciation. I hypothesize a model of deperiglaciation with three components based on observations in the excursion region:

1) thermokarst formation — melt-driven devoluming causing the decay, settling, and collapse of regions containing excess ice. The formation of ground ice scars is a thermokarst process.

2) thermokarst breakouts — the liquefaction and rapid erosion of portions of the landscape as the melting of internal ice carries the water content of the material beyond the plastic limit. Evidence for these exists only as voids in the landscape, which are obviously open to many interpretations.

3) thermokarst-derived hyperconcentrated stream scour. Down-drainage from thermokarst breakouts streams will be provided with periodic, extreme flows of fluid mud and rock. Highly energetic floods may carve multiple deep channels and transport large clasts. The association of thermokarst breakout scars and scoured stream channels is informative.

4. *Other Pleistocene landforms*

a.Terraces. Central Pennsylvania is quite literally "periglacial" in the sense that the land has been affected by its position at the ice margin. In particular, the Susquehanna River is bordered by a well-formed stream terrace of Wisconsinan age, made of fresh outwash gravels that fill a paleochannel to 10 m depth, and grading directly to Wisconsinan moraines (especially on the North Branch). Increasingly higher terraces are increasingly weathered. Containing coarse sandstone clasts, they invite correlation with increasingly early glacial advances whose ages can be inferred from deep-sea isotope records (Engle, et al. 1996). Or stepped terraces may reflect the tectonic evolution of the region as progressive, episodic uplift stranded a sequence of non-glacial alluvial surfaces, in which case we know very little about their ages.

b.Fans. A related issue to terraces is the development of fans where mountain streams disgorge onto the valley floors. The fans may be correlated to river terraces and controlled by them, or they may be correlated to episodes of deperiglaciation, or they may be essentially outwash surfaces caused by glaciation within the valley. Evidence from the trip supports all three theories, unfortunately.

c. Dunes & loess Two distinctive aeolian deposits are present on either side of the West Branch of the Susquehanna at Lewisburg. Immediately E of the Wisconsin terrace are distinct parabolic dunes showing a WNW prevailing wind. West of the river — up wind? — is a sizable hilltop silt deposit interpreted as a loess. Both would be products of an era of summer alluviation, and winter mobilization of sand and silt from an unvegetated terrace surface.

II. DAY ONE

A. SUNRISE CHURCH REGIONAL OVERVIEW

Structural and leveling history of central Pennsylvania

Structure. We are looking nearly directly up the axis of the Sand Mountain anticline, Spruce Run synclinal valley, to the north, and then Nittany Mountain anticline, and more beyond in both directions. This is the broad and complex end of the Nittany anticlinorium, presenting a dozen of these anticlinal noses in Union County alone. Looking south down a “front” of these mountains it is clear that some subsurface discontinuity has defined a hinge here.

Topography. Millions of years of leveling have stripped off kilometers of softer rock, but left the Tuscarora standinghigh — except at the occasional water gap. We stand on the Clinton formation, a variable, but generally resistant, Devonian shale immediately up section from the Tuscarora. The more vigorous leveling in the narrow Spruce Run valley has removed almost all of this rock.

The typical sigmoidal periglacial hillslopes are visible from here — a low gradient (<8%), shaly foot slope in the creeped and soliflucted Laidig soil; a steep and blocky slope in the DeKalb soil (transported by slide and boulder creep and limited by detachment rates at the top) beginning at the Tuscarora outcrop at 400 m, and the flat top of the mountain across which rock is moved slowly by creep.

PreWisconsinan glacial material is present on every side of us here. Presumably the ice front extended a distance into Spruce Run valley, and rose up onto the snout of the anticline, but did not crest the ridges.

The upper reaches of two big creeks — Spruce Run to our left and Little Buffalo Creek down the hill to our right — are within 500 m just west of us. The pattern of two streams flowing from one mountain valley suggests that the stream courses are inherited here from a broad fan lapping around this upland on both sides, and covering most of the lowlands. A broken surface 20 m below us to the SW — 30 m above present drainage — is demonstrably a fragment of such a fan. We will see clear examples of this surface in a few hours.

B. STOP 1. SPRUCE RUN ROAD WIND TRANSVERSE CORRUGATIONS

The effects of snow accumulation on periglacial slope processes

The colluvial footslopes of the great ridges are characteristic landforms of central Pennsylvania. At this spot we will consider (1) the sedimentology, form, and genesis of the hillslopes themselves, (2) the several kinds of distinctive wind-transverse corrugations that have developed upon them, (3) patterned ground, and (4) the oversized channels of Spruce Run, below us to the south.

Colluvium.

Periglacial colluvial diamicton is ubiquitous in the central Ridge-and-Valley. One fourth of Union County is covered with the soil association we're standing on. In the present case, Tuscarora quartzite clasts — transported from the Tuscarora outcrop more than 1000 m upslope — are supported by tan loam. The loam incorporates fragile fragments of shale bedrock, and much of the clay content is likely from the bedrock, as well. At the next stop we will see a section of the hillslope, showing the colluvium only a meter or so thick, atop weathered shale. This evidence suggests that the slope processes moving this material are thin — a mobile skin only a meter or two in depth — and are able to roll relatively fresh parent material up into the surface layers. The sorted stone nets and stripes described below are driven by heaving, which would also serve to creep this material downslope.

Hints can be seen, in the N ditch 80 m W of the crest of this riser, of the standard “brown-over-red” colluvial section. It is frequently observed in these slopes that one or two meters of brown — presumably Wisconsin — colluvium overlie red — preWisconsinan — colluvium. Bright red soils are taken to reflect subtropical weathering regimes that this land hasn’t seen since the previous interglacial. Marchand asserted that high-chroma red soils at the surface were of Sangamonian age or earlier.

This also supports a thin-colluvium model, with the brown layer being the transported sheet. Footslopes are convex-upward in long section. I suggest that this form reflects in part the increasing clay content — from increasing incorporation of shale bedrock — in a downslope direction, which increases plasticity and creep rate.

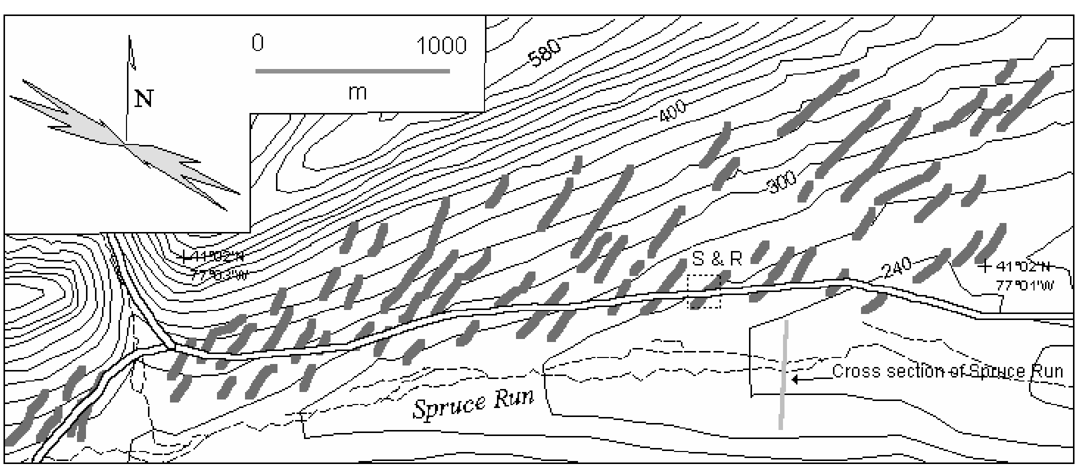

Figure 4: Wind-transverse corrugations in the valley of Spruce Run. E & W features are welts, middle ones are steps-and-risers. “S & R” indicates Figure xx.

Wind-transverse corrugations

The 8 m ridge crossing the slope diagonally before us is an example of one class of wind-transverse corrugations [WTCs], which cover these footslopes (see Figure 4). WTCs are "elongate low ridges, 10 to 30 m wide, more than 80 m long, and more than 1.5 m high, that occur in subparallel groups in unconsolidated material on low-to-moderate slopes in an environment showing periglacial influence" (Marsh 1998, from which most figures and some more text in this section is taken). There are three distinct types of these features, occurring in different landscape positions. This is a step-and-riser ... "widely spaced, 3- to 15-m-high, asymmetrical steps and risers on south-facing hillslopes of up to 8°." (See Figure 5.) The other two kinds are *welts* — "closely spaced, 1.5-m-high, symmetrical welts on slopes of less than 3°" — and *ramparts*, "closely spaced, 2- to 5-m-high basin ramparts adjacent to ground ice scars on nearly flat valley bottoms."

WTCs are among the most widely distributed periglacial landforms in the region, but their origin is obscure. They are recognizable as kindred features to each other on the basis of their highly distinctive and consistent orientations (see Figure 8). For the 732 corrugations that I measured off air photos, the mean trend is NNE-SSW (028°-208°) with a standard deviation of 13° (see Figure 7). This

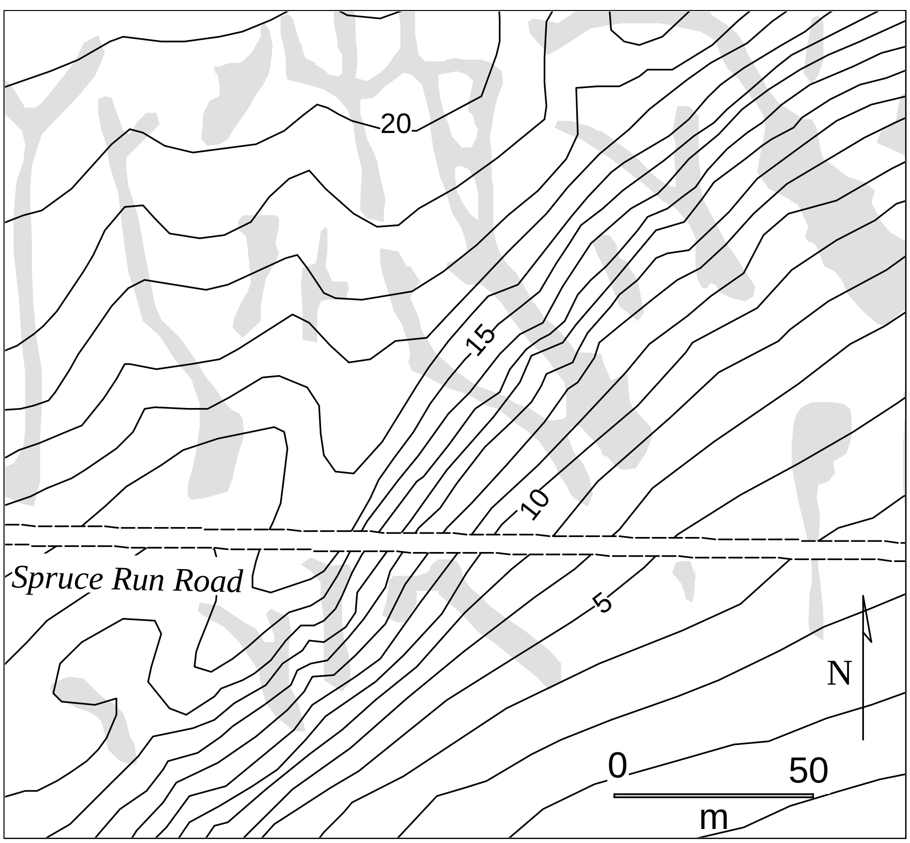

Figure 5: Step-and-riser along Spruce Run Road ... note ESE-facing riser, slight welt along crest, sorted patterned ground better developed above feature than below.

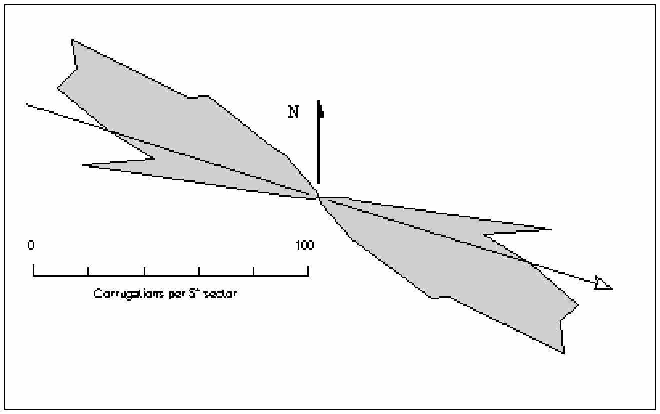

Figure 7: Orientations of 732 WTCs, measured from air photos and maps, diagramed as direction normal to ridge . Arrow shows 104° paleowind from dune measurements

orientation is unrelated to topography — most slopes are near N or S. This orientation is unrelated to any obvious structural lineation … and they do not occur on bedrock, in any case. But the orientations do cluster nicely around a direction transverse to the wind. Present-day winds at Williamsport (30 km N) average about 98° (normal to 8°-188°), but a measured paleowind is even closer. Stabilized parabolic dunes (that we'll see tomorrow), 300 to 700 m long, of presumed earliest Holocene/latest Pleistocene age lie just east of the Susquehanna terrace across from Lewisburg. The average trend of the axes of 18 dunes is 104°± 4°. This is highly similar to the orientation normal to the corrugations in the down-wind direction: 118°± 13°.

This is a typical WTC step-and-riser. Steps and risers occur on long south-facing hillslopes that are covered with loamy colluvium and have a slope of < 12°. They are distinctly asymmetrical in cross-section, with an 8 m high, 20-30° steep riser on the downslope (down-wind … SE) side, and with a slight welt at the crest which has formed a swale on the tread large enough to have captured minor drainage. Periglacial soil features — sorted patterned ground — are better developed above steps and risers compared to below them. Steps and risers are the highest and longest of the wind-transverse corrugations. The largest steps & risers — just up the road from here — are up to 1000 m long, and 18 m high at the upper reaches where they merge into the steep, blocky mountain slope. Some of these features are large enough to have been mapped on 7.5' quadrangles (Figure 6). Steps-and-risers on steeper slopes will be more strongly aligned *across* the slope compared to those on flatter slopes (Figure 9). Steps and risers occur in generally parallel groups, but they are less regularly spaced, and further apart — about 130 m— than other WTCs. Excavations into risers near here (and examination of the road cut right here) reveals no consistent fabric suggesting flow or transport.

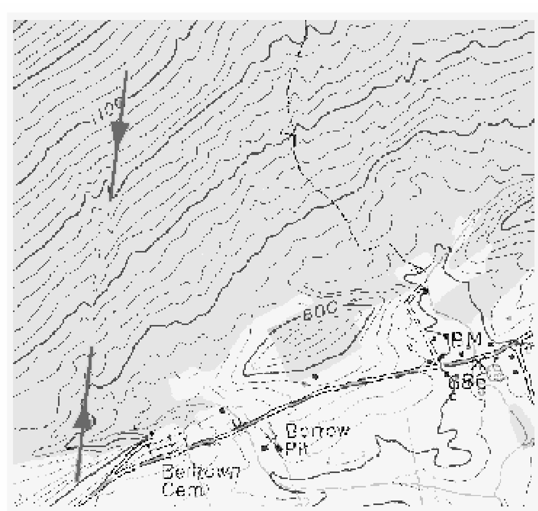

Figure 6 : Wind-transverse steps-and-risers visible on Alfarata 7.5' topo sheet (45 km SE.)

We entered a field of welts when we moved onto this gravel road (and we'll see two large ones at the next stop). “Welts are typically 1.5 m high, and 50 to 500 m long. They occur on nearly flat deposits of unconsolidated sediment, are arranged in parallel groups, are sinusoidal in cross-section, and are regularly spaced at 35 to 60 m. In narrow upland valleys filled with colluvial bouldery

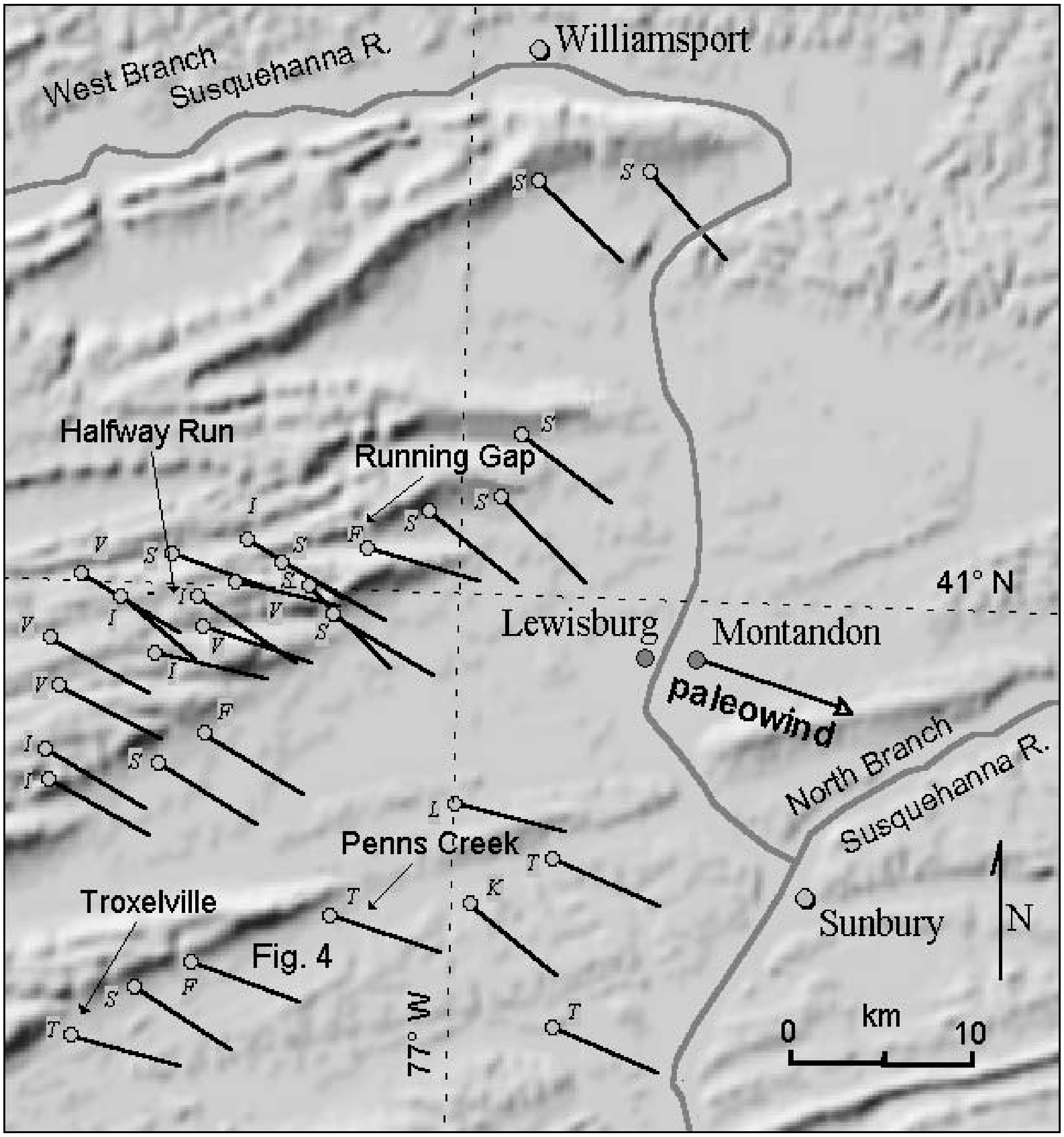

Figure 8: Locations and orientations of several types of WTC in central Pennsylvania, and location and orientation of Montandon paleowind dune field.

loam, they may extend the width of the valley. They are also widespread on preWisconsin cobbly till on the wide lowland valleys close to the Susquehanna River. In the lowlands, “nets” of corrugations in two different orientations are common. Welts are common in areas dominated by either of the other types. The low-slope area (< 5°) through which we just passed supports welts, whereas areas like where we are, upslope and upwind to the west and northwest are covered with steps and risers. The higher, and better-drained, eastern end of the valley of Halfway Run, at Stop 3, supports long, straight welts, while basins and ramparts have developed in the lower western portion of the valley. These relationships support the identification of the three types of features as variants of a single phenomenon." The third type of WTC, ground ice ramparts, will be discussed at Stop 3.

Genesis. These are not aeolian features. The wind neither deposited this diamicton, nor did it cut a step on the lee-ward side of the feature. These are not the results of gravitational slope transport. They are larger than solifluction lobes, their internal clasts lack the bench-parallel fabric to be expected in a rolling or flowing mass, and their orientation is consistently oblique to the slope.

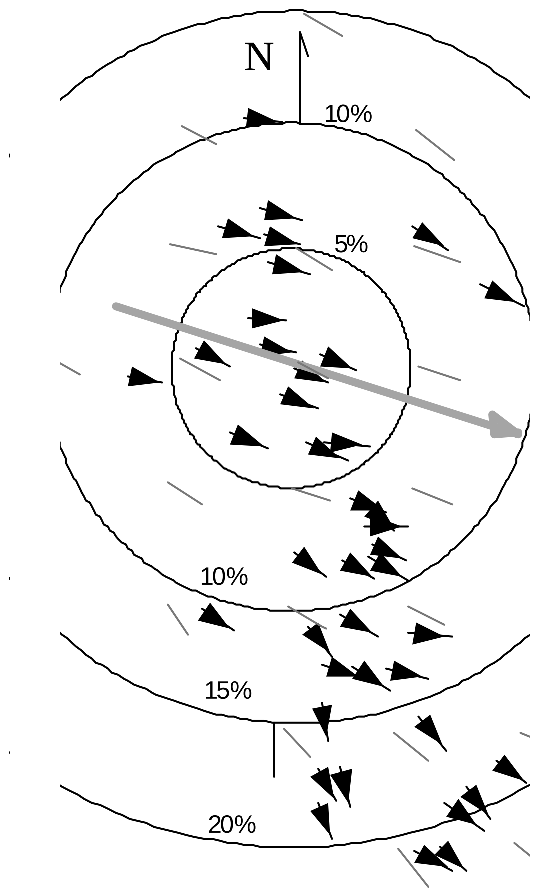

Figure 9: Step-and-riser orientations (normal to arrows) compared to. slope angle and amount (circles); n=173. Large arrow is direction of paleo-wind; light vectors show regression model, r^2=0.60.

I suggest that these are various types of nivation features, sharing loamy diamictic host sediment, modest relief, moist soil conditions, linear expression, and a wind-transverse orientation. "Nivation" includes most periglacial processes that would be accelerated at the edges of long-lasting snow pack (Thorn 1988), so these features are polygenetic in detail.

My theory is that welts are the primordial form of WTC, and the other two types developing from them under particular landscape conditions. The whole

Figure 10: Wind transverse snow drifts between welts, showing the bare and heave-prone position of the WTCs. (Looking N toward New Berlin.)

process starts as systematic regional winds drive the development of elongate welts between parallel, periodic transverse snow dunes. I suggest differential frost heave — heaving laterally away from an insulating snow patch, for example — as a driving force for welts (Figure 10). Heave is a likely cause, as welts commonly surround shallow undrained basins and occur only in deep, loam soil near the water table. (Loam soils are "frost susceptible," in that permeability is high enough for water to move through, and clay content provides opportunities for cryostatic suction upon through capillary layers too small to freeze near 0°, thus drawing more water toward ice masses.) We should expect that the height of welts is related to the depth of annual freezing. On nearly-flat surfaces, welts are typically 1.5 m high. Higher welts, like we'll see at Running Gap, were presumably enlarged by erosion: the big welts occur on hillsides sloping parallel to the welt, so water would be channeled between pairs of welts.

Clusters of steps and risers are common upwind and upslope from fields of welts — like here — and the fields terminate to the NW (upwind) with risers cut into sandstone bedrock. The step-and-riser form is a wave that originates as a welt, and propagates upwind through the footslopes of the mountains. "Frost action associated with accumulated snow may mobilize the material at edge of the welt, and snowmelt may move the sediment away. The welts should thereby retreat upwind with a steep face, creating steps and risers." Eventually the step-and-riser reaches an immobile position where soil is too dry and sandy, and slope too steep, to have permitted welts to initiate in place.

"The movement makes the step an older surface than the area below the riser, consistent with the observed better development of periglacial soil fabric on steps than on the areas below the risers. Masses of loose rock occur on the risers where sorted stripes intersect steps and risers; presumably these boulders were winnowed out of the colluvium by the retreat of the features." This suggests a slow rate of S & R retreat. "Steps and risers do not occur on slopes facing anywhere in the 180° sector toward the wind, although welts do. In this situation, snow accumulation occurs upslope from the welt, so melt water cannot flow away from the drifts effectively to erode scarps."

The welt that is often found on the crest of the S & R is a distinctive feature. Fair-sized streams find themselves confined behind this welt and flow across the slope, along a highpoint on the land just meters from a big drop. My idea about the welt's creation is that crest of the step-and-riser would have been blown snow-free while drifts would grow nearby either way. Welts will grow, by the processes described above, and subsequent drainage (or "consequent drainage," literally) finds itself trapped.

Sorted patterned ground.

Good — not great — examples of sorted stone nets and stripes occur above the step of this feature. On a flat berm 100 m above the riser (near the clear-cut), sorted stone belts — 1-2 m wide, extending one to two meters into the ground, and made of Tuscarora clasts to 2 m in major dimension — are arrayed in nets with a 5 to 10 m period. The cell space within the nets is relatively clear of clasts. Tabular clasts in the belts are aligned with long axes parallel to belt and normal to the ground. As we move onto steeper slopes, we find nets becoming elongate down slope, then they grade into parallel or isolated stone stripes. Stone stripes frequently end — and sometimes start — in rock fields.

A standard model of the formation of sorted patterned ground presumes that the active layer in a permafrost landscape acts as a slow convective system. Heave brings boulders to the surface, of course, either because they can conduct heat out of the ground faster than looser soils, so that ice grows at their base and pushes them up, or because they are frozen into a lifting surface soil. The initiation of a cellular pattern is a crucial step in the development of sorted patterned ground, probably initiated by tension cracking under cold-period contraction (like for non-sorted patterned ground). Having developed their perpetuation is easy to comprehend: during each freezing cycle, fine-grain material in the center of the cells heaves up further than the stone in the nets. This creates a small topographic slope toward the perimeter down which rocks shift. The greater heaving of the fines may cause more rapid creep of the centers of the polygons, elongating them down-hill, and eventually forming stripes.

Oversized channel of Spruce Run

Spruce Run, flowing in the middle of this valley, has an unusually large channel, created by a system with much higher energy than the present stream. At its widest, (a kilometer SE of here) the stream plain is 400 m in width, and contains nine sub-channels (Figure 11). The sub-channels are generally braided in pattern, 10 m wide, and separated by boulder bars 1.5 m high. The record or near-record small-stream runoff of January 1996 did not occupy more than half

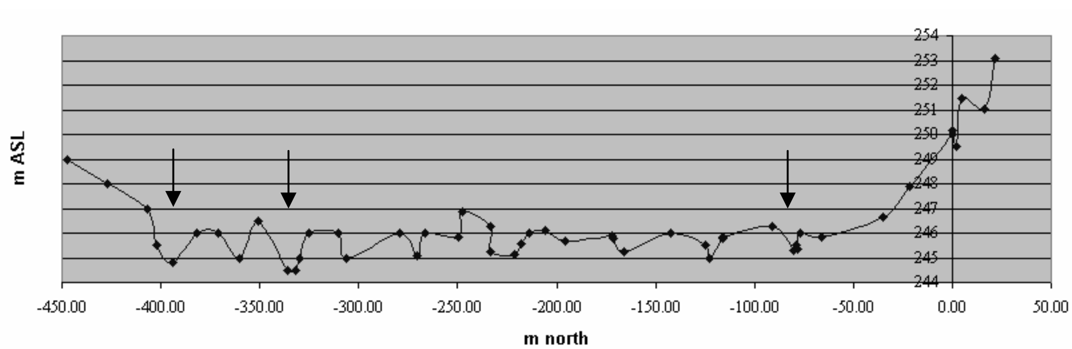

Figure 11 Cross section of the Spruce Run valley immediately below Lyman Gap trail (as located on Figure 4). About 9 channels are present, of which three (marked by arrows) now carry flowing water.

the channels. The edge of the wide channel truncates the footslope we're standing on into a steep bluff, and bevels periglacial welts on the slope. This suggests a timing for the cutting of the channel after welt-forming processes ended. Stone stripes continue to 1 m above the stream plain, suggestign that little erosion (and more deposition?) was involved in the shaping of these valleys. A bouldery lag may be present 1 m below that plain, to judge from stream banks.

I suggest that the distinctive channel pattern was formed by highly energetic hyperconcentrated stream flow (and perhaps rapid deposition) during a small number of catastrophic thermokarst breakout events. These events would be most likely during deperiglaciation in times of long-term warming. Spruce Run shows this exaggerated channel only down-steam from the several tributary valleys that are (by my observations) scoured out in a fashion consonant with thermokarst breakout.

This stream plain continues out into the lowlands, where it lies as a valley train along Spruce Run. It is clear there that the pattern is complex. On Buffalo Creek, which we will cross later this morning, three fluvial surfaces are apparent in the train, but even the first one above the stream one is cryoturbated. Thus it was constructed before the end of vigorous frost action — perhaps a whole periglacial cycle before the end.

C. STOP 2. RUNNING GAP TRIBUTARY GAP / FAN COMPLEX

Short and long term down-cutting history.

The surfaces and sections visible at this stream gap give important clues about the evolution of the periglacial landscape. Several fan surfaces are cut into each other, and into the bedrock. Distinctive patterns of wasting by stream and slope processes have occurred since the end of periglaciation.

Fan surfaces

At least three levels of fan are apparent at Running Gap.

1. a 30 m wide piece of lower fan surface lies east of the stream long the road.

2. 6 m higher lies a (slightly ambiguous) 50 m wide fan surface at the shoulder to Running Gap Road, covered with creeped boulders.

3. 12 m above the first fan is a bedrock fan surface, ca. 300 m wide, on both sides of the gap.

High fan. The highest fan surface bears large WTC welts … they are highly noticeable — even dangerous — where the road rolls over them as one approaches from the east. A shale pit just west of the stream reveals that the higher fan contains weathered shale bedrock at a shallow depth; to the E it also has bedrock near the surface.

A shale upland immediately adjacent to the gap is a distinctive feature at fans throughout these intermontane valleys. Presumably the shale surface is a strath level that was protected by a boulder layer at the time that equivalent portions of this shale — which continues in the subsurface up and down the strike valley, of course — were being eroded. The shale is now probably protected by the proximity of the gap: sheet flow, ground water, slope processes that would attack the shale at all diverted away, to the east.

Lower fans. Stop 6 at Bear Gap, right after lunch, will help us put the forms of the lower fans into some perspective. On the basis of comparisons to other fan systems in the area, I interpret the lower fan sections like this: the middle fan — represented by a scrap near Running Gap Road— is the main periglacial transport surface within which creep hauled boulders, and across the impermeable surface of which seasonal stream drainage ran. During deperiglaciation this surface was disrupted by thermokarst processes: the fan itself de-watered, collapsed, flowed, (hence fan fragments on the valley walls above us, and the fans' slope toward the stream) and also vigorous torrents of mud and debris came from above (hence the blocky lower fan surface into which the stream is sharply cut). Those torrents were the agents that sculpted the wide channels of Spruce Run down stream from here. The source of the material was the two lateral (strike) valleys above us. They both are sharply dissected into a more gentle periglacial upland. This truncation can be seen both at the heads of the two larger streams — where their well-organized V-shaped forms end at a 5-10 m bluff, above which lies an irregular, periglacially deformed, poorly drained, gently rolling valley floor — and it can also be seen along the valley sides, where scraps of a gentle bouldery hillslope adhere to the steeper hillslope. Stop 8 is a small example of this. I interpret these landscape disjunctions to be the upward limit of progressive thermokarst failure moving headwardly into ice-rich valleys. The volume of material (ice and sediment, but not counting simultaneous meteoric contributions) that may have been removed through Running Gap during deperiglaciation is on the order of 500,000 m^3 — on the basis of a maximum dimension for the wedges filling the tributary valleys being 10 m vertically, 100 m wide, and 750 m long.

I have no good reply to the assertion that the valleys may have looked like they do now all through periglaciation. Certainly the cold-period valleys had both low-discharge higher sections where slope processes dominated (Bear Gap, Stop 6, for example) , and higher discharge lower sections where stream processes dominated (the Susquehanna, for example). I would say that the model of landscape evolution that has thermokarst evacuation of smaller valleys accounts for more elements of the post-periglacial landscapes we'll see today — evacuated features in the uplands, scoured valleys at gaps, and deposition into lower valleys.

A standard controversy about fans like this middle one concerns how active they have been during the Holocene. A reassuringly uniformitarian model holds that large debris flows have been low frequency events throughout the Holocene, and the fan pieces we see are presently in gradual evolution. I assert that these fans are substantially relict landforms. Debris flow features — scars, chutes, berms, and terminal lobes — are nearly non-existent in these hills. Where they are found, they are typically within steep-sided valleys that I interpret as having been thermokarstically evacuated. I suggest that most periglacial landscapes were too flat for debris flows when active, that the thermokarst failures — were they technically debris flows? — removed most of the available mobile material, and that weathering has not produced enough residuum yet. This interpretation is pretty much specific to this region and this interglacial. Further south in the Appalachians, in regions with less periglacial activity, the thermokarst removal would have been less vigorous and enough material may remain for significant debris transport onto a fan like this. And during a longer interglacial than we've had so far, chemical weathering of upland rock, in combination with downcutting in the upper valleys, could create conditions for significant debris flow activity on a fan like this.

Spring flow / headward erosion

A small stream cuts headwardly into the side of the western scarp of the middle fan. Steep-headed spring valleys like this are widespread at the margins of colluvial sheets, as fluvial processes increase their influence on the periglacial landscape, reclaiming the interglacial landscape. The valley below this spring — cut, at least in part, by the spring — is parallel to the WTCs just west of us. This suggests that some subsurface alignment of porosity echoes the surface features. Springs often cut up to the faces of WTCs, and are fed abundant groundwater at that place. Perhaps they are fed by water channeled in boulder deposits between or within corrugations of an earlier cycle. Immediately downstream the runoff from the stream bifurcates around an elevated feature aligned with the WTCs …perhaps part of an exhumed periglacial WTC of an earlier generation. The generation could be an earlier period of periglaciation — preWisconsin, presumably — or else it is a "pre-latest-Wisconsin" feature that was rolled over and buried by later periglaciation. The ground ice features at Stop 3 may be similarly persistent features located at bouldery groundwater conduits which are themselves located by the corrugations. This spring is transporting weathered shale to the surface, a material found both in the colluvium and in the bedrock beneath it.

Bedrock-colluvium relationships

Evidence from the shale pit cut into this fan, immediately west of the gap, is that transport of diamicton across this hillslope is a thin process, at the same time that the shale bedrock has been deeply deformed. The section shown in the pit has recently been mostly destroyed by erosion-&-sedimentation-control treatment, but can be reconstructed (Figure 12). Bedrock is Rose Hill ?? shale dipping 40-60° S. All of the shale in the pit, to 4 m depth, had been physically

Figure 12 Mega-creep in east wall of Running Gap shale pit, 1988. White line follows a single layer of the broken shale bedrock, bent 120° from dip (see arrow – 70° toward the right) and transported 15 m downslope. Note the few boulders dropped from thin colluvial layer atop section.

weathered into flat, 5-15 cm clasts. Traces of bedding in the broken rock showed that the upper layers had been transported 20 m or more downslope by creep. A few ice wedge casts were visible in the upper layers of the section. The depth to which creep had worked in this pit is probably 6 m, to judge from the geometry of the distorted layers. It is difficult to visualize how freeze-thaw cycles could work effectively on the rock to that depth. Perhaps desiccation cycles could do the job, but it is more likely that some other mechanism than small cyclic change in volume was at work. I had wondered whether pore pressure — confined above by frozen ground and fed below by the groundwater system at the gap — would be effective in driving deep deformation … there are suggestions in the literature. This section is unique in my experience in the region.

The upper shale layers were moderately stained with red oxides, suggesting that it had weathered near the surface through the Sangamonian. A WTC welt heads on the west edge of the pit. The diamictonic welt material forms a slight ridge upon the weathered bedrock; there is no evidence that the bedrock was deformed by the processes that formed the welt. This observation is consonant with a shallow refraction seismic survey of the lower reaches of this same welt (100 m below the road). That survey (Figure 13) showed a horizontal surface taken to be weathered shale, 5.5 m below the crest of the welt, and 1.5 m below the swale between two welts.

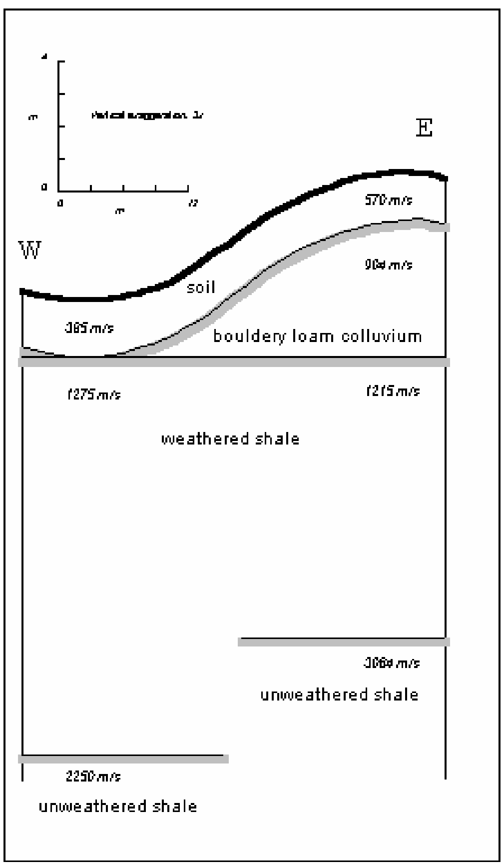

Figure 13 Seismic line interpretation for welt below running gap.

We will see repeatedly through the day the conditions for the formation of WTCs apparent here: the processes creating them are very effective at mobilizing wet diamicton, and they seem to be effective at stripping off such material from a shaley bedrock, but they distort (and presumably move) *only* the diamicton. It is difficult to understand how the large clasts in the diamicton are important to this process — they are of many lithologies and angularities, and vary from 10 to 200 cm in major dimension — so perhaps the sand-loam matrix is the critical part of the relationship between landform process and sediment. But the relationship is strong, indeed.

D. SAND MOUNTAIN CRYOPLANATION SURFACE (NON-STOP)

Concordant summits in the ridge and valley.

The classic geomorphic controversy in the Ridge-and-Valley is the genesis of the flat ridge crests, like this one. The last stop on Sunday addresses this question directly, but it is worth noting the features f flat ridge-tops as we pass this one. Several horizontal surfaces are apparent between Cooper Mill Road and the fire tower. Lower surfaces have gradual slope off the mountain on one side, and an abrupt scarp on the other. These are plausibly cryoplanation surfaces – sites of vigorous nivational retreat against the hill, and creep-based transport across the upper slope. Almost all ridge crests are flat-topped. The upper-most surface (upon which the fire tower stands), however, is barely sloped, has a thick, sandy soil, and little evidence of periglacial soil processes.

E. STOP 3. HALFWAY RUN GROUND-ICE SCARS

Heavily deformed and well-preserved periglaciated valley

This isolated valley shows ground ice scars, ramparts, welts, thermokarst scars, and boulder sheets. The features developed in a narrow, water-rich, cold, upland valley, and were preserved especially well.

Ground-ice scars

This bog — called Cattail Bog — is the first recognized, first described, most-measured, and probably best defined ground ice scar in the eastern US. At least 50 similar features are present along this stretch of Halfway Run, and hundreds more are found in similar situations in central Pennsylvania (Figure 15). The features are elliptical basins, 2 to 9 m deep, typically filled with bog, measuring about 20 by 50 m (and up to 150 m) in plan, bounded by a curving rampart 1 to 3

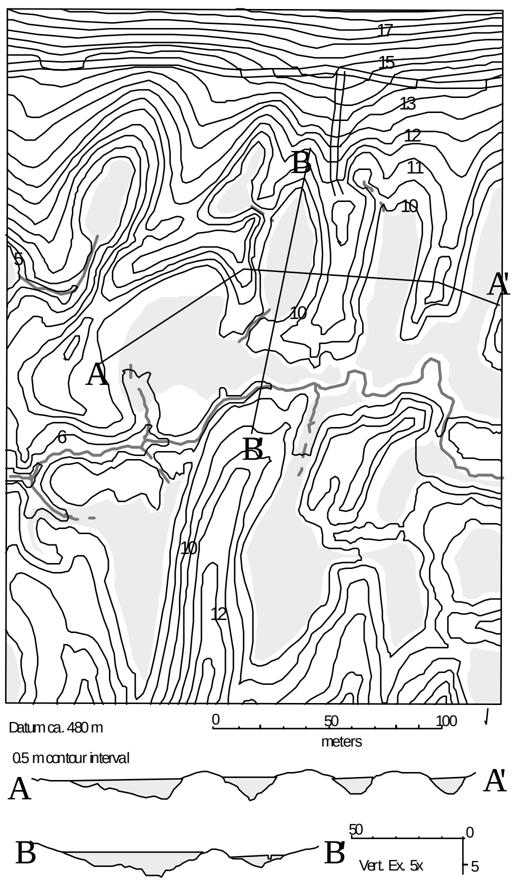

Figure 14: *Topography, section, and distribution of wetlands at Cattail Bog. Ruled areas indicate boulder surfaces.*

m high. The upper ends of the ramparts merge with the hillslope at their upper ends (

Figure 14: *Topography, section, and distribution of wetlands at Cattail Bog. Ruled areas indicate boulder surfaces.*

). Nearly every basin has a seep at its upper end which has cut back into the colluvial mantle like the spring at Running Gap (Stop 2). The ramparts, and the interiors of the basins, are the familiar colluvial diamicton from the surrounding hillslopes. The bedrock here is Ordovician-age Reedsville shale; the slopes of this anticlinal valley are Bald Eagle sandstone.

I identify these as ground ice scars on the basis of their depth below grade — only perennial ice (or karst — but the bedrock isn't soluble) could maintain a depression to many meters depth. By definition, these basins establish the former existence of permafrost in central Pennsylvania. The presence of a seep — fed from the sunny south-facing slope above us — suggested to me that these were open-system pingos; that they grew as ice froze onto the seep and was forced up by hydraulic pressure. I was probably wrong about their genesis — seduced by the word "pingo?" — for these reasons: hydraulic pressure cannot evenly lift an elliptical feature like this, and the temperature conditions for pingo growth are pretty severe: a continuous frozen layer is necessary to maintain water pressure, and a sufficient rate of cooling to export the latent heat of freezing an entire spring.

A more plausible explanation is that these are “mineralogical palsas” (Seppälä1988). The essential difference is that the growth of the ice body for a palsa is by segregation from wet sediment, and the force lifting the overburden is cryostatic rather than hydrostatic. The palsa concept is not without shortcomings. Because the term correctly refers to a feature developing in peat, this use is either an extension or a misuse. One would hope that a generic term for segregation ice bodies could be accepted, of which there are both peat and mineral versions.

In either case, the landform is created by the growth of an ice body roughly the shape and size of the basin, and probably some meters above present grade.

Figure 15: Oblique air photo of Halfway Run ground ice field, viewed from the NE. The map in Figure 1 is the right half of the image.

The bases of nearby scars are roughly the same elevation, suggesting a permeability discontinuity that localized freezing – fine (heavable) over coarse (permeable) would be expected. Shallow refraction seismography identifies a velocity increase at that same depth — 2.5 m in this area — that resembles the colluvium/weathered shale interface seen at Running Gap — although the shale is the more friable Reedsville formation. The material in the ramparts bears a fabric with tabular clasts preferentially oriented vertically and normal to the ramparts — suggesting compression against the ramparts, or perhaps slumping of sediment off a raised ice body.

Basin fills are typically (from bottom up), clean, washed, bleached (reduced?), weathered sand clasts; a “soil-like layer” of sylvan detrital material; large pieces of wood; gyttja; watery peat; peat; and sphagnum. The wood is pine, dated to 12.8 ka; this date was some time after thawing finished — and perhaps well after, since other evidence suggested treelessness in this area during the full periglacial. Some of these basins have continuous, banded silty layers begging for palynological analyses.

Palsa scars occur here and elsewhere in silt-rich, bouldery sediment on low gradient surfaces within a few meters of the water table. Most of the scars occupy colluvium-filled intermontane valleys like this one, extensive deposits of preWisconsin till and fan deposits, the distal ends of debris fans, or occasionally deep and cherty limestone weathering mantle. (The wind-transverse orientation of the scars on limestone, elaborated below, is why I don't believe these depression are merely karst basins.) Isolated scars occur on uplands and on saddles in upland valleys, but they are more often circular than elongate.

Ground-ice scar ramparts

The ramparts of these ground-ice features *are* WTCs, per the definition — linear ridges of local diamicton of greater than 1.5 m height and 80 m length, oriented transverse to the paleowind direction. These ramparts can be shown to be related to welts in several ways.

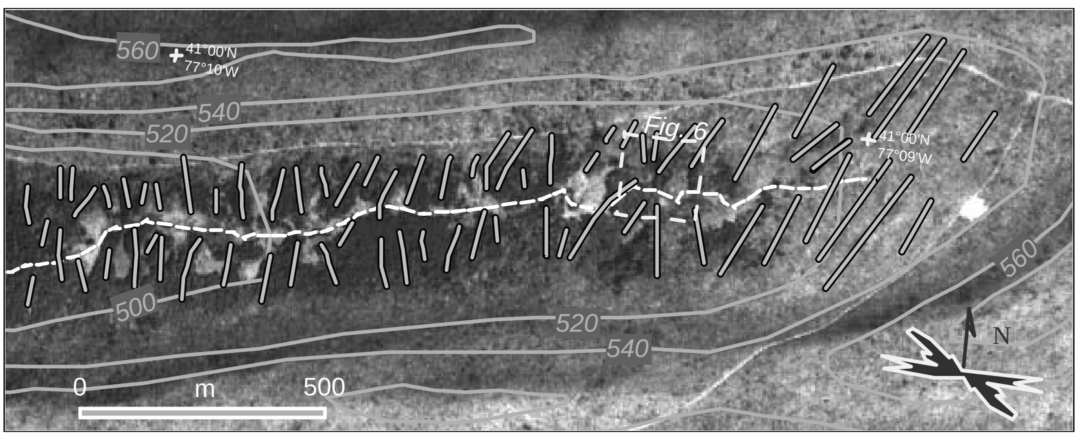

Figure 16: The upper valley of Halfway Run, showing ramparts (surrounding light-colored bogs within ground-ice scars) and long welts (to the east). Note the two favored orientations.

First, a series of delicate welts lie in the eastern end of this valley. (Welts on these west-facing slopes are lower than welts with other orientations, they are often longer, and lack a sharp down-slope face. Because the prevailing winds would accumulate snow on the upslope side of the features, wasting would not be accelerated. These welts presumably show the heaving and ground-ice influences upon WTC development, but not the nivational ones.) As one travels down the slope, the welts grade smoothly into ground ice ramparts — a more pronounced basin is associated with them, first a round pit of seasonal-frost mound size, then the more elongate basins like we see here.

The other relation between ramparts and WTC can best be seen on the map of this small region here (Figure 14). The ramparts are greater than the palsa scars they are adjacent to, in two senses. First, they extend up the hillslopes beyond the limit of basin formation, where they become welts in the ordinary sense. Second, they can be followed all the way across the valley ... for example, the E rampart of Cattail Bog connects (with an offset) to the W rampart of Cranberry Bog, due south. Valley-wide WTC welts are common in narrow valleys like these even without ground ice scars; their damming effect on drainage is a cause of the common elongate wetlands that fill upland valleys — Pine Swamp in the mountains S of Coburn, Centre County, (40 km W) is confined and created by such welts.

This relationship — that ramparts are the dominant features in the valleys — suggests that the ground ice scars were located between, and oriented by, pre-existing welts, and that the alignment of the features was initiated by the processes that worked on welts. "In areas of very shallow groundwater, the freezing at the welt may approach groundwater. At some point, the growth of segregation ice by freezing at the water table becomes the dominant process. The ice mounds within palsas would then begin to develop in the spaces between welts, and eventually invert the topography. The ice bodies maintain the orientation between the welts and between adjacent palsas, creating elliptical scars." (Marsh 1998) (A slightly different model would have freezing at the snow-free welt begin to involve groundwater, and have the ground ice grow at the site of the welt, so the present ramparts were previously between welts. However, this model would not account for the extension of the welts beyond the scars, mentioned above.

The ramparts near Cattail Bog demonstrate a surprising characteristic of WTC —they are bimodal in orientation, they are apparently transverse to two different winds. Mode 1 of the WTC orientations is normal to about 125°, Mode 2 is normal to 93°. There are more Mode 2 WTCs in this valley than anywhere else in the area. The welts at the E end of the valley, mentioned above, favor Mode 1, while the ramparts within the valley tend toward Mode 2. All of the ramparts here are at Mode 1, except one approaching the W side of Cattail Bog. The rampart defines a ground ice scar to its S that has been obliterated and is only observable by vegetation patterns and through augering. My present hypothesis is that Mode 1 — matching the dune field at Montandon — is the newer direction, and that Mode 2 is an earlier form that has been overprinted in most places. But is the earlier orientation early Wisconsin (compared to late Wisconsin Mode 1), or is it from 2 or more entire periglacial cycles ago? It would be hard to believe that this landscape represents but a single cycle of welt and ground ice growth; and surely welts grown here during earlier periglacial episodes would affect the most recent episode through impacts on topography, sedimentology, and hydrology of this landscape. Renewed periglaciation, even thousands of years from now, would be shaped by the existing topogaphy and sediment.

Degradation features

The freshness of this periglacial landscape is almost startling, but the very distinctiveness of the features lets us comprehend how much has happened since periglacial times. I see evidence of two stages of late Pleistocene thermokarst leveling, and one event of historical aggradation.

First, the central part of this valley was apparently degraded to a level 1 to 1.5 m above the present alluvial surface during the time that ice bodies were still present. The ends of the ramparts near the middle of the valley are planed off at that level, and an extensive bouldery surface (a lag?) occurs at that level — see the berm 70 m west of the outlet of Cattail Bog on Figure 14. I picture a planation event — either as the ice mounds were melting at the terminal Wisconsin or perhaps cyclically in earlier, comparatively warm periods. Ice within the basins protected them from in-fill, and raised local baselevel to a meter above the present floodplain, so a broad channel snaked down the middle of the valley between ice mounds, and aggraded into lower spaces between the mounds. This stream cut the lag surfaces, and also laid some flat-topped sand bodies, unassociated with ramparts, in the middle of the valley.

The second stage that I see here is a more ordinary thermokarst outbreak event. Ground ice scars W of the Cattail region map are empty of fill — lowered to 2 m below the mapped ones — and connected to Halfway Run through 2-4 m wide flat-bottomed, boulder-floored channels. Up and down the length of this valley, most ground ice scars connect to Halfway Run with these channels — witness Cranberry Bog. I hypothesize these to be thermokarst features cut by vigorous mud/water flow during terminal deperiglaciation. The large welt at the edge of the map prevented excavation to the same degree of the many scars E of it. Perhaps the first erosional event shifted Halfway Run out of its lower channel to the WNW and superposed it on a blocky section of the welt that resisted downcutting. The features have also been protected from erosion in the millennia since that time by beavers (among other agents). Beaver dams occur every few hundred meters along the creek — at Cattail Bog, and at the W edge of the map, for two examples.

The third fluvial deposit is an extensive sand sheet of approximately 40 cm depth lying along the stream. This deposit is widespread and continuous, and quite visible because it supports the alder communities along the creek. Sticks and slash are present below the surface of this layer. I see it as the product of historic, post-logging deposit. The influence of logging is obvious in the hemlock stumps upon the bogs, and the exotic spruces planted in rows. This historic fill resembles apparently logging-derived deposits along lowland streams.

F. STOP 4. BUFFALO VALLEY FAN SURFACES AT "MOUNTAIN VISTA"

Widespread scraps of alluvial surface, covered with "till"

Most of the “till” deposits in Buffalo Valley are in landscape positions more reasonable for fan deposits, although the material is probably glacial in origin.

Fan surfaces

Many continuous graded surfaces occur at different levels in Buffalo Valley, each of which is a plausible component of a fan. The smooth surface heading E at Forest Hill (Rt. 192 & Buffalo Road intersection) is an especially good example. One lithological unit in the valley — the Moyer Ridge member of the Bloomsburg shale — is especially resistant, and seems to represent the fan surface well in most places. The knob above the Forest Hill store is of that member, and stands at a plausible fan level. The surfaces are often covered with rubified diamicton (like the Allenwood soil) that is conventionally called till. In other cases they are devoid of any material other than residual soil.

Modeling fan surfaces

I made a numerical model of the past fluvial surface described by certain of those pieces, and compared it with the landscape. To make the model, I associated these various little surfaces with the four main tributary streams feeding into the valley, plotted a gradient for each paleo-stream by graphing spot elevations against distance from where the stream leaves the mountain and selecting a most plausible good fit. I made a model of the elevation of each fan described by those graphs — a cone with an apex at the stream head — and merged them together, with a plausible stream surface for Buffalo Creek, and with a known river terrace. The surface (Plate 1A) looks something like a circus tent. I compared these surfaces with the 30” DEM of the region within ArcView GIS, and present the zones of near-match as Plate 1B. Colored areas are the intersections of the DEM with 4 m sections parallel to the cone model. Large areas of any color are likely fan surfaces, although which color represents a fan will vary across the map due to the imprecision of the models and to erosion.

There is no reason to believe that the GIS represents a single-aged surface — no independent age information is available. But the several fans are similar to each other. Although each was determined independently (except Laurel Run, the furthest W), each is a consistent 30 m above contemporary stream level with a very similar gradient. Each grades to a surface of Buffalo Creek that is also about 30 m above present level. Most of them head at a high notch above the present stream — we will drive through one of these after lunch. For Rapid Run — on whose fan Forest Hill lies — and for North Branch of Buffalo Creek, where we will visit next, the notch is NE of the present stream.

Bedrock surfaces are elevated above these fans over about 20% of their area, compared to 70-80% of the area above present stream plains. Although it is undeterminable how much more of the landscape used to be above that fan surface, the extent to which the hard Moyer Ridge member was leveled suggests that these were wide fans that had been thoroughly cut. A fan surface about 20 m higher still is apparent in some places, especially at Spruce Run and North Branch of Buffalo Creek.

Fan material

A soil pit is cut into Allenwood soil? on private land at “Mountain Vista” development — after the writing of this guide. A classic high chroma red soil comprising a matrix supported diamicton is expected. Surface exposures suggest that the predominant clast is a 10-30 cm rounded piece of sandstone. The nearby road section shows the soil to be only decimeters thick, over Bloomsburg shale. (If the diamicton material were deeper, it would be expected to show WTCs.) This is a highly plausible fan deposit. The type site for the Laurelton Till is on a fan surface much like this one, which we'll cross after lunch. The only depositional fabrics I've seen in Union County in near-surface “tills” are fluvial — imbricated shingle at I-80 and New Columbia Road, and indurated sand deposits near Black Run

The morphology of these surfaces suggests that the Laurelton till is not till. However, it seems to be glacially derived material — on the basis of the complete absence of deposits like this in otherwise similar situations beyond the presumed preWisconsin glacial limit, 30 km south of here. (Our definition of the glacial limit will be circular for the moment, until we decide whether this is glacial material, but the presumed preWisconsin glacial limit is a sharp S limit to heavily weathered diamicton bearing mixed lithologies, broadly parallel to the Wisconsin limit, 60 km to its N.) The preWisconsin diamicton occurs in thicker bodies in places where more glacial deposition would be expected — the south side of ridges — and it occurs in strata of differing weathering levels.

A compromise model of the landscape would have these orange deposits to be (mostly) reworked preWisconsin till. Glaciation brought till into these valleys and left it in loose, fluvially disorderly piles. Stream processes reworked and spread that till onto pre-existing ancient fan deposits. Did glaciofluvial activity rework the material soon after its deposition? Or did more ordinary stream action do the job over an extended period? Some parts of the valley seem quite glacial. White Deer Creek by I-80 and the river, and just N of Laurelton, as two examples, show complex erosional and drainage patterns, and probable superposition of a spillway onto an anticlinal snout in the same place where landforms with morainal characteristics are located.

I suggest that glaciation dumped till onto an existing smooth landscape much like the one in the model — especially at the heads of the fans in the glacial-lee of the mountains, which was therefore able to mobilize and widely distribute the material into the pattern we now see. This theory — that glaciation happened onto a higher level “old age” surface — has the implication that we shouldn't find till or first-generation fan deposits below this graded surface, unless we introduce the complexity of later glaciations that don't disturb the fan surfaces, etc. We can also (vaguely) correlate this fluvial surface with the terraces of the Susquehanna.

Boulder train

Leaving "Mountain Vista," we drop into the narrow valley of N. Branch Buffalo Creek, the drainage that created the fan surfaces we'll visit to the west. By the model of the thermokarst outbreaks, as seen as Spruce Run, this valley should be full of fresh boulder train. However the surface that the road runs on is not apparently latest Wisconsin (as the outbreak deposit should be) … this surface is above all known floods in the valley, and the bouldery material of which it is made is heavily cryoturbated, when seen in section.

Old Shingle Road Fan

Old Shingle Road traverses the topography with clearest fan morphology. The Bloomsburg formation there is cut into a simple conic section 4 km long and 500 m wide. We will rise up out of the stream valley onto the fan surface, headed almost directly toward the gap, with the fan also grading off to the S. Oil Well Rd., approaching the fan surface from the S, shows significant cobble deposits – and aeolian sand—at the break in slope. We will leave the fan toward the S, and drop into very deep valley, below the previous fan surface. The stream of this valley is now attacking the weaker rock at fan edge to the NW, inverting the topography.

G. STOP 5. BUFFALO GAP BOULDER SLOPE AND DEBRIS FAN

Large boulder slope and fan

The most energetic periglacial activity in the region probably happened at Buffalo Gap, N of Hartleton. The relatively small stream cut a large canyon into the flank of the mountain … there is evidence of a doubled section of the Tuscaraora here (and therefore perhaps a fault.) We will travel onto private land to climb the fan and access the rock slide, although the slide itself is on State Forest land and is accessible across public land from Molasses Gap Trail via Old Shingle Road.

Lunch is available at the top of the fan. I had previously scheduled lunch at a nearby Pennsylvania Dutch restaurant, but I relented. Figure 17 diagrams their menu.

Buffalo Creek Fan

No other stream in the region presents such an emphatic fan — this one is 2 km in radius and drops 95 m over that distance (Figure 18). The surface is barely dissected by its stream — 1 or 2 m in most places — and is covered with small boulders in a silty matrix. This fan seems to be more the equivalent deposit to the valley boulder trains at Spruce Run and Centennial— poorly drained, silt-rich, rounded boulders, near current stream level — rather than the high older fans near the last stop. We have thought of this fan as the product of recurrent debris flows, perhaps both in the late Pleistocene and the Holocene. Scraps of a

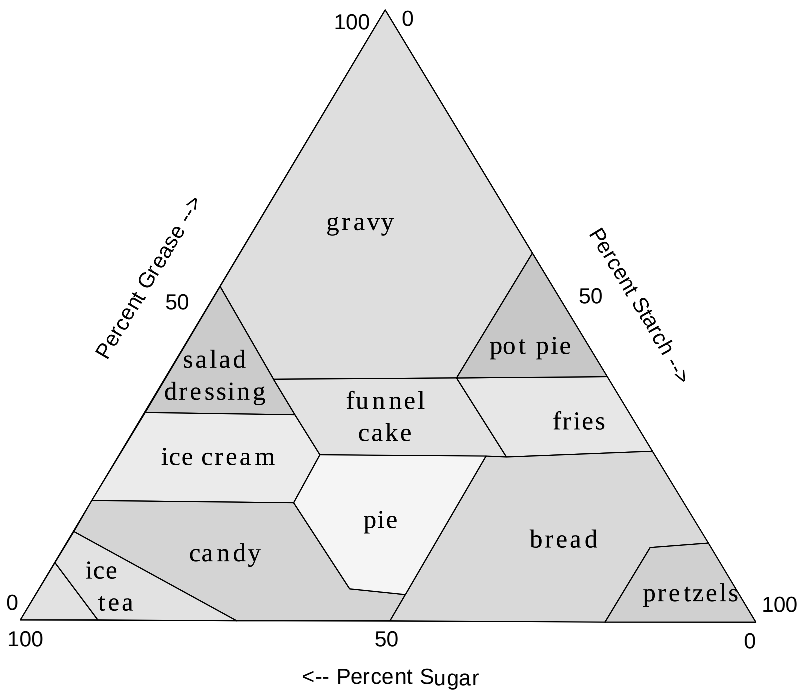

Figure 17: Food texture diagram for Pennsylvania Dutch cooking

higher fan — similar to the fan at previous stop, but closer to stream level — are visible at the edges of this fan.

The fan is very different from the freshest terrace deposits of Buffalo Creek within the gap. Narrow, blocky ledges lie 3-4 m above stream level, apparently fed onto a near-horizontal surface of periglacial transport from the adjacent hillslopes. No matrix at all is visible in the stream-cut section. (We'll look more closely at a valley-side boulder terraces like this at Cherry Run, after Stop 7.)

Goosenecks block field

This boulder slope is 200 m high and 450 m wide, and extend 3.5 km along both sides of the stream. A road — 19th C. product of a deluded turnpike plan — traverses the slope. Excavations above the road show the fabric. Large (3-4 m) blocks of Tuscarora from an outcrop at the crest of the hill seem to float upon smaller, round “baby heads” (as mountain bikers call them) along a 25° slope. A subtle relief in the block slope seems to show pits, 20 m x 40 m, oriented down slope — perhaps collapsed ice bodies within the slope? The Tuscarora blocks are uniformly bleached and heavily encrusted with lichen, except in the lower reaches by the stream where fresher hillslopes have been activated by recent lateral stream erosion, and the blocks are pinker. These newer hillslopes are steep — 32° — compared to the rest of the field. The difference in slope and in freshness suggests that older parts of the block slope were moved by some process not presently at work. I suggest that boulder creep moved the rocks downhill under periglacial conditions, that the slope is hyperstable under present conditions, and that most of the fan is preserved from a Pleistocene state.

Lesser versions of boulder slopes are nearly continuous on the upper reaches of the Tuscarora ridges, but unless they are undercut by streams, they are

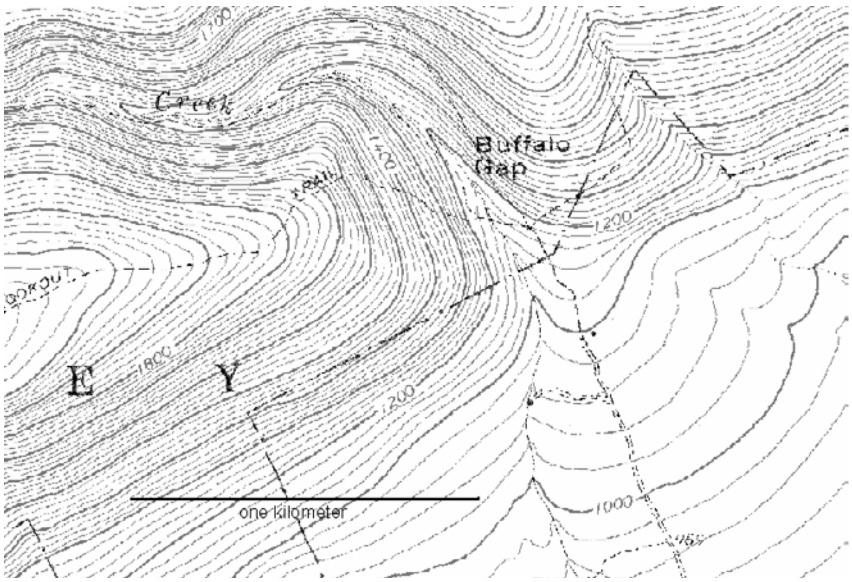

Figure 18: Fan at Buffalo Gap, above Hartleton. Note road bed climbing road slope at the gap. Land north of dash-dot line is State Forest.

generally much shorter (ca. 30 m), only a few blocks deep, more diverse in block size, and forested. Patches of trees on the face of the Gooseneck blockslope are not apparently rooted in mineral soil near the surface. A thick organic duff produced by leaves acts like a soil, so a patch of trees is self-supporting in the long run, and might be expected to expand across the hillslope.

H. LAURELTON TILL FIELD

PreWisconsin till on an alluvial surface

This is a classic central Pennsylvania preWisconsin end-moraine – which means that the interpretation is controversial . It is morphologically appropriate for a moraine. A mass of heavily weathered diamicton — of a sort we'll see in section tomorrow — lies in a continuous valley-transverse mass. The type site of the Laurelton Till is 300 m SW of the intersection of Weikert and Chapel Roads. The feature interrupts or diverts small-stream drainage, and obliterates the differentially-eroded topography upon the Devonian shales and limestones underlying it — suggesting that it is the result of a significant deposition event. Immediately to the west of the moraine is a feature interpretable as a spillway: a 500-m broad valley (occupied by a small stream) parallels the drift feature, and cuts evenly across the small ridges-and-valleys. Drainage on top of the moraine is poor, with small wetlands scattered about on it — Marchand suggested that these were ice-shove morainal features.

Most — but not all — of the glacial aspects of this landform can be accounted for by periglacial processes. The deposit is a piece of a fan, on the basis both of its position beyond the outlet of Laurel Run and its vertical position and gradient (as demonstrated by the fan model described at Stop 5; see Plate 1B). Immediately N of the "moraine" we will pass next to a wind gap a few meters above this graded surface, through which ancestral Laurel Run may have flowed. The "morainal" topography atop the feature (which is very similar to the topography at the Penns Creek "moraine" that we'll see late today) is simply a set of WTC welts … any silty, blocky material in central Pennsylvania would be periglacially deformed in the same fashion. The spillway is problematic, if the "moraine" is graded – since the spillway wouldn't cut more deeply than the main deposit, and would be graded to some higher level Penns Creek, by the evidence of the fan gradient. Perhaps the "spillway" is inverted topography at the edge of the fan, where more recent erosion is favoring the shale over the till.

I suggest that we don't need to choose between geneses. Most Quaternary landscapes in central Pennsylvania have developed under alternating and interacting glacial, periglacial and fluvial influences. A glacial front at this point should have confined abundant proglacial flow — all of the drainage from the mountains to our N, then certainly under periglacial influence themselves — around its snout. We might have been hard pressed to differentiate fan from outwash, and outwash from moraine, even if we had stood here in the middle Pleistocene.

Immediately NW of the intersection of Paddy Mt. Rd. and Weikert Rd. is a sharp, linear ridge of red rock. This is the Moyer Ridge member of the Bloomsburg formation, the best marker for erosional surfaces in this valley. Paddy Mt. Rd. crosses the nose of the Paddy Mountain anticline a few dozen meters E of the low windgap that seems to have fed the top of the "moriane."

I. STOP 6. BEAR GAP PERIGLACIAL VALLEY FILL

Exceptionally well-preserved periglacial surface

This valley is distinctive for what did *not* happen. It shows very little evidence of vigorous post-periglacial erosion of the valley. I present it as a model for the pre-erosional condition of other valleys. These valleys were logged in the1880s. An old road runs up the east side of the gap along the blazed trail. (The four most common historic artificial landforms in the forest from the brutal logging that occurred from 1880-1910 are roads like this, "tramways" —light rail lines to haul out logs, log chutes —unlined 1 m hemi-cylindrical trench drag-ways –, and ten meter square pads used to fire charcoal.) No other human impact is apparent. The bouldery fan is exceedingly difficult to walk on … please be careful.

Form

The mouth of the gap is filled with matrix-free, 0.5 m boulders in a graded surface at approximately 12% slope (Figure 1). A valley-parallel boulder fabric is

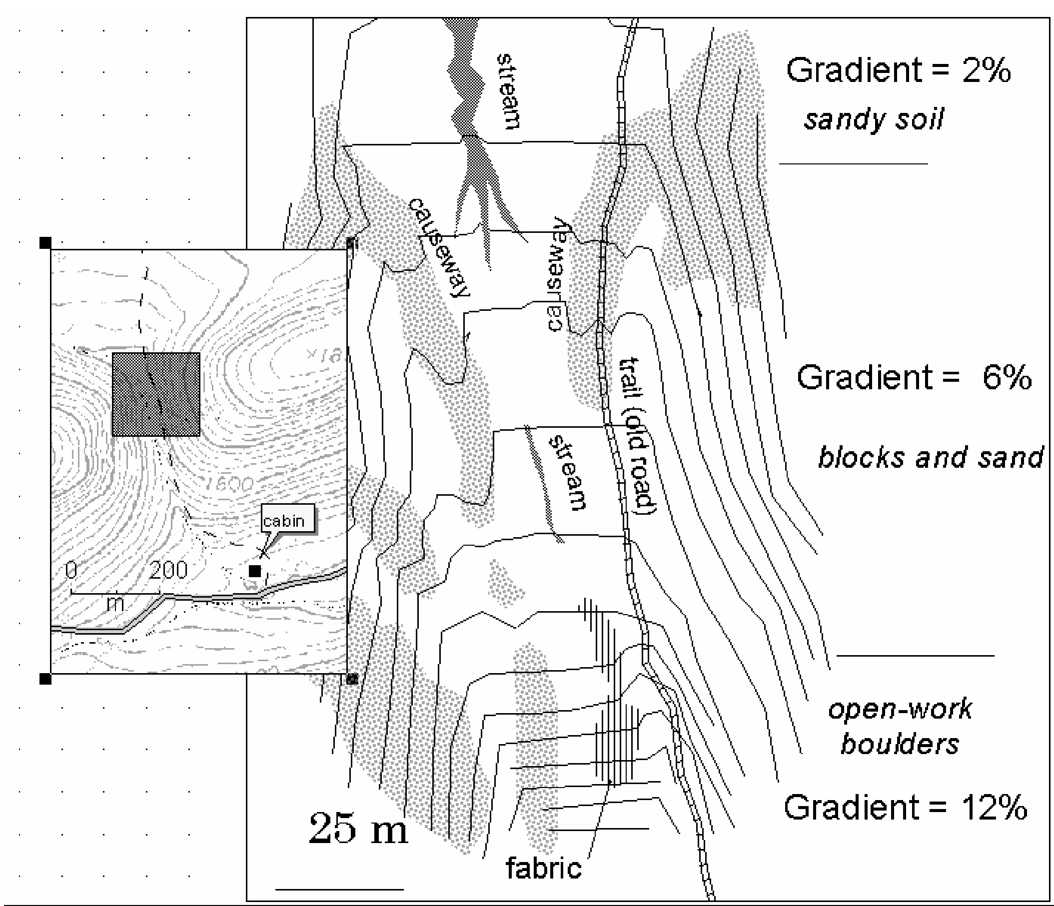

Figure 19: Topography of upper Bear Gap; 1 m contour interval. Block fields shown in stipple.

common in the middle of the valley. Water can be heard to flow at depth across the width of the lower fan. Although a linear collapse runs down the middle of the fan, there is no surface channel evident except within the old road. This was probably cut during the floods immediately after the clearing and burning of the landscape – the most vigorous erosion in the Holocene was in the 19th Century?

Four hundred meters above the road, a natural feature resembling a raised "causeway" extends onto the blocky surface from the narrowest part of the gap on both sides, more pronouncedly on the W side. In form these causeways resemble medial moraines — they angle and curve away from the apparent source region at the foot of the outcrop and toward the center of the gap. They are raised 1-2 m above the boulder fan, 3 m wide, flat topped, and their composite clasts tend to be oriented parallel to the causeway. The causeways end rather vaguely in the middle of the fan.

The bouldery part of the fan stops rather abruptly above the outcrop, and is replaced by a lower-gradient silty surface that is continuous upslope to the upper, flat, strike valley where WTCs are found. Stream incision is more pronounced in this upper part of the gap, and the springs feeding the streams are cutting headwardly into the colluvial mantle.

Interpretation

This fan dewatered like other fans that we have seen, but it dewatered slowly enough — or the resisting force in this narrow valley was high enough — that most of the surface let down vertically and did not fail horizontally. The irregularities in present valley provide a measure of the volume of ice previously present in the fan, so the top of the fan suggests how much material was removed from other fans.

The lower fan was made of ice-matrix boulder fill. The top surface was continuous enough that sediment from the upper gap was transported across the boulders without flushing in to form a mineral matrix. (It is implausible to me that post-periglacial stream flow would have removed a mineral matrix from the width of the boulder field – only a (hidden) boulder-filled valley would have been eroded.) Boulder creep and gradual shaer of the ice matrix dragged the mass downslope and deformed the surface somewhat. Little pedological cryoturbation would be possible without frost-susceptible fines. The causeways are the remnants of boulder-rich stripes — fed from the outcrop — within the ice-rich transport sheet. Similar causeways are seen in other gaps. The height difference between the causeways and the bulk of the fan define the minimum excess ice in the system — beyond the porosity of the boulders and any lowering of the causeways. I estimate 1-2 m of deflation, and most of another meter of porosity. The fabric of the causeways has been less deformed than the fabric of the deflated fan, and perhaps the transport-parallel clast alignment we see there was widespread across the fan.

Upper slope

The upper slope was filled with silty material by stream processes and solifluction, burying an older valley. That valley eroded during deicing, but escaped the outbreak failure that purged the other valleys we've visited. The master stream below this gap has been scoured somewhat by some break-out from above. Ongoing erosion is reclaiming the pre-periglacial form of the upper valley, but only very slowly because the boulder fan is resisting degradation.

J. STOP 7. WOODWARD GAP ROAD SORTED STONE STRIPES

Patterned ground in section.

A few tens of meters up the west-side of Woodward Rd. to the right of the intersection, the roadcut sections into some sorted stone stripes. Vertical columns of boulders show up ca. every 15 m. Presumably these columns are rocks drawn into the ground by a convention-like overturning of the surface layers (see Stop 2). The problem with this model is that depth of the columns can be several meters, much deeper than expected for the active layer. Perhaps the stripes are formed at the same time that the landscape accretes from down-slope movement, thus they form in the upper layers of the soil, while those upper layers are continually buried, and print their form upward.

K. CHERRY RUN VALLEY FILL

Section of periglacial valley fill.

Cherry Run shows features of Bear Gap, in a much bigger system. It shows how a big stream might indicate that it had previously been blocked like a small stream. The broad, flat upper reaches of the stream — near the junction of Paddy Mt. Rd. — are distinctly periglaciated — a low gradient surface with welts and ground ice scars and sorted patterned ground. The middle reaches, below Rupp Hollow Rd., are entrenched and dissect the periglacial upland, in the fashion suggestive of thermokarst failure. The lower reaches, below Ole Mingo Rd., have an irregular bouldery fan bounded by steep slopes that shed debris flows onto the flats — again, evidence of a “purged” valley. Just above the gap, two channels of Cherry Run (one abandoned) are cut 2-3 m into the surface, and meander against the upper end of the boulder fan feed by the Tuscarora outcrop — just like in Bear Gap. A section of the boulder fan is visible in the stream bank, apparently matrix-free to 3 m. The contact between the (lower) boulder fan and the (upper) silt fan can be seen to be nearly vertical — silt accumulation happened at a rate controlled by growth of the boulder fan.

I see this site as evidence of extremely vigorous erosion, by hyperconcentrated thermokarst out-flow from the cutting into the flat at the upper reaches of the Cherry Run “canyon” and the sides of the lower reaches. The channel at the gap was apparently flushed of boulders to several meters, channels above it are wide and deep and laterally unstable, and the fan below it shows extensive irregular boulder bars to 2 m height. Stop 15, on Sunday afternoon, will explore a smaller version of mountain valley landforms suggesting extreme erosion.

L. PENNS CREEK TERRACE LEVELS

Higher fluvial level of Penns Creek.

Penns Creek is a major tributary of the Susquehanna, and has some distinctive behaviors in this area.

The headwaters of the creek are in Penns Valley, a branch of the limestone Nittany Valley near Penn State. The stream cuts across five or six large ridges on its way through the narrows to our west. Ted Oberlander referred to Penns Creek as an "obstinent" stream — a cross between a consequent stream and an obstinate one. (The railroad grade along Weikert Rd. bore the line that used to be

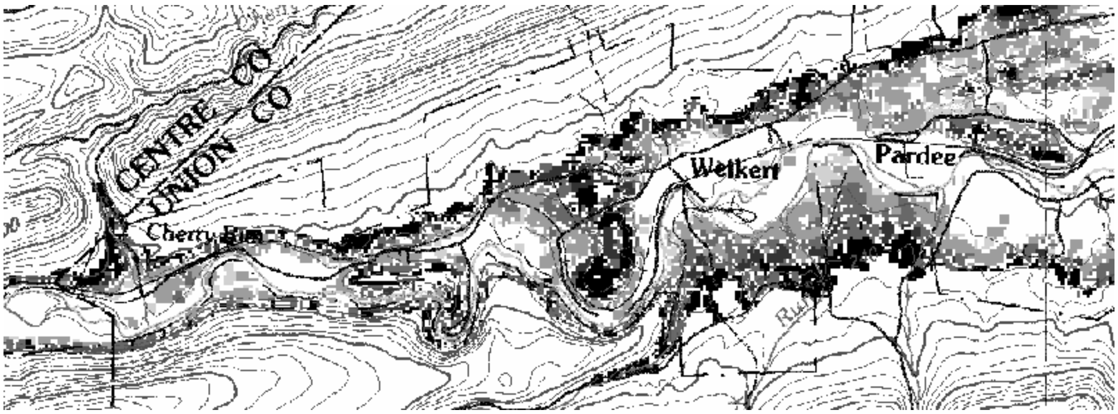

Figure 20: : Fan surfaces above Weikert on Penns Creek .. gray shades are each 3-m thick graded surfaces intersecting the topography, the highest is darkest. Cherry Run Gap is left of "Centre Co." Map is approximately 8 km wide.

the primary access to Penn State — although the valley is too narrow for a road. Now a trail in the State Forest, the grade passes through two scenical tunnels.)

A well-defined terrace is present at 40 m above stream level (Figure 20). This terrace grades into a less-well defined surface cut at the tops of the Bloomsburg formation across Buffalo Valley. This surface may represent the pre-glacial plain of Penns Creek. It is roughly the level that the smaller fans (Stop 4) grade to, and is the level of higher Susquehanna terraces. The importance of a higher

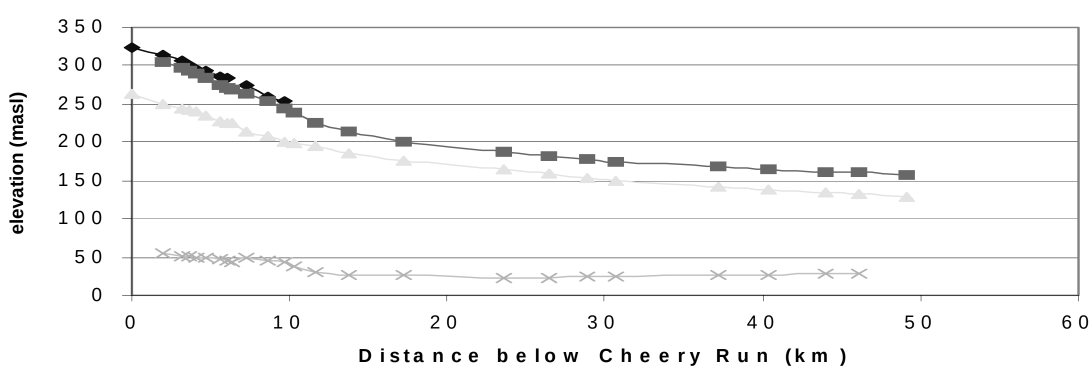

Figure 21: Gradient of Penns Creek surfaces .. highest, high, current, difference, respectively.

course of Penns Creek through this valley lies in several problems presented by the lower Penns Creek — its present narrow and structure-blind valley across Snyder County, a major abandoned stream channel heading at the Penns Creek "moraine", and some high erosional features east of that spot. This will be reviewed after Stop 10.

The terraces of Penns Creek are identifiable on morphological grounds only, there is no obvious gravel deposit upon them; I interpret them as terraces rather than as non-fluvial plain of low relief because they lack any slope toward the middle of the valley, and because the presence of other broad fans and terraces is established in the region. They are located beyond the limit of known glaciation — the Laurelton moraine, 5 km E – suggesting again that our understanding of glaciers and of terraces or fan surfaces are confounded with each other. The longitudinal profile of the terrace surfaces exhibits a break-in-gradient at approximately the same place than the present stream does, where it leaves the narrows (Figure 21). This is somewhat surprising to me, as I expected the much more mature stream that cut this terrace to have developed a gentler gradient through the mountains.

M. STOP 8. SHORT MOUNTAIN TOR

Weathering remnant protected by elevation above the soil layer.

A brief look at a tor. We approach the top of Short Mountain from Weikert along a long, but now familiar pattern of: 1) a fan near the stream surface, 2) a bit of terrace at Weikert Run Road, 3) a “purged” periglacial valley in the gap of Coral Run, 4) the undisturbed (“blocked”) periglacial valley floor where we meet Hunter Rd., 5) springs cutting vigorously into this surface along Hunter Rd., and 6) some well-defined ground ice scars on a periglaciated surface just out of sight to the east where we leave Hunter Rd.

The tor, at the ridge crest, is a free-standing mass of conglomeritic Bald Eagle sandstone, 3 m high by 8 m wide by 40 m long. Tors are weathering remnants preserved by being isolated from intra-soil moisture. In this case, it is protection from freeze-thaw that preserved the tor. Examination of the rock surface shows essentially no cracks into which water could accumulate, to force apart two blocks. Beneath our feet, the same rock has been kept wet, and is vulnerable to fracture under conditions of deep freezing. The rock of the tor is different from all other weathered Bald Eagle, because it is undergoing granulate disintegration — releasing pebbles from the conglomerate. This is likely a chemical weathering process. All other Bald Eagle has been fractured by frost, and shows large angular pieces.

A standard model of tor formation involves multiple cycles of downcutting — chemical weathering within the soil sculpts the rock, then leveling reveals it. The idea that this particular rock was chemically weathered within the soil is appealing, on the basis of its rounded form and dissolved cement. Sandy soils (of perhaps great age … see Stop 16) E of Short Mt. Rd. apparently still hide similar knobs of the Bald Eagle. But that cycle of sub-soil weathering may be unnecessary. After being revealed by rapid local erosion, the rock would be subjected only to chemical weathering, whatever its previous state.

Most tors are developed on flat lying rock … but their development on vertical rock is demonstrated here. In either case one set of fractures — joints or bedding — will be vertical which may aid drainage. And the weathered rock would be supported from below even if the surrounding beds are removed, in either of those cases.

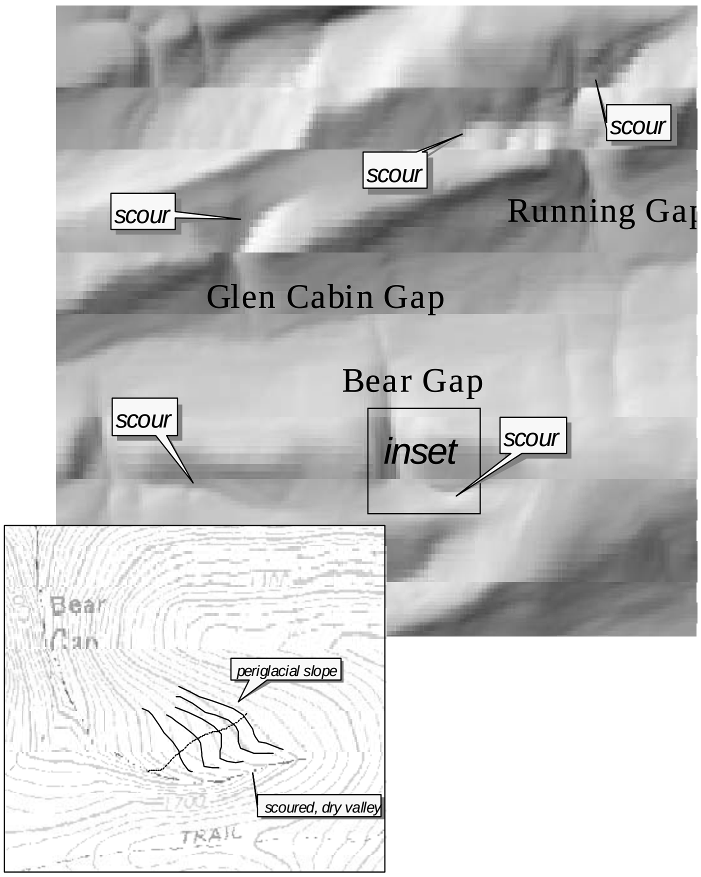

Figure 22: "Corrected" contour + stream map showing dry scoured valley cutting periglacial slope of Bear Gap.

M. STOP 9. SHORT MOUNTAIN ROAD DEBRIS-FLOW SCAR

Abrupt transition from periglacial valley fill to scoured valley.

Just below the elbow on Short Mountain Road, an obivously periglacial landscape gives way to a deep "fluvial" valley. Above the transition we find a wide, flat valley with no surface drainage, and large sorted stone stripes, containing boulders to over 1 m. Over a 50 m distance along the valley, the valley form changes to steep-sided and V-shaped. The lower valley, however, is not convincingly a stream valley, as it has no surface water in places, and there is no recognizable channel and no recognizable stream-worked rocks. Within the transition zone, two stream channels appear on edges of the valley (inverting the topography), then a steep scarp shows several enormous boulders — to 3 m — in the periglacial valley fill.

I interpret this scarp as the top of a debris-flow scar. The valley below is substantially flushed of loose material, and the steam is flowing in a landform made by much larger agents than itself. Perhaps these very large boulders stopped the upward propagation of the flow, but boulders nearly this large lay by themselves in the middle of the valley 300 m ahead. A flat-but-bouldery section of stream is developed upstream of the narrow gap below us, perhaps the resting place of some of the transported debris. There is no direct evidence of the timing of the flow, so it might be quite recent. My present hypothesis, however, is that the debris flow was created during periglacial degradation — a time of poorly consolidated, recently de-iced sediment, and of abundant excess water. Several small (4 m x 20 m) debris-flow lobes enter the lower valley from the position of the present road. It seems common for small debris flows to enter these valleys after major degradation had evacuated them.

N. TROXELVILLE MORAINE

The glacial limit?

Another of the sweeping deposits of allochthonous diamicton considered to be a moraine. Like most moraines, the Troxelville moraine is a surface graded to a gap to the N. This was one of the last of Marchand's many moraines …only isolated erratics occurred beyond here. Marchand considered the deep boulder deposits along the Juniata— 40 km WSW — to be moraines, although most now accept Katkin's analysis(1986) of them as terraces. Leaverett's end moraine is 13 km SW, at the foot of Shade Mountain. Marchand found two strata of till at that point. It is unknown how he differentiated two strata of till from two strata of reworked till. We will pass isolated heavily weathered sandstone erratics on an upland saddle a few hundred meters N of the next stop – but that position is a good location for an old fan, as well as till.

O. STOP 10. BENFER SHALE CHIP COLLUVIUM

Deep periglacially weathered and transported shale

A periglacial deposit of remarkable extent has developed along steep streams above Middle Creek and is visible in a shallow quarry cut into the hill side. Variously known as grèzes litées, head, or shale chip colluvium, the deposit forms under periglacial condition from highly friable shales on steep slopes. This bed, the Marcellus shale, is especially productive, as is the Reedsville in the Ordovician section. These deposits are highly visible, because road builders with bulldozers are fond of them, and lay them open for us.

What is distinctive about grèzes litées is the innumerable thin beds of alternating coarse and fine shale debris. Present theory of the development of grèzes litées relies on solifluction — a centimeter-thick layer of saturated flow, rolling over a tiny front of chips, and covering the relatively coarser layer with the watery fines behind it.

There is an interesting long-term meso-scale geomorphic landscape evolution visible here. The extent of the grèzes litées demonstrates considerable retreat of the upper slope, to provide the sediment. We are probably seeing products of multiple cycles of periglaciation here. The bedding of the grèzes litées dips variously to the S, W, and E, which are across the topography here. Has the entire valley to the E, where the road runs, been cut since the end of periglaciation? Or is this deposit much older? An ice wedge at the S end of the top of the pit cuts into the grèzes litées — implying that the periglacial deposit was in place and somewhat stable during a periglacial episode. However, the top layers would be weathered to a high-chroma red if they were at the surface through the Sangamonian … unless that soil was truncated. Evidence of a truncated soil above an ice wedge is seen at the next non-stop. Some moderately high-chroma shale chips are mixed into the bulk deposit at the N end of the pit – recycled grèzes litées or transported shale-soil C horizon? An indurated, high-chroma red, grèzes litées deposit is visible in a road cut W of Freeburg, 25 km E of here. That one is clearly a periglacial deposit from a preWisconsin cold period, weathered during at least the Sangamonian and perhaps other hot interglacials.

P. MIDDLEBURG ROAD ICE WEDGE

Cycles of periglaciation

The road E from Benfer rolls over dissected terrace surfaces associated with glaciofluvial activities we'll see at Stop 10. The two cobbly terraces split by the North Branch of Middle Creek are graded to the level of Marchand's moraine.

On a dangerous corner, a clear ice wedge is cut into a shale surface on the left. The surface is probably the level of the middle terrace — 12? m above Middle Creek. The ice wedge is of classic form — 1.5 m deep, deforming adjacent beds upwardly, filled with small, vertically-oriented clasts that had fallen into the open cracks. This is probably what the nonsorted patterned ground wedges at Stop 14 would have looked like in section. What is distinctive is that the fill is preWisconsin soil — high chroma red — which is not now present in the section. The wedges developed during a periglacial period, before some highly effective process removed every trace of bright soil, but the process did not lower the rock significantly. A few erratics sit atop the shale surface.

Turning N off Middleburg Rd., we climb onto the middle terrace (190 m ASL) of the Middle Creek system, and see off to the NW a high terrace – 210 m – that matches the major outwash event described below. Crossing the 2-km ridge to the T at ___ Rd., we see upland N and NE (including the cemetery) at that same high terrace level.

Q. STOP 11. PENNS CREEK MORAINE (?)

A complex glacial landscape — Till, ground ice scars, and two or three outwash surfaces

Outwash

We approach the Penns Creek glacial deposit from downstream, so we see the outwash deposits first. A high graded surface extends down the valley parallel to N. Br. Middle Creek. This surface is bedded with cobbles, grades 6 km up to the moraine and 40 km along to the high terraces of the Middle Creek that match the __ m terraces of the Susquehanna. It is very plausibly an outwash surface — except its gradient is exceptionally low compared to the fans in Buffalo Valley that might be also outwash. The surface has a gradient of 1.5 m/km — exactly the same as lower Penns Creek. The lower terrace, next to N. Br. Middle Creek in the middle of the valley, has a gradient of 2.9 m/km. (The Susquehanna has a gradient of 0.4 m/km, by contrast.) This surface is comprehensible as a combined proglacial stream/outwash channel, carrying the flow of Penns Creek when its outlet was blocked by ice, as was suggested for Laurel Run at the Laurelton Moraine.

Moraine

Is this moraine a moraine? Again, we have gravelly deposits that occur only in bodies transverse to the valleys. A wide range of lithologies in angular clasts is found in these bodies. The E side of the morainal position drops steeply toward the village of Penns Creek in a way that suggests the previous presence of ice. But, again, this feature has essentially no relief above its fluvial level; it is graded neatly from its highest point to the river 40 km away. (See Plate 2.) Again, we understand the glaciers as agents creating more fluvial landscapes than narrowly glacial ones.

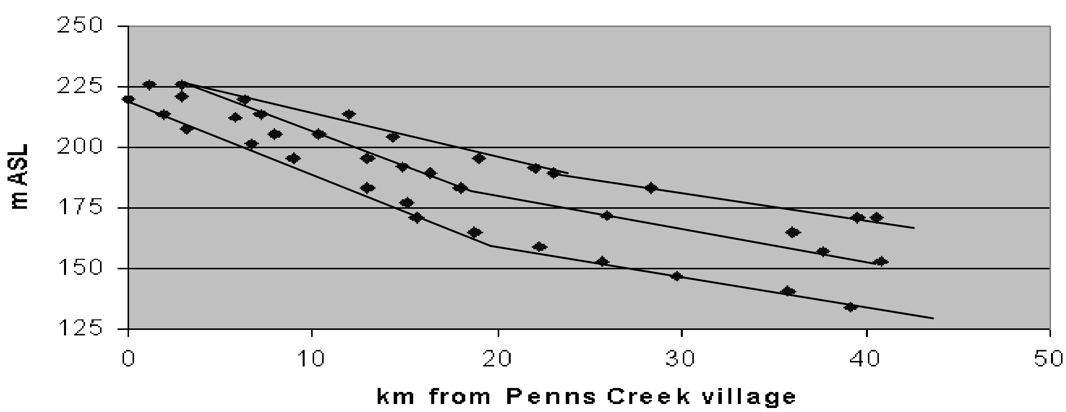

Figure 23: Mid Levels of Middle Creek – lowest is contemporary stream, middle level is a Marchand's Troxelville moraine level, and highest level is low-gradient outwash surface from Penns Creek Till to ___ Susquehanna terrace.

This moraine is also heavily deformed periglacially. The deepest ground ice scars in the region are on the Penn Creek feature. One of them is 6 m deep. These scars are filled with much more of a saprist muck, compared to the more fibrous stuff at Halfway Run. A radiocarbon date run on a messy sample from one of these bogs yielded a date of 8.3 ka.

R. LOWER PENNS CREEK

Erosional amphitheaters & diverted drainage.

Forty five m above Penns Creek, immediately E of the village of Penns Creek, is a distinctive fluvial surface (Figure 24). It is clearly a terrace of Penns Creek,

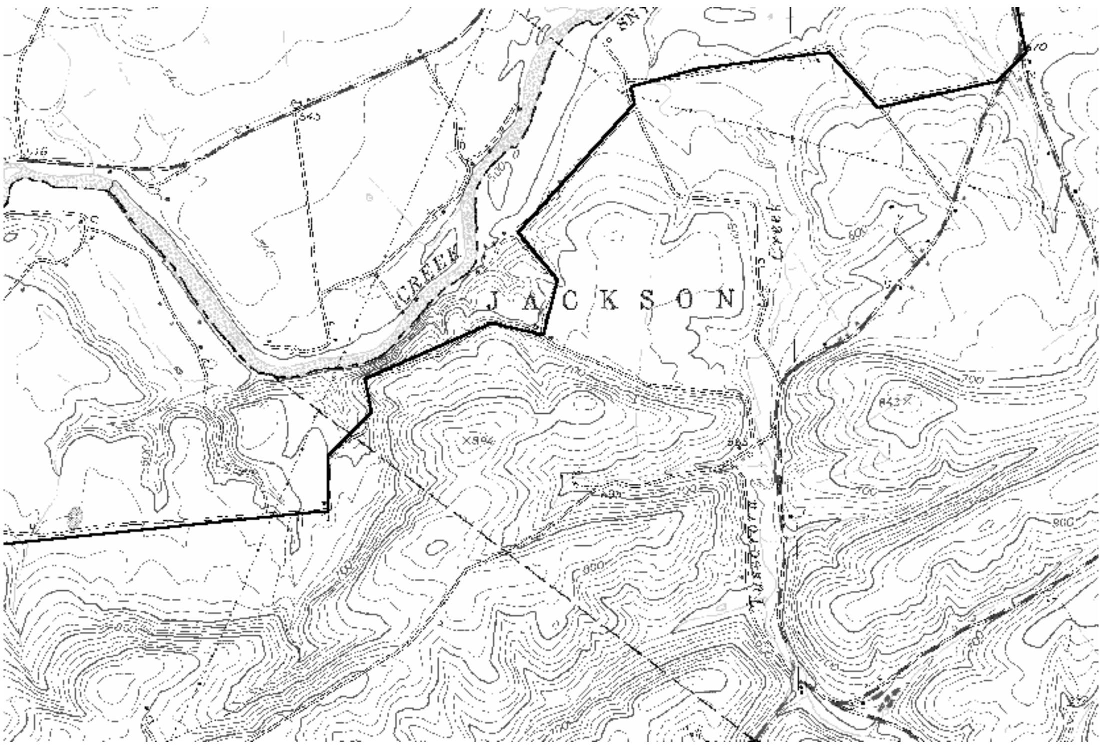

Figure 24: Amphitheaters cut above Penns Creek, just E of Penns Creek village. Image is 4.5 km wide. Dark line is trip route.

but it marked by three semicircular bites at terrace level — each1500 m long and 400 m wide — into the upland. These are certainly the product of lateral corrasion by a meandering stream. These amphitheaters are floored with periglacially deformed diamicton.

No other high terrace of Penns Creek is seen south of Shamokin Mountain (the doubly plunging anticline between us and Lewisburg, and this position was not occupied long enough to remove the cusps between the meanders). The position is slightly below the level of the Penns Creek moraine. I believe this surface to be a briefly occupied position of Penns Creek drainage — like the Middle Creek outwash surface — during glacial derangement. If ice stood to the north and east of this position, water would be diverted around its front, would run down Middle Creek at one ice position, and then shift to the present (but then unoccupied) channel of Penns Creek. That channel is obviously new, on the grounds of being narrow and indifferent to structure.

III. Day 2

A. Stop 12. Bucknell Loess Deposit

Extensive silt deposits on an upland.

Bucknell is draped with silt, some of which is aeolian and some of which is fluvially reworked. The top of campus is underlain by till that is cut to the level of the ___ terrace. (The bedrock is silty Tonoloway limestone, and between the till and the limestone lies a soupy 80 cm layer of weathering debris that flows into excavations.)

The loess layer on the top of campus is 1.0-1.5 m thick, is essentially unbedded, is composed of loose, angular quartz fragments and a weak wash of clay, and is of subdued relief. The deposit is known to thicken downslope to the N (where construction has been more common). On the slope the silt is interbedded with thin layers of coarse-sand-sized shale clasts — like sheetwash deposits in a farmer's field. At the bottom of the slope, the silt is up to 4 m thick, and bedded in layers of different color and clay content. The lower levels in these deposits are deformed into flame structures typical for saturated fine sediment.

The simplest account of the deposit is that loess settled on the landscape, occasional wash transported it down the hillslope, and it moved into standing water at the bottom of the hill. Loess is commonly associated with rivers, of course — the winter-dry, desiccated meltwater channel produced billows of dust that blanketed the countryside, built loess deposits, and subdued topography. There is a challenge to this model in Lewisburg — the loess is on the presumably up-wind side of the river. Some dust surely moves against the prevailing winds, but here we would have to see almost all of it going west. Extensive loess isn't know E of the river.

I suggest that the silt came from the west, and blew toward the river. The presence of a silt layer here is related to slackwater deposits backed into Buffalo Valley, laid as thick silt within ponded waters of the flooding Pleistocene Susquehanna. This would also account for the deformed lower layers of the silt deposit – it is itself a slackwater deposit. Much of Lewisburg is underlain by deep silt — at least 3 m — but no relation to a loess deposit is asserted for much of it. And loess is very narrowly constrained on the landscape. Nowhere else is it as thick as on campus, and only patchy deposits are found anywhere else in the region (although most regional soils have a silty cap consonant with 2-10 cm of silt).

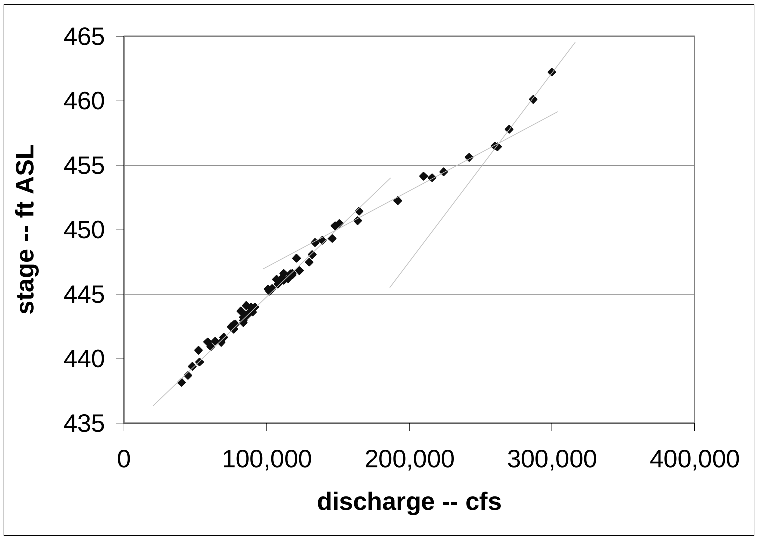

Figure 25: Discharge-stage curve for the West Branch of the Susquehanna at Lewisburg.

The plausibility of slackwater deposits rests on hydrological and on sedimentological evidence. The discharge-rating curve of the West Branch of the Susquehanna at Lewisburg *steepens* at high discharge. The curve is tamely convex-upward, from the base of the gage at 428 ft until a depth of 455 ft and discharge of 250,000 cfs, when it begins to climb steeply and linearly. (See Figure 25). This effect may have to do with the limited capacity of the river in the 8 km-long narrows downstream of Lewisburg, or we may be seeing the effect of flooding on the North Branch — that joins this branch 12 km downstream — being propagated upstream at highest stages. During the late Wisconsin, when the bed of the river was 9 m higher than it is now, this effect would have begun to show up at relatively lower discharges, and easily laid a silty plain, as shown in Figure 26.

Buffalo Creek, 6 km west, shows an extensive silty deposit at elevations

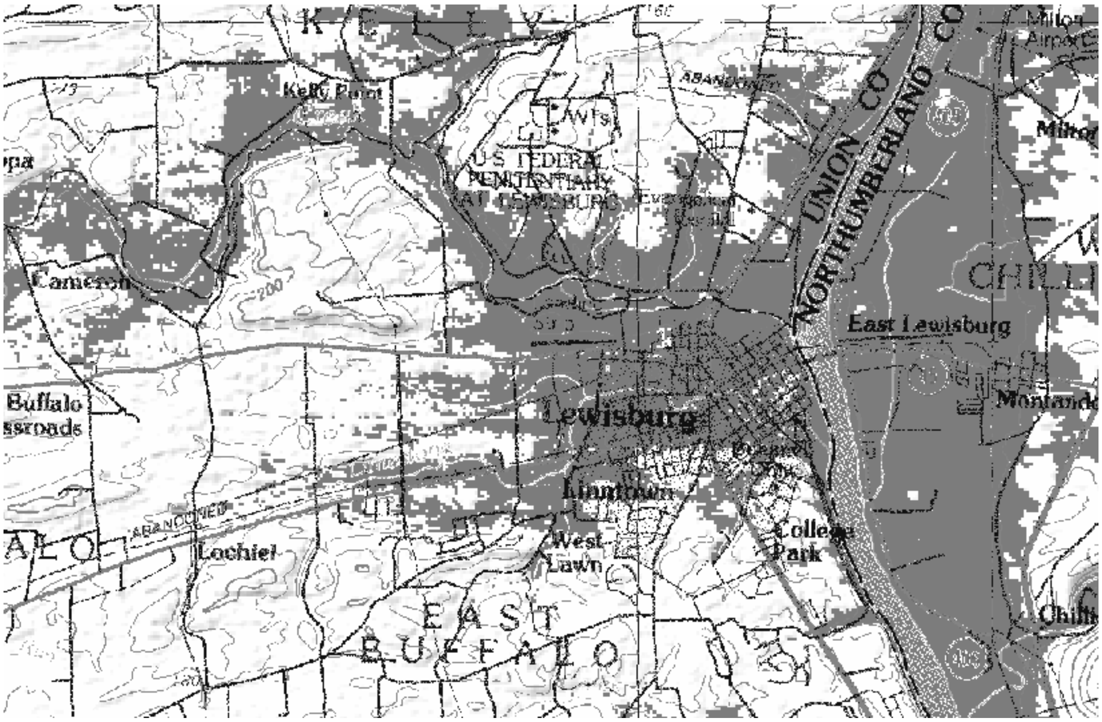

Figure 26: Presumed distribution of slackwater deposits at the same depth above the Wiconisn terrace as the modern 50 year flood. Map is 6 km wide.

between 480 and 500 ft. A manure tank excavation at Mazeppa (7 km W of Lewisburg) cut 4 m into silt, where a thick layer of woody peat was encountered. The wood is dated to _____ BP (ldfjl). This is a position where a stream terrace — aggrading to the rising level of the West Branch — is to be expected, but the thick silt deposit is surprising. If we take the level of the Weis Center for the Performing Arts on campus — where the flame structures were seen in silty deposits — as the level of a slackwater deposit, it would be 490 ft. A recurrent flood to that level would cover 15 km^2 of land N and W of Bucknell with silt; another 15 ft of depth —direct flood depth, or the gradient of streams flowing into the river — would extend coverage to 30 km^2.

B. SUSQUEHANNA TERRACE AT MONTANDON MARSH

Wisconsin outwash gravels

The 140 m elevation alluvial surface here is the Wisconsin terrace of the river — Peltier's Binghamton terrace (1949) — built up with outwash gravels from the melting ice sheet that covered much of the West Branch drainage. Airphotos show traces of meandering or braided channels at this level (Figure 27). Ten meters of coarse, inhomogeneous alluvium underlay this 1.5-km-wide graded surface. The alluvium is sand and gravel to 10 cm, with an occasional (ice-rafted?) boulder.

The river has cut down to 130 m ASL, and is widening its meander belt within the terrace, but it is not yet down to its lowest interglacial level. At the west end of the Lewisburg bridge, the river is flowing on bedrock, but beneath the middle part of terrace a paleochannel of 1 or 2 m additional depth is found from well logs (see Figure 28). At least 2.5 m of silt are found below river level at the mouth of Buffalo Creek in N Lewisburg, although this may be related to the limestone bedrock.

Figure 27: Latest terrace of the West Branch at East Lewisburg (lowest left). Streamlined bed lies between river and dark wetland at edge of uplands; dunes to the east. 2 km wide.

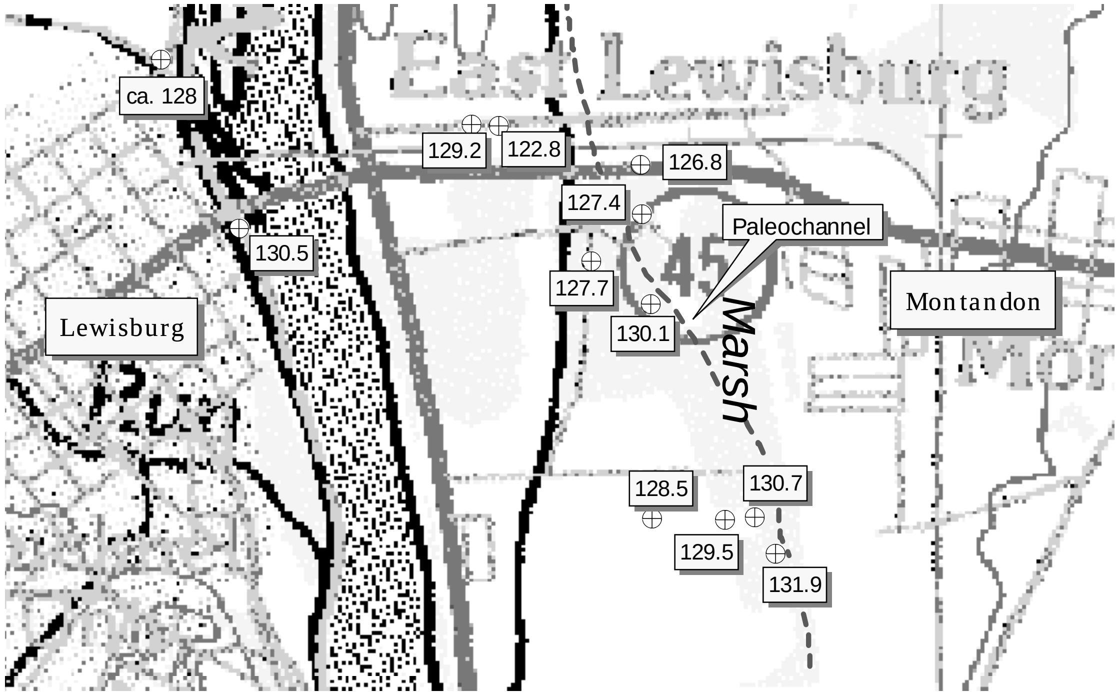

Figure 28: Elevation of bedrock beneath Wisconsin terrace of West Branch at Lewisburg, showing apparent bedrock channel 2 m below present stream level. Data from Ressler (1998)

The Montandon Marsh is a high quality riverine wetland, situated by the pooling of groundwater in a late, high channel, where the sloping hinterland meets the flat river plain. The open sedge marsh – site of 5 Species of Special Concern – extends 1 km north of here; wooded wetland continues another 4 km. Surface morphology of the plain suggests a (late, high) paleochannel snaking from the middle of the terrace 1 km N, to this narrow wetland. Kochel reports layered muck and silt beneath the wetland, in contrast to coarser gravels elsewhere beneath this surface. Because the terrace faces excavation for gravel over the next decade, this wetland will need careful monitoring. A limestone masonry lock of the Susquehanna Branch of the 1840's Pennsylvania Canal lies just on the other side of the wetland.

South of the marsh road is a streamlined dune, first of a 2 km chain. (The brick house on the dune to south was built at the river's edge and transported inland to escape flooding.) The dune line — in conjunction with the parabolic dunes we'll see at the next stop just E of here — is reminiscent of the linear fore dune at a beach. It is located upwind of the paleochannel, and may match it in time. No evidence of this dune is present to the north. It is doubtful to me that the dune would have survived repeated inundation by floodwaters. Was a dune that developed during times of low river flow being destroyed by larger discharges at the time that the channel was abandoned?

C. STOP 13. MONTANDON DUNE FIELD

Fossil dunes at the edge of the terrace

This is the largest riverine dune field in Eastern Pennsylvania (Figure 27). About 10 km² of landscape are covered with at least a few cm of sand sheet, and dune forms are found on half of that area. At the edge of the terrace, well-formed parabolic dunes stretch ESE onto a 10-15 m rise. It is this orientation — 104°, measured from air photos — that establishes the comparison for the WTCs.

The sand is well sorted, moderately rounded quartz grains with significant clay content. The obvious model for the genesis of this field would be that this is river sand blown a short distance from the Pleistocene bed at the level of the present terrace. Summer glacial melt would provide abundant sand, while windy, desiccated winter low-flow conditions would permit mobilization. Smaller, ephemeral dune forms would be expected upon the river plain between meltwater events. The clay content of the dunes might be loess, or it might be more-recently-weathered sand-sized shale clasts involved in the dune building events.

The dune field extends about 1 km E from the terrace edge, reaching an apparent maximum sand depth of ca. 20 m at the Montandon cemetery. A sand sheet subdues topography for several km east of the dunes, feathering out about at Chillisquaque Creek. The dunes interrupt small drainage, creating several forested wetlands. Blowout regions within the dune belt N of Montandon show hectares of ventifacts, which are also present in road cuts and foundation holes S of Montandon. The dune field itself lies over the presumed pre-glacial path of Chillisquaque Creek. Its present path involves an abrupt southward jog that ensnares it in the sandstone outliers of Montour Ridge — likely a proglacial stream, much like the path of Penns Creek, seen yesterday.

Aeolian deposits are common in this valley — such as the loess at the last stop — and dune sand occurs elsewhere along the river and at the edges of fan fragments W of the river. Certain of those dunes (crest of the hill on Hospital Road — UTM 340,218 / 4,539,754) appear to be of preWisconsin age on the basis of heavy grain staining and iron-hydroxide accumulation in a presently well-drained situation.

D. STOP 14. LEWISBURG MEDICAL PARK PATTERNED GROUND

Rectilinear net of cracks.

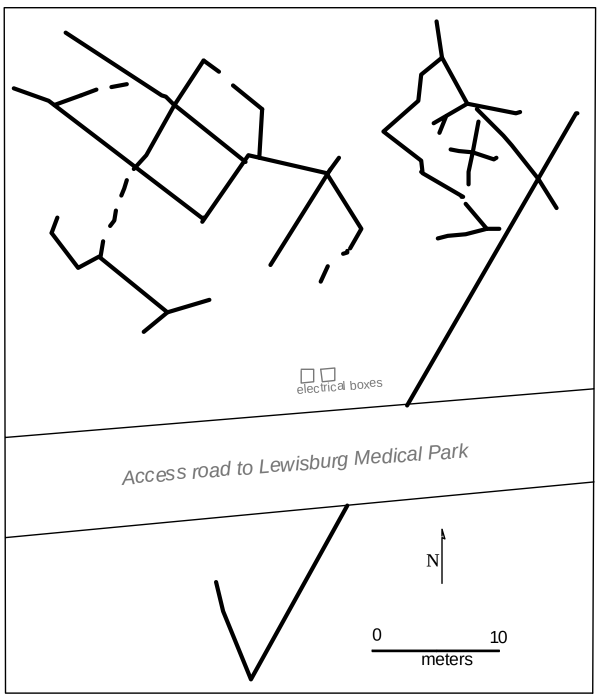

Figure 29: Mapped pattern of non-sorted patterned ground, Lewisburg Medical Park.

Several hectares of land was leveled in preparation for construction of a medical park. Beige stripes on the scraped bedrock surface identify a net of ice wedge casts — soil fallen into ice cracks (see Figure 29). Modern frost heaving is more effective in that soil, re-activating the wedges in miniature (and in reverse ... the wedges are compressing the rock; the rock is not in tension as when the cracks formed). We are seeing the bottom of truncated wedges here; I guess that ca. 1 m of soil is removed; ca. 30 cm of wedge remains. Elevation is 160 m.

Ice wedges are formed as frozen ground contracts, inviting water and soil to enter. In the spring the expanding ground is deformed upward around the wedge, permitting it to open again in the winter. The patterning of the ground into generally hexagonal nets reflects periodic release of stress diminishing the tension between them; the effect is identical to the creation of hexagonal mud cracks as a bed of drying alluvium shrinks and cracks.

Host rock here is Devonian-age Marcellus shale (like the shale chip colluvium); highly friable black shale, that weathers into a tan soil. The rock is nearly flat-lying on the axis of an anticline. Initial topography was also nearly flat. The sub-rectangular orientations of the wedges demonstrates a plausible pair of joint sets in the shale, both at roughly 45° to the principal stress axis. The wedges formed in pre-existing zones of weakness. The ca. 7m period of the wedges is probably cryogenic, but it may be structural. Tiny seasonal unsorted frost nets are often present on this site in the spring — 5 cm nets of shale clasts heaved into raised-edged webs.

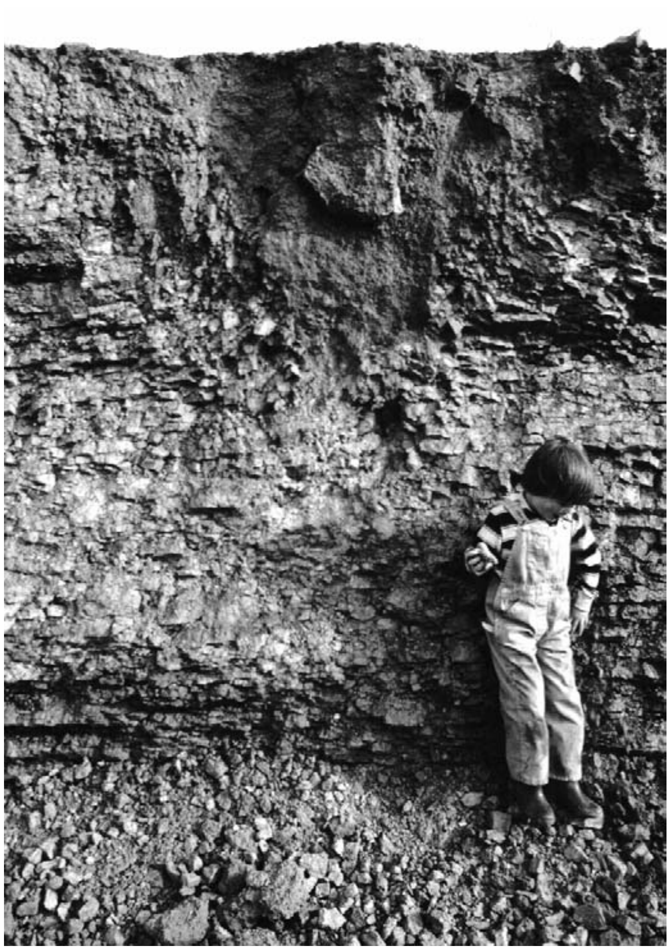

Figure 30: Ice (sand) wedge developed in Bloomsburg Shale near Lewisburg. Note upbent layers and vertically oriented fill to 1.5 m depth.

Ice wedges are consistently present in foundation pits cut into shale uplands like this one. They are typically 1.5 m deep, lined with a wedge-shape body of sand or soil of 10 cm width at the top and pinching to 0 cm by the bottom, with clasts in the wedge oriented parallel to the wedge (see Figure 30). They are surrounded by bedrock bent upward by the compressive force of Spring warming and expansion. The wedges often curve away from the vertical at the lowest 20 cm. Within a foundation hole, the wedges seem to be oriented to two intersecting directions, and spaced about 10 m apart from each other.

I judge this surface to match the Qt3, the Warrensville Terrace of Engle, Gardner, and Ciolkosz. (1996), on the basis of elevation. E,G&C correlated terraces at Muncy (30 km N) and Marietta (150 km S), with the fifth and highest terrace at 140 m above river level (Table 1).. Interpolation of these surfaces to the Lewisburg area gives good matches with three or four levels of rock cut and alluvial surface. (High alluvial surfaces standardly show periglacial deformation.) After careful soil chronosequence work established relative ages, E,G,&C correlated their terraces according to glacial advances. This correlation is an extension to the several alluvial lower terraces that head in moraines, per Peltier (1949). Two points suggest that the effort to correlate terraces to glacial maxima may unnecessarily constrain a landscape history. First, these seem to represent widespread stases in leveling — correlated with the several broad fan surfaces in Buffalo Valley, for example – rather than short cold periods. Second, the flight of terrace steps at Muncy are north of the limit of glaciation for at least some of the advances. It is hard to see how a surface behind the ice front would be more representative of glacially related fluvial processes that of long term leveling. These would therefore be tectonically controlled features, with no necessary connection with the relatively brief, climatically controlled episodes of glaciation.

Table 1:Terraces of the Susquehanna, after Engle, et al. (1996)

Terrace⇩		at:⇨	Muncy⇩	Lewisburg⇩	Middle Creek⇩	Marietta⇩
km S of Muncy⇨			0	25	50	150
	Glacial correlation⇩	ka bp⇩	Elevations in m (ft)⇩			
2a	MM/EM Pleistocene	300 -770	188	175 (573’)	162	109
2	Laurelton / Muncy		175	162 (531’)	149	97
3	L/M-Pleistocene (“Illiniosan”) Warrensville	130-300	164	151 (496’)	138	
4a	Late Pleistocene Olean	17-25	156	143 (470’)	131	
5a	Late Wisconsin “Binghamton”	16	150	138 (451’)	125	75.5
river		0	141	129	117	70

E. STOP 15. ALLENWOOD TILL

Till body over limestone on a high terrace.

Near the original type site of Allenwood soils, we will look at soil sections into a preWisconsin till. Diamicton lies to depths up to 10 m at this site. We are at the level of the Qt2a terrace, although, as we'll see, some lowering should have occurred since this surface was established.

We know this site very well, because it was fought over earlier in the decade because of a proposed hazardous waste incinerator. Several hundred acres of land was acquired by USPCI, of which this is the NW corner. The actual plant was intended to be built on the crest of the hill here. The requirements for incinerator siting in Pennsylvania require significant unconsolidated sediment and ready highway access. This is otherwise a poor site for a hazardous waste facility. Bedrock below is carbonates. Test borings in the SW corner of the field suffered repeated loss of fluid within the rock. The wetland in the farm field 30 m SE of the turn on the road is underlain by a void, according to a seismic line. The slope of the field beyond the hedgerow to the S overlies a 10 m drop in the bedrock underneath the till mantle. Thus we see lowering of the till through solution, but the lowering is uneven. Whereas strike is roughly E-W, and all layers might be expected to be lowered by solution at a constant rate, yet the W end here is more pitted. I interpret the pattern to reflect differences in the supply of water to the soluble rock, caused by the impermeable till. Where perforations develop through the till, solution will be concentrated, and will localize lowering in a self-amplifying pattern. These perforations make wetlands, and the wetlands in turn invite ground ice development — by the evidence across the river and W of here on this till surface. Elsewhere (SW of

Mifflinburg, W of Mt. Pleasant Mills), very deep and regular WTC scars are established on weathered chert overlying limestone, on the Eliber soil. I interpret these as WTC-guided karst features — welts and perhaps ground ice scars develop in the chert weathering debris, and localize subsequent solution into a wind-transverse pattern that lass indefinitely and is rejuvenated during cold periods.

The defeat of the incinerator project was mediated by soil scientists. The siting criteria forbade use of prime farmland. The soil at the top of the hill is Allenwood. Allenwood 'A' is prime farmland, but 'B' isn't. The hilltop was mapped as AoB … no AoA was mapped in Union County. Obviously the slope at the top is less than 3°. It was shown to the satisfaction of SCS officials that the soil was AoA, and the map was updated. This required USPCI to resubmit its plan, setting the project back some months, and contributing to its economic infeasibility. Subsequently the Bush administration — as nearly its last official act — ruled that the map cannot be changed, and therefore the top of this hill is legally steeper than 3° … a federally mandated a cone, I presume.

Union County purchased this land for an industrial development park, when USPCI chose to abandon the site. The county has not committed itself to preserving the prime farmland that saved its environment. Test pits are dug into the hill top. The expected soils are Allenwood, the wetter Washington.

F. STOP 16. COVE ROAD CATASTROPHIC FLOOD

Braided and anastomosing flow below an evacuated valley.

Evidence of extreme erosion is found where White Deer joins a lesser tributary. Upper White Deer Creek, coming from the SW, shows terraces, scarps, and other evidence of thermokarst? evacuation. Just below Dunbar Road, where the creek crosses the road, several features suggest enormous stream energy in the past. A broad fan stretches NE, covered with boulder bars bearing clasts to 1 m. The tributary stream is entrenched beyond the far edge of the fan. The tops of the boulders bear algae and lichen, suggesting some age. Below the fan (most accessible from 150 m down the road) the surface of the valley bears five abandoned, sub-parallel channels in a broad sinuoidal sweep against the near valley wall. A section is cut by the stream into the surface that these channels are upon. Open-work, imbricated boulders to 80 cm lie 2 m deep, with hints of bedding. The lower end of this surface is deeply grooved by dry channels.

I interpret this surface as a construction of a few huge transport events at the time of ice degradation. Extreme capacity of a hyperconcentrated breakout brought boulders to this turn, where velocity decreased and deposition occurred. Coarse boulders lay at the uphill side, the curving flood scoured back into the near bank, multiple channels were built during deposition, and then the cleaner waters behind the flood began to cut the now-dry channels into the bottom of the fan.

Present White Deer Creek, and its Dunbar Trail tributary, are cutting into the relatively shaley bedrock at the edges of the fan, inverting topography.

G. STOP 17. WHITE DEER MOUNTAIN WEATHERING MANTLE

Deeply weathered, extremely flat, unperi-glaciated surface on the highest ridge top.

Flat mountain tops

The distinctive features of this upland are first, that this ridge is roughly concordant with the various ridges around us, and second, that ridge tops are locally flat. This would be W.M. Davis's Schooley surface; a remnant upland of an extensive erosional surface dating from, perhaps, the late Paleozoic. The existence of such an “old age” surface is useful to account for the broadly parallel river patterns on the Atlantic slope, which feature rivers headed SE in bold disregard for rock hardness beneath themselves. Penns Creek, between Stops 6 and 7, illustrates this grain-transverse pattern.

One or two hilltops won't resolve this venerable dispute, especially in the face of strong objections, and powerful alternative models, from modern geomorphologists. But the hilltop material does give us useful information relevant to the debate, and periglacial processes provide an alternative explanation. Any model of the origin of these uplands must account for the action of vigorous processes during the Pleistocene. Two processes are relevant here. First, nivation and related processes are understood to cut benches into hillsides … snow accumulates at some high level on a mountain side, accelerates heave/weathering/solifluction/etc., below itself, and the bench widens into the hill. Heaving and cryoturbation are thought to transport material to the edge of the hilltop, where it is cast into the colluvial system. The processes together are cryoplanation. These processes should be more active at colder, higher elevations, thus higher hills should be lowered faster, and hills would tend toward concordancy. Benches cut into hillsides are common in this region; broad, sharp-sided remnant uplands on hilltops suggest partially completed cryoplanation. Hilltops are typically boulder-strewn, and those boulders are arrayed in strings and nets that indicate periglacial deformation. All of this argues that these uplands are not remnant erosional surface, and that much lowering has happened in the last few hundred millennia, let alone the last 60,000,000 years.

Except that this pattern is not true for the very highest of the summits in this region, as one these anticlinal axes of the Tuscarora where the lowest dip of the hardest rock, giving the highest upland. These uplands are the largest nearly-flat surface in the Appalachians other than floodplains and stream terraces. This is especially surprising when you consider that they are also the highest surfaces, too. These surfaces are covered by extensive surfaces of deeply weathered Tuscarora quartzite. Fine sand — with heavily weathered quartzite fragments and a few percent boulders — lies 2-3 m deep. The surface bears scattered sorted patterned ground. The deep, well-drained soil is an improbable material for periglaciation, as water is not retained near enough to the surface to freeze. (This is in contrast to the condition of many periglaciated soils in lower mountains of the Tuscarora that are quite low in porosity ... wetlands on rocky ridge-crests are surprisingly common.)

The model of relict ancient surfaces that were thoroughly leveled long ago, and since subjected to only chemical weathering is better than a model of actively eroded, cryoturbated upland in some kind of long-term adjustment to ongoing down cutting — because of the paucity of periglacial features, the lack of "frost-susceptible" (wet and loamy) soils, the low occurrence of boulders or other recently weathered rock, and the wide, low gradient surface on those uplands. Relict upland surfaces of great antiquity are well-known in Australia; no theoretical impediment to their presence in Pennsylvania is known.

It is plausible that both models are correct — the thick, dry soils protect wide Tuscarora uplands, while thinner, wetter, and clayier soils on narrower ridges have permitted ongoing denudation that is demonstrated by their disturbed soils, irregular surfaces, and lower elevations. The sandy upland at White Deer Mt. seem to be an erosional remnant … the flat, sandy upland is surrounded by a slope down to the more familiar bouldery, periglacially disrupted, badly drained colluvial surface. (The model of relict-upland-*and*-ongoing-leveling constrains rates of leveling for the narrower ridges, since they were presumably near the level of the broad tops at the time of leveling.)

White Deer Mountain

The very top of White Deer Mountain carries thick sand weathered from the Tuscarora quartzite. A borrow pit in the deposit shows amorphous yellow sand with heavily weathered quartzite clasts, small gravel, and occasional boulders. This is not (predominately) aeolian or fluvial. Little sign of periglacial influence is visible one the surface — only sparse sorted patterned ground polygons. The soils is too coarse to expect much heaving to have happened, for lack of clays to develop cryostatic suction, and for lack of near-surface water on this high hill.

Shallow refraction seismography along the muddy road at ridge top shows 2.5-3.5 m of sand (although the geophone spacing was too wide for absolute confidence), and 10 m of broken rock. (Figure 31) Highly angular Tuscarora fragments are seen in the road bed at about the right distance down the slope to represent the same material. This is rather different from the rounded (and larger) boulders found in periglacial transport on other parts of the landscape.

We are on the highest part of the topography for many kilometers, but it is also one of the flattest. (Figure 32)A 1 km line to the north would encounter no more than 5 m of relief. The soil section derivable from the materials on the road bed is the same from both directions — a steep climb brings us from a periglacially deformed, boulder-covered, (apparently) shallow-soiled mountain top, up through sharply broken rock, to several meters of heavily weathered sand. One can see why William Morris Davis would have, we can presume, described this as the an ancient land surface stranded by subsequent downcutting.

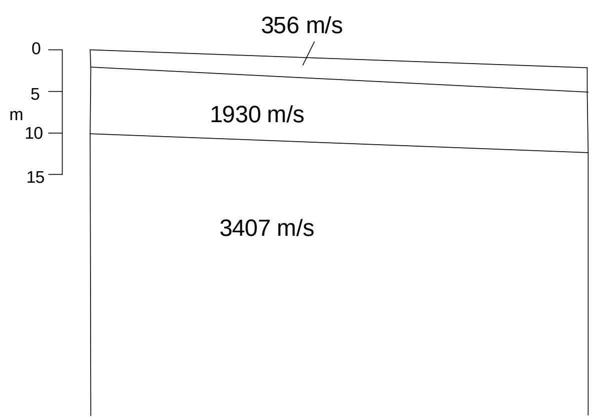

Figure 31: Seismic section of the top of White Deer syncline … interpreted as 3 m weathered sand and7 m in situ *broken rock overlying the Tuscarora.*

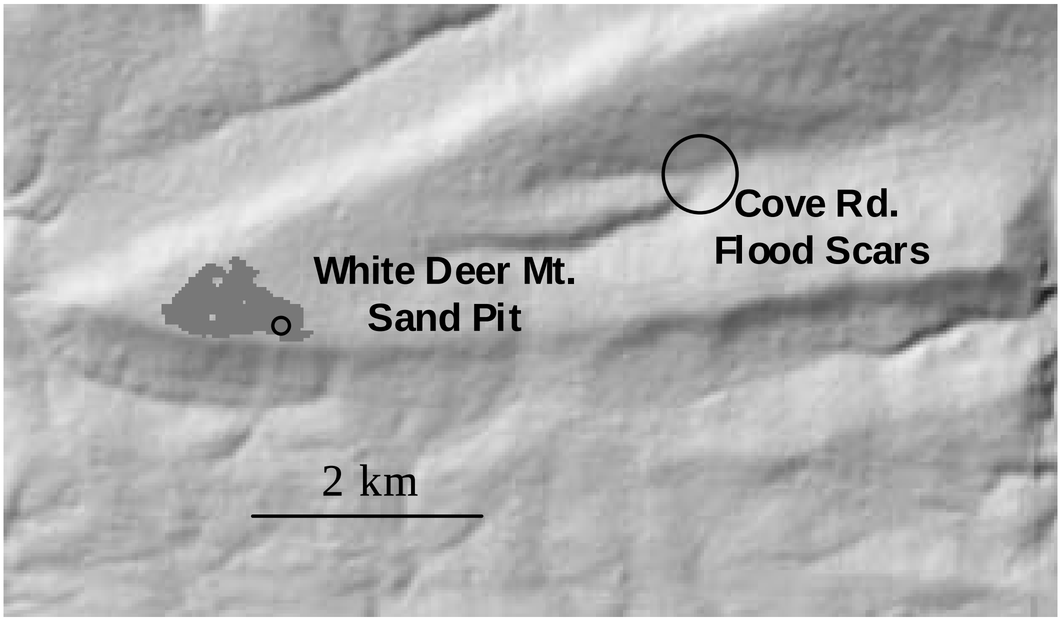

Figure 32 Area atop White Deer Mountain between 660 and 670 MASL shown in grey – 1.2 km maximum length, 0.5 km² area. Previous stop located NW.

Those opposing this interpretation need to answer these questions: How long does it take to weather Tuscarora to a minimum depth of 3 m? If this is a surface involved in some quasi-equilibrium process of ongoing downcutting, why is the depth of weathered sand so different over a few tens of meters from here to the ridge crest in the E? And what process is transporting material off the flat plain 500 m north of us in an ongoing fashion, in the absence of evidence of periglacial effect?

IV. REFERENCES

Ballantyne, C. K. (1987). The present-day periglaciation of upland Britain. *In* “Periglacial Process and Landforms in Britain and Ireland“ (J. Boardman), pp. 113-126. Cambridge University Press, Cambridge.

Ballantyne, C. K., and Harris, C. (1994). “The Periglaciation of Great Britain.“ Cambridge University Press, Cambridge.

Berg, T. M. (1980). “Geological map of Pennsylvania. (scale 1:250,000)“ Pennsylvania Geological Survey, Harrisburg.

Braun. D.D. (1994) “Late Wisconsinan to Pre-Illinoisan (G?) glacial and periglacial events in eastern Pennsylvania” 57th Annual Friends of the Pleistocene, Northeastern Section, Conference Fieldtrip Guidebook: Bloomsburg, PA

Engel, S.A., Gardner, T.W., Ciolkosz, E.J., (1996) “Quaternary soil chronosequences on terraces of the Susquehanna River, Pennsylvania,” Geomorphology 17:273-294.

Inners, J. D., Braun, D. D., Ackerman, J. R.. (1988) “Bedrock and glacial geology of the North Branch Susquehanna Lowland and the Eastern Middle Anthracite Field” Field Conference of Pennsylvania Geologists (53rd : 1988 : Hazleton, Pa.), Geological Survey of Pennsylvania, Harrisburg, PA

Chase, C. (1977). Central Pennsylvania sand dunes. *Pennsylvania Geology* 8, 9-12.

Clark, G. M., (1992). Periglacial geomorphology *In* “Central Appalachian Periglacial Geomorphology“ (G. M. Clark, Ed.), pp. 42-88. Pennsylvania State University Department of Agronomy, University Park.

Clark, G. M. and Ciolkosz, E. J. (1988). Periglacial geomorphology of the Appalachian Highlands and Interior Highlands south of the glacial border — a review. *Geomorphology* 1, 191-220.

Eckenrode, J. J. (1985). “Soil Survey of Union County.“ United States Department of Agriculture, Washington. Scale 1:20,000.

Katkin, T.L. (1986) “Fluvial terraces of the Juniata River Valley in central Pennsylvania. Unpublished MSc thesis, University Park, PA. 283 pp.

Marchand, D.E., Coilkosz, E.J., Bucek, M.F., Crowl, G.H. (1978), Quaternary deposits and soils of the central Susquehanna Valley of Pennsylvania” 41st

Annual Friends of the Pleistocene, Northeastern Section, Conference Fieldtrip Guidebook: University Park, PA

Marsh, B. (1998) Wind-transverse corrugations in Pleistocene periglacial landscapes in central Pennsylvania. *Quaternary Research* 49, 149-156.

Marsh, B. (1987). Pleistocene pingo scars in Pennsylvania. *Geology* 15, 945-947.

Peltier, L.C., (1949) "Pleistocene terracs of the Susquehanna River," Pennsylvania Geological Survey, 4th Series, Bulletin G-23,151 pp.

Ressler, T. R. (1998). "GIS modeling and assessment of groundwater flow at Montandon Marsh, central Pennsylvania" Bucknell University senior thesis in geology.

Seppälä, M. (1988). Palsas and related forms. *In* "Advances in Periglacial Geomorphology" (M. J. Clark, Ed.), pp. 247-278. John Wiley & Sons, Chichester.

Thorn, C. (1988). Nivation: A geomorphic chimera. *In* "Advances in Periglacial Geomorphology" (M. J. Clark, Ed.), pp. 3-32. John Wiley & Sons, Chichester.

Thorson, R. M. and Schile, C. A. (1995). Deglacial eolian regimes in New England. *GSA Bulletin* 107, 751-761.

Washburn, A. L. (1980). "Geocryology: A survey of Periglacial Processes and Environments." John Wiley & Sons, New York.

Watts, W. A. (1983). Vegetation history of the eastern United States 25,000 to 10,000 years ago. *In* "Late Quaternary environments of the United States" (H. E. Wright, Ed.), pp. 294-310. University of Minneapolis Press, Minneapolis.

Williams, P. J. and M. W. Smith. (1989) "The frozen earth : fundamentals of geocryology" Cambridge University Press, New York.