GEOLOGY 106

FIELD TRIP ACROSS THE

APPALACHIAN OROGENIC BELT

Saturday, April 30, 1994

STOPS:

1. Windy Hills Bridge, Newark DE
2. Rock Church, Fair Hill MD
3. Gold 'N Green Quarry, Parkesburg PA
4. The Bike Store, Mohnton, PA
5. Stone Cliff Park, Reading PA
6. PA 61, Shoemakersville, PA
7. Blue Mountain, PA
8. Deer Lake, PA
9. Lavelle I, PA
10. Lavelle II, PA
11. Lavelle III, PA
12. PA 901, Excelsior, PA
13. Bear Valley strip mine, Shamokin, PA

FIELD TRIP ACROSS THE APPALACHIAN OROGENIC BELT

April 30, 1994

Welcome to the Geology 106 field trip. Welcome also to GEOL 110 and GEOL 667 and other students. This trip is a group outing, during which you will see a lot of rocks, learn a lot of new concepts, cement a lot of familiar concepts, and make connections between the old concepts and the new ones. This is a trip of integration, of synthesis, of new awareness. So oil your mental engines, sharpen your observation skills, crank up the memory, clear out your voice to ask questions, and prepare to have a rocking-good time.

On the trip you will cross the Appalachian orogenic belt from one side to the other (well, nearly the other), and you'll see representatives of all the major rock types and structural zones in the belt. We'll make 13 stops (if we stay on schedule). We'll trace the history and evolution of the eastern side of North America through about 450 million years of earth history, from late Precambrian to Jurassic. We'll experience Paleozoic history in caricature. We'll be able to integrate what we see today with material from the textbook and the laboratory exercises. By the end of the day you will have a better, more holistic view of what an orogenic belt is, and how deposition and deformation interplay to create a mountain range.

A WORD ABOUT SAFETY:

There is a **DEFINITE NEED** on this trip to keep your wits about you at all times, to **THINK SAFETY** at all times, and to stay alert when you're off the bus. Most of the outcrops are in road cuts with active auto and truck traffic, and the rest are along active railroads or in mines. The need to **THINK SAFETY** cannot be overstressed. The roadways are all busy, high-speed ones, and motorists don't take kindly to students standing on the actual driving-lane pavement rather than on the shoulder. Follow these two guidelines to the letter, please:

1. Never (repeat, **NEVER**) step onto the active traffic lanes. Stay on the shoulders, and preferably behind the guardrails.

2. Always think ahead; be aware of where your next step is going, make sure that place is firm and safe. Don't jump from rock to rock; step from rock to rock. Never get off-balance; that's when falls and twisted ankles happen.

REGIONAL GEOLOGIC SETTING

The next several pages contain maps of the Appalachian orogenic belt, but no explanatory text; if I wrote a regional geologic setting there wouldn't be a guidebook at all. We'll discuss these maps on the outcrop, and build the regional setting as the trip progresses.

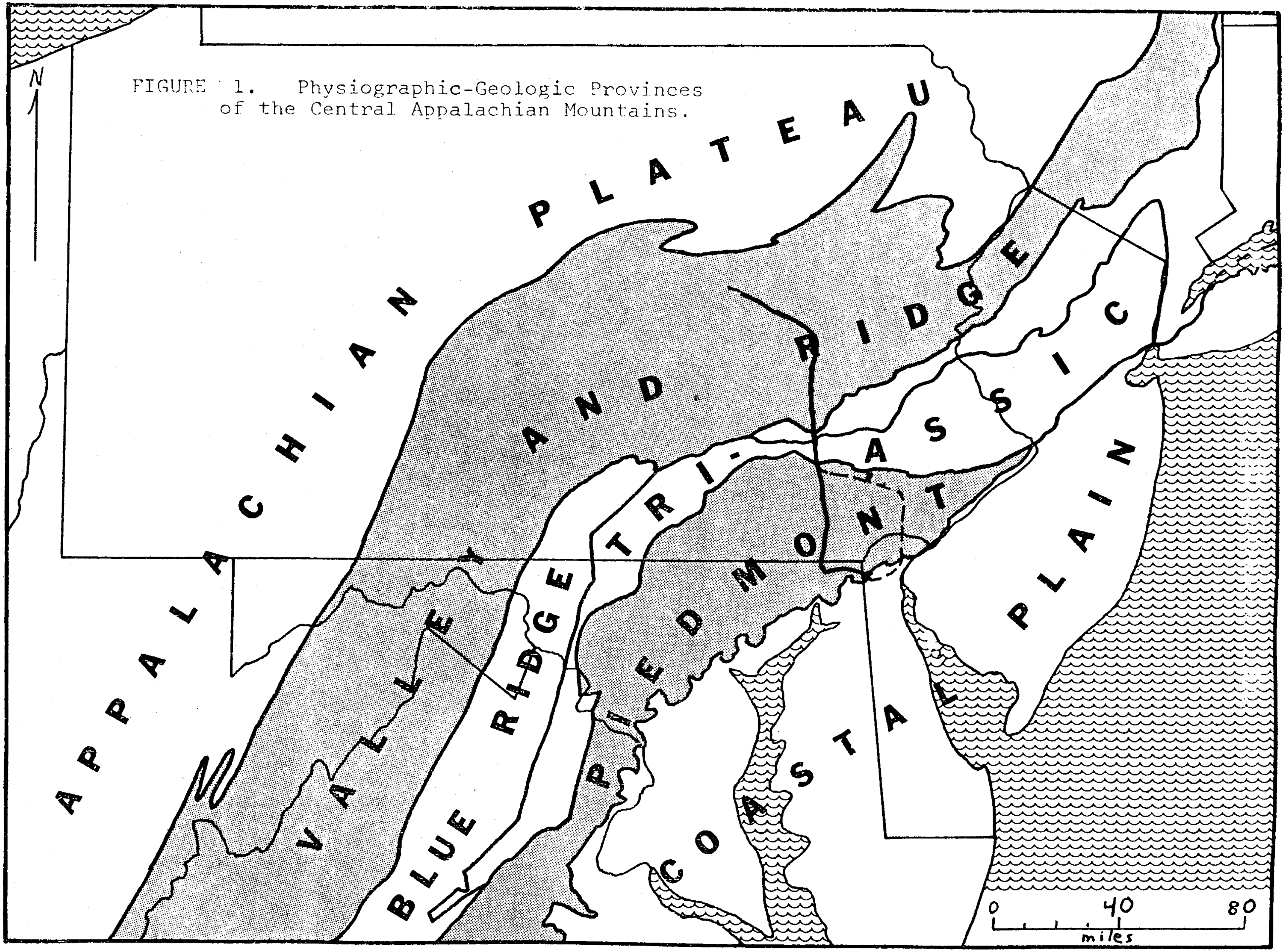


FIGURE 1. Physiographic-Geologic Provinces of the Central Appalachian Mountains.

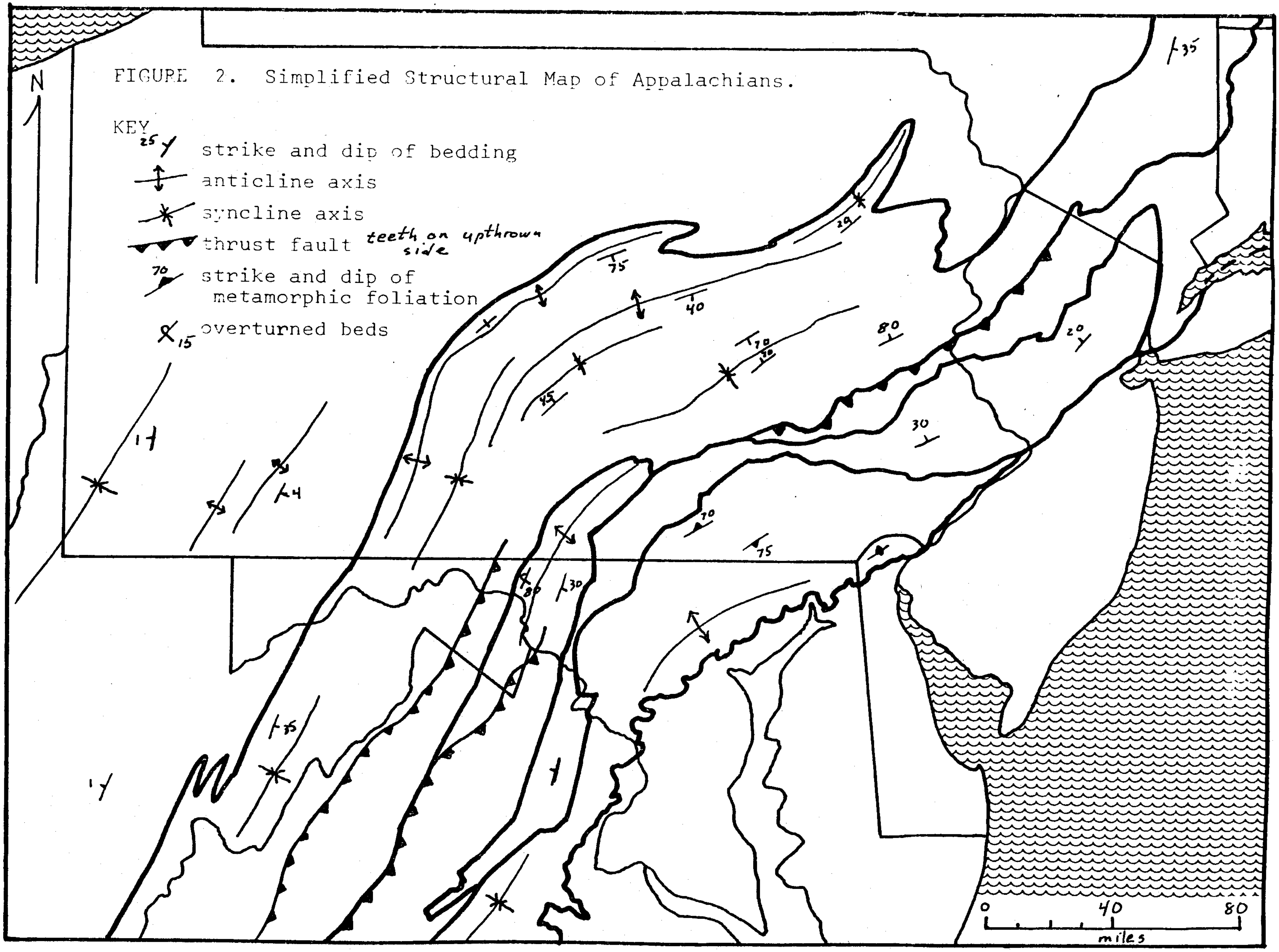


FIGURE 2. Simplified Structural Map of Appalachians.

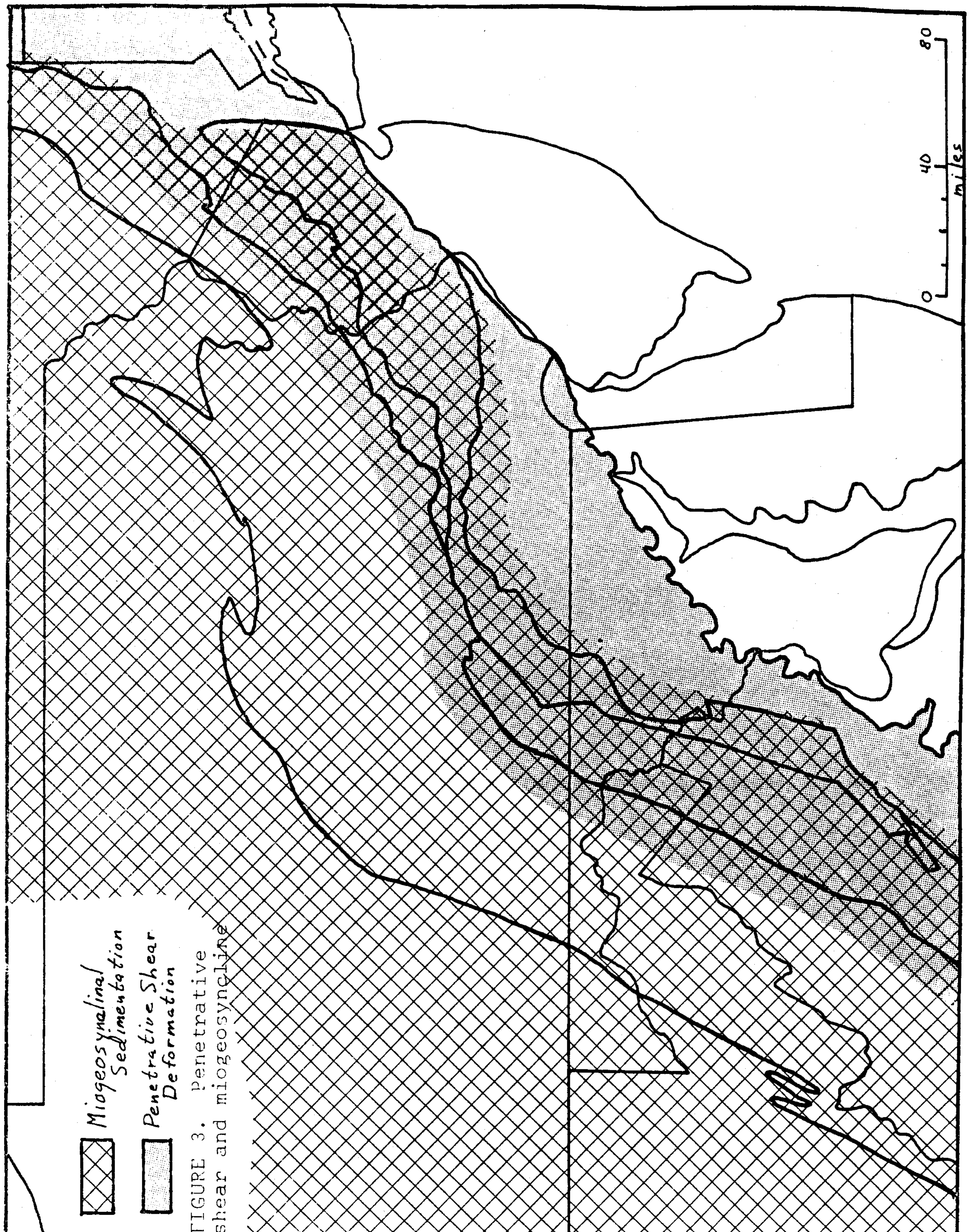
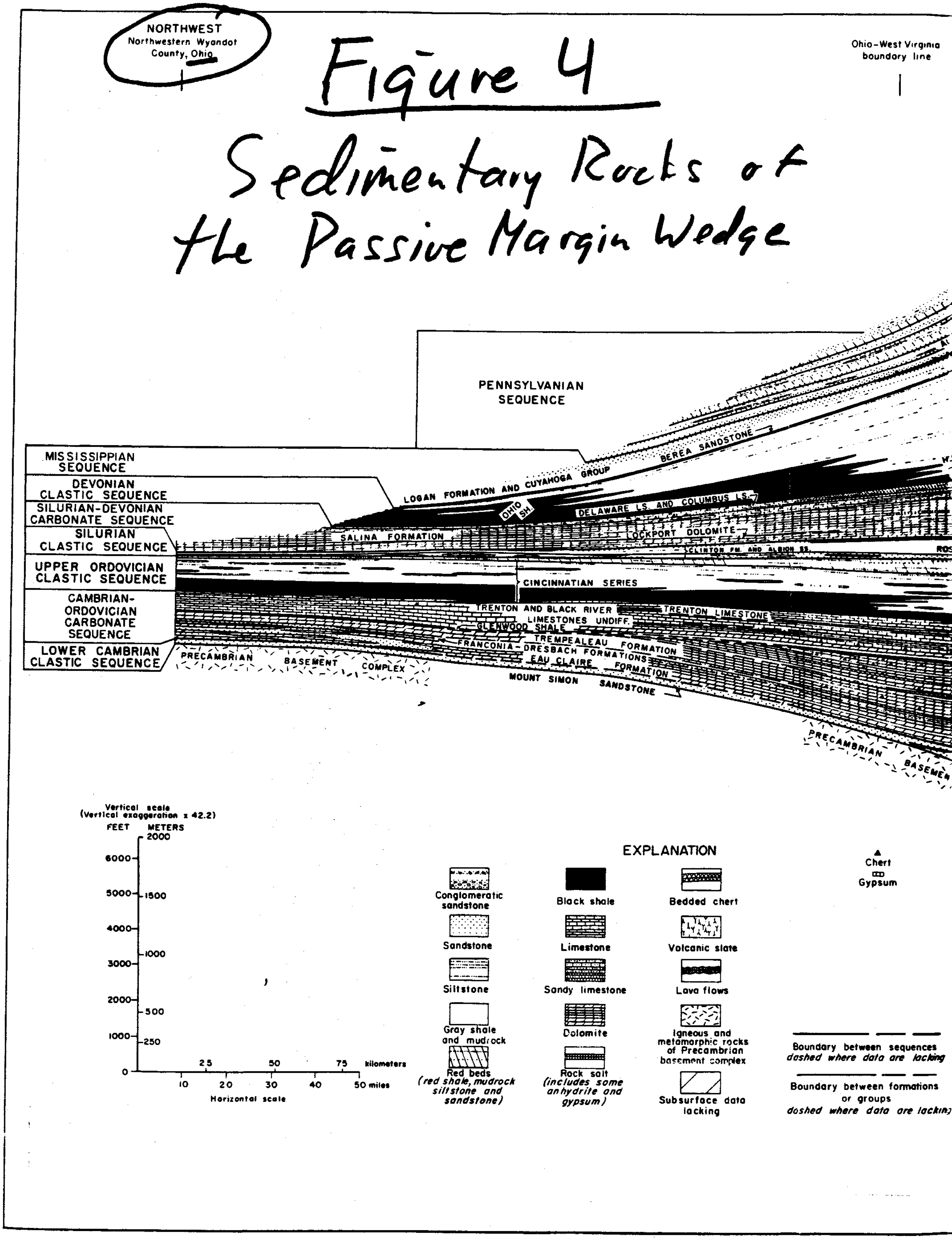
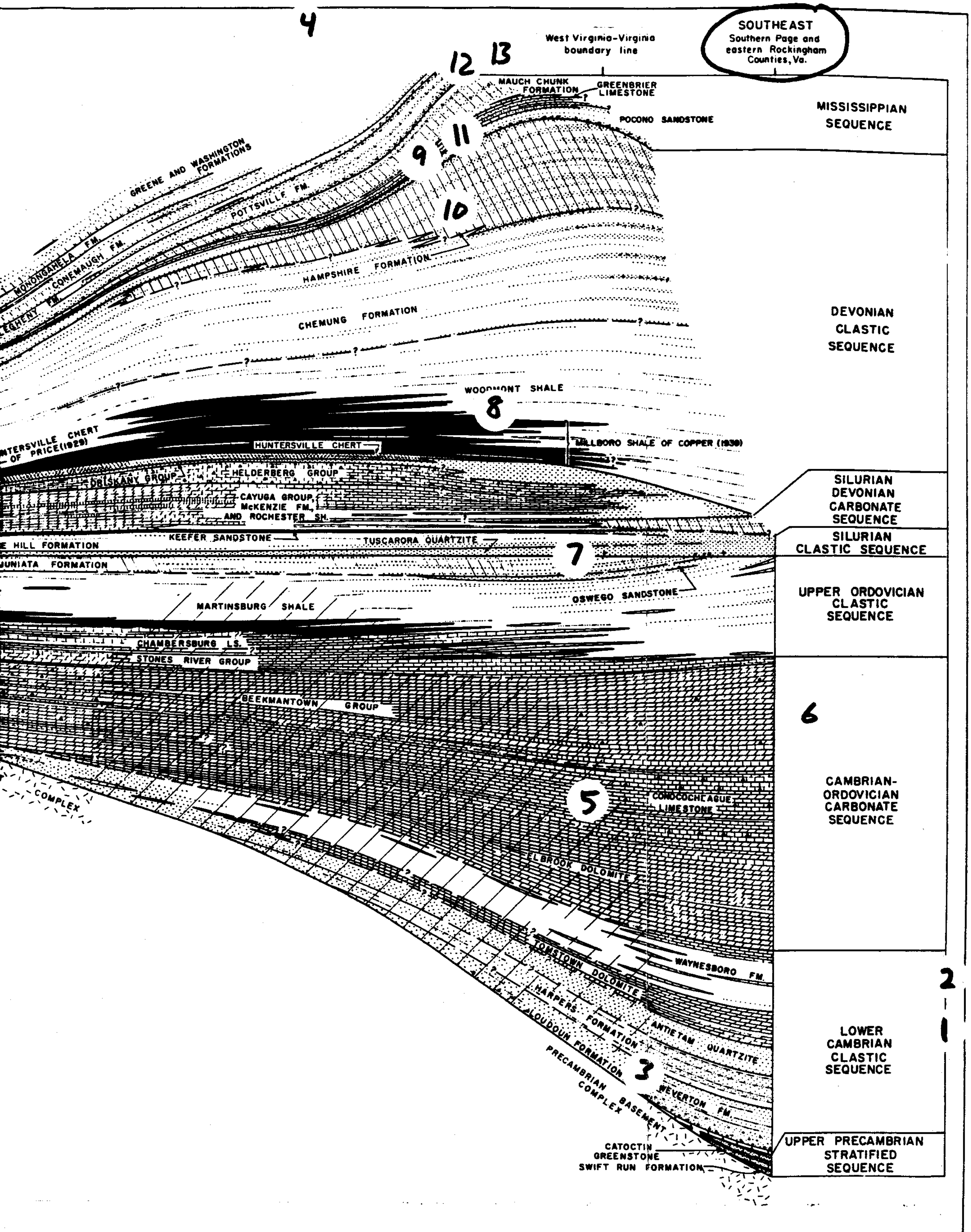


FIGURE 3. Penetrative shear and miogeosyncline

Figure 4

Sedimentary Rocks of the Passive Margin Wedge





SOUTHEAST
Southern Page and eastern Rockingham Counties, Va.
West Virginia-Virginia boundary line
MAUCH CHUNK FORMATION
GREENBRIER LIMESTONE
POCONO SANDSTONE
GREENE AND WASHINGTON FORMATIONS
MONONGAHELA FM.
CONEMAUGH FM.
ALLEGHENY FM.
POTTSVILLE FM.
HAMPSHIRE FORMATION
CHEMUNG FORMATION
WOODMONT SHALE
HUNTERSVILLE CHERT OF PRICE (1929)
HUNTERSVILLE CHERT
MILLBORO SHALE OF COPPER (1930)
ORISKANY GROUP
HELDERBERG GROUP
CAYUGA GROUP, McKENZIE FM., AND ROCHESTER SH.
KEEFER SANDSTONE
TUSCARORA QUARTZITE
JUNIATA FORMATION
OSWEGO SANDSTONE
MARTINSBURG SHALE
CHAMBERSBURG LS.
STONES RIVER GROUP
BEEKMANTOWN GROUP
CONOCOCHEAGUE LIMESTONE
ELBROOK DOLOMITE
WAYNESBORO FM.
TOMSTOWN DOLOMITE
HARPERS FORMATION
ANTIETAM QUARTZITE
LOUDOUN FORMATION
WEVERTON FM.
PRECAMBRIAN BASEMENT COMPLEX
COMPLEX
CATOCTIN GREENSTONE
SWIFT RUN FORMATION
MISSISSIPPIAN SEQUENCE
DEVONIAN CLASTIC SEQUENCE
SILURIAN DEVONIAN CARBONATE SEQUENCE
SILURIAN CLASTIC SEQUENCE
UPPER ORDOVICIAN CLASTIC SEQUENCE
CAMBRIAN-ORDOVICIAN CARBONATE SEQUENCE
LOWER CAMBRIAN CLASTIC SEQUENCE
UPPER PRECAMBRIAN STRATIFIED SEQUENCE
4
12
13
11
9
10
8
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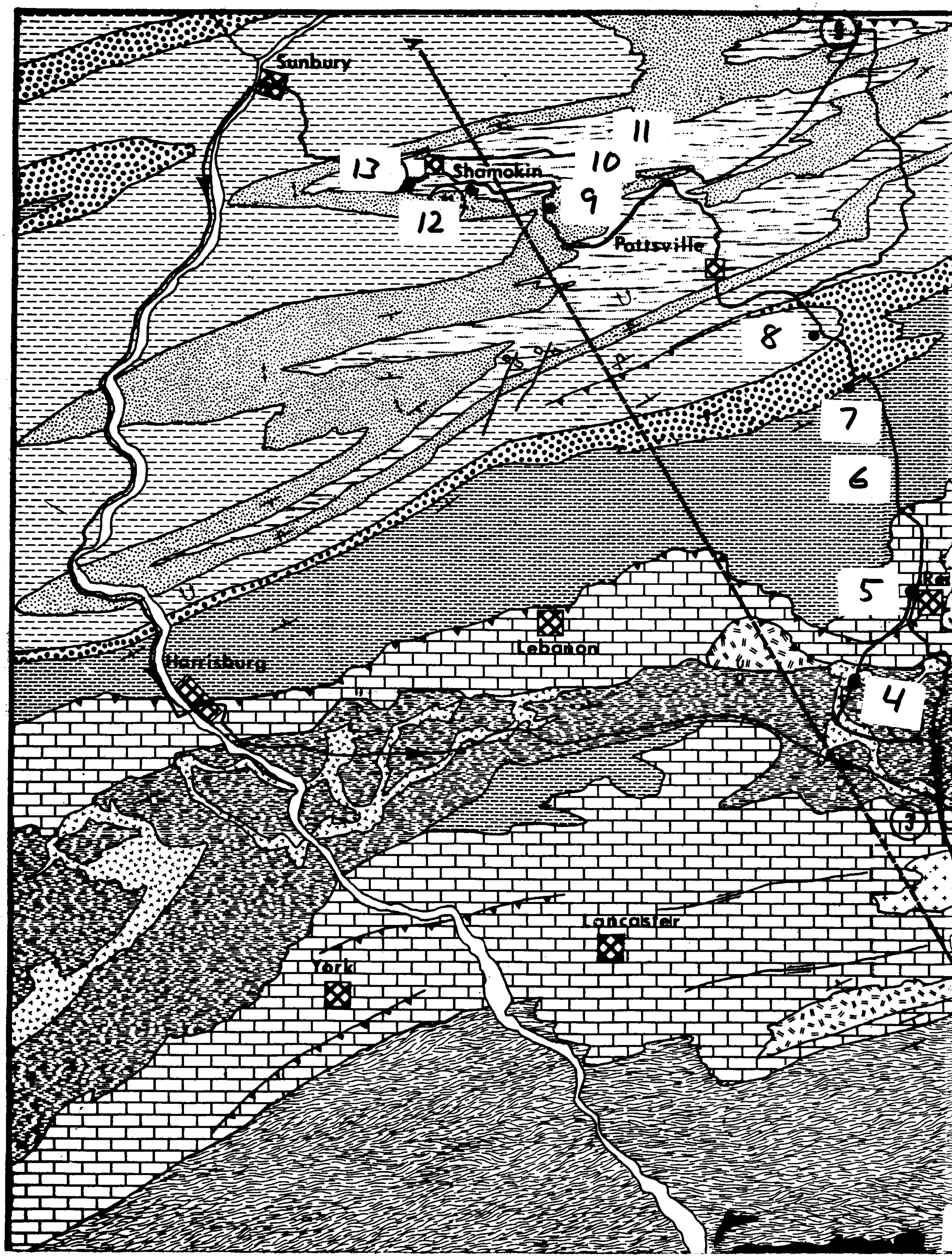
3
2
1



Sunbury
13
Shamokin
12
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Pottsville
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7
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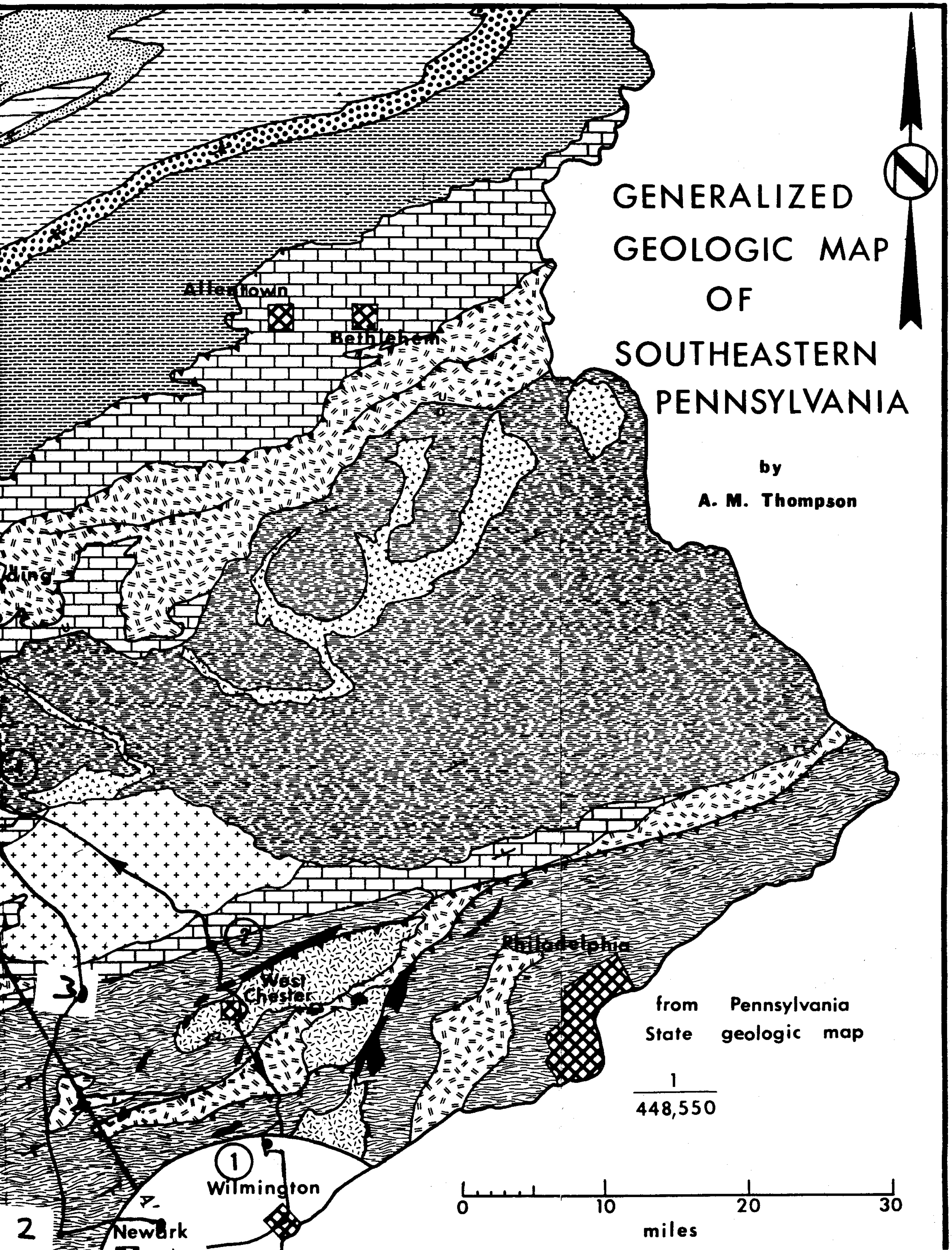
4
3
Lebanon
Harrisburg
Lancaster
York


GENERALIZED
GEOLOGIC MAP
OF
SOUTHEASTERN
PENNSYLVANIA
by
A. M. Thompson
N
Allentown
Bethlehem
Philadelphia
West Chester
Wilmington
Newark
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2
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from Pennsylvania State geologic map
1/448,550
0
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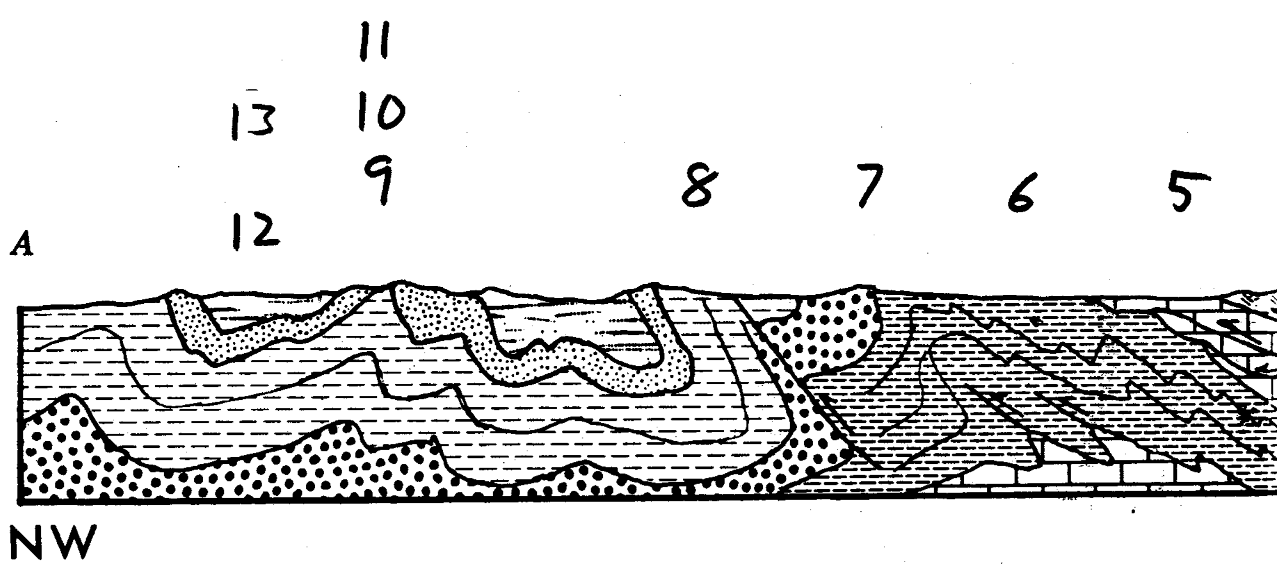
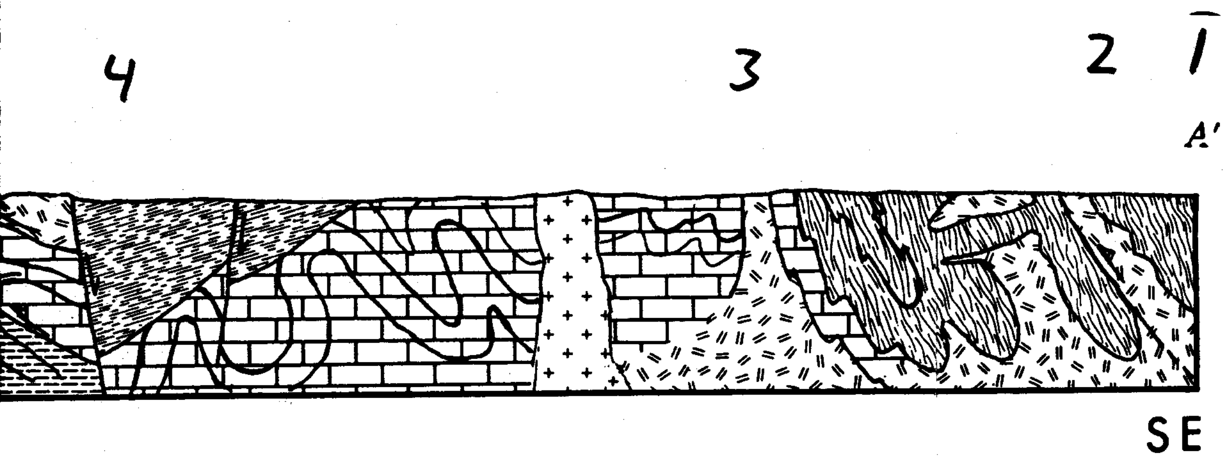


SCHEMATIC CROSS-SECTION A



ALONG LINE A-A'

STOP 1: **WINDY HILLS BRIDGE**

Stop 1, 2 and 3 lie in the **PIEDMONT PROVINCE** of Figure 1, and also in the **penetrative shear deformation** zone of Figure 3. Stops 1 and 2 lie east of the zone of **miogeosynclinal sedimentation**.

The rocks here belong to the **JAMES RUN FORMATION**, of Cambrian or latest Precambrian age. They are **intensely deformed and metamorphosed**, and they are an excellent example of rocks in the core zone of an orogenic belt. They are strongly layered rocks; they may have been sedimentary rocks at one time, or they may have been volcanic rocks, or the layering may have been generated by the processes of deformation. It's hard to tell.

These rocks are some of the most interesting and puzzling in Delaware. Delaware contains just a small segment of the Appalachian orogenic belt, running NE across northern New Castle County. The rocks exposed in Delaware are some of the most intensely deformed and highest-grade-metamorphic rocks in the entire Appalachians.

Regardless of whether the rocks were originally sedimentary or volcanic, they almost certainly originated in an **orogenic setting** rather than a cratonic one.

Look for the following features in the rocks:

- **HIGH-GRADE METAMORPHIC ROCKS**: the rocks here are alternating light and dark **gneisses** and **schists**. The schists contain abundant mica, and the gneisses contain abundant quartz and feldspar. Two distinct varieties of gneisses can be seen. One is **amphibolite**, a dark green to black rock. The other is **quartz-feldspar gneiss**, a light-colored rock. These metamorphic rocks used to be other kinds of rocks before they were metamorphosed; it's hard to determine what the parent rock types were.

- **IGNEOUS ROCKS:** there are streaks and small masses of **granite** here and there. The granite contains quartz, K feldspar, plagioclase feldspar, and a little mica. Note the granite is massive and not layered, there is no preferred orientation to the grains. The granite is coarse-grained, and because of the large grains is termed **pegmatitic** granite.

- **SEDIMENTARY ROCKS:** unconsolidated muds and sands in the bank above the hard rocks. These sediments are probably part of the floodplain of White Clay Creek.

- **UNCONFORMITY:** angular unconformity between flat-lying, very young sediments of the floodplain above, and strongly deformed, very old, metamorphic rocks beneath. Put your hand on it. 600 million years of earth history are not represented across that very narrow boundary.

  The sediments above the unconformity represent materials belonging to the Atlantic Coastal Plain geologic province. This outcrop marks the eastern edge of exposure of the Appalachian orogenic belt.

- **DEFORMATION:** folds, faults, joints, mylonite, and partial melting have affected these metamorphic rocks.

  Layer-parallel shear, and stretching: Look in the amphibolite bands toward the west end of the outcrop and find thin light-colored layers with very tight, strung-out folds within the layers. Look for single, light, coarser grains that have been rotated and sheared out into very thin white stringers. These are evidence that there has been intense shearing and stretching within those layers. Note that the light layers don't show these features; the conclusion is that the dark layers were weaker than the light ones, and flowed internally more easily.

  Walk to the eastern end of the outcrop, on the knob in the creek, and observe a beautiful **small fold**. Is it an anticline or syncline? How do you know?

  Observe how the fold has been **intruded by granite**. One limb of the fold is largely missing. Can you find the other limb?

  Mylonite: Look close below the unconformity surface and find dark, layered rocks that are folded and contain light fragments of other rocks in them. These rocks are **mylonites**; they represent ground-up earlier rocks that were caught in a fault zone and progressively crushed to fine powder. The coarse light grains represent pieces of earlier rock that weren't crushed. The pieces were part of an earlier pegmatitic granite. The sequence of events here was: shearing - pegmatite intrusion - more shearing and creation of the mylonite - folding of the mylonite - more shearing.

  Anatexis: look closely at the quartz-feldspar gneiss layers and find small places where the delicate, fine layering of the gneiss disappears and is replaced by slightly coarser grains with no layering and a massive look. These are places where the gneiss melted to form small pockets of granite magma. The process of melting is called **anatexis**, and its presence here indicates that the rocks were very hot (maybe 1000-1100° F) and close to melting during the metamorphism.

There were at least <u>**four periods of deformation**</u> that affected these rocks.

STOP 2: ROCK CHURCH

This stop is on private property belonging to Rock Presbyterian Church. Please be courteous and respectful of the property.

The rocks exposed here lie in the **PIEDMONT PROVINCE**, and again belong to the <u>**JAMES RUN FORMATION**</u>. These rocks are <u>**metamorphosed and deformed**</u>, but are less intensely metamorphosed than those at Stop 1. They consist of <u>**amphibolite gneiss and schist.**</u> They contain the dark green minerals <u>chlorite</u> and <u>epidote</u> and <u>amphibole</u>

The parents of these rocks submarine, <u>**basalt pillow lavas**</u> that extruded onto the floor of some former ocean (probably Iapetus, or proto-Atlantic, Ocean). The basalts are probably part of a large <u>**ophiolite**</u> complex that was scraped off the descending American plate and emplaced by thrust faults into its present position. Other parts of the ophiolite are present in Maryland, southern Pennsylvania and northern Virginia. The presence of ophiolite here indicates that these rocks, and this area, probably went partway down the subduction zone in the Taconic orogeny.

These rocks have been <u>**correlated**</u> with the rocks at Windy Hills, and both belong to the same formation. However, the rocks here are clearly different from those at Windy Hills: the rock types are different, the metamorphic grade is different, the style of deformation is different. And there are no fossils. You might well ask, how can they be correlative? Answer: difficult to say. Probably on the basis of similar location relative to other, known rock bodies. Correlation is one of the hardest, most complicated tasks in all of geology.

Features to observe at this exposure include:

- <u>**deformed pillow structures**</u>: Look low on the front wall, in the massive (unlayered) central portion, and you can make out elongated, flattened zones defined by darker, thin (1-2 cm), finer-grained rims. The pillows are maybe 10-50 cm in long dimension, and are flattened by the deformation. They are difficult to see at best, and may be invisible today.

  Features of the original lava: <u>**vesicles**</u> = small (1 mm) gas-bubble holes, where gas bubbled out of the lave when it extruded. They are filled with white minerals now, and are easily visible. They are <u>**deformed**</u>, into elongate, pencil-like shapes, and give the rock a distinct linear appearance.

- <u>**Folds**</u>: The rocks have folded several times, and you can find fold axes, fold limbs, and different geometric shapes of folds.

- **Pods of quartz and feldspar:** there are large masses of quartz and feldspar in the rocks. I'm not sure what their origin is, or why they're here.

- **Joints**: find the long, straight, regularly spaced, nearly vertical fractures that cut all the rocks. These fractures are called **joints**. They formed later than the folding deformation, because they cut all the folds and are not affected by the folds.

STOP 3: GOLD 'N GREEN QUARRY, PARKESBURG

This stop is in a privately owned quarry,and we are here by the good graces of the owners (one is a UD grad). Please respect the property and its contents. DO NOT ENTER THE DEEP PIT TO THE REAR RIGHT; STAY ON THE HIGHER GROUND TO THE REAR LEFT.

The rocks here are still within the **PIEDMONT** province, because they show penetrative shear deformation (see Figure 3). They are on the margin of a large anticline that exposes Precambrian basement rocks in the center. However, they are part of the miogeosynclinal, passive-margin wedge (Figure 3). They belong to the **CHICKIES FORMATION**, of latest Precambrian age.

The Chickies is a **quartzite and metaconglomerate**, a sequence of quartz sandstones and quartz-pebble conglomerates that have undergone high-grade metamorphism. The parents of quartzite clearly are sedimentary sandstones. This particular sandstone was clean, mature and well-sorted when deposited, with little clay matrix. During metamorphism there wasn't much in the rock besides quartz to make new metamorphic minerals, and the quartzite has the same minerals as the original sandstone (although grain shapes are clearly metamorphic).

The cleanness and maturity of the original sandstone suggests a cratonic tectonic setting of deposition, even though the rock came into an orogenic-subduction zone later in its history. The Chickies is the basal, lowest rock unit in the **passive margin wedge** of sedimentary rocks that developed on the eastern margin of North America during Late Precambrian through Middle Ordovician time (see Figure 4). The sand was produced by weathering of craton and basement rocks to the north and northwest, in Canada and the US midwest. Remember the Taconic Orogeny laboratory? The Chickies is similar to the sandstone facies on the Upper Cambrian map of that exercise. This sequence of rocks developed on the trailing edge of what was the "American" plate of that time. After the plate motion reversed in middle Ordovician time, this trailing edge became the leading edge, and the eastern parts of the passive-margin wedge were partially subducted, metamorphosed and deformed. Thus the Chickies.

Features to observe at this outcrop include:

- strong, **parallel bedding** in the quartzites. It was probably made more parallel by the metamorphism.

- Look for **cross-bedding** in the sandstones. It might be visible, might not be. Look for truncation of bed contacts by other beds, look for T-junctions.

- Which way do the rocks **dip?** (You are facing east).

- Which way would you drive to find **older rocks**? **younger rocks**? Which way to the **anticline**? to the **syncline**?

- This quarry is a veritable gold mine of interesting imported rock types; we could spend the whole day here. Notice especially the

    coarse-grained **red sandstone**: we'll see more of that the next stop. Jurassic, from the rift basin.

    dark gray, coarse-grained **gabbro**: the coarse-grained, intrusive equivalent of basalt. An igneous rock - look at the crystals and the difference between its texture and the sandstone's. Jurassic, from the rift basin.

STOP 4: THE BIKE STORE, MOHNTON

The vacant lot just beyond the Harley-Davidson shop can be soft and wet, and you need to be careful to stick to the higher ground. Stay away from the highway, because it's a blind curve with high-speed traffic.

This site is located within the **MESOZOIC RIFT BASIN** (labelled "Triassic" on Figure 1) that runs continuously from New York state to Virginia. The basins are of Late Triassic and Early Jurassic age, are younger than anything in the Appalachian orogenic belt, and are not genetically related to Appalachian events in any way. The Appalachian orogenic belt involved compressive deformation and shortening of the earth's crust; the Mesozoic rift basins involved extensional deformation and lengthening of the crust. The extension is related to the **breakup of Pangea** - the rifting apart of the supercontinent of Pangea in early Mesozoic time. This rift basin is one (of many) early, failed attempts at breakup; the new Atlantic Ocean didn't open up here, but opened later farther east, and preserved this basin on the segment of continent that drifted west from the mid-Atlantic ridge. This rift basin was a precursor of the new Atlantic Ocean.

The rift basin has a wedge shape, thickest on the north edge and thinning to zero on the south edge. The sedimentary strata dip to the north. Look across the highway to the north; the ridge on the skyline is the north edge of the basin. The north edge is marked by a normal fault, in which the south side, our side, was dropped down. The high lands on the upthrown side were subjected to intense erosion, and generated coarse sand and gravel sediment that became the sandstones and conglomerates of this outcrop. The skyline ridge to the north is underlain by older rocks that were the very source for the pebbles in this conglomerate.

The rift basin contains two major kinds of rock: terrigenous, red, clastic sedimentary rocks ranging from shale to sandstone and conglomerate, and intrusive igneous rocks of gabbro composition (that we saw at the previous stop). The rocks here are **cobble and boulder conglomerates** and **coarse-grained red sandstones**.

Observe in these rocks:

- the **pebbles, cobbles and boulders** in the conglomerates. Are they smooth or angular? Are they sorted into beds of similar clast size, or are they unsorted and mixed together regardless of size?

- How far away (relatively) is this location from the source of these sediments?

- Look at the **matrix** between the pebbles, i.e. the sandstone. Is it well sorted or poorly sorted?

- Which way do the rocks **dip**? north or south? toward the fault or away from the fault?

When we're done looking at the rocks, you can visit the bike store for a minute. T-shirt time.

STOP 5: STONE CLIFF PARK, READING

PIT STOP, LUNCH STOP. Eat lunch first, then look at the rocks. **NO HAMMERS PLEASE**; this is a city park.

The rocks here are **limestones and dolomites** of the Conochocheague Formation, of upper Cambrian age. These rocks are part of the passive margin wedge of the early Paleozoic eastern margin of North America (see Figure 4), and were deposited in a cratonic tectonic setting. These rocks are typical of cratonic-setting deposition: little to no terrigenous clastic sediment, no quartz sandstones, shallow-water deposition, lots of fossils. There was little to no uplift of any source area, no sediment from outside the area of deposition, and the carbonate sediment for these limestones came primarily from the breakdown of animal and plant skeletons close to the site of deposition.

The rocks contain many interesting features related to carbonate deposition. Look for the following features as you examine the rocks:

- **interbedded limestone and dolomite**: the gray beds and lamination are **limestone**, and the buff to tan lamination are **dolomite**. Limestone is made up of calcite, whose formula is $CaCO_3$, whereas dolomite the rock is made up of the mineral dolomite, $CaMg(CO_3)_2$. The dolomite beds contain more magnesium than the limestone beds. Both are very-fine-grained; the particles are clay size. Fine-grained, clay-size carbonate rocks of any composition are lumped into the term **micrite**.

- The magnesium was concentrated in the locations now occupied by dolomite by the actions of blue-green algae, which grew as mats and slimy coverings over beds of calcite. The resulting interlayered calcite/dolomite bedding is actually considered a fossil (= any evidence of prehistoric life), and is called a **stromatolite.** This particular expression of stromatolite is **stromatolitic layering**, or **cryptalgal lamination**.

  Another expression of stromatolite is seen in the little reentrant just north of the spur. There, you can see stromatolitic layering arranged in isolated columns and separated by buff dolomite. These are **domal** or **columnar stromatolites**. These were domes and protruberances on the sea floor that were capped by algal mat and were eroded on either side by currents.

  Modern stromatolites are confined in their occurrence to locations away from terrigenous sediment input and to the intertidal zone, between high and low tides. There is no reason discovered so far to doubt that ancient stromatolites can be interpreted the same way. Thus, stromatolites are useful in **establishing ancient sea level** positions. You're looking here at part of a 520-million-year-old tidal shoreline complex. If you listen closely, you can hear the surf, and with imagination you can see the beach umbrellas.

- Look for beds of medium-blue-gray rock, especially near the playground. These rocks are **oolite**, or **oolitic limestone**. Oolite contains nearly spherical, sand-size grains of calcite (ooids) that you can see with good eyes or a hand lens. The ooids grew to sand size as small specks of earlier minerals were progressively coated with calcite as they rolled around on the sea floor in response to current flow. Oolite is a clastic rock, but is not terrigenous. Oolite often occurs in association with stromatolite, and represents current flow resulting from tidal rise and fall on the tidal flats where the algal mats lived.

- The oolitic sandstones show **cross-bedding** and **ripple marks**, features you would expect in traction-transported sediment.

The rocks have undergone **deformation**, during the Alleghanian orogeny in the Pennsylvanian and Permian. Several mutually incompatible kinds of deformation are present:

- Look for short, 10-50 cm veins filled with white calcite. These are **tension gash** veins. They indicate that the rock has been pulled apart, put under tension, in a direction normal to the veins. So the rock has been stretched.

- Look for **stylolites**, up close and personal. Stylolites are tiny, clay-lined discontinuities in the rock, that are fairly rare and are oriented usually normal to bedding. They represent places where calcite has been dissolved and removed from the rock. The dissolving occurs during compression, and the stylolites develop normal to the compression direction. So the rock has been compressed.

- Look for **dip and strike** of bedding - the rock layers are inclined, and dip to the south.

- Look for **cleavage** - a parallel splitting property that cuts across bedding. Cleavage forms during folding, and grows parallel to the axial planes of the folds. Cleavage usually has a different dip than the bedding. The cleavage here dips steeper than bedding, and from the relative dips of cleavage and bedding you can figure out which limb of the fold these rocks are on.

- Tensional and compressive deformation clearly cannot affect a rock at the same time and place; they are mutually exclusive. So the deformation must have been in a sequence of pulses.

Work out a **sequence of events** in the formation of these rocks. Just like you did in class and lab.

STOP 5: PA 61, SHOEMAKERSVILLE

CAUTION: This land is privately owned, and the owner is worried about liability. YOU MUST SIGN THE LIABILITY WAIVER SHEET IF YOU WANT TO EXAMINE THE ROCKS HERE.

The rocks here are interbedded **limestones and shales**, and belong to the **VIRGINVILLE FORMATION**, of upper Cambrian age. These rocks were not deposited just here, but originated somewhere to the southeast. They were transported into this location in the upper plate of a **thrust fault**; the distance of transport was at least 20 or 30 km. The fault itself if not visible here, and its presence is inferred from regional geologic relations. The sequence of rocks above the thrust, including the Virginville and the Windsor Township Formation to be seen at the next stop, constitute the **Hamburg Klippe**. The klippe was thrust to the northwest over Middle Ordovician rocks of the Martinsburg Formation, during Middle or Late Ordovician time.

The regular interbedding of the strata is called **ribbon bedding**. The shales have yielded a few fossils, including trilobites; the limestones have a gastropod or two, and some microfossils, but are notably barren of fossils.

These rocks present an interesting dilemma in your attempts to infer cratonic or orogenic tectonic setting. The limestones say cratonic, but the shales say orogenic. Actually, many people who know these rocks think they are transitional from cratonic into orogenic (how's that for hedging?), and represent a former limestone cratonic setting in the initial stages of being pulled down into deep water as it approached a subduction zone. The rocks older than these are limestones; the rocks younger than these are shales, graded-bed sandstones (next stop) and turbidity-current deposits.

Look in the outcrop for these features:

- The limestones are very-fine-grained, and are true **micrites**. They weather light gray, and are distinctive. Look closely inside the limestones for delicate, small **lamination** and **cross-lamination**. The currents, if any existed, were very weak and unable to move much sediment around.

- The **shales** are black or dark gray, and often contain very thin, orange-weathering, delicate, very continuous lamination of **siltstone.** The siltstones contain quartz, and with the shales represent real terrigenous sediment. The clay of the shales ultimately came off a land source area, but may be considered pelagic.

- Note the regularity of the bedding. Bedding in both rock types about 1 to 3 cm thick.

- Note how heavy the specimens of the rock are. What could cause rocks to be heavier than other rocks?

- The limestones are often in flattened, oval, lens-like shapes, called **lenticular bedding**. Notice that lenses tend to occur at the same horizons in the rock. The lenses at any one horizon used to be part of a single, continuous bed, that has been pulled apart, or extended parallel to the layering. Lenticular bedding is evidence of layer-parallel extension in a time when the rock materials were still fairly soft and non-brittle.

- Look for **stylolites** in the limestones: small, tiny discontinuities looking like fractures, that may have some black clay on them, oriented normal or at high angles to bedding direction. Again, stylolites indicate that rock material has been removed by dissolving, and that the rock has been shortened in a direction normal to the stylolite. Stylolites indicate that the rock has undergone compression.

- The outcrop is on the crest of an upright **anticline**. Identify each limb, and find the crest and the axis. Find the **orientation of the axial surface** (the imaginary plane of "symmetry") of the fold. Work out what the directions of compression must have been to generate this fold.

- Look closely in the shales, especially on exposed bedding surfaces, for a light, delicate, parallel striations that run parallel to the axial surface orientation. These striations are **cleavage**, and here you can see clearly the relation of cleavage to the geometry of the fold. The cleavage planes penetrate throughout the rock, although they are weakly developed.

- Look for **faults** that affect both limestones and shales. Bedding sequences do not continue across the faults, and the faults **truncate** the bedding. Notice the limestones are broken up, reduced in grain size, and brecciated along the fault surfaces.

STOP 6: BLUE MOUNTAIN

This exposure is along the old Reading Railroad line, and the tracks may still be used by commuter trains. Be EXTREMELY CAREFUL of the possibility of trains; keep your ears open, listen for trains; there won't be much time to move if one appears.

This outcrop exposes the **TACONIC UNCONFORMITY**, that separates lower, Lower Ordovician rocks of the **Windsor Township Formation** from upper, Lower Silurian rocks of the **Shawangunk Conglomerate** (see Figure 4). It is an angular unconformity, and there is a nearly right-angle T-junction between lower and upper strata. The unconformity is not now in its position of origin; after its formation it was folded during the Pennsylvanian Alleghanian Orogeny, and has been rotated 90_{o}. The unconformity means that the lower rocks were undergoing deformation, uplift and erosion during Middle and Late Ordovician time, and that coarse terrigenous clastic sediment was later supplied to this area. The terrigenous sediment is inferred to have been eroded off a major mountain range that lay east of here. This episode of deformation and mountain-building was the **Taconic Orogeny**, the first great range of mountains uplifted in the Appalachian orogen.

The rocks below the unconformity are the **Windsor Township Formation**. They are sandstones and siltstones in beds up to 50 cm thick. They show graded bedding, and probably represent deposition from turbidity currents in a deep ocean basin. They clearly represent an orogenic tectonic setting.

The rocks above the unconformity were deposited after the uplift and erosion, on a mountain-front alluvial-plain land surface cris-crossed by braided river systems.

Look for these features in the exposure:

- Examine the unconformity itself. How close do the two sides come to each other? Do you see them actually in contact? Does this invalidate the interpretation of "unconformity"?

- Find **graded bedding** in the Windsor Township Formalin. Which way is up? Do the rocks get finer-grained upward? or downward? are the rocks right-side up? or upside down?

- Examine the very lowest, basal Shawangunk. What kind of rocks are they? What kind of rock is the highest Shawangunk you can find? Is there any change in grain size? Why would grain size change?

- Construct the **sequence of events** that best explains the evolution of the relations here.

STOP 7. DEER LAKE

This is an abandoned PENNDOT road-gravel pit on the west side of PA 61. Be careful in your climbing around; the rocks are cleaved and the edges of the rock fragments are damn sharp.

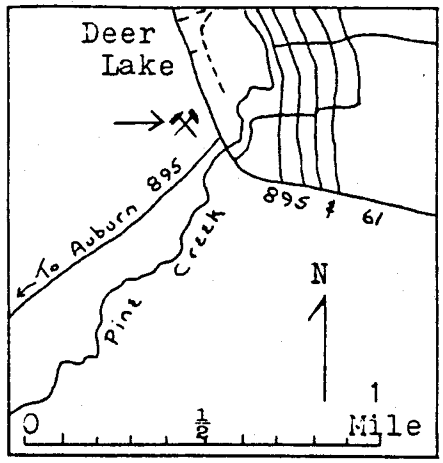
The rocks here belong to the **MAHANTANGO FORMATION**, of Middle Devonian age (see Figure 4). The Mahantango is a richly fossiliferous **siltstone**, with rare sandstone and shale. Fine specimens of shallow-marine invertebrate animals and plants may be collected, including brachiopods, pelecypods, crinoids, coelenterates, bryozoans, trilobites, algae and others. The fossils are molds of the shell exteriors, and are best seen and found as orange-brown stains on slightly weathered surfaces. Diagrams of individual genera are shown on the following page as an aid to collecting. The most common fossil types are the razor clam Cypricardina, another razor clam not figured, algae, and the brachiopod Rhipidomella. Trilobites are rare, and constitute the most significant, prestigious and status-generating finds.

Data on the paleoecology of modern relatives of these fossils are instrumental in environmental interpretations of the Mahantango. Many types, especially the corals and crinoids, require clear, warm water to survive. Bryozoans thrive in slightly agitated water where silt is the major sediment type. The abundance and diversity of pelecypods further suggest shallow-water environments, with several different sub-environments within the general shallow shelf. Several pelecypod genera are true clams, who have a moderate tolerance of salinity fluctuation and can withstand limited fresh-water dilution. Other pelecypods are primitive oyster, mussel and scallop types (Lioptera, Cypricardina, and Gervillia, respectively), and not only had high salinity tolerances but built reefs and banks in the intertidal zone of brackish environments (i.e., at sea level, in nearshore zones). Calcareous algae are restricted to water less than 100 feet deep, and their delicate preservation precludes post-mortem transport.

Bedding is scarcely visible, and the strike and dip of the formation must be read from a map. The bedding has probably been destroyed by widespread burrowing, by trilobites, gastropods and unpreserved worms, who lived on and within the bottom sediment and fed by ingesting sediment and extracting organic nutrients. But the bulk of the shelled animals were probably suspension feeders, who extracted nutrients from the water itself by a filtration process. To support so prolific a suspension-feeding fauna, the water must have been continuously and gently agitated, i.e., shallow.

Purely on paleontology, then, you can interpret the Mahantango

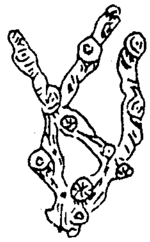
Devonian
Fossil Assemblage
Hamilton Formation
Deer Lake
Schuylkill County, Pennsylvania

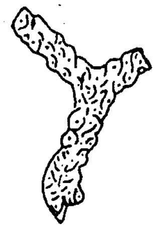


Coelenterata

Anthozoa

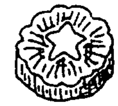
Tabulata


Aulopora


Trachypora

Echinodermata

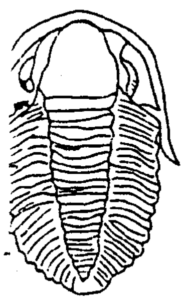
Crinoidea

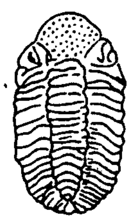

(enlarged)

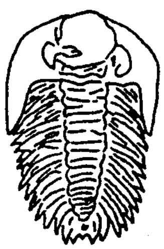

Columnals

Arthropoda

Trilobitomorpha


Dechenella

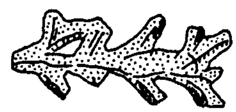

Phacops

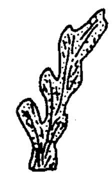

Greenops

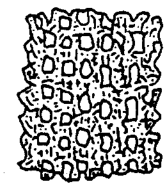

Phacops (Cephalon)

Bryozoa

Gymnolaemata

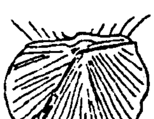

Taeniopora


Sulcoretopora

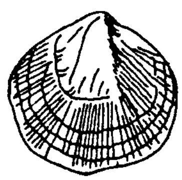

Fenestella

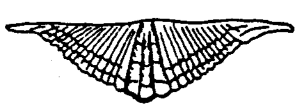
Brachiopoda

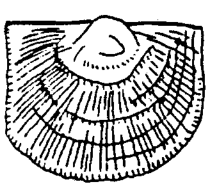
Articulata

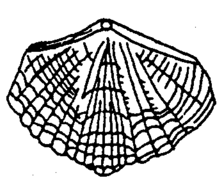

Chonetes

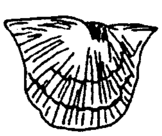

Camerotoechia sp.


Rhipidomella

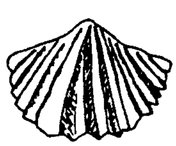

Mucrospirifer

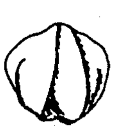

Leptostrophia


Elytha


Douvillina


Camerotoechia sp.

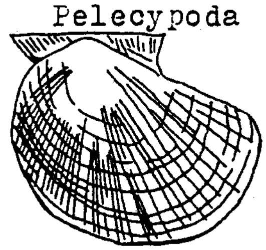

Tylothyris

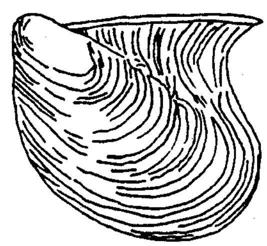

Ambocoelia


Tropidoleptus

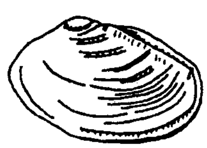
Mollusca

Pelecypoda

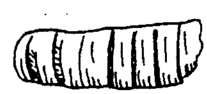

Aviculopecten


Liopteria


Cypricardina


Paleoneilo

Cephalopoda


Michelinoceras

Original shell material has been dissolved away, leaving molds and casts

Age of the rock: about 320 million years.

Reference: Fossil Collecting in Pennsylvania, by Donald M. Hoskins as representing shallow, gently agitated, relatively nearshore, open-marine shelf deposition. The Mahantango probably represents a **cratonic tectonic setting**, but that setting was soon to turn to an orogenic, foreland basin setting in late Middle Devonian time. The Mahantango comprises the uppermost unit in the Hamilton Group, a series of dark, generally fine-grained, marine Middle Devonian rocks. The Hamilton rocks are dark because of their high content of finely divided organic matter. They overlie earlier cratonic-setting, carbonate strata of Upper Silurian and Lower Devonian age, and represent the last shelf-association deposits before the influx of large amounts of terrigenous clastic sediment from the second great Appalachian orogenic event, the **Acadian orogeny** of Late Devonian time.

STOP 9: LAVELLE I

We will make three short stops in the Lavelle area, to examine the component parts of a large anticline fold, and to see how geologists infer the presence of a fold from dip and strike evidence.

The rocks here are **interbedded sandstones and shales** belonging to the **MAUCH CHUNK FORMATION**, of upper Mississippian age (see Figure 4). The rocks are also called **redbeds**, a name used to underline the consistently maroon, dark red-brown color. The color is due to the presence of small amounts of very-fine-grained, widely disseminated iron oxide of the mineral **hematite**, Fe_2O_3. Hematite forms in sedimentary environments that are exposed to atmospheric oxygen, thus, in nonmarine depositional environments. Nearly all redbeds accumulated in environments related to river/floodplain, coastal-flat, and/or desert environments. These environments may occur in either cratonic or orogenic tectonic settings. One major occurrence of redbeds is in **clastic wedges**, which are thick wedges of terrigenous clastic sediment that were shed off rising and eroding orogenic mountain ranges; a modern example is the sediment delivered to northern India by the rivers draining south off the rising Himalaya orogenic mountains. This sediment is nearly all nonmarine, and may be syn-orogenic, concurrent with the rising mountains, or post-orogenic, created after the uplift is complete. This sediment is called **molasse** by French and Swiss geologists, and contrasts in character and in time with earlier, pre-uplift sediment they termed **flysch**. Flysch is marine, generally deep-water sediment of the type we saw earlier at Windy Hills Bridge and Blue Mountain.

The rocks are **sandstones and shales**, interbedded on a scale of less than a meter.

Observe these features:

- try to find **graded bedding**, that is, the continuous transition from sandstone to shale. It may be hard to find.
- From the graded bedding, if you find it, determine which way is **toward younger rocks**.
- Determine **which way the rocks dip**. North? or south?
- Where is this location in relation to the Line Mountain anticline?

As the bus comes around the curve to the left and you get a good look at Line Mountain ahead, determine whether the bedding here dips **toward or away from** Line Mountain. Makes a difference to what we'll see next.

STOP 10: LAVELLE II

This exposure is on the axis of Line Mountain as it plunges gently east. The rocks here are coarse- and medium-grained **quartz sandstones** of the **POCONO SANDSTONE**, of Lower Mississippian age (see Figure 4). The sandstones show excellent, large-scale **cross-bedding**, and the inclination of the foresets is so strongly developed that you'll probably think it's the true bedding. But it isn't. The foresets dip consistently gently north, while the true bedding is very nearly horizontal.

The true bedding changes dip direction within the outcrop, from very gently north at the north end through truly horizontal in the central parts to very gently south at the south end. Thus, the change in dip direction defines the **axis of an anticline**. The anticline is very large, and is broad and open.

High up on the east face of the cut is a relatively unfractured, continuous bed of sandstone that is the best definer of structure. It shows that, in the middle of the cut, the beds are essentially horizontal. They begin to dip gently south at the south end of the cut, as this bed indicates.

Look closely at the foreset beds, and you'll find that they are defined by thin layers of differing mineral composition, i.e., light and dark layers. The cross-bedding developed by **traction transport** of sand grains in water currents flowing in **braided rivers** across a pretty featureless Mississippian alluvial plain. The Pocono sandstone and Mauch Chunk Formation both are post-orogenic, molasse deposits, and they record the occurrence of a second orogenic, mountain-building event in the Appalachians east of here, the **ACADIAN OROGENY**, in Late Devonian time. The orogenic deformation of the Acadian affected only rocks in New England and Canada, but the sediment from that range was shed far and wide across the eastern part of the continent.

An unusual feature is exposed at the north end of the cut. On the west side, a low rounded "knob," or hummock, of sandstone is exposed. It appears to poke up through the higher sandstones, and resembles an anticline. Bedding in and near this structure appears to be up-folded, i.e., anticlinal, and conforms to the shape of the hummock. However, several bits of evidence suggest that this is not an anticline and that variations in rock thicknesses may be causing the apparent structure.

- The rocks of the hummock itself are weathered more extensively than the overlying sandstones, and something approaching a fossil soil may be preserved at the top of the hummock. If all this is so, then the hummock has somehow been exposed to weathering longer than the surrounding sandstones.

- Moreover, the sandstone beds alongside the hummock, at road level, are continuous across the crest, but thin drastically, from eight feet on the sides to two feet over the crest. This indicates that the hummock is not a tectonic fold, but must have already existed when the sandstones were deposited. The entire hummock was under water, but more sand was deposited on the flanks than on the crest. Analogous situations have been documented in modern braided environments, where water flows more easily around bars or impediments than over them.

So what we are looking at may be an original, pre-depositional topography: an impediment to water flow, a topographic "high," maybe even a bedrock island poking up into a braided channel complex and offering resistance to flow. That this was a small, local feature is indicated by its failure to carry across the road to the east side of the cut (although there are hangups with the east side also).

To do here:

- Find the cross-bedding. Examine a foreset: does the grain size change from top to bottom?

- Find the true bedding. What is the angular discordance between true bedding and the foresets?

- Examine the sand of the sandstone. Is it **well sorted? immature? mature? poorly sorted? monomineralic (= one mineral only)? conglomeratic?**

- Is the Pocono older or younger than the Mauch Chunk? Where on the anticline would you expect younger rocks to be exposed? older rocks?

- What direction would you expect bedding north of this exposure to dip? Why? what's your reasoning?

STOP 11: LAVELLE III

This is a bus-window stop to view the **MAUCH CHUNK FORMATION** on the <u>**north**</u> side of Line Mountain.

- How do you know it's Mauch Chunk Formation?
- Which way do the beds dip? South or north?
- As we come out of the core of the anticline, which way are we going - toward older beds or toward younger beds?
- Based on all three stops in the Line Mountain anticline, draw a cross-section of the anticline, and put the three stops on your sketch. Show the surface of the ground, and show the beds in the air where they have been eroded away.

In putting the last three stops together and synthesizing the directional information, you have done what geologists do in identifying and locating folds in the field.

STOP 12: EXCELSIOR

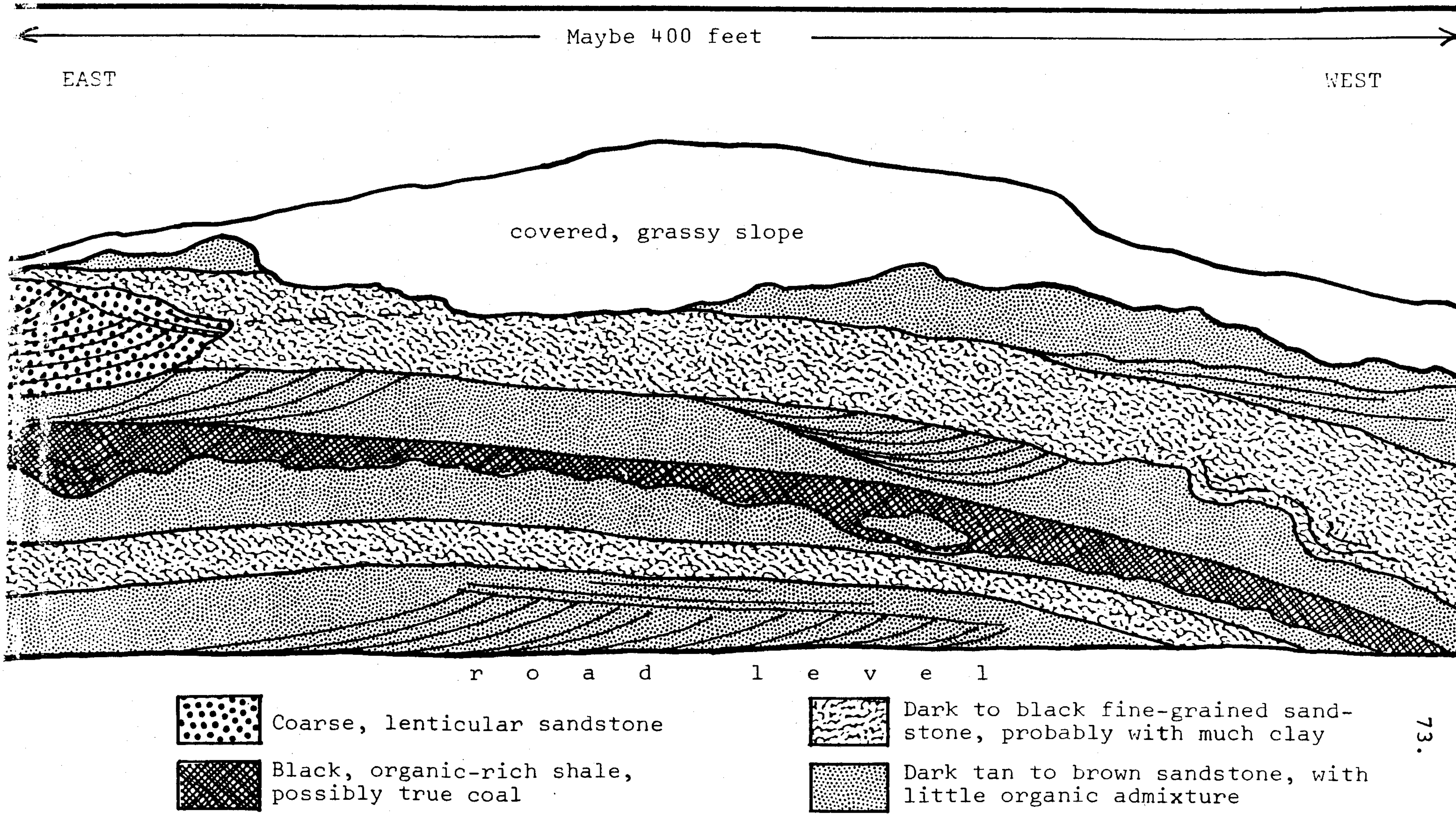
The rocks in this outcrop belong to the **LLEWELLYN FORMATION**, of middle Pennsylvanian age (see Figure 4). The highway here is nestled up against a ridge of **Pottsville Formation** sandstone and conglomerate to the south, and the rocks here are probably near the base of the overlying Llewellyn. The rocks are of middle Pennsylvanian age, and can be precisely correlated on the basis of abundant plant fossils with rocks in western Pennsylvania and Ohio. The Llewellyn is structurally beat up, and these units here probably do not carry across the valley without folding and faulting.

The rocks of the Llewellyn consist of **interbedded sandstones, siltstone-shales, black rocks** (resembling organic-rich shales), and **anthracite coal**. The generally dingy, dark color of the rocks is due to fine-grained plant remains, which have been distilled (preservation by distillation) to the carbon residue you see. The sandstones have not been washed and sorted, and all the rocks are immature.

The most interesting aspect of this outcrop is the manner in which the lithologies are related to each other. A sketch map is provided to help you in tracing units through the outcrop (next page). The rock units are vertically interbedded in several different ways. The focus of interbedding is on the contacts between lithologic units; pay attention to whether they are erosional, scoured surfaces, or gradational over some distance. There are several undoubted erosion surfaces in the outcrop; units are of quite irregular thickness, and often fill depressions in the tops of underlying beds. Several other contacts appear gradational, but when you look closely they may in fact be erosional.

The rocks appear to contain well-developed primary structures. The lowest sandstone is cross-bedded, as is the sandstone at mid-crop level. Channeling is developed in several units. Look at the rocks more closely, on a small scale, and you will probably find many more primary structures.

One feature contributing to non-repeating lithologies here is the lateral non-persistence of rock units. Lithologic units change shape along the outcrop, and some almost die out entirely. The black, "almost"-coal bed thins, over a "high" near the center of the cut, and thickens to either side. The bed immediately below the almost coal nearly disappears to the west, below a probable erosion surface. The channel sand at the east end, if it is in fact a channel sand, is lens-shaped. The resulting picture one gets is of a depositional environment with ultra-rapid lateral facies changes, bedrock islands of "highs" in low-lying areas, probably swamps, which were flanked by encroaching forests and other organic growths. Similar conditions are identifiable in the



SCHEMATIC SKETCH OF STOP 9 OUTCROP OF LLEWELLYN FORMATION. APPROXIMATE, NOT FIELD CHECKED. DRAWN FROM PHOTOGRAPHS. IN DESPARATE NEED OF FIELD CHECK.

Recent in the Everglades and other swamps.

These rocks belong to the **Orogenic association**, and are post-orogenic in their timing. They qualify as molasse, and reflect continuing erosion of the Acadian orogenic belt mountain ranges to the east. Sediment transport was to the west, toward the sea in what is now Illinois and Kansas.

STOP 13: BEAR VALLEY STRIP MINE

DINNER STOP

The rocks here belong to the **LLEWELLYN FORMATION**, of early Middle Pennsylvanian age (see Figure 4). They have been deformed into anticlines, synclines and thrust faults during the **Alleghanian Orogeny** of early Permian age. This outcrop contains some of the best-displayed Alleghanian structure and plant fossils in the entire Appalachians, and makes a spectacular final stop.

THE MINE

The Bear Valley strip mine consists of an elongate gouge in the earth, about 30-60 m below road level and extending west from this site for several kilometers. The coal taken out from this mine was contained in beds of coal, the Mammoth No. 8 and No. 8 ½ coals, totalling about 7 m in thickness. These coals occur in the basal 80 m of the Llewellyn Formation, and crop out low on the flanks of the Pottsville ridge that forms the southern margin of the basin; the ridge is just beyond the south highwall of the mine. We will examine the easternmost part of the mine. The mine was active until about 1960.

THE ROCKS

The **LLEWELLYN FORMATION** includes all post-Pottsville strata in eastern Pennsylvania, and in this area consists of 500-600 m of **interbedded conglomerate, sandstone, shale, organic shale and coal**. The initial thickness is not known because of modern erosion. The formation contains more than 30 minable coal beds, with 10 of those in the lower 80 m.

Examine the sandstones of both the Llewellyn and Pottsville, and you will find them to be fairly well sorted but compositionally immature; there are numerous black rock-fragment grains and particles of organic matter in the sands.

The Llewellyn contains nonmarine fossils, and is nonmarine in origin. The considerable amounts of finely disseminated organic matter that color most of the rocks black resulted from the distillation of abundant terrestrial plant remains. Precise time correlations of these plant species with those in the coals of western Pennsylvania and farther west establish the Middle Pennsylvania age of the rocks, and support the idea that these rocks are the eastern, nonmarine facies of time-equivalent marine deposits of the Mid-Continent.

Almost all lithologies in the Llewellyn can be seen in the mine. In the east wall, several thin coal zones can be seen; they were too thin to be economical, and were not mined. The south highwall of the mine is composed of carbonaceous shale (not coal) and sandstone, which directly underlay the coal which was mined.

Many parts of the mine, particularly the south wall, contain numerous large <u>concretions</u> made up of <u>siderite</u> (iron carbonate, $FeCO_3$). The siderite was chemically precipitated from oxygen-deficient pore waters after final deposition of the sediment.

THE STRUCTURE

The large-scale structural setting is this: this part of Pennsylvania is underlain by a large, east-plunging, fairly tight syncline in Mississippian and Pennsylvanian rocks. The syncline is outlined by high ridges of Mississippian **<u>Pocono</u>** and Pennsylvanian **<u>Pottsville</u>** sandstones. The central part of the syncline contains younger, Pennsylvanian, coal-bearing rocks of the **<u>Llewellyn</u>** Formation. The weak shales and coals of the Llewellyn give the central portions of the syncline a topographically low area, and the entire region is known as the Western Middle Anthracite Basin. It includes the towns of Shamokin, Mount Carmel, Shenandoah, Mahanoy City, Ashland and Frackville. The Bear Valley mine is located on the south margin of the syncline, and lies on the north side of the Pottsville ridge.

The sandstones and conglomerates of the Pocono and Pottsville are extremely strong, hard-to-deform, <u>competent</u> rocks, much stronger than the relatively soft and weak, <u>incompetent</u> shales and coals. During the deformation that created the syncline, the Pocono and Pottsville sandstones transmitted the stress to other rocks, without being greatly affected. The Llewellyn, however, with its great thickness of weak shale and coal, absorbed most of the stress and deformed extensively. The competent limbs of Pocono and Pottsville in the growing syncline closed in on the weak Llewellyn like jaws of a vise, and caused much internal folding and thrust-faulting throughout the weak rocks. The thrust planes dip steeply toward the center of the syncline, and the inner blocks have moved up and past the outer blocks. A good analogy is the sliding of inner sheets up and over outer sheets when a thick stack of sheets of paper is down-folded in the center; each slip plane represents a thrust fault. One of these thrust faults may be exposed in the mine.

As a result of the intense folding and thrusting, the minable coal beds have been difficult to locate, and large parts of the valley have been torn up in the search. The economics of strip mining dictate that a minimum of rock other than coal be moved; therefore, strip mining moves around rather than through structures, and leaves behind the structures in rocks below the target coal beds intact. The floor of the mine represents the top surface of the rocks just below the target coal bed.

STRUCTURAL FEATURES IN THE MINE:

A combination of two anticlines and two synclines form the floor of the mine. The central anticline is termed the **whaleback anticline**. Walk out on the crest of the anticline, but be **EXTREMELY CAREFUL, AND DON'T FALL OFF.** The drop is straight down for 50 feet. The anticline has an **axis**, the line where the folding is concentrated. The axis of the whaleback is nearly horizontal, but bedding to plunge east near the east end. Locate axis, and walk it out.

The **synclines** are filled with either water or debris, and the axes and actual folding aren't visible. But you can confidently infer the positions of the axes.

The limbs of both anticlines and synclines are cut by **faults**, that move blocks of rock into the whaleback and/or along the bedding. Several of the faults show **slickensides**, which are smooth and parallel grooves on the fault surface caused by sliding of the two sides past each other. Some of the faults are vertical, others are horizontal. The faults are mostly **normal faults**, and indicate that the rock has been extended. The faults formed after the anticlines and synclines formed.

Even more spectacular than the whaleback anticline is its termination at the east end of the mine. The whaleback abruptly disappears there, and is replaced in the east wall by a symmetrical, open syncline strikingly outlined by light-colored sandstones. The anticlinal axis can be traced to within 3 of the syncline. This structural juxtaposition is quite difficult to interpret, and presents a good exercise in geologic reasoning.

So try your luck. How do you explain your ability to look along the axis of an anticline directly into the axis of a syncline? Here are some hints to consider:

1. Look to the left of the syncline on the east wall, and find the asymmetric anticline, whose north limb is over-turned. Could this be the continuation of the whaleback? If it is, what path must the axis follow to remain continuous and yet approach so close to the syncline axis?

2. Consider why the coal company stopped mining at this particular place: could it have anything to do with the disappearance of the anticline? Could there perhaps be a cross-fault between anticline and syncline, and the coal company mined up to the cross fault and stopped

3. Consider the southeast corner of the pit, where the

synclinal east wall meets the south highwall. The bedding plane, while dipping steeply, contains some large wrinkles, which are not reflected in the overlying synclinal sequence. Could the wrinkles actually develop in to synclines and anticlines? How far does a fold structure continue, anyway? Don't all folds have to stop somewhere? and how do they stop? Think about the folds in a wrinkled rug - do they die out along their length? Could rocks deform like that too? Could the whaleback anticline simply die out, by flattening out?

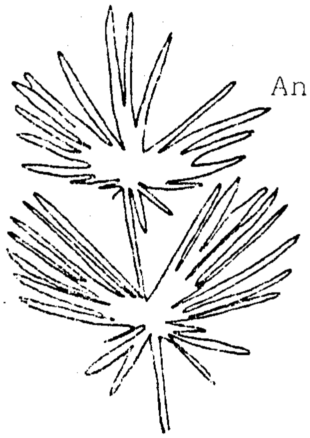
4. The lack of continuity of syncline, whaleback anticline and overturned anticline at the end of the pit could suggest that the two sides are separated by a fault of some kind. Could the positions of the structures be consistent with movement on fault blocks? a strike-slip fault? a thrust fault? And if this is true, the fault must pass through the pit at the east end, between the anticline and the wall. Is there evidence there for a fault? What would you look for to postulate the presence of a fault?

In summary, your opinions and conclusions are as good as anyone else's.

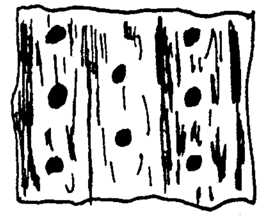
THE FOSSILS

The debris from the mining operations, which may be found anywhere in the mine area, contains abundant fossil remains of terrestrial plants. Most of the fossil plants were unique to the Pennsylvanian Period, and include scale trees, other types of trees and large plants, ferns, and other plant types. Diagrams of the more commonly found plant types are shown on the following page. Leaves, bark, stems, scales, branches, logs, and occasional stumps and other parts of the plants may be found in abundance. Virtually every piece of shaly rock is fossiliferous. Collect away, with the coal company's blessings; the best collecting is probably on the tailings piles at above road level. But be careful of footing.

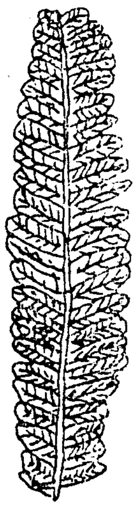
ELEMENTS OF PENNSYLVANIAN FLORA
Llewellyn Formation



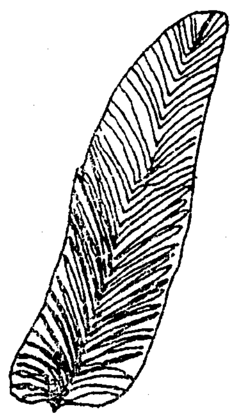
Annularia sp.



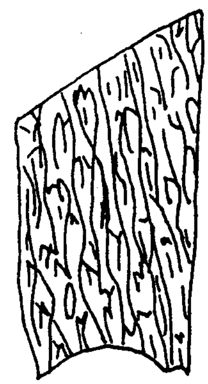
Sigillaria sp.



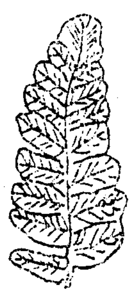
Pecopteris sp.



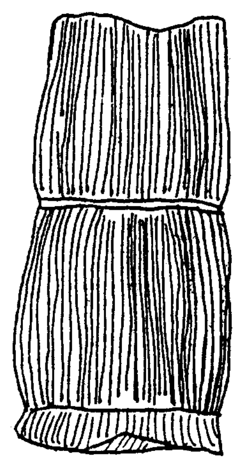
Neuropteris sp.



Lepidodendron sp.



Neuropteris sp.



Calamites sp.