GEOMORPHOLOGY OF SOUTH-CENTRAL NEW YORK

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PHYSICAL SETTING

South-central New York is part of the Glaciated Appalachian Plateau (Fig. 1). The topography is diverse, however, as indicated by the fact that parts of three different geomorphic sections comprise the region. Nearby adjacent physiographic provinces further lend great variety to this New York-Pennsylvania twin-tiers area.

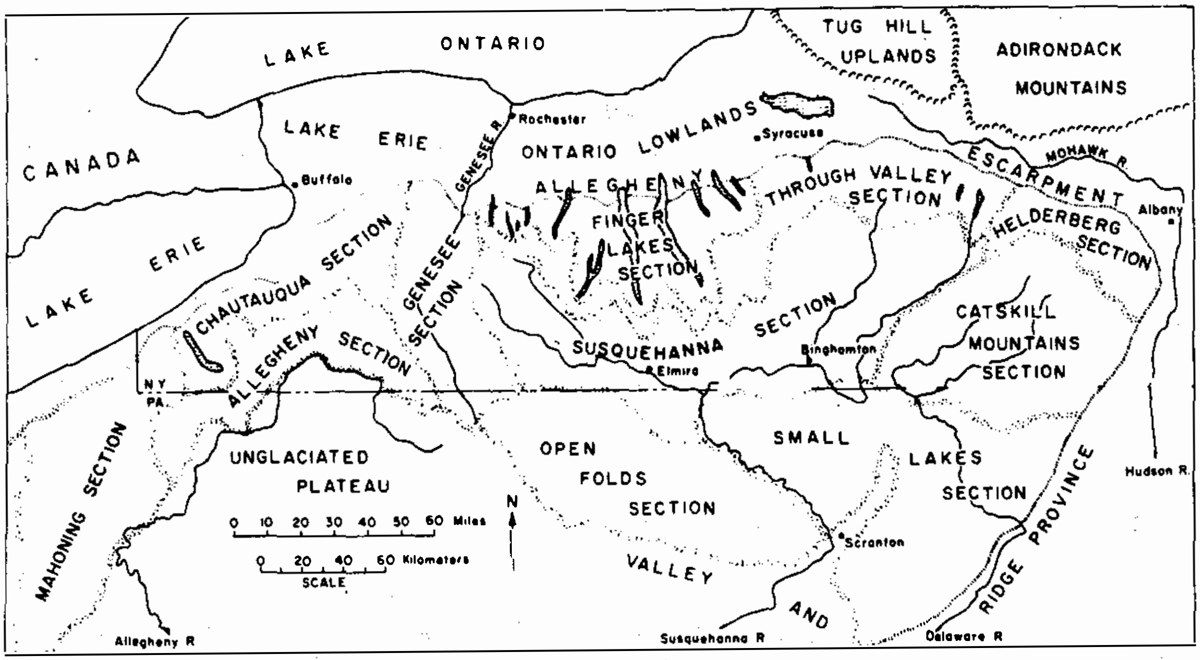


Figure 1. Map of geomorphic sections of the Glaciated Appalachian Plateau with adjacent provinces.

The Binghamton metropolitan area (of 200,000 people) is nestled in the Susquehanna section. As can be seen in Figure 2, three rivers dominate in the scene -----the Susquehanna, the Chenango and the Tioughnioga Rivers.

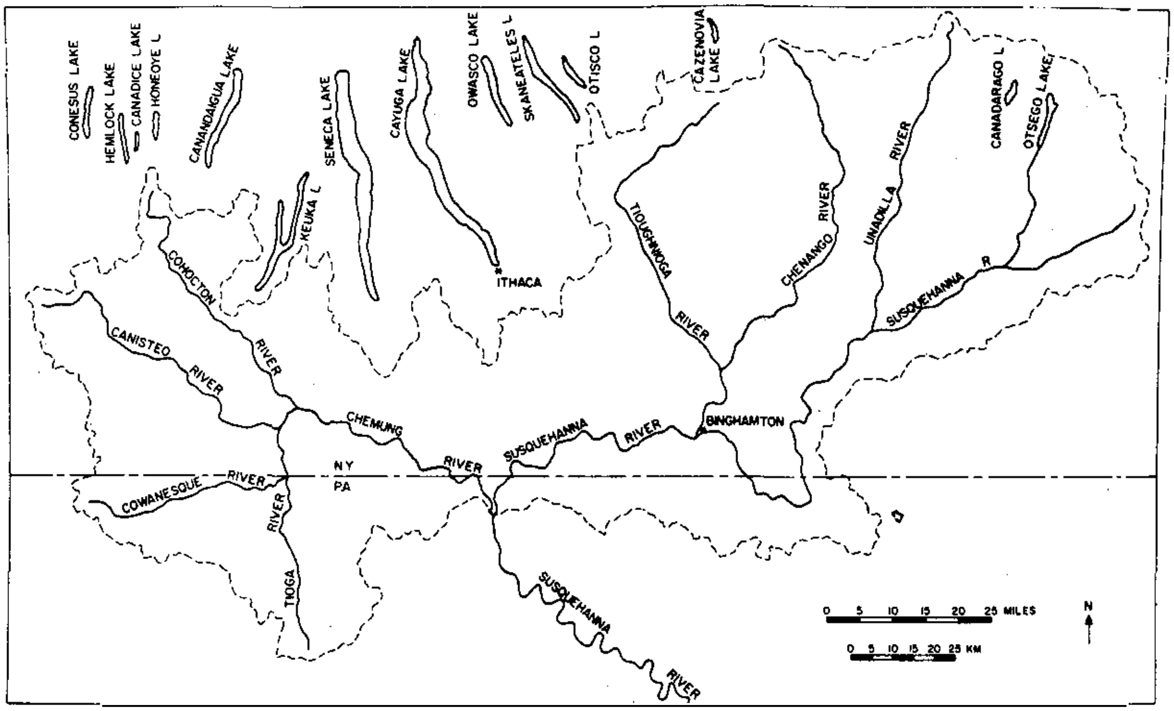


Figure 2. Map of Susquehanna River Basin hydrographic features.

In the east, the more rugged Catskill Mountain Section rises to elevations in excess of 4,000 ft. In the south, the Small Lakes Section is dotted with several hundred lakes and wetland areas. The Binghamton area lies at the heart of the region and is particularly interesting because it: (1) forms the transition zone between the higher and more rugged Catskills on the east with the more typical Appalachian Plateau to the west, (2) contains the unique configuration of the Great Bend area, (3) illustrates the problem of the evolution of two major river systems, the Susquehanna and the Delaware, and (4) contains a wealth of unusual landforms perhaps unmatched in most other parts of the plateau.

Relief in the Binghamton area exceeds 1,000 ft. with river elevations about 800 ft. and higher hills rising above 2,000 ft. A particularly unusual feature of the region is the highly erratic course of the Susquehanna River which changes directions several times before finally leaving the region at Waverly and eventually reaching sea level at

Chesapeake Bay. For millennia the landscape has been sculptured by fluvial, gravity, and finally glacial processes. Without glaciation, the region would more closely resemble parts of West Virginia with its steep ridge-and-ravine topography. Instead the New York hilltops have been reduced in elevation, and the valleys partially filled with deposits giving an overall effect of reduction in relief and hillslope steepness. Without the advantage of glaciation, the population would be much smaller because floodplains would be narrow, groundwater supply would be less plentiful, and there would be an absence of abundant sand and gravel deposits which provide an important mineral base to the economy.

PREVIOUS STUDIES

Most of the early surface geology work in the region was focused on the problem of explaining the evolution of drainage (Coates, 1963a). Three general views prevailed concerning the evolution of streams and the topography: (1) They are mostly derived from rather continuous denudation processes dating from post-Permian time. (2) They are largely post-Cretaceous and inherited from either a peneplain condition or a cover of Cretaceous sediments long since removed. (3) The features have developed from drainages that have become adjusted to the structural fabric.

The work of Tarr et al. (1909) provides one notable exception to the rule that very little glacial investigation of the region had been done prior to 1960. Rich (1935) provided the most detailed mapping of the Catskill region. Although MacClintock and Apfel (1944) and Fairchild (1925) briefly looked at the south-central New York localities, many of their conclusions have proved erroneous. Even soil surveys (as in Tioga County) have been shown as inaccurate on such matters as character and thickness of till. The following list indicates several of the early misconceptions about the region:

1. <u>The region was often characterized as containing dendritic drainage</u>. However, on the broad-scale drainage is arcuate with individual segments displaying pseudo-parallel patterns that also contain trellis drainage as in the upper reaches of the Chemung, Cohocton, and Canisteo Rivers.

2. <u>Effects of glacial erosion were considered minimal</u>. Although ice erosion was not as severe as in the Finger Lakes to the north, when combined with glaciofluvial erosion,the landscape produced by glacial processes has been greatly modified from its original fluvial character.

3. <u>The thickness of till is minimal, ranging from 3-10 ft</u>. Coates (1966) has shown that the average thickness of till exceeds 60 ft.

Starting in the 1960's, the SUNY-Binghamton group began to develop a series of publications and reports dealing with the surface geology of the region. Glacial features were discussed in the following works:

Coates (1963a,b, 1966); Harrison (1966); Coates, Landry, and Lipe (1971); Cadwell (1972); Coates (1973), King and Coates (1973); Kirkland (1973); Coates (1974); Coates and Kirkland (1974); Fessenden (1974); Coates (1976b); Aber (1976, 1979); Caprio (1979); Gillespie (1980); Stone (1981); and Phelan (1981). Hydrology characteristics were emphasized by Coates (1972); Flint (1968); and Rideg (1970). Topographic relations were stressed in Coates (1963a, 1963b); Conners (1969); and Coates (1976a).

BRIEF GEOLOGY HISTORY

Bedrock in the region is predominantly composed of clastic sedimentary strata of Upper Devonian age. West of Windsor, except near hilltops, rocks are mostly shale and silitstone of marine origin. East of Windsor and south of Great Bend rocks are largely sandstone of terrigenous origin. All rocks were part of the Catskill delta-alluvial-plain environment. In this region conglomerates, red beds, and limestone are exceptionally rare.

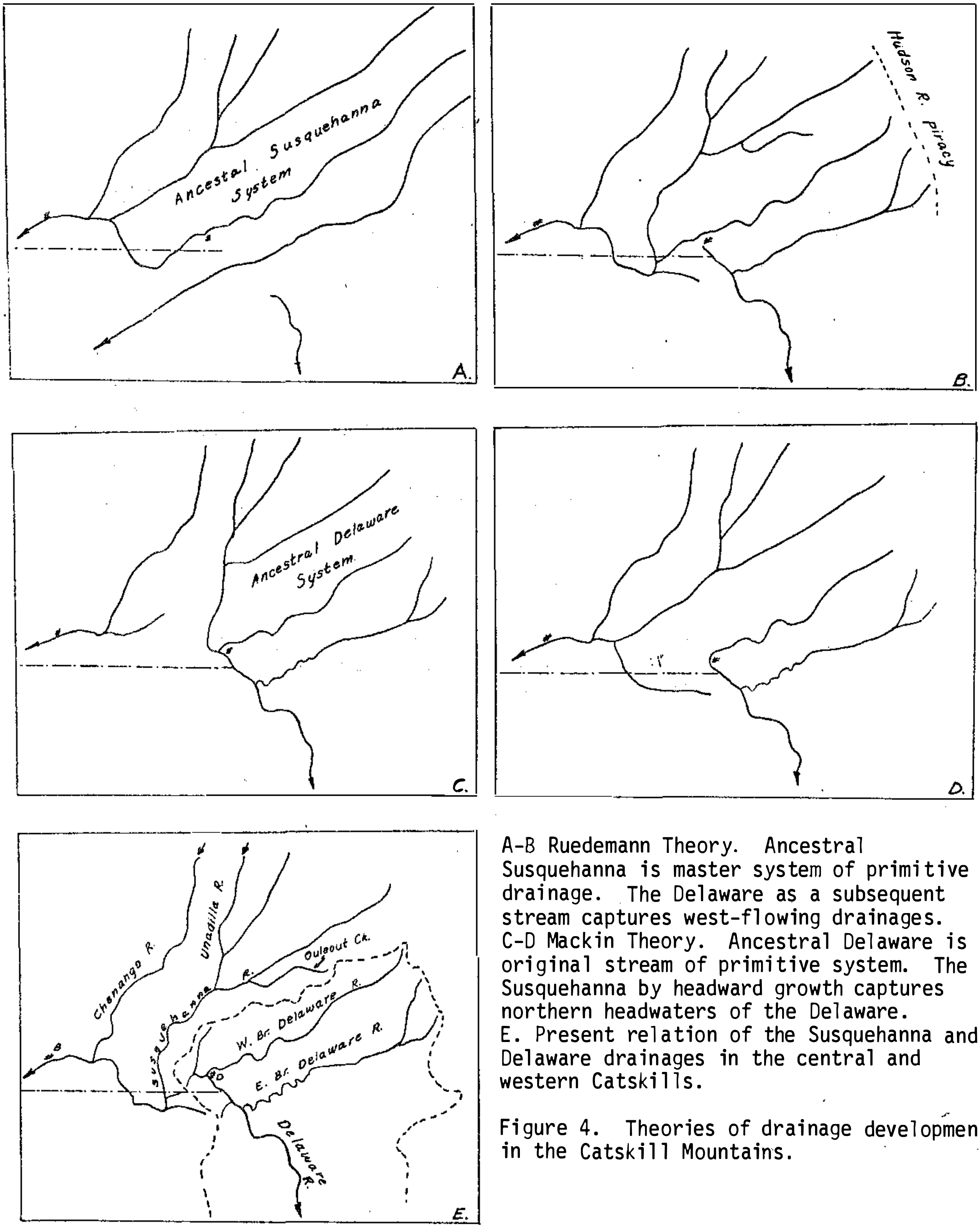
Although the rocks appear to be horizontal at any given outcrop, when viewed on a larger basis the architectural flavor of the region is a homocline with a regional dip of 10 to 40 ft/mi in a southerly direction. The strata have also been gently flexed into a series of east-and northeast-trending folds, but with dips less than 1°. The Catskill Mountains are generally conceived as a gentle synclinorium with axes that plunge southwestward from the upturned rim on the east.

The topographic character of south-central New York has been sculptured by many millennia of fluvial and gravity processes after the region was uplifted. Then, finally, during the past few million years glacial processes have placed in indelible overprint on the terrain. The key to this evolution has been the development of the Susquehanna River and its bizarre geometry....probably the most erratic of all American rivers (Fig. 2).

A variety of hypotheses have been presented in attempts to explain the anomalous course (for a fuller discussion of these ideas see Coates, 1963a, p. 22-24). For any hypothesis to be valid, it obviously must be in accordance with facts. Among these should be the consideration that: (1) The flow of several rivers is contrary to the regional structural fabric, such as the direction of flow of the Tioughnioga, Cohocton, Canisteo, and Chemung. (2) The arcuate character of the major part of the Chemung and Susquehanna Rivers in New York (Fig. 2), is an anomaly. (3) The magnitude of post-Cretaceous denudation could exceed 1 mi, and denudation since post-Permian time could greatly exceed 2 mi. (4) The present-day structures and lithologies where streams are currently eroding may not correspond with conditions when streams were eroding at formerly higher elevations. Figure 3 provides a list of the many different ideas that have attempted to explain drainage throughout the region, and Figure 4 illustrates some of these.

Figure 3. Listing of different hypotheses as explanations for the origin Appalachian drainage.

1. The original drainage was northward, but, through a reversal, the rivers now flow south.
2. The original drainage was west and southwest due to the development of consequent streams flowing first off the Adirondacks and later off the Catskills.
3. Drainage evolution through capture processes by headward-eroding streams that became adjusted to structural trends along joints, faults, and folds.
4. A variation of No. 3 with successive stripping of various thrust belts and sheets. First proposed by Meyerhoff and Olmstead (1936) but can now be resurrected as byproduct of the new plate-tectonics and overthrust belt ideas.
5. Development of a Tertiary peneplain with drainage superposed through the underlying sedimentary rocks.
6. A regional covering by Cretaceous sediments with subsequent superposition through them onto underlying Paleozoic rocks.
7. Capture of the southwest- and west-flowing Susquehanna by the Delaware system because of the Delaware's advantage of steeper gradient and shorter distance to sea level.
8. Capture of the Delaware system by the Susquehanna system.
9. Large-scale drainage derangements caused by glacial diversions over the nearly 2 million years of Quaternary time.



A-B Ruedemann Theory. Ancestral Susquehanna is master system of primitive drainage. The Delaware as a subsequent stream captures west-flowing drainages.
C-D Mackin Theory. Ancestral Delaware is original stream of primitive system. The Susquehanna by headward growth captures northern headwaters of the Delaware.
E. Present relation of the Susquehanna and Delaware drainages in the central and western Catskills.

Figure 4. Theories of drainage development in the Catskill Mountains.

Whatever the final verdict, it is obvious the Susquehanna has had a long and checkered history. The river has probably involved a combination of consequent flow, piracy of other stream segments, and glacial diversions. For example, the turnaround of the river in the Great Bend area is a particularly vexing problem, especially when the unusual differences in valley-fill sediments are considered. Bedrock depths are generally 200 ft. or so northeast and west of Great Bend whereas in the curvature segment bedrock is less than 100 ft. deep.

The final chapter for landscape development of the region was written during the ice ages of Quaternary time. Thus about 2 million years of glacial and interglacial episodes have been available to cause a re-fashioning of what formerly had been a predominantly fluvial terrane. The Laurentide ice sheets buried the Binghamton area with ice more than 3,000 ft. thick and the glacial margin extended south into Pennsylvania for 60 additional miles. The heritage of these times is reflected not only in landform changes caused by ice and meltwater erosion and deposition, but also by periglacial activities and more recent geomorphic events.

A particularly intriguing series of landforms occur along the valley wall on the south side of the Susquehanna River between Binghamton and Waverly. Instead of a somewhat continuous series of parallel hillslopes, there are many scallop-shaped reentrants or arcuate hollows. The SUNY-Binghamton campus is situated in one, and other good examples occur 2 mi west and again 5 mi west. It may be of importance to note that the location of the reentrants is usually in line with a south-trending drainage that joins the Susquehanna on the opposite side of the valley. Could their origin be linked to ice and meltwater erosion of valley-type ice tongues, or to a much-displaced thalweg of the Susquehanna River?

In summary, present-day landforms are a blend of erosional and depositional features that have been imprinted by many different processes acting under different environmental conditions.

GLACIAL EROSION

The movement of ice throughout the region was related to the amount of relief and the glacial source area. The main ice sheet at first advanced southward thrusting into the embayment now formed by the Finger Lakes to the north, where considerable erosion occurred. For example, as much as 1,200 ft of deepening was created in the Seneca and Cayuga troughs. South of the Finger Lakes, major valley erosion was accomplished in suitably oriented valleys, those with orientation mostly parallel with the outflow from the Ontario basin. This radial belt suggests divergence of the ice as it moved away from the confining topography of the Allegheny escarpment. However, this radiating pattern is interrupted by the arcuate geometry of the Chemung and Susquehanna Rivers and major tributaries. Coates (1974) has suggested the positions of such valleys may have been influenced by ice-margin drainage, in much the same fashion that parts of the Missouri and Ohio Rivers reflect ice-margin positions. East of Binghamton the direction of ice flow was influenced by the higher topography of the Catskill Mountains which caused a more southwesterly flow as indicated by striations in the area. Such ice flow was also enhanced during glacial maxima when in the north the ice sheet overtopped the Adirondacks producing southwesterly flow. This chain of events is described by Coates and Kirkland (1974) in which they trace the history of growth and decay of the ice sheet.

Two other aspects of the processes associated with glacial and interglacial times have served to flavor the landscape; the sequential series of landforms that have developed and the accentuation of forms with each succeeding glacial and interglacial stage. The following evolution of landforms was described as a continuous hierarchy of features throughout the region (Coates and Kirkland, 1974): (1) notch stage, (2) col stage, (3) overflow-channel stage, (4) sluiceway stage, (5) through-valley stage, (6) finger-lake stage, and (7) composite-valley stage. The notch stage forms when proglacial meltwaters create a V-shaped entrenchment at a drainage divide. Continued erosion, aided by advance of the ice,serves to hollow out the notch to produce a gentler and flatter floor during the col stage. Depending on the vigor of the processes and character of preglacial terrane, an overflow-channel stage or spillway may be formed. This occurs when a flat-floored channel extends immediately down-gradient from the drainage divide. The sluiceway stage evolves when the meltwaters have moved some distance from the divide and are deeply entrenching a gorge at lower elevations. Such valleys are larger, longer, and lower than the overflow channels. These long, narrow, steep-walled chasms at first only contain minor tributaries which provide evidence for their glacial rather than fluvial heritage and origin. For example, the anomalous morphology of such valleys proves they did not form through a normal fluvial cycle with headward erosion and the development of a nicely adjusted and articulated drainage network. Instead,the glacial meltwaters incised new terrain that is dissimilar to adjacent fluvial systems. The sluiceway north of Waverly and the sluiceway south of New Milford, Pa., are excellent examples of this development (Fig. 5). The most complex of these forms is the one associated with the Tioughnioga River. This sluiceway has a "beaded" valley configuration whereby amphitheater-type valley segments alternate with severely narrowed and constricted portions. Such aberrant features,when added to the unusual southeast valley gradient (which goes against the topographic grain of the region), indicate the Tioughnioga is a multicyclic sluiceway that required more than a single glacial episode for its formation. Thus it was repeatedly occupied by meltwaters during various glaciations.

Another landform created by glacial meltwater erosion is the umlaufberg (Fig. 6). There are many of these features with various sizes and shapes through the region. In this region, umlaufbergs are bedrock outliers within a valley surrounded by glacial drift that is

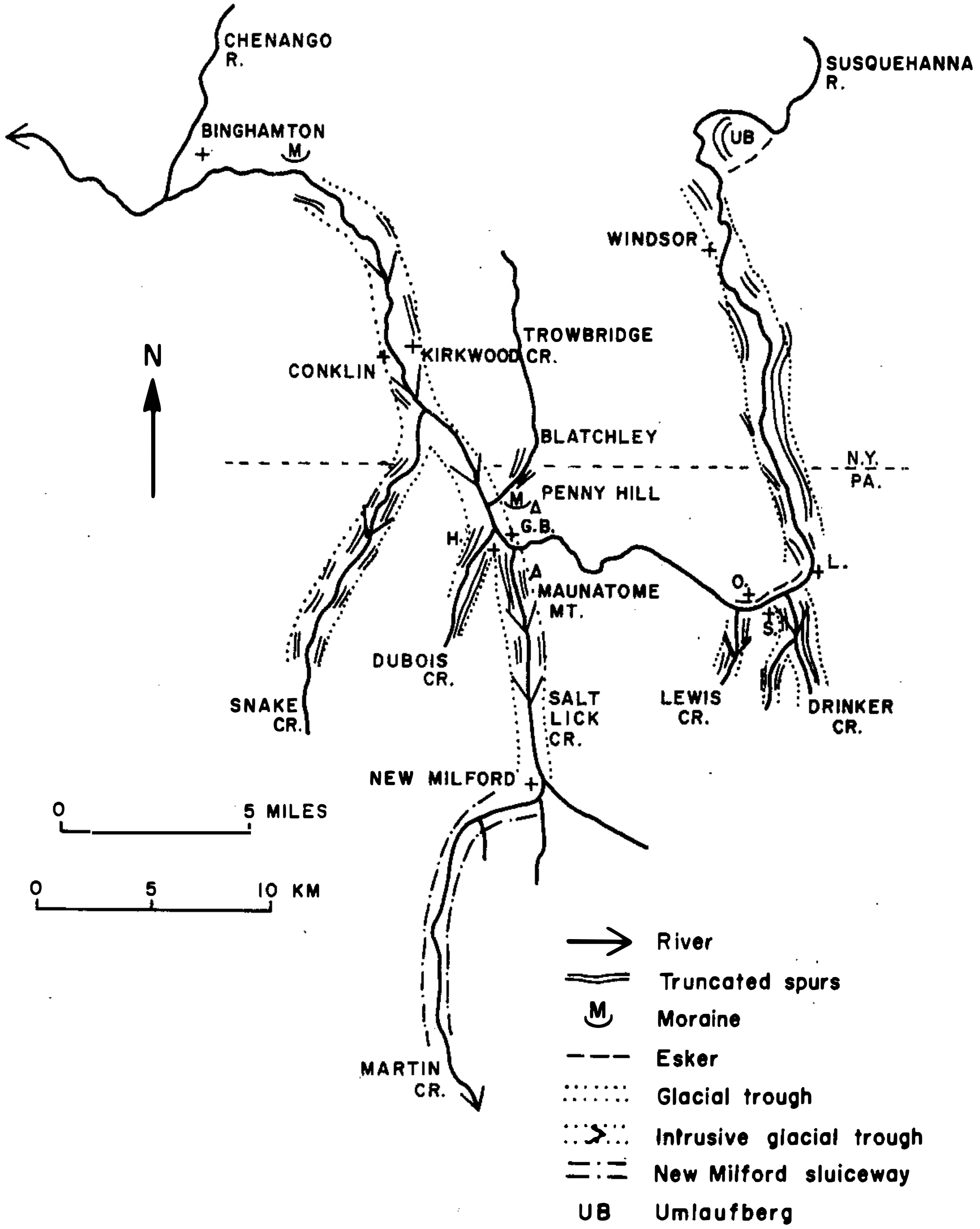


Figure 5. Glacial features of the Great Bend region.

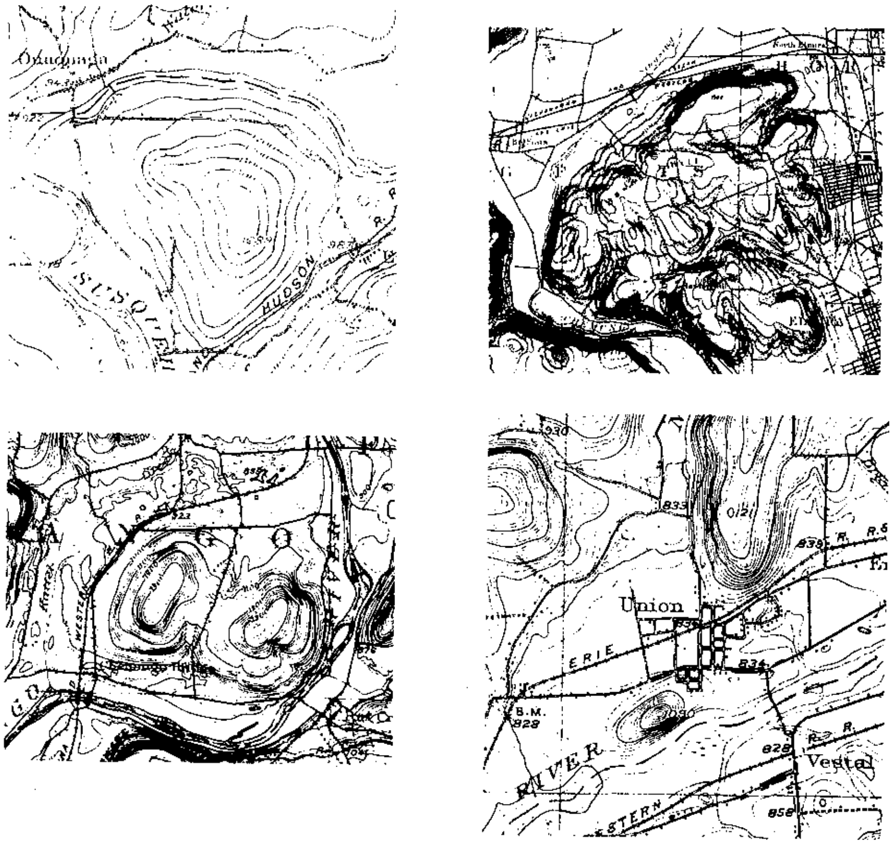


Figure 6. Maps showing variations in umlaufberg size and perfection in development. Copied from U.S.G.S. topographic maps, scale 1:62,500.
A. Single cycle. Susquehanna River near Windsor (Ninevah Quad.). Umlaufberg is 1.6 mi long.
B. Double cycle, Chemung River near Elmira (Elmira Quad.) Umlaufberg is 5 mi long.
C. Multicycle. Chenango River near Binghamton (Binghamton Quad.) Umlaufberg is 2 mi long. Note that it is double crested.
D. Multicycle end member. Susquehanna River at Union. (Apalachin Quad.) For scale the "Union" lettering is 0.4 mi long.

typically stratified. Their common bond is their origin. They form when an ice margin forced meltwater drainage to flow over what formerly was part of a bedrock spur or divide. Such drainage diversion produced a new entrenched channel, and upon retreat of the ice a bedrock knob remained with valleys surrounding it. Umlaufbergs can be important in deciphering glacial history because they range in type from those formed by a single glacial episode to those that are multicyclic (Coates, 1974). The size and shape of the umlaufberg, the character of the surrounding valleys, and the degree of tributary development in the contiguous terrain aid in determining the relative age of the features. The best examples in the Binghamton area occur at Roundtop Hill, Vestal; Roundtop, Endicott; and at Chenango Bridge. There is even a completely buried bedrock hill at the confluence of the Susquehanna and Chenango Rivers which means during former times the Chenango River flowed southwest instead of south at that position.

GLACIAL DEPOSITION

There is a large variety of glacial deposits and their landforms in south-central New York. The materials include different types of till, as well as both ice-contact and outwash stratified sediments of meltwater origin. Furthermore each of these sediment types comprise special landforms that are distinctive in their morphology.

Till Composition

Two distinct types of till occur in the region. The Olean or "drab" till was named from its type locality at Olean, N. Y., and the Binghamton or "bright" till was described for our area of the same name. MacClintock and Apfel (1944) did the first study of these materials and argued they were formed by separate ice sheets with the Olean being older. Olean till is clay-rich with a high percentage of local rocks in the gravel-size range. The erratic count (or "exotic" rocks) is generally less than 8 percent of far-travelled materials. Such composition imparts a dull or "drab" appearance. In contrast, the Binghamton till is more sandy, contains clasts that are more rounded, and may contain erratic gravel that comprises 20 percent or more of this size range. These exotics (rocks from outside the drainage area) are generally limestone, chert, red sandstone, and igneous-metamorphic crystallines. The Valley Heads drift, which occurs north of our study region, has many similarities with the Binghamton composition. Denny (1956) was the first to challenge the age concept of MacClintock and Apfel because he found no evidence of Binghamton drift in the Elmira area (also see Denny and Lyford, 1963). Instead he proposed that the Binghamton was contemporaneous with the Olean and had formed as the result of incorporation of erratic-rich valley gravels. Moss and Ritter (1962) also support this view and used pebble lithologies, heavy-mineral coatings, and texture ratios as documentation. Coates (1963a) described the Binghamton drift as simply the valley facies of the Olean which was usually an upland till. Thus these units were regarded as end-members of a lithologic continuum of Woodfordian age (Late Wisconsinan). In a study of valley-fill sediments and well borings, Randall and Coates (1973) show that ice-margin oscillations occurred, and the presence of transitional drift types indicate only a single major glaciation period.

More recent studies of upland tills in the region have revealed some new insights on their characteristics. Aber (1976) studied the lithology of upland drift by examining cuttings from deep water wells. He discovered gravel units interbedded between till units and also found interstadial conglomerates in the material. He ascribed these units to different time zones, interpreting the section as representing an older Wisconsinan event that was subsequently covered with a newer Woodfordian event.

In attempts to obtain greater resolution and understanding of upland drifts, Caprio (1979) and Gillespie (1980) undertook quantitative mineral and chemical analyses of tills to discover if there were significant differences, and, if so, whether such variations could be attributed to time lines. These studies showed that the amount of exotic rock-mineral matter in the drift is a function of textural size. In general, there are higher ratios of exotics for smaller grained materials. Even the sand-size material in Olean drift may contain appreciable amounts of exotics. The use of a ratio between purple and red garnets was also found to be instructive. For example, high ratios (more purple than red) indicate a primary provenance from the Montreal, Canada, region via Lake Ontario and then southward transport of materials. The lower ratios (with increased red garnets) indicate provenance from either the north and central Adirondacks or the Canadian shield west of Toronto, Canada. These detailed studies are supportive of the glacial-flow model developed by Coates and Kirkland (1974) for movement directions of the ice sheet during advancal and retreatal phases.

The Laurentide ice sheet invaded the region, moving through the St. Lawrence Valley and Lake Ontario, then spread out, radiating southward from the Ontario Basin. The Adirondacks acted as a barrier to flow until ice thickness reached sufficient depths to overtop the mountains, which then become an outflow center. During deglaciation and ice thinning, glacial movement once again was restricted to flow through the St. Lawrence and Ontario areas. This chain of events would be largely repeated during each glacial stage of Quaternary time. During interglacial stages, the valley-fill sediments become reworked by fluvial processes and lay in wait for the next ice inundation to incorporate the gravels into the newest drift.

A problem still remains concerning what to do with the name "Olean". As Coates (1976b) indicated, it should only be used as a lithologic description for one type of drift. It cannot be used in a time-stratigraphic sense because the age of such materials range from perhaps 50,000 ybp (years before present) in some parts of the state to 13,000 ybp in other parts. Clearly it represents several different time episodes.

Till Distribution and Landforms

Till is widespread throughout the region and nearly ubiquitous on all hillslopes and uplands. However, it is not of uniform thickness. Although average till thickness is more than 60 ft, south-facing slopes contain six- to ten-times-thicker drift than north-facing slopes. The steep slope south of the SUNY-Binghamton campus is representative of those sites with thin till. Till thickness is also small in the high-level cols across which ice passed. The upland topography away from major valleys contain hills with pronounced asymmetry, with south-facing slopes only half as steep as those on the north. Such hills in the Binghamton area have an average relief of 340 ft. The asymmetry is a function of the amount of underlying drift. Thus the till thickness is usually more than 90 ft. on south slopes but less than 20 ft. on north slopes. At sites such as near Hawleyton (south of Binghamton) and at West Windsor (east of Binghamton) till thickness reaches 250 ft. These asymmetric topographic forms have been called "till-shadow hills" (Fig. 7) by

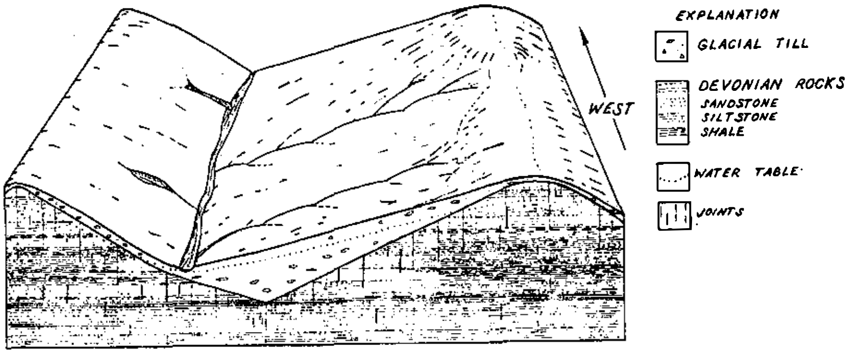


Figure 7. Diagrammatic sketch of a typical till-shadow hill.

Coates (1966) because the thick drift on the south is clearly a function of glacial deposition on the down-current side of an obstacle (in the same manner that water and wind deposits form on the lee side of a rock).

Till is also the primary constituent of several other landform types. Hubbard (1906) was the first to describe mounds of till in valleys which he compared to drumlins. He called them "drumlinoids", although they do not possess elements of streamlining. These small hills are rarely more than 60 ft high and contain slopes of 12-15 percent. They are restricted to valleys with roughly north-south orientation and occur as isolated hillocks within the valley. Castle Creek and Choconut Creek are typical sites where seven to eight of the forms occur along the valley trend. A detailed study has not been done of these forms, but it is known their composition is largely till with thicknesses to 100 ft.

Several other landforms comprised of till occur in the region. There are more than 20 examples of arcuate hollows near drainage divides of south-sloping valleys where lakes or wetlands have till mounds or ridges that help form the depression. St. Johns Pond (Fig. 8), Beaver Lake, Ansco Lake, Sky Lake, and Deer Lake are typical sites. Between Binghamton and Elmira, several north-draining valleys contain blockages of till hills. During deglaciation imponded waters behind the till plugs were forced to incise new channels, and in some cases, as at Tracy Creek, the new channel missed the old valley and was instead cut into bedrock. The

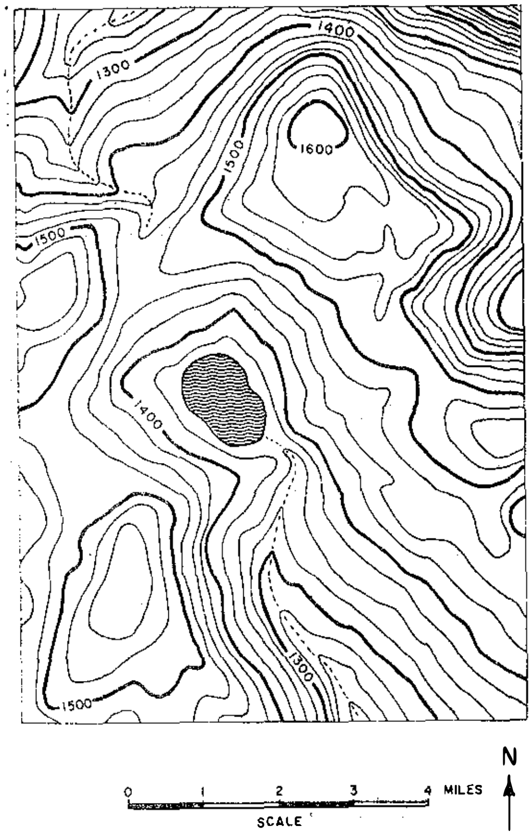


Figure 8. Simplified topographic map of St. Johns Pond area, north of Binghamton, N. Y. Drawn from U.S.G.S. Castle Creek, Quadrangle, 1:24,000 scale.

SUNY-Binghamton campus is built on still another variation of till landform...a ribbed moraine. This feature is a transverse ridge constructed of glacial deposits as the ice was ascending the valley sideslopes during its southward movement. Other examples of these moraines also occur in the region.

GLACIAL MELTWATER DEPOSITS

Glaciofluvial and glaciolacustrine deposits are largely confined to the valleys, but occur locally on valley walls. Valley fill in the major rivers, as the Susquehanna and Chenango, is rarely more than 200 ft, and for smaller streams is rarely more than 100 ft. The economic significance of such deposits should be stressed because the glacially-deposited sands and gravels are not only important mineral resources, but, where below the water table, comprise the only significant aquifers in the region. The texture of these deposits can be dependent on valley orientation as Coates (1972) has pointed out, and can even influence stream regimes (Fig. 9). For example, valley fill in south-draining

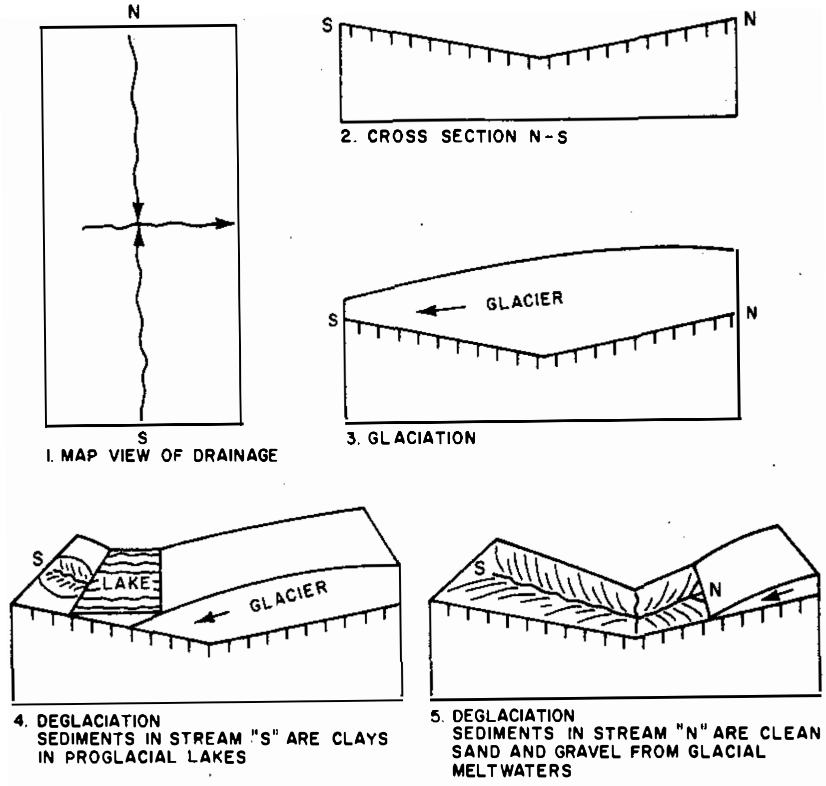


Figure 9. Diagrammatic sketch illustrating differences in meltwater sedimentation in north- and south-flowing stream channels.

valleys is coarser because the fines could be removed by free-draining meltwaters. However, in north-draining valleys, valley fill is finer because of increased blockages and ponding of water which prevented the flushing out of the fines.

South-central New York has a rather complete array of meltwater sediments and landforms they create. Good examples are abundant for both ice-contact deposits and outwash.

Eskers

The two largest eskers are those at Center Lisle (west of Whitney Point) and Oakland, Pennsylvania,(20 mi. southeast of Binghamton). The eskers are several miles long and reach heights of 100 ft. Several smaller eskers are present at some of the stagnant-ice sites such as north of Windsor and at Apalachin.

Kames

These hills composed of ice-contact sediments occur at numerous localities including Apalachin, Kattelville, Whitney Point, Windsor, Gulf Summit, Chenango Forks, and Tioga Terrace. They contain a wide assortment of sediment sizes and bedding characteristics. Many are composed of drab drift with appreciable contents of silt and clay. The best kame terrace and valley train in the region is immediately north of Binghamton at Hillcrest. It can be followed for several miles and forms a rather level surface upon which the community has been built.

At several localities, there is a mixture of both ice-contact features and outwash materials. The best example of this is the topography that forms Chenango Valley State Park and adjacent areas. Here 'dead-ice terrane' is prevalent throughout a several square-mile area. Much of the park contains many tens of kettle holes that formed when ice blocks melted within outwash materials creating a pitted outwash plain. Kame and kame-delta deposits occur both north and south of the park. Other occurrence of these features are in the dry valley north of the Chenango Bridge umlaufberg - the site of the former thalweg of the Chenango River.

Outwash Deposits

Outwash forms the great majority of meltwater deposits in terms of area covered and volume of sediments. These materials constitute the most productive sand and gravel operations (Stone, 1981), and are important aquifers for the villages of Endicott, Johnson City, and Vestal. These deposits are restricted to valley environments so their landform equivalent is referred to as a "valley train". Sediments in the Barney & Dickenson gravel pit typify such deposits. Here the materials are commonly well sorted and show cross bedding and other features indicative of the changing character of the meltwater streams that formed them.

Because there is an absence of well-defined recessional moraines in the region (as compared with the excellent development of such landforms in the Midwest) early workers argued whether the decay of the ice sheet occurred by a process of downwasting or backwasting. Cadwell (1972) and Kirkland (1973) tested the morphologic sequence model, first used successfully in New England, to determine if the same deglaciation characteristics were appropriate for the New York region. Indeed the model works. For example, in the Chenango Valley, Cadwell (1972) showed there were six primary zones of backwasting, with several smaller episodes within each major set (see Cadwell, this guidebook). Thus each zone is marked by a distinctive meltwater sequence that includes kames, kame deltas, and outwash materials all graded to the margin of an ice tongue in the valley.

PERIGLACIAL FEATURES AND HOLOCENE TIME

Periglacial processes can be important terrain sculptors in regions contiguous to ice margins or at higher elevations above the glacial ice. There is a variety of features that developed from periglacial activity in the Binghamton region. These include modest-size block fields, tors, patterned ground, and solifluction lobes. These landforms are especially well expressed in the Windsor quadrangle (USGS 1:24,000). King and Coates (1973) have described some of the forms, and especially call attention to the concavo-convex slope profiles which are so common throughout the area (Fig. 10). For example, southwest of Windsor, thick till deposits mantled the slopes along the tributaries of south-draining valleys. During the vigorous periglacial period, and probably prior to complete forest development, the hillslope materials underwent extensive creep and spread out as lobes into the valley. These solifluction lobes caused streams to take winding courses between the

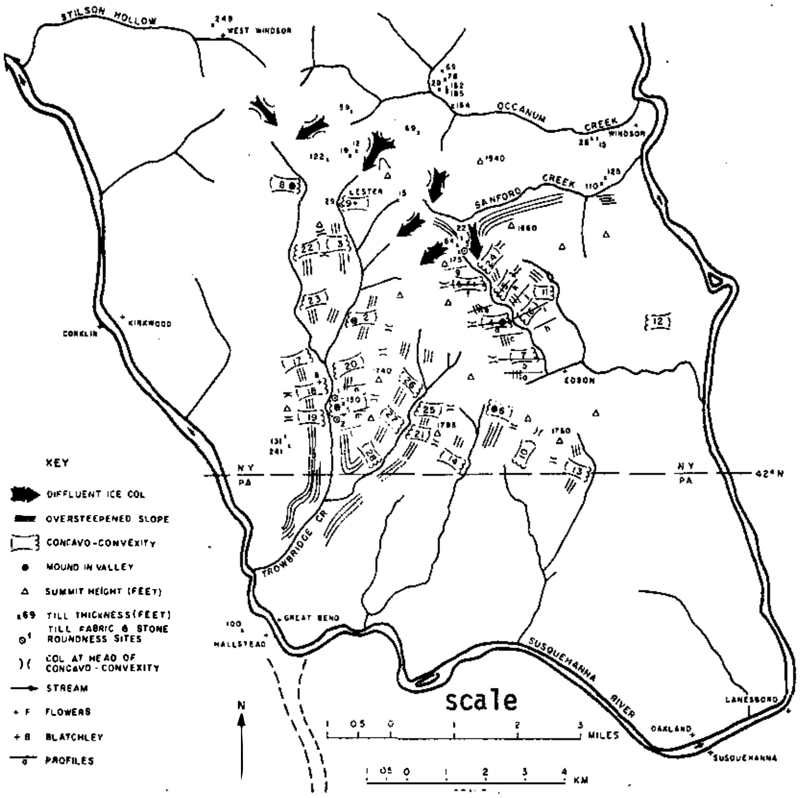


Figure 10. Distribution of periglacial-type concavo-convex landforms in the Windsor-Great Bend area of the Susquehanna. (From King and Coates, 1973).

east and west competing lobes.

Another indication of the absence of slope-stabilizing vegetation in the region is the occurrence of many alluvial fans. These developed in postglacial times when the hillslopes were mostly barren. Fluvial processes combined with sheet flow and mudflows to entrain and mobilize the surface materials and move them downslope into the larger tributaries. These deposits clogged the termini of the channels and built the alluvial fans which also diverted the channel of the master stream at the base.

Tors and small-scale rock cities can be found at a number of localities in the Binghamton area. These include the bedrock features at Ingraham Hill; Table Rock Ridge; Progy Hill; Penny Hill and Roskelly, Pennsylvania; and interfluves of Martin Creek, Pennsylvania. It is possible that other sites in the region may have undergone nivation processes with the creation of features that resemble nivation hollows and altiplanation surfaces.

The glens and waterfalls of the region also attest to a direct lineage from glacial times. Although these are fluvial features, they did not form from the usual fluvial landscape process. Instead they originated when a former fluvial valley was buried with till. During the re-establishment of drainage in postglacial times, the consequent stream failed to discover its former channel. Instead it started its new life at a position above bedrock which it thereby incised as a superposed stream. Doubleday Glen was thus carved more than 100 ft. into bedrock, and of course Watkins Glen and Enfield Glen in the Finger Lakes are prime examples of this type of heritage.

The major rivers of the region, such as the Susquehanna and Chenango, are now busily at work excavating the thick glacial valley-fill sediments. It is of interest to note that the Susquehanna does not contain the free-swinging type of meanders such as the Mississippi River. Instead there are many positions where the Susquehanna has occupied its same channel for more than 4,000 years. Other streams in the area also have unusual qualities and many are misfit. Some, such as the Tioughnioga River, are overfit, a condition where the stream should have carved a larger valley. Many other are underfit, where the valley is much too big to have formed from the small amount of water the stream now carries.

The valley-fill sediments are not exclusively glacial in age. Holocene deposits have been dated at several sites where they overlie glaciofluvial materials. At the junction of Little Choconut Creek with the Susquehanna River, floodplain silt was dated by wood fragments 6-8 ft below the ground surface as being 1690 ± 100 ybp. At another site on the west side of the Bevier Street Bridge, Chenango Valley sediments with wood and other organic materials were encountered in test well borings. Sediments at a depth of 24 ft were 2648 ± ybp, and those at 45 ft were 3801 ± 60 ybp. These deposits occurred in an environment interpreted to be kettle holes that had been infilled with more recent materials (Randall and Coates, 1973).

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ROAD LOG FOR WESTERN CATSKILL - GREAT BEND AREA

The purpose of this trip is to examine geomorphology in the region to the east and south of Binghamton. The evolution of the Chemung, Delaware, Susquehanna, and Tioughnioga Rivers will be discussed. A variety of erosional features will be seen and much emphasis will be placed on glacial deposits and the landforms they create. The starting point of the trip will be the upper part of the SUNY Binghamton campus.

CUMULATIVE MILEAGE	MILES FROM LAST POINT	ROUTE DESCRIPTION
0.0	0.0	STOP 1.

STOP 1. CAMPUS OVERVIEW. This site is the southernmost of three east-trending ridges which comprise a ribbed moraine sequence. The SUNY campus is situated on two of the ridges. Furthermore, the campus is nested in a reentrant in which the bedrock hillslopes have a scalloped form. Roundtop Hill, an umlaufberg, can be seen to the north. The drainage divide to the south contains a col, or saddle, which was the position for override by the glacier. The moraine is composed of bright till (Binghamton-type) with a fabric transverse to the ridge (or parallel with ice transport). Bedrock is more than 120 ft below land surface. All glacial deposits on this trip are Late Wisconsinan. Embark. Travel east on ribbed moraine with SUNY nature preserve and wetlands to south.

1.0	1.0	East entrance of SUNY campus. Continue east to Murray Hill Road and turn right (south).
1.4	0.4	STOP 2.

STOP 2. STAIR PARK. Walk into park going south along Fuller Hollow Creek. Stream flows on bedrock, yet the floodplain appears to be in alluvial materials. Why has stream chosen a more difficult channel to occupy? Walk to 30-ft exposure of bright till (Binghamton lithology). What is the fabric of the till? Within Fuller Hollow there are good examples of fabric wherein some show extending flow and other compressing flow characteristics of the glacier. Such bright drift shows the history of materials. The ice moved south over the valley-fill sediments of the Susquehanna River, incorporating them into the basal load and then depositing them south of the river along thrust planes as the ice was forced to move up and over the hillsides. South from this stop the drift changes composition, passes into a transitional facies and finally becomes true "drab" till (Olean lithology) higher up on the hillsides. Embark. Travel north on Murray Hill Road.

2.1	0.7	Route 434. Turn left (west). In distance note the Roundtop Hill umlaufberg. The highway uses the meltwater channel that separates the hill from the former upland parent spur to the south.
2.6	0.5	Turn right on Johnson City bridge over the Susquehanna River and travel to Oakdale Mall area. The river flows west on valley-fill sediments about 200 ft thick comprised largely of glaciofluvial and glaciolacustrine materials. Near Route 17, wood at about an 8-ft depth in alluvial materials was dated at 1690 ± 100 ybp.
4.7	2.1	STOP 3.

STOP 3. This 25-ft exposure east of Oakdale Mall consists of drab till (Olean lithology). This is typical of lodgment till plastered on the south sides of hills that produce asymmetry of hills, or the "till-shadow effect". What type of fabric would you anticipate from such a depositional environment? Embark and travel to Route 17 going east at Exit 70.

6.4	1.7	Bedrock exposure of Upper Devonian Rhinestreet Formation consists of marine shale with some siltstone.
8.7	2.3	Chenango River. Note floodwalls, and revetment-type levees (armored with riprap) built by U.S. Army Corps of Engineers. Near this site, floodplain sediments in a former kettle were dated at 3801 ± 60 ybp at a 45 ft-depth. Thickness of valley-fill is about 200 ft.

9.1	0.4	Turn right toward I-88 and Route 7 going north, exit 72N.
9.6	0.5	Binghamton brickyard and hillside quarrying of Rhinestreet Formation. The highway is adjacent to old Chenango Canal that connected Binghamton with the Erie Canal. The trend of the canal along here is called the "tow path" by residents.
12.3	2.7	Exposure of kame-terrace valley-train sediments that comprise Hillcrest. Note highly cemented character of materials.
13.2	0.9	Turn left over Chenango River at Chenango Bridge. Here valley fill is less than 100 ft thick. Note the umlaufberg, which is double crested. This part of the valley is more youthful because river was diverted from its earlier course on north side of umlaufberg. Keep right on north side of bridge, through stoplight and travel on Kattelville Road.
14.8	1.6	Turn left on Prentice Road. Note the route has been along west side of umlaufberg into the old valley of the Chenango River. This is now a "dry valley" filled with a congestion of glacial deposits and sand and gravel pits.
15.1	0.3	STOP 4.

STOP 4. ROSE GRAVEL PIT (now owned by Barett Paving, Inc.). Travel into east part of pit, 1.2 mi. These materials occur in a very complex sedimentary environment. This can be considered a pitted outwash plain (sandur), that also includes valley train, kame, kame terraces, and extensive progradational deltaic sequences. Although the deposits were formed during a single glacial stade and are comprised by materials of the same general provenance, there is great heterogeniety in the sediments from outcrop to outcrop. Thus the pit contains both pure outwash-type sediment as well as ice-contact deposits. There is a full range of textures from clay to silt, sand, gravel, cobbles, and boulders. Bodies of till also occur within some sequences. The extent, both laterally and vertically, of the cemented units pose serious problems for the miner. Geologically the problem is to determine the origin and time of cementation. For example, did it form in the vadose or groundwater zone? Did it form soon after deposition, or later in the Holocene? Aber (1979) has attempted to answer some of these points. Although much of the material is bright, there are also occurrences of drab drift. Why? Embark and continue on Prentice Road to Route 12.

16.7	1.6	Route 12 turn right (east).
17.7	1.0	Highway ascends a wind gap. This is one of three high-level notches along a north-trending ridge formed as overflow channels when ice occupied the Chenango Valley and meltwater streams discovered high outlets.
20.6	2.9	STOP 5.

STOP 5. CHENANGO FORKS. This is junction of the Chenango River flowing southwest and the Tioughnioga River flowing southeast. The exposure typifies the many different sedimentary features at junctions of two different ice lobes, with contrasting histories and meltwater regimes. This is a kame environment with deposits that range through glaciofluvial, glaciolacustrine, and unsorted materials. What is the origin of the large bouldery unit? Possibilities include flowtill, mudflow - debris flow, ablation till, etc. Are there others? Embark and travel north on Route 79.

21.9	1.3	STOP 6.

STOP 6. LANDSLIDE. This landslide consists of a series of slumps that cover a 7-acre area. It was caused when the road was cut into the lower hillslope. The increased slope and removal of material destabilized the materials. The hydraulic head increased and drainage from a road above the slide funneled water onto the mass. The hillside materials are composed of sediments susceptible to piping which enhance lubrication and movement of materials in the mass. Some pipes have been measured to be about 2 ft in diameter and extend many feet into the hill. The south side of the area is composed of drab till. Most of the slide occurs in glaciolacustrine silt and fine sand with clay more than 60 ft thick. Glaciofluvial beds occur immediately north of the slide area. What was the environmental setting when the deposits formed? Embark and travel north.

22.2	0.3	Bedrock.
22.5	0.3	Drab (Olean lithology) till. These sequences are typical of the Tioughnioga River, a multicycle sluiceway or beaded river. The river is anomalous because it flows southeast across the structural grain of the region. The valley alternates between narrow walls which are younger parts of the system, and wider valleys which represent positions where the river discovered its previous valley. Return south to Chenango Forks.

22.4	1.9	Turn left at Chenango Forks and then take first right over the Chenango River to Pigeon Hill Road and continue south. The road passes between many kettles which comprise this pitted valley train. Cadwell (1972) dated peaty materials in a kettle as 16,650 ± 1,800 ybp.
27.2	2.8	Old gravel pits on both sides of road. Sedimentation is outwash type.
27.8	0.6	STOP 7.

STOP 7. CHENANGO VALLEY STATE PARK. Drive to parking lot near twin lakes. Separating Lily Lake to the north and Chenango Lake to the south is a crevasse filling. The lakes occupy kettle holes. The park contains tens of kettles of various sizes. These were stranded "land icebergs" that were overwhelmed by meltwater deposits when active ice was to the north. Embark from park going east to Route 369.

29.4	1.5	Route 369 south, turn right.
30.0	0.6	Turn right at Virginia City. STOP 8.

STOP 8. HALE GRAVEL PIT. Good example of outwash deposits. Bedding shows characteristics of the shifting meltwater channels that provided avenues for deposition of the materials. Although these are outwash deposits, they contain deleterious ingredients and so fail to pass state (magnesium sulfate soundness test) requirements for use as highway concrete (>18 percent loss on 10-cycle test). Why? What is the lithology of the sediment?

31.5	1.5	Return to Route 369 and turn right going south.
33.9	2.4	Bedrock. The Chenango River enters a more youthful part of its system, with the umlaufberg separating it from the former thalweg. Bedrock in or near a stream invariably means the channel is not located at the major thalweg.
34.9	1.0	I-88 going east.
44.1	9.2	Belden Hill. One of highest elevations in this area. Drainage divide between the Susquehanna and Chenango Rivers.
46.8	2.7	Take Route 79 south through Harpursville.
48.3	1.5	On east side of Susquehanna is "The Plains" one of largest terraces in the region. Along the road there are many stagnant ice features.
49.2	0.9	Start of 0.6-mi - long esker that parallels the highway on east side.

51.2	2.0	Turn east over bridge at Ouaquaga and bear left on other side of bridge. The road arcs around the Windsor umlaufberg.
54.2	3.0	STOP 9.

STOP 9. TOWN OF WINDSOR GRAVEL PIT. Turn right onto dirt road and proceed to working area. This is a beautiful "textbook" example of a kame, a hill composed of ice contact deposits. Meltwater erosion was responsible for dissecting the umlaufberg from the upland connection to the east. The deposits fall within the range of drab lithology and contain glaciofluvial, glaciolacustrine, and poorly to unstratified drift. What is the origin of the latter? Embark, travel east to East Windsor Road and south to old "17".

55.4	1.2	Note kame-and-kettle topography and the character of the umlaufberg,which can be considered "youthful" because of the lack of tributaries on it and the adjacent highlands.
57.6	2.2	Turn east (left) on old "17".
59.2	1.6	Damascus. Continue east on old "17" which now rises on a steep grade up Tuscarora Mountain.
61.4	2.2	Sky Lake, one of three natural lakes in Fly Creek. This is drainage divide between the Delaware and Susquehanna Rivers. We are now in the Catskill Mountains, both geologically and geographically. The bedrock now consists mostly of terrigenous sandstone. Relief is 1500 ft and more, and the Delaware system drains the west and southwest part of the mountains.
62.0	0.6	Deer Lake, second in the lake chain in Fly Creek.
64.2	2.2	STOP 10.

STOP 10. FLY POND. Picture stop. A till barrier imponds this and the others have similar dams. What is the origin of these barriers? Depth to rock is reported to be 160 ft in the valley. There are also two smaller till mounds in Fly Creek. Embark and continue east on old "17".

65.8	1.6	STOP 11.

STOP 11. KAME DELTA. At 1450 ft elevation this is an unusually high level deltaic deposit. However, it forms part of the large picture with a major lake that occupied the Gulf Summit area.

66.2	0.4	Turn left (south) toward Gulf Summit. Note this area appears to be a major topographic low. Within it are numerous kames and kettles.
70.3	4.1	Travel down road and observe character of the drainage divide at Gulf Summit. Return to railroad and view the deep bedrock notch. This was the spillway for drainage of the proglacial lake that occupied this topographic low. Although Wisconsinan-age meltwaters helped to incise the lowermost 70 ft, the higher features may have been initiated during earlier glacial stages.
70.5	0.2	Turn left on dirt road going southeast.
71.1	0.6	STOP 12.

STOP 12. VIEW OF SPILLWAY AND OVERFLOW CHANNEL. This is headwater area of Cascade Creek, a Susquehanna River tributary. The Catskill sandstone shows vestiges of stream erosion. North of the road the hillslopes contain varying degrees of blockfields, a reminder of periglacial climatic conditions. Embark and continue southeast on dirt road.

76.6	5.5	Turn south (left) on blacktop road toward triple cities of Pennsylvania, Lanesboro, Susquehanna, and Oakland. This is the Great Bend area where Susquehanna River arcs from a south flow, to an east flow, then a north flow. The unusual stone masonry bridge was built in 1848 by a Scotsman, Kirkwood, after several earlier contractors had gone broke attempting to build a span across the valley. Route 171 going north.
78.9	2.3	Cross bridge and Susquehanna River and turn right.
79.5	0.6	STOP 13.

STOP 13. OAKLAND ESKER, largest in the region, with total length about 4 mi. Here it is on north side of the river but it can be followed northward where the river has incised it and the esker continues again on east side of river. The esker is not a simple ridge, but is double in several parts, such as near the outlet on the west side of Oakland. Side slopes are steep and esker exceeds a height of 100 ft. At the top there are depressions and undulating topography. Exposures here and at other outcrops show bedding ranging from horizontal to some units whose dips exceed 45°. Till and flow till are interpreted to be part of some sequences. The sparse number of exotics indicate the drift is drab type. Was this a supraglacial (open to the sky) or subglacial esker? Return to Route 171 and continue west.

81.4	1.9	Western limit of esker.
88.3	6.9	Penny Hill on north side of road. There is a "rock city" at top of the hill, another indication of periglacial conditions.
88.8	0.5	Take I-81 going south out of Great Bend, Pa.
91.2	2.4	Hanging delta on east side of highway. This is the valley of the north-flowing Salt Lick Creek. The straightness of the valley, truncation of spurs, and anomalous southern extension indicate valley sculpture by ice and meltwater erosion.
96.1	4.9	Exit on Route 492 to New Milford and to Route 11.
96.8	0.7	Turn south on Route 11 at New Milford and enter the New Milford sluiceway.
98.3	1.5	The most recent meltwater erosion starts here.
98.9	0.6	STOP 14.

STOP 14. PICTURE STOP FOR THE NEW MILFORD SLUICEWAY. This is the south-trending Martin Creek valley, with bedrock walls of Catskill cross-bedded sandstone. This is a "youthful" type or first-cycle sluiceway because of the imperfect development of tributaries and absence of till. The feature was developed when meltwaters from a proglacial lake to the north drained south through spillways formed during earlier glacial times. The Great Bend region had a long and involved history throughout Quaternary times. The unusual geometry of the Susquehanna River implies it is an ice-marginal valley, such as parts of the Missouri and Ohio Rivers.

100.9	2.0	Return to New Milford and proceed north via Route 492 and I-81.
106.4	5.5	STOP 15.

STOP 15. HANGING DELTA. This delta owes its development to events in Little Egypt Creek, the north-flowing stream on the east side of Maunatome Mtn. Along this north-south ridge there are a series of high-level notches occupied by ice and meltwaters during different glacial and proglacial times. Drainage in Little Egypt was blocked by ice to the north causing the eventual overflow of the proglacial lake into Salt Lick Valley, where another lake received the sediments. Typical deltaic structures occur: topsets, foresets, and a general lobate pattern of strata that dip away from the central core. The materials are drab and currently used by the Pennsylvania Highway Department. The deposits are more than 150 ft thick. How did the massive sandstone block become emplaced within the sediments? Continue north on I-81 to New York State line.

115.0	8.6	Take Kirkwood exit and bear right.
115.3	0.3	STOP 16.

STOP 16. DOUBLEDAY GLEN. The Rhinestreet Formation forms bedrock of the area. Note the fabric of unconsolidated materials on top of rock. This is colluvium. Although composed of till it is not in place, having moved downslope by solifluction processes which produced the preferred orientation of the slabby clasts. Walk into the glen. Evolution of this feature is somewhat similar to the famous Finger Lake glens. They developed during postglacial time when a high-level consequent stream starts its new trajectory. Because till covered the preglacial valley and diverted streams to the south, many of the newly developing consequent streams were forced to carve new bedrock chasms. Thus when streams miss their former valleys, they incise rock and form narrow, steep-walled valleys. Where former valleys were encountered, the walls are gentler, not in rock, and wider. Return to I-81 toward Binghamton.

122.2	6.9	New York State Hospital built on unusual till knob. What is its origin?
131.6	9.4	Return to SUNY campus via Route 17 and Exit 70S.

FIELD GUIDE MAP