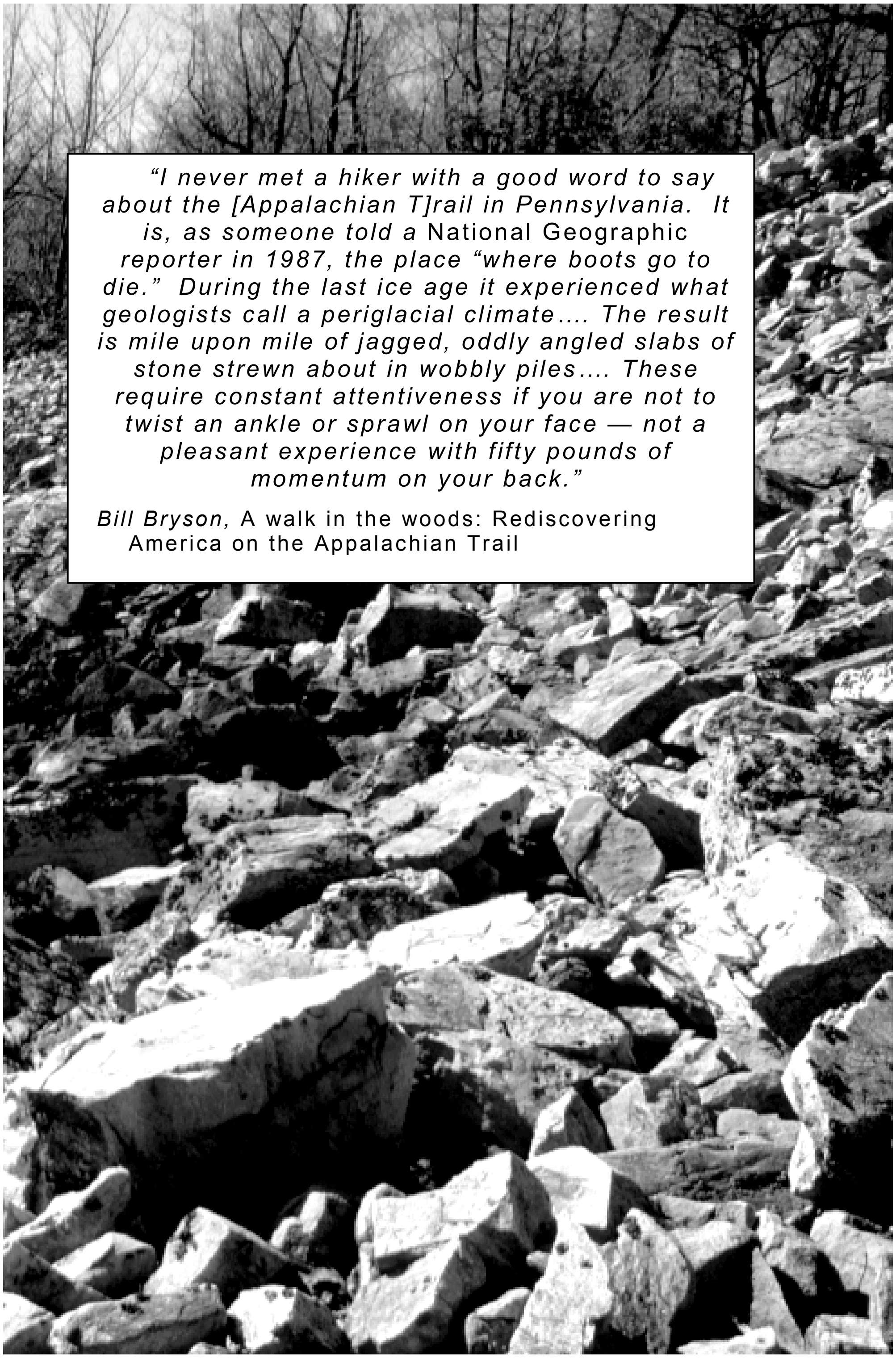
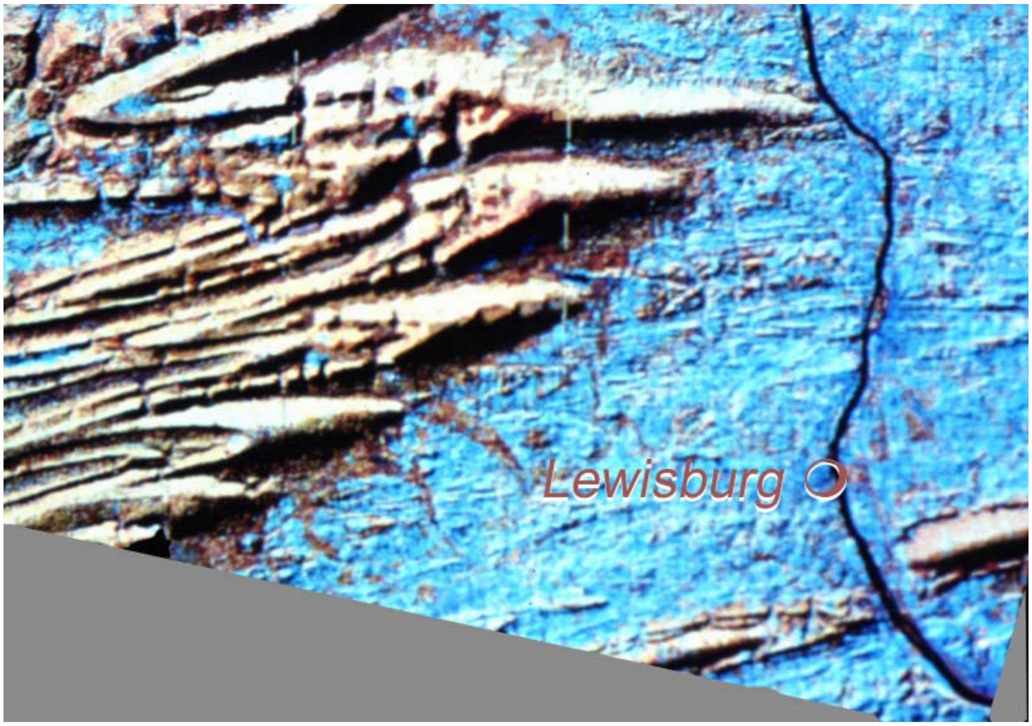
GEOMORPHOLOGY OF CENTRAL PENNSYLVANIA

by Ben Marsh, from 1999 Friends of the Pleistocene guidebook.



> *"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

Ridge-and-Valley physiographic province.



Union County lies 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 (Figure).

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 landscape is typical of the mountainous regions W of Lewisburg. The ridge-formers strike 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 W, thick Ordovician-age carbonates sections surface within breached anticlines and create the elongate, low relief, fertile, limesone valleys typified by Nittany Valley around Penn State.

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 RB Winter Park, 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. One can see some evidence of Pleistocene derangement of medium-sized drainage nearer the river.

Soils of central Pennsylvania

Here are 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.

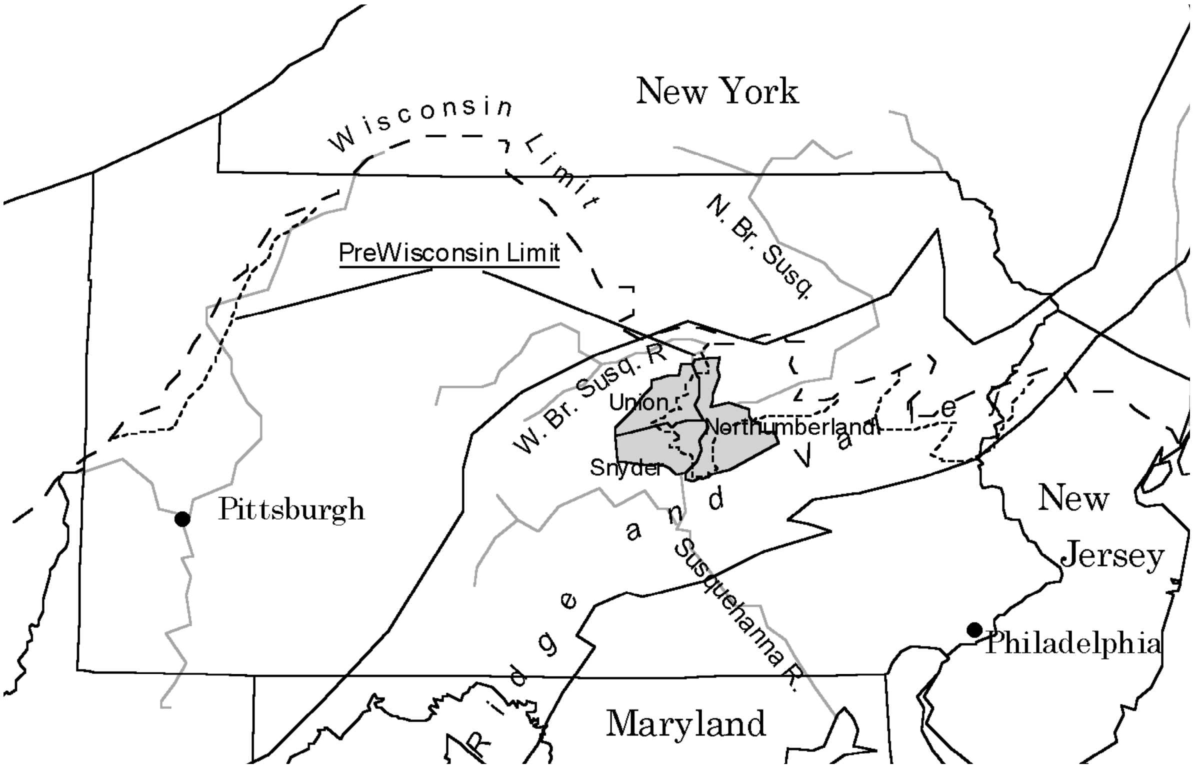


Figure 1: Field sites in three central Pennsylvania counties, with respect to political, physiographic, and glacial boundaries.

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 by 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 thinner and rocky.

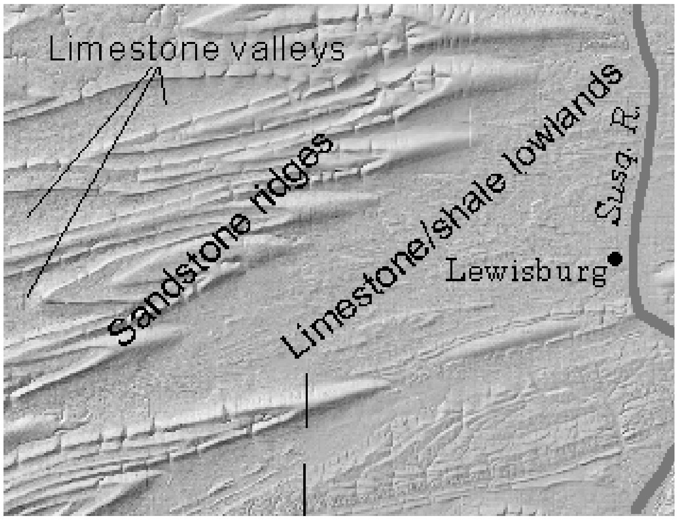


Figure 2: Landform regions of the central Susquehanna valley.

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 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.

PERIGLACIAL AND GLACIAL LANDSCAPES

Central Pennsylvania shows some of the best relict Pleistocene periglacial landforms in the eastern US. Periglacial features are those landform elements formed under very cold, but not glacial, conditions primarily by the growth and loss of ice crystals in the soil. Many typical periglacial landforms and soil structures have been described in central Pennsylvania (Clark 1992, Clark. and Ciolkosz 1988). One can easily find excellent examples of 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.

Glaciation

A complex — and controversial — pattern of glacial advances is recorded in central Pennsylvania. It is generally agreed that the latest Wisconsinan ice stopped about 50 km N of Lewisburg, and that preWisconsinan ice extended about 40 km S (Figure 2). The Wisconsinan deposits are fresh, sparse, and thin, the preWisconsinan materials are 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 (Marchand et al 1978) 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. 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 glacial bodies, mapped by the pattern of remnant deposits, violates our understanding of ice physics.

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 a discussion of Pleistocene climates. While many weathering and soil features are ambiguously created by deep annual freezing as well as permafrost, deep ground ice scars – as one can see are RB Winter Park – require an average annual temperature well below 0°. Paleobotanical evidence of tundra vegetation in Pennsylvania (Watts,1983) concurs with the geomorphic requirement for 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 characteristics now observed in the Arctic, and periglacial features may be distinct from contemporary models.

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 some layers in 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 the gradient over which present slope processes can transport material. *Creep*, of course, would be very active because of the greater depth of annual freezing from cold winters and greater heat flow across 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 S-facing hillslopes in central Pennsylvania are lower in gradient than N-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 S-facing slopes. However, 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 entering from an ice-free zone 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 pingos and palsas 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 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 pushes the water content of the material beyond the fluid limit. Evidence for these exists only as voids in the landscape, which are obviously open to many interpretations.

3) thermokarst-derived hyperconcentrated stream scour and fill. 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 broad, anastomosing stream channels is informative.

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, 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 alluvial surface.

BIBLIOGRAPHY

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

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.

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

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.