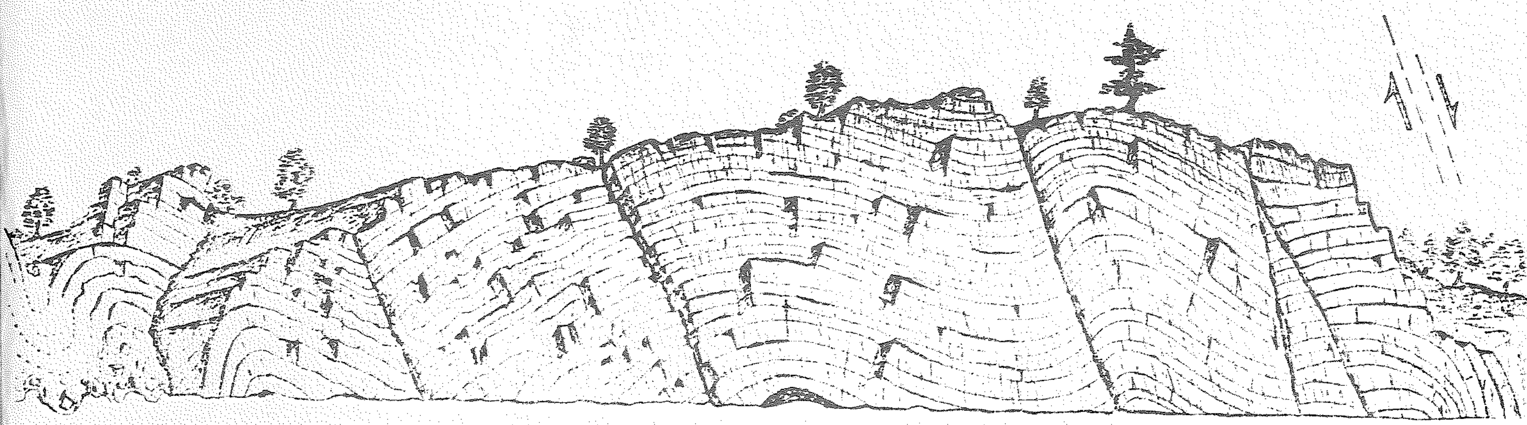
Guidebook

2nd ANNUAL FIELD TRIP
HARRISBURG AREA GEOLOGICAL SOCIETY

Susquehanna River Valley
Harrisburg to Wrightsville



April 16, 1983

HOST
Harrisburg Area Community College

GEOLOGY ALONG THE SUSQUEHANNA RIVER

SOUTH CENTRAL PENNSYLVANIA

FIELD EXCURSION GUIDE

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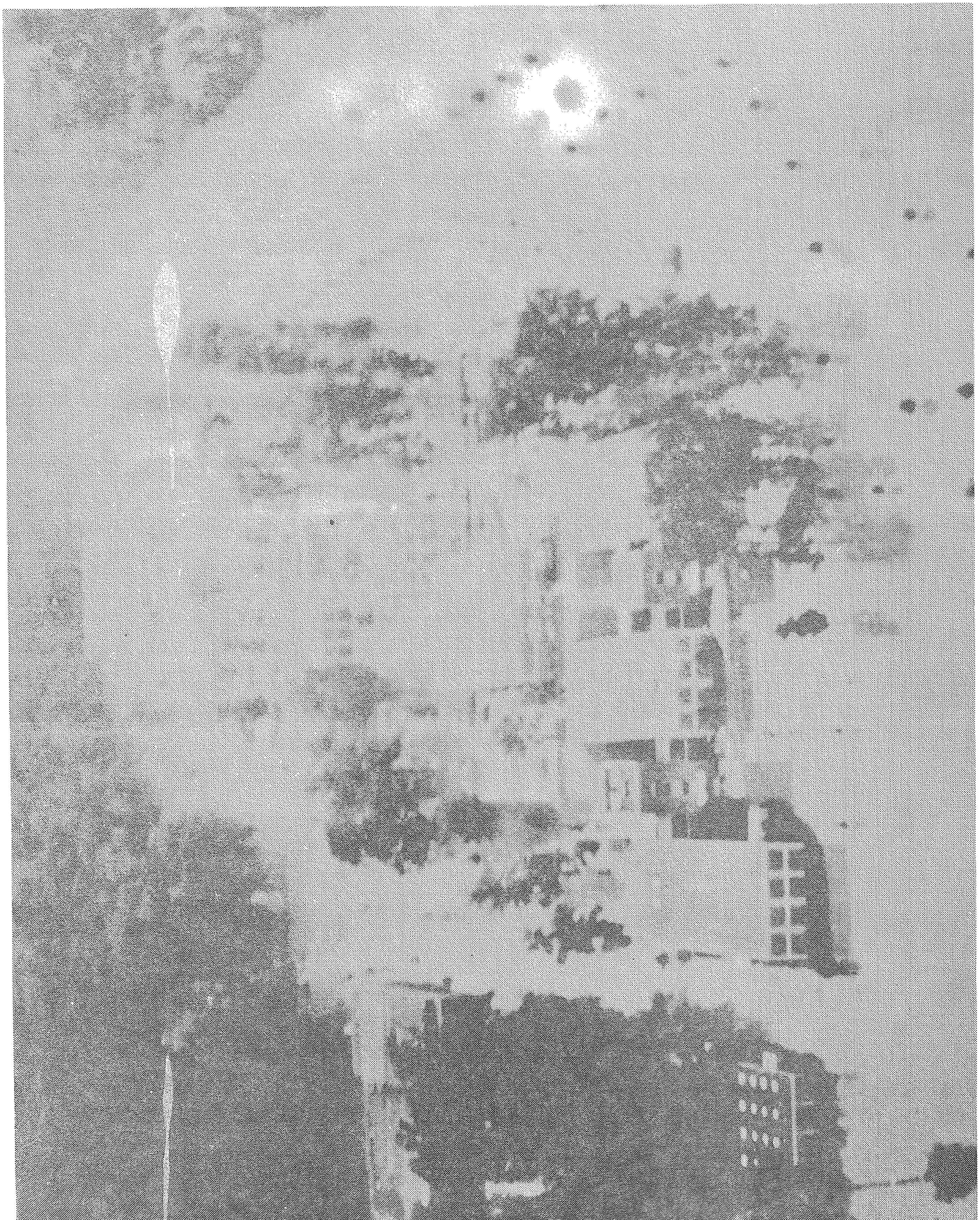

PREFACE

The concept of an annual field trip sponsored by the Harrisburg Area Geological Society (HAGS) resulted from an informal post-meeting discussion following a monthly meeting in 1981. Although members and friends of HAGS may work in specialized areas related to geology, they may not have an opportunity to gain a broad perspective of the problems and resources typical to the area. Therefore, in an attempt to promote an awareness of the geologic setting of South-Central Pennsylvania, HAGS decided to sponsor an annual spring field trip which would appeal to geologists with diverse interests and professional backgrounds.

Noel Potter organized the first trip to the Blue Ridge province in Pennsylvania in 1982. This second trip is a traverse along the Susquehanna River from Harrisburg to Wrightsville. However, these excursions barely touch the surface of an extremely diverse region. We would challenge and encourage others to come forward with ideas and leadership suggestions for proposed future trips.

I would like to take this opportunity to thank the contributors to the guidebook noted on the title page; to express my gratitude to Bill Sevon and Noel Potter for their encouragement and assistance with the roadlog, to Jack Purvis of Dunn Geoscience Corporation for his final draft of several figures; to Ed Mentzer of Harrisburg Area Community College for printing photographs, and to Tom Holtzman of Diocesan Publications for his assistance and suggestions in the printing of this guidebook. A special note of thanks is due to Kathy Littleton, a prospective professional geologist, for her role in typing, editing, and organizing the material for this publication.

J. Ronald Mowery

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Frontpiece: Harrisburg Area Community College during Tropical Storm Agnes, June 23, 1972. Photo by John M. Lynch.

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INTRODUCTION AND OVERVIEW OF THE TRIP

The purpose of the trip is to examine early Paleozoic stratigraphy, mid- and late Paleozoic deformation, Triassic deposition and subsequent geomorphology in several exposures along and near the Susquehanna River between Harrisburg and Wrightsville. The trip route is shown in Figure 2.

The trip begins on the campus of Harrisburg Area Community College located on the floodplain of the Susquehanna River within the Great Valley. In this vicinity, the bedrock is the Hamburg sequence, an allochthonous accumulation of argillites with an age greater than the Martinsburg Formation. At this stop we shall discuss sedimentary tectonics and later deformation of the emplaced materials. Another point to consider is the size and volume of the Susquehanna River during periods of deglaciation in the Pleistocene.

From Stop 1 to Stop 2, we shall continue in the Hamburg Klippe to the Harrisburg Cold Storage Warehouse, the southern limit of the Hamburg sequence in this area. Here it comes into a fault contact with the Hershey Formation. At this point we shall discuss the tectonic behavior of several units which are thrust-faulted nearby, and an attempt will be made to link the thrust plates observed here with those on the West Shore of the Susquehanna River.

Enroute to Stop 3 we shall cross lower Ordovician carbonates which may be seen behind some of the buildings on the east side of Cameron Street. At Stop 3 we shall observe coarse river gravels that stand about 80 feet above present river level and discuss this and other terraces found along the Susquehanna River.

About a mile south of Steelton the route will cross the major unconformity which exists between lower Paleozoic carbonates and red Triassic sediments which dip gently in a northward direction. Stop 4 is the Visitors Center at Three Mile Island. From here the Gettysburg formation, overlying soils and the foundation for the nuclear power plant will be discussed. There has been some concern about groundwater discharges from the island into the river. There are some interesting hydrologic conditions associated with the geology on and near the island and these will be discussed while at the Visitors Center.

Continuing southward, we cross the unconformity from the Triassic Basin back into Cambrian carbonates near Bainbridge. We are now moving down-section on the north limb of an anticline with its axis located south of Columbia. Chickies Ridge is a prominent ridge extending from the Chester Valley westward into York County. Several miles south from Bainbridge this ridge may be seen on the horizon. We shall stop at Chickies Rock and walk along the railroad. Some of the oldest fossils to be found in Pennsylvania, Scolithus linearis, may be seen in this outcrop. Other excellent sedimentary and structural features may be seen along this cut. Here we may consider some geomorphic problems regarding the Susquehanna River and correlation between the Chickies and lower Cambrian (?) sandstones in the Blue Ridge.

While crossing the Susquehanna from Columbia to Wrightsville, one may consider why a nearly continuous string of towns and cities seem to spring up along U. S. Route 30 from Chester to Gettysburg, including the towns we are now passing through.

Our lunch stop will be at Sam Lewis State Park which is underlain by the Chickies Formation. On a clear day Blue Mountain north of Harrisburg may be seen on the horizon to the north, and Safe Harbor dam on the Susquehanna may be seen to the south. From this point the role of structure and stratigraphy in landscape development can be observed. Further, indications of post-Triassic geomorphology will be pointed out and an opportunity will be given to discuss the observations.

The route now returns to the Triassic Lowlands to Stop 7, an exposure in the Hammer Creek Formation. Sedimentary cycles with coarse, angular carbonate veins which cross-cut some of the clastic particles suggest post-depositional deformation. Rock from this site has been quarried, slabbed, and finished into a beautiful natural veneer similar to that which now encases the Penn Charter in the William Penn Museum in Harrisburg.

Finally, the trip concludes with a stop at the Union Quarry in the Epler Formation at Rheems. Here alternating layers of limestone and dolomite have been intensely deformed producing classic recumbent folds, contrasts between competent and incompetent deformation, boudinage, bedding plane faults and slickensides. This quarry has probably been photographed by more authors for freshman textbooks in geology than any other quarry in Pennsylvania.

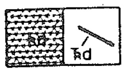
MAPS PERTINENT TO THE TRIP

There may be some who would wish to take the trip independently. For those, the following list may be useful.

A. U. S. Geological Survey 7½ minute maps: Harrisburg West, Harrisburg East, Steelton, Middletown, Elizabethtown, York Haven, Columbia West, Columbia East.

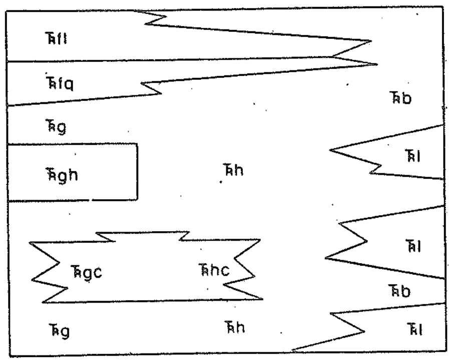
B. Geologic maps: the Geologic map of Pennsylvania (Berg and others), 1981, scale - 1:250,000; Geology and Mineral Resources of the Middletown Quadrangle, Stose and Jonas, 1933, scale - 1:62,500; Lancaster 15' Quadrangle, Jonas and Stose, 1930, scale - 1:62,500; Harrisburg West Area, S. Root, 1977, scale - 1:24,000; Geology and Hydrology of the Martinsburg Formations, Carswell et.al., 1968, scale - 1:24,000.

TRIASSIC



DIABASE

Dark gray, medium to coarse grained; composed of labradorite and various pyroxenes; occurs as dikes, sheets, and a few small flows; includes sheets (Adams and York Counties), and dikes of probably younger (Early Jurassic?) Rossville-type diabase which is identifiable as lighter gray, having distinctive, sparse, centimeter-sized, calcic-plagioclase phenocrysts in chilled margins.



LIMESTONE FANGLOMERATE (TRfl)

Yellowish-gray to medium-gray, angular limestone and dolomite pebbles, cobbles, and fragments set in a red, very fine grained quartz matrix; a few shale-clast interbeds.

QUARTZ FANGLOMERATE (TRfq)

Well-rounded quartzite pebbles, cobbles, and rare boulders set in a reddish-brown, sandy matrix.

DAUPHIN, YORK, AND ADAMS COUNTIES

GETTYSBURG FORMATION (TRg)

Reddish-brown to maroon, silty mudstone and shale containing thin red sandstone interbeds; several thin beds of impure limestone.

HEIDLERSBURG MEMBER (TRgh)

Red, green, and gray shale and argillite, and minor thin beds of gray arkosic sandstone; some quartz conglomerate and limestone conglomerate.

GETTYSBURG CONGLOMERATE (TRgc)

Red, pebbly, arkosic sandstone and conglomerate.

BERKS, LANCASTER, AND LEBANON COUNTIES

HAMMER CREEK FORMATION (TRh)

Reddish-brown, fine- to coarse-grained, quartzose sandstone and a few red shale interbeds.

HAMMER CREEK CONGLOMERATE (TRhc)

Cobble and pebble quartz conglomerate interbedded with red sandstone.

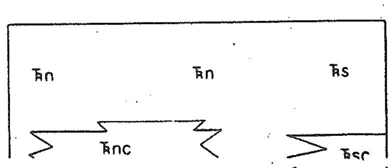
MONTGOMERY AND BUCKS COUNTIES

BRUNSWICK FORMATION (TRb)

Reddish-brown shale, siltstone, and mudstone, containing a few green and brown shale interbeds; red and dark-gray, interbedded argillites near base. Youngest beds in Brunswick may be Jurassic in age.

LOCKATONG FORMATION (TRl)

Dark-gray to black, thick-bedded argillite containing a few zones of thin-bedded black shale; locally has thin layers of impure limestone and calcareous shale.



NEW OXFORD FORMATION (TRn)

Red mudstone, shale, and fine-grained sandstone interbedded with light-gray to buff, commonly arkosic sandstone.

NEW OXFORD CONGLOMERATE (TRnc)

Quartz or quartzite pebbles, cobbles, and rare boulders set in a red, sandy, ferruginous matrix; some silica cement; some feldspar clasts.

STOCKTON FORMATION (TRs)

Light-gray to buff, coarse-grained, arkosic sandstone; includes reddish-brown to grayish-purple sandstone, mudstone, and shale.

STOCKTON CONGLOMERATE (TRsc)

Quartz cobbles set in a poorly sorted, sandy matrix; includes conglomeratic sandstone.

ORDOVICIAN

GREAT VALLEY AND NORTHERN PIEDMONT

CUMBERLAND VALLEY SEQUENCE

Om (Omgs, Oml)

MARTINSBURG FORMATION (Om)
Gray to dark-gray, buff-weathering shale. Omgs—abundant impure sandstone (graywacke) interbeds. Oml—dark-gray, thin-bedded, platy, argillaceous limestone containing some beds of shale.

Oc

CHAMBERSBURG FORMATION
Dark-gray, cobbly, argillaceous limestone; abundant irregular shale partings; some metabentonite beds present.

Osp

ST. PAUL GROUP
Very finely crystalline, "birdseye" limestone at top and base; granular, fossiliferous limestone, black chert, and dolomite in middle.

Ob — BEEKMANTOWN GROUP

Ops

PINESBURG STATION FORMATION
Light-colored, thick-bedded, finely laminated dolomite; some limestone.

Orr

ROCKDALE RUN FORMATION
Mostly limestone; some dolomite interbeds; some chert near middle and top; stromatolitic limestone in middle; pinkish marbleoid limestone and chert at base.

Os

STONEHENGE FORMATION
Stromatolitic, fine-grained limestone; includes coarser grained and conglomeratic, siliceous, laminated Stoufferstown Formation at base in most of Cumberland Valley.

HAMBURG SEQUENCE

Oh (Ohsg, Ohg, Ohl, Ohe)

HAMBURG SEQUENCE ROCKS
Allochthonous rocks of the Hamburg klippe: Oh—predominantly greenish gray, gray, purple, and maroon phyllitic shale, often silty and siliceous, including some wildflysch having autochthonous Martinsburg matrix; Ohsg—shale containing zones of conspicuous graywacke; Ohg—predominantly graywacke; Ohl—conspicuous limestone; Ohe—andesite extrusives. Recent research indicates that Hamburg sequence rocks are Early to Early Middle Ordovician in age.

Oco

COCALICO FORMATION
Gray phyllitic shale, maroon shale, and silty, siliceous shale; some interbedded argillaceous and quartzose sandstone; predominantly allochthonous, and probably closely related to Hamburg sequence, but does include some autochthonous elements.

Od, Od

METADIABASE
Dark-greenish-gray diabase; weathers medium gray to brown, forming rounded cobbles and boulders.

LEBANON VALLEY SEQUENCE

Om

MARTINSBURG FORMATION
Dark-gray, slaty to phyllitic shale, calcareous at base. Probably only lower part of Martinsburg Formation is present; overlain by Hamburg sequence rocks.

Oha (Ohm, Oan)

Ohm

HERSHEY AND MYERSTOWN FORMATIONS, UNDIVIDED
In descending order: Hershey—dark-gray to black, thin-bedded, argillaceous limestone. Myerstown—medium- to dark-gray, platy, medium-crystalline limestone; carbonaceous at base.

Oan

ANNVILLE FORMATION
Light-gray, massive, high-calcium limestone; mottled at base.

Oo

ONTELAUNEE FORMATION
Light- to dark-gray, very finely to medium-crystalline dolomite containing interbeds of light-gray limestone; interbedded nodular, dark-gray chert at base.

Oe

EPLER FORMATION
Very finely crystalline, light-gray limestone interbedded with gray dolomite; coarsely crystalline limestone lenses present.

Ori

RICKENBACH FORMATION
Gray, very finely to coarsely crystalline, laminated dolomite; dark-gray chert in irregular beds, stringers, and nodules; bands of quartz sand grains in lower half.

Os

STONEHENGE FORMATION
Gray, finely crystalline limestone containing dark-gray silty laminations; numerous edgewise conglomerate beds.

LEHIGH VALLEY SEQUENCE

Om (Omgs, Oml)

MARTINSBURG FORMATION (Om)
Gray to dark-gray shale and slate. Omgs—shale containing conspicuous graywacke; includes autochthonous sandstone and shale of Shochary Ridge. Oml—local limestone masses (wildflysch).

Ojk

JACKSONBURG FORMATION
Dark-gray shaly limestone (cement rock) having slaty cleavage; basal medium- to thick-bedded limestone (cement limestone) increases in thickness eastward.

Ob — BEEKMANTOWN GROUP

Oo

ONTELAUNEE FORMATION
Medium-dark-gray, finely crystalline dolomite, massive to finely laminated; weathers grayish yellow; thick-bedded, dark-gray chert at base.

Oe

EPLER FORMATION
Thick-bedded, medium- to medium-dark-gray, finely crystalline limestone, weathering light gray; yellow dolomitic laminae; interbedded medium-dark-gray, finely crystalline dolomite, weathering yellowish gray; edgewise conglomerate; fossil-fragment and oolitic lenses.

Ori

RICKENBACH FORMATION
Medium- to dark-gray, coarsely crystalline dolomite in lower part; medium- to medium-light-gray, finely crystalline dolomite in upper part; chert lenses, beds, and nodules.

Os

STONEHENGE FORMATION
Medium-light-gray to medium-gray, finely crystalline, thick-bedded limestone, containing dark siliceous laminae, edgewise conglomerate beds, and fossil-fragment lenses; dolomite beds increase in number eastward.

ORDOVICIAN AND CAMBRIAN

O€c

CONESTOGA FORMATION
Light-gray, thin-bedded, impure, contorted limestone having shale partings; conglomeratic at base; in Chester Valley includes micaceous limestone in upper part, phyllite in middle, and alternating dolomite and limestone in lower part.

CAMBRIAN

GREAT VALLEY AND NORTHERN PIEDMONT

LEBANON VALLEY SEQUENCE

Ꞓr — RICHLAND FORMATION
Gray dolomite, in part oolitic, interbedded with medium-gray limestone and dark-gray oolitic chert.

Ꞓms (Ꞓm and Schaefferstown Formation)

Ꞓm — MILLBACH FORMATION
Pink to white and gray, finely laminated limestone and interbedded finely crystalline dolomite; numerous stromatolitic limestone beds.

SCHAEFFERSTOWN FORMATION
Gray limestone containing siliceous and argillaceous laminae; thin bedded.

Ꞓsb (Ꞓsc and Ꞓbs)

Ꞓsc — SNITZ CREEK FORMATION
Thick-bedded, medium- to coarsely crystalline dolomite, in part oolitic, containing laminated limestone and sandstone interbeds.

Ꞓbs — BUFFALO SPRINGS FORMATION
Light-gray to pinkish-gray, finely to coarsely crystalline limestone and interbedded dolomite; numerous siliceous and clayey laminae; stromatolitic limestone beds near top; some thin sandy beds.

Ꞓzc — ZOOKS CORNER FORMATION
Medium-gray, finely crystalline dolomite, silty to sandy, containing numerous siliceous and argillaceous laminae.

Ꞓl — LEDGER FORMATION
Light-gray, locally mottled, massive, pure, coarsely crystalline dolomite; siliceous in middle part.

Ꞓk — KINZERS FORMATION
Base—dark-brown shale; middle—gray and white spotted limestone and marble having irregular partings; top—sandy limestone which weathers to a fine-grained, friable, porous, sandy mass.

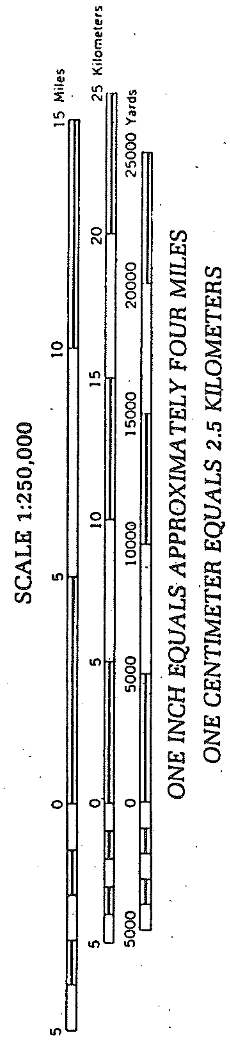
Ꞓv — VINTAGE FORMATION
Dark-gray, knotty, argillaceous dolomite; impure light-gray marble at base.

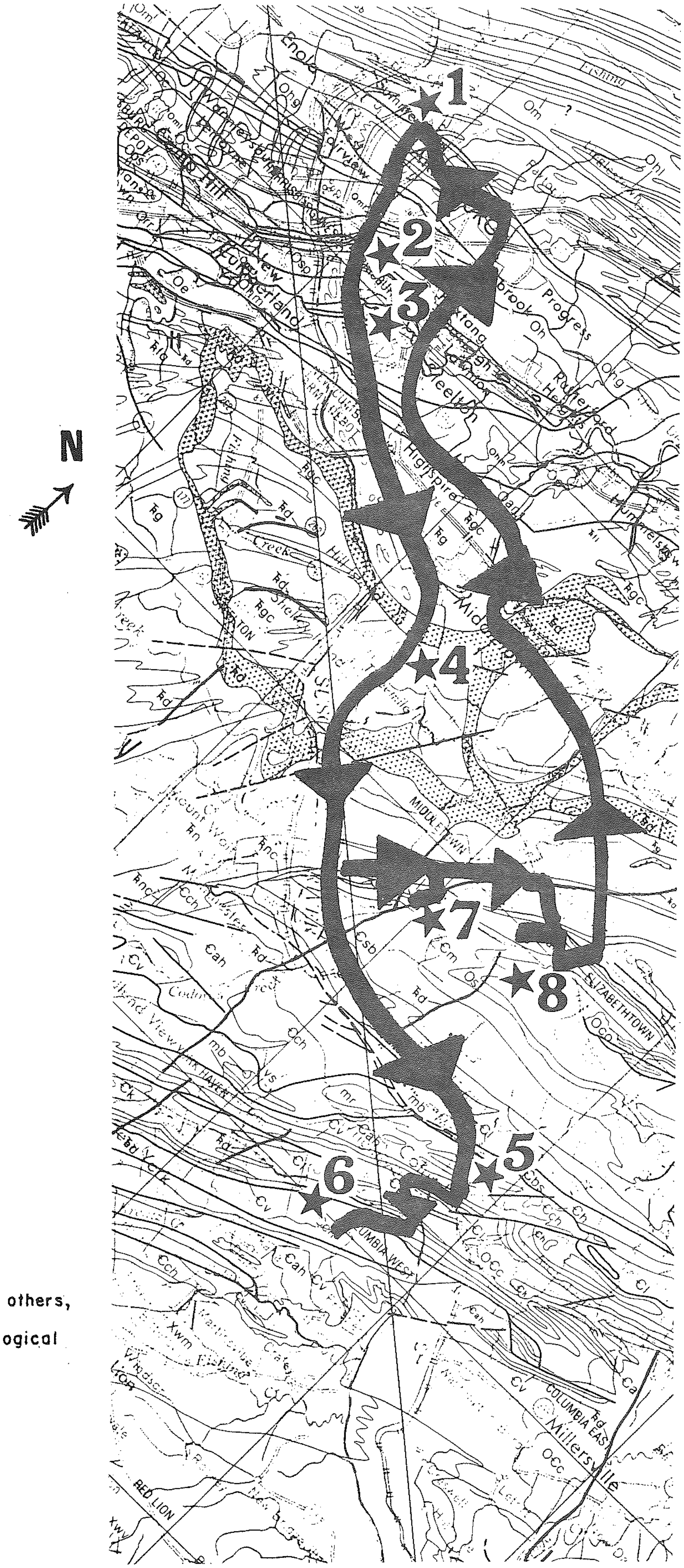
Ꞓah (Ꞓa and Ꞓh)

Ꞓa — ANTIETAM FORMATION
Gray, buff-weathering quartzite and quartz schist.

Ꞓh — HARPERS FORMATION
Dark-greenish-gray phyllite and schist having thin quartzite layers.

Ꞓch — CHICKIES FORMATION
Light-gray, hard, massive, *Scolithus*-bearing quartzite and quartz schist; thin, interbedded dark slate at top; conglomerate (Hellam Member) at base.





★ Field trip stop

—✦— Field trip route

Base map and explanation from: Berg, T. M. and others, 1980, Geologic map of Pennsylvania: PA Geological Survey, 4th ser., Map 1.

FIG 1.

ROAD LOG

Increment milage	Cumulative milage	
0.0	0.0	Stop 1. East Parking Lot, HACC Campus - 30 minutes Ron Mowery

EAST PARKING LOT
HARRISBURG AREA COMMUNITY COLLEGE

Harrisburg Area Community College is built on an abandoned channel of the Susquehanna River which begins just north of Pa. Route 39, about 1½ miles north of the campus, and continues southward along Paxton Creek and Cameron Street in Harrisburg toward Steelton. Here on campus, the channel is filled with more than 26 feet of river gravel, as determined from drill cores for building foundations. The Susquehanna River is located about a mile west of the campus, and normal river levels are about 20 feet below campus elevations. The bluff to the east of the campus is about 80 feet above the campus terrace and was the east bank of the Susquehanna River during the Pleistocene deglaciation period. A thin veneer of river gravels covers the upper surface. Due west of this point is the Enola railroad yard, built on a terrace of about the same elevation as HACC campus, and to the west of the railroad yard is an equivalent bluff and upper terrace. The distance from bluff-to-bluff across the Susquehanna is about 2¼ miles, and during the Pleistocene deglaciation the river must have been more than 80 feet higher than at present. River discharges were several orders of magnitude larger than those today.

The rock exposed on the eroded face of the bluff is an unnamed member of the Hamburg Sequence (Geol. Map of PA, 1981), consisting primarily of graywacke beds several feet thick, and shale interbeds ranging from several inches to about a foot in thickness. The strike of the beds here is about N50°E, and the dips are consistent with regional dips in the area ranging from about 40° to nearly vertical toward the southeast. Several hundred yards to the southeast of this exposure, the axis of a minor syncline could be seen in an old roadcut until recent highway construction covered the site.

At this exposure there are some fine examples of sedimentary primary structures typical of Martinsburg deposition. On the exposed bedding planes, groove casts, tool marks and ripple marks may be seen. In cross-section, shale chips, crossbedding and other laminar features may be observed (See Figure 2). Of particular interest are the assymetrical flute structures or sole marks found on many of the shale/graywacke interfaces. These scoop-like structures (See Figure 2) are frequently associated with turbidity currents, and may be produced in soft muds as a sandy slurry moves downward over a current-mud interface excavating a spoon-shaped glob from the mud with the steepest face in the up-current direction. The primary structures indicate a sediment flow in this area as originating from about 70^{o} west of north. This appears to contradict the generally recognized regional sediment flow which is considered to be about 70^{o} east of south.

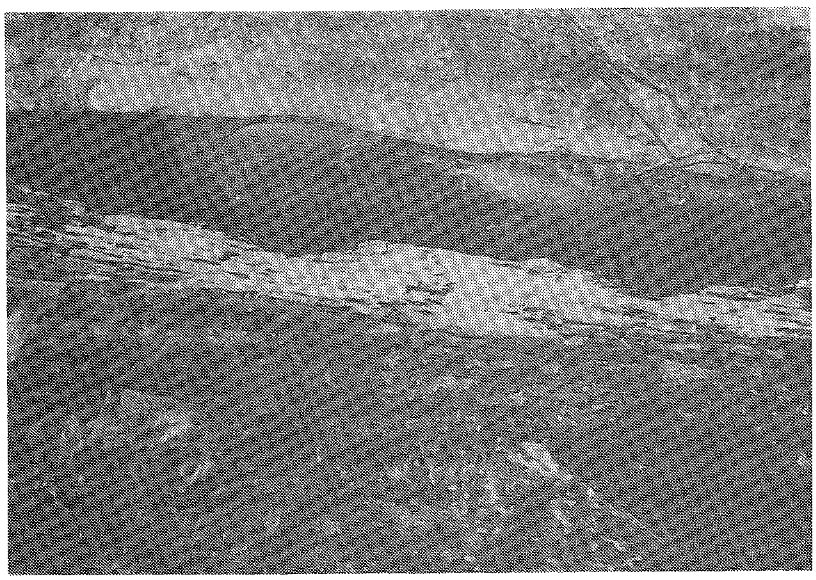


Figure 2. Load Casts seen at Stop 1. Current scoops out spoon-shaped furrows in soft mud with steep face on upstream side. Silt or sand later fills in the fluted molds and these are preserved as the convex cast seen in the photograph. Current direction was from left to right.

In the less competent shale interbeds separating the more competent graywacke units, shear fractures within the shales and slickensides on surfaces indicate bedding plane faults.

Several hundred feet to the north of this exposure, high calcium limestone layers between the graywacke units and shales exist ranging from several inches to several tens of feet in thickness. Their abrupt and angular margins suggest an allochthonous origin from earlier Ordovician and Cambrian carbonates further to the south. One of the larger carbonate blocks was uncovered during the construction of I-81 in the mid-1970's. Although this is now excavated and removed and the edges covered by vegetation, the block had a thickness of about 90 feet and a width of more than a quarter of a mile. The edges were sharp with no sedimentary transition from shale to carbonate.

No formal nomenclature exists to integrate the local Hamburg Sequence into tectonic units or a time-sequential order. Although several investigators have recognized discrete units based on graptolite facies and sedimentary tectonics (cf. MacLachlan, 1975; Platt in Carswell et. al., 1968; Root, 1977; Guidebook for 47th Annual Field Conference, 1982), a generally accepted sequence has not been found. To date, too few graptolite fossils have been found in this area to establish a reliable subdivision of units in the Harrisburg East area. Therefore, it becomes apparent that the opportunity exists to develop a stratigraphic/tectonic sequence in this area and integrate it into a regional model.

Bus leaves from front of telephone booth on main drive. Exit HACC Campus turning left to Industrial Road.

0.4	0.4	STOP sign. TURN LEFT onto Industrial Road.
0.2	0.6	STOP light. TURN RIGHT onto Cameron Street. Continue on Cameron Street through 3 stop lights to Berryhill Street just before underpass.
1.6	2.2	Pass under State Street Bridge. Building ahead on right, 100 N. Cameron Street, was site of Pennsylvania Geological Survey (ground floor) during Agnes flood of 1972. Flood level reached ceiling of ground floor.
0.7	2.9	TURN LEFT onto Berryhill Street just before underpass.
0.1	3.0	TURN RIGHT into parking lot of Harrisburg Cold Storage.

Stop 2. Harrisburg Cold Storage - 45 minutes

Dave MacLachlan

HARRISBURG COLD STORAGE WAREHOUSE
SOUTH SIDE OF BERRYHILL STREET
½ BLOCK EAST OF CAMERON STREET
HARRISBURG

Exposures extend from Berryhill Street southerly along east edge of parking lot and then generally southeasterly along the railway spur. Abundant quartzitite pebbles and some boulders in soil overlying these cuts indicate an extension of the terrace gravels which will be considered in detail at Stop 3. The relative isolation of these exposures combined with structural complexities in this belt and continuing investigations has resulted in several somewhat variant interpretations of this area on several maps published in the last 15 years (Pa. G. S. Bull. G 44, W 24, EG 4, A 148 ab, 1981 State Map, and also Root and MacLachlan, G. S. A. Bull. v. 89, 1978). To clarify or obfusticate, the present interpretations are not exactly any of the above, though including elements of several.

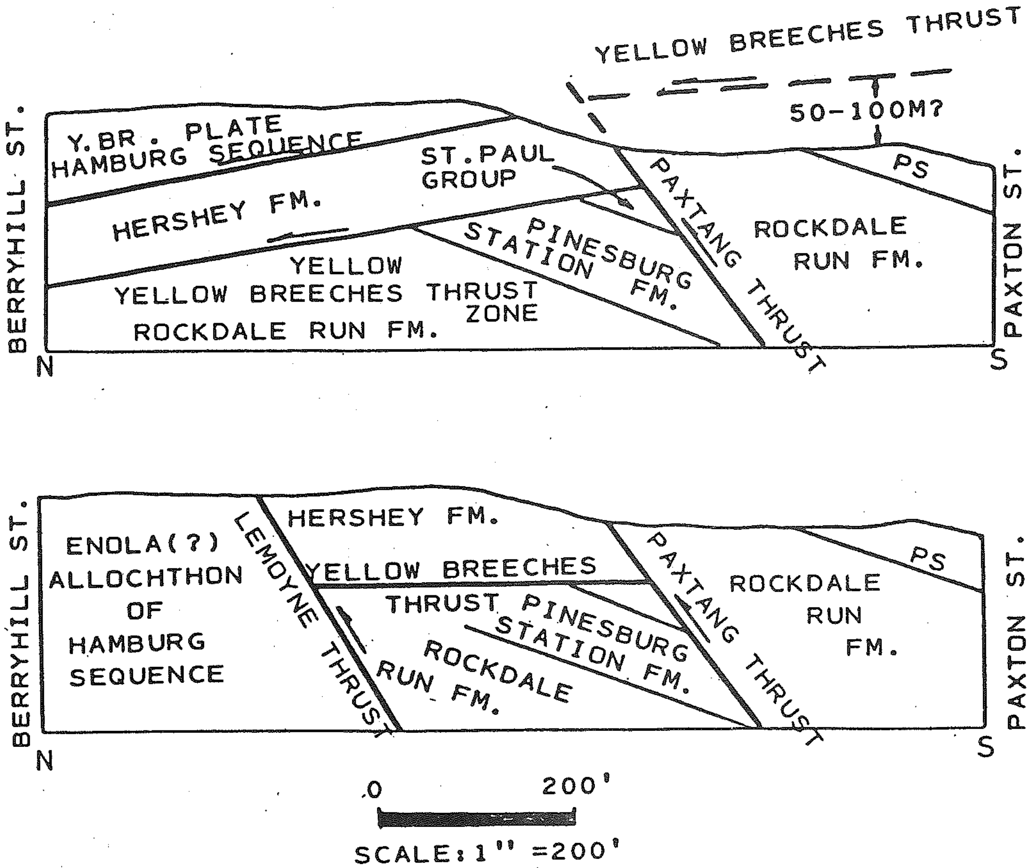
Exposed at the north end of the cut is a phyllitic argillite with multiple cleavages which clearly belongs to the Hamburg Sequence, as do most of the argillaceous rocks of the Harrisburg area. These rocks had been called Martinsburg Formation in all reports prior to 1978; though Deepkill age graptolites were reported near HACC by Stose and Jonas (1927), and several subsequent authors have remarked or elaborated on their untypical character. Root and MacLachlan (1978) generally delimited the allochthonous rocks west of the Susquehanna River and provisionally assigned rocks on strike with this exposure to the (?) Enola allochthon (but referred to the polyallochthonous assemblage only as rocks of Taconic affinity). The tectonostratigraphic name Hamburg Sequence is derived from the Hamburg Klippe of Stose (1946) but first applied in this sense in the Sinking Spring Quadrangle (MacLachlan et. al., 1975). With recognition that the Hamburg Klippe, though comprising a multiple thrust stack formed progressively during the Taconic orogeny, forms a major stratigraphically and structurally distinct terraine, the name Hamburg Sequence was extended to the Susquehanna River region on the 1981 State Map. The youngest rocks of the Hamburg Sequence are lower Middle Ordovician (<u>Nemagraptus gracillis</u> z.), somewhat older than the base of the

Martinsburg Formation; the oldest dated rocks are Upper Cambrian in Berks County. Apparent stratigraphic level of associated wildflysch in the Martinsburg Formation sets emplacement of the allochthons about a quarter to a third of the way through the time of Martinsburg deposition. Names for stratigraphic units within the Hamburg Klippe have not been established in the Harrisburg area, though some units mostly not represented here have been named at the eastern end of the Klippe.

Following a covered interval there are strongly cleaved, thick-bedded shaley limestones with a zone of coarse, angular limestone conglomerate of Beekmantown Group derivation near the southern end of the exposure. Silty laminae are sometimes evident in the parking lot, though the bedding is generally obscure. The thick bedded character becomes more apparent along the railway, though the cleavage remains much more conspicuous. This rock is clearly the Hershey Formation which is exposed in several places along the Yellow Breeches thrust zone on the south side of the limestone valley (formerly exposed under the Rozman Brothers building near Stop 3, photo in MacLachlan, 1967, Pa. G. S. Bull. G 44). It is definitely not the Chambersburg Formation as shown by EG 4 and the 1981 State Map. Rock along strike between the Paxtang and Lemoyne thrusts west of the river is probably correctly identified as Chambersburg Formation, however. The confusion of these rocks of vaguely similar aspect and comparable age along the same strike belt, but belonging to entirely different stratigraphic sequences, is readily understandable; the lack of continuity with the West Shore exposures is essentially a function of the amount of displacement along the steep thrusts.

The covered interval concealing the contact between the argillites and the Hershey Formation is, unfortunately, characteristic of thrusts in the Great Valley, and the attitude of the thrust has not been established in this exposure. The question is of some significance because it is the critical factor for discriminating between the alternative cross-sections. I presently prefer the first interpretation because I believe that the (?)Enola allochthon of Lemoyne (Root, 1977, A 148ab) was mis-identified. It appears without associated wildflysch in contact with basal Martinsburg Formation limestones which are older than the emplacement age of the type Enola allochthon to the north. It appears to be a hardrock thrust sheet which I deduce to be an outlier of the Yellow Breeches thrust sheet rather than an intra-Martinsburg allochthon of the main "shale" belt. The second interpretation is simply an updated version of the section I showed in the 1966 Pennsylvania Field Conference Guidebook which accomodates data obtained by subsequent mapping on the West Shore. The presence of the Lemoyne thrust at this locality is not a major issue. Assuming correctness of the second section, the Lemoyne thrust converges with the Paxtang thrust less than a quarter mile east of here, and terminating it under the river to the west is a direct projection of the trends in Lemoyne. Minor structures in this area may resolve the issue; be alert. I contend that bedrock structure and stratigraphy here are essentially identical to that at Stop 3, though present exposure in that area is poor.

The age relationship between the low angle and high angle thrusts is of interest here because it leads to the conclusion that the steep thrusts are not directly related to the folds of the Cumberland Valley. In Cumberland County the crop pattern at the western edge of the Yellow Breeches plate shows that the sole thrust dip is quite gentle and scarcely folded, but the thrust truncates the Cumberland Valley fold structure down to the Lower Cambrian. The steep thrusts, however, offset the Yellow Breeches thrust implying a significant interval between the Cumberland Valley folding and the steep thrusting and three stylistically distinct episodes of Alleghanian deformation in this area.



ALTERNATIVE CROSS-SECTIONS BETWEEN BERRYHILL ST. AND PAXTON ST. THROUGH STOP 2 AREA.

Figure 3. Cross-section of cut behind Harrisburg Cold Storage Warehouse on Berryhill Street.

		Leave parking lot and TURN LEFT onto Berryhill Street.
0.1	3.1	STOP sign. TURN LEFT onto Cameron Street. Continue on Cameron Street through 2 stop lights until Gibson Street. Note limestone outcrops behind some buildings on left.
1.2	4.3	Entrance to the Harrisburg City Incinerator on left.
0.4	4.7	TURN LEFT onto Gibson Street just past sign on left for Rozman Brothers. Gibson Street is Steelton borough boundary.
0.1	4.8	TURN LEFT into parking lot of Quaker City Motor Parts.

Stop 3. Quaker City Motor Parts - 45 minutes

Bill Sevon and Noel Potter

QUAKER CITY AUTO PARTS

On the east side of the building, the weathered Hershey Formation occurs in the slope. Nearby are several unweathered boulders of the same material, and a close examination of these rocks will reveal complex crenulation folding, slickensides along some bedding planes and quartz veins separated from this argillaceous limestone during deformation. In the cut along the building weathered bedrock from the Hershey Formation is exposed. This residuum is a saprolite from the low-grade metamorphic limestone. The same crenulated texture of the unweathered rock is reflected in the C-horizon of the soil in the slope.

The surficial material of interest at this stop is exposed in a southwest facing cutbank behind the Quaker State Auto Parts building. Both bedrock and unconsolidated surficial materials are exposed in the cutbank. The surface at the top of the cutbank has probably been disturbed by man to some extent, but most of the original sequence is probably preserved. The bedrock-surficial contact at the south end of the cutbank is at 355-360 feet elevation, and the upper surface is about 370 feet. Elevation of the Susquehanna River in this area is between 290 and 300 feet, thus making the upper surface about 75-80 feet above the present river. This deposit is topographically distinct from compositionally similar materials exposed farther upslope along Gibson Street. The higher surface, which underlies the Harrisburg incinerator, is at an elevation between 390 and 400 feet.

The material exposed in the cutbank comprises clay, silt, sand, gravel, and boulders. Bedding is not obvious in the weathered exposure, but a freshly cleaved face would probably reveal good stratification. The gravel appears to occur mainly in the lower part of the deposit, but locally occurs throughout most of the thickness of the deposit. The gravel is dominantly smaller than 2 inches in diameter, but larger cobbles are common and several boulders occur. The boulders appear restricted to the lower part of the deposit and are definitely associated with the gravel. The upper 6 feet of the deposit at the northwest end of the main cutbank is mainly silt with some sand and scattered pebbles. The material tends to weather to form a vertical face and has a damp color of yellowish brown (5YR4/6). A soil profile is not readily apparent in this exposure and the deposit appears to be weathered throughout its entire thickness. Weathering rinds occur on many clasts and some clasts are completely rotted.

Composition of the clasts is dominated by sandstones, many of which are readily identifiable as being derived from the Tuscarora Formation. Most of the boulders, including the largest one, are Tuscarora. Other clasts are not readily assigned to a specific source rock. Chert pebbles are common and Ronald Mowery reports finding igneous and metamorphic rock from the site. The clast composition of this deposit appears identical to that of the nearby higher level deposit.

Analysis of this deposit is interesting. The terrace nature of the deposit and its relationship to the Susquehanna River are obvious. The topographic distinction between the cutbank deposit and the higher deposit also seems certain. The presence of igneous and metamorphic clasts indicates association of the deposit with glaciation. The color and degree of weathering of the material are reminiscent of Sangamon (post-Illinoian) weathering present elsewhere in the State.

The literature is of little help with this deposit. No detailed work related to this specific locality exists. Both Ashley (1933, p. iv) and Peltier (1949, p. 3) refer to detailed maps and notes of Hickok and Moyer which might have included this deposit, but the work was never published and materials once on file at the Pennsylvania Geological Survey have disappeared. The Dauphin County soils report (Kunkle and others, 1972) describes the area only as urban land on alluvial materials. Some interpretive correlation can be made with the work of Peltier (1949): the higher surface under the Harrisburg incinerator would be his Highspire terrace of pre-Illinoian age and the cutbank deposit would be either an Early or Late Illinoian terrace. The bedrock surface in the cutbank might also be a rock bench cut during the presumed Somerville partial peneplain development.

Questions to be asked here:

1. What are the dynamics involved in transporting the contrasting sizes of materials present here?
2. Is the fine-grained sediment at the top of the deposit a flood plain deposit or loess?
3. What is the age of the deposit?
4. Is the cutbank deposit of different age than the topographically higher deposit?
5. When was the rock bench cut?
6. How much bedrock has the Susquehanna River eroded since the cutbank sediment was deposited?

0.1	4.9	Leave parking lot and TURN RIGHT on Gibson Street.
		STOP sign. TURN LEFT onto N. Front Street (equals Cameron Street to north). Proceed through Steelton.
1.9	6.8	Entrance to Hempt Brothers quarry on left.
0.5	7.3	Outcrop ahead on left is in Triassic red beds. Contact with limestone occurs in covered slope about here.
4.3	11.6	STOP light at Middletown Borough boundary just past Penn State Capitol Campus on left. TURN RIGHT onto PA 441 and cross bridge.
0.1	11.7	STOP sign. TURN RIGHT THEN LEFT following PA 441 South.
0.5	12.2	Cross Swatara Creek. Swatara Creek joins the Susquehanna River a few hundred yards to the southwest.
2.0	14.2	Plant entrance to TMI on Right.
0.7	14.9	TURN LEFT into TMI Visitors Center and park in parking lot.
		Stop 4. Three Mile Island - 20 minutes
		Richard E. Wright and Carlyle Westland

STOP NO. 4
THREE MILE ISLAND

1.0 Introduction

The foundation investigation performed for the Preliminary Safeguard Analysis Report (PSAR) for Three Mile Island served as the basis for the design of structures at TMI. The following synopsizes this investigation and has been extracted from a paper presented to the Pennsylvania Electric Association Structures and Hydraulics Committee in May of 1968. Since that time, of course, there has been an accident at the Island and there was much concern over a potential meltdown. Quoted below is an excerpt from the report by Richard E. Wright and William J. Santamour relative to the integrity of the foundation system to assimilate that kind of unlikely event.

In addition to the Reactor Building, other structures are also founded on rock. However, the bearing capacity of the fluvial sediments was adequate to sustain loads by other structures such as the cooling towers. The President's Commission on the Accident at TMI stated that: "Our calculations show that even if a meltdown occurred, there is a high probability that the containment building and the hard rock on which the TMI-2 containment building is built would have been able to prevent the escape of a large amount of radioactivity."*

1.1 Depositional History

TMI resulted from fluvial deposition by the Susquehanna River. The carrying capacity of the river sharply decreases just north of TMI after the stream crosses an east-west trending very resistant diabase dike and flows south across the easily erodible Gettysburg Formation, until it is again restricted and deflected by a second diabase dike just south of Three Mile Island.

Boulders first deposited in this wide-channel, low velocity section of the river became nuclei for the gradual accretion of river sediment which resulted in the growth of most of the islands in this area. TMI consists of two such nuclei. The area between them consists of fine-grained materials, deposited in a low energy fluvial environment between the two depositional islands.

2.0 Bedrock Geology

TMI is underlain by the Gettysburg Formation and is regionally encircled by a Triassic diabase dike and sill complex, located one mile upstream, 0.2 miles downstream, 2 miles east, and 8 miles west from the island.

Bedrock generally occurs at elevation 277 feet, 6 to 30 feet below natural ground surface. Rock types vary from brick-red to brown and occasionally gray, interbedded, fine to medium-grained sandstone, to brick-red shaly siltstone and shaly claystone, to red and

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* Report of the President's Commission on the Accident at Three Mile Island, John G. Kemeny, Chairman, October 1979, p.14.

green limy shale. All rocks possess seismic velocities of 8,500 to 11,500 ft./sec. One to three feet of weathered rock occurs above an undulating overburden-bedrock interface resulting from differential weathering rates of the various rock lithologic types.

2.1 Primary Structure

Regional dip is northwest at 10° to 50°. Attitudes measured in surface outcrop near the island vary from N 65° to 80° E with 35° to 70° northerly dips. In the excavation for the Reactor Building, the attitude of bedding is N 70° to 75° E, 35° NW.

2.2 Secondary Structure

2.2.1 Jointing

Although jointing is conspicuously recognizable and moderately to closely spaced (from several inches to several feet), it is basically discontinuous along strike.

Well-developed, near vertical jointing is conspicuous along a N 10° E trend. A set of strike joints which dips at 45° to 55° southeast, thus intersecting bedding in a perpendicular manner often forms incipient southward dipping circular joints which become recognizable after they open, following excavation. A third prominent set of vertical joints strikes N 10° W. Minor joint sets occur at N 80° W, dipping 50° to 60° S, and as near vertical structures striking N 30° to 40° W and N 40° to 50° E.

2.2.2 Faulting

Due to the inter-relation of faulting with the overall geologic and seismic considerations as they would affect structural design, considerable effort was made to establish the validity of earlier published work, which showed faults extending across TMI.

No evidence of faulting which transects the island was seen in the field from available rock exposures along the east bank of the river, or along the western periphery of the island. Aerial photographs as well give no suggestion of faulting through the island.

Stose and Jonas, (1933)* mapped a hypothetical NE trending fault which they projected through TMI approximately 0.5 miles south of the site. Based on the data collected for the PSAR, it was concluded that such a hypothetical fault does not exist, nor is there evidence to substantiate the projections of other hypothetical faults across the river immediately north and south of the island.

In addition, diamond drilling was performed in the Reactor Building area to obtain detailed lithologic data for correlation of rock strata. This work confirmed that no displacement of strata exists in the foundation of critical structures.

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* Stose, G.W. and Jonas, A.I. (1933), Geology and Mineral Resources of the Middletown Quadrangle, PA, U.S.G.S. Bulletin 840.

The type stratigraphic column is represented by Boring RB-3NX (Exhibit 1) and served as the basis for correlation of rock types shown on the Geologic Map of the Bedrock Surface (Exhibit 2). This map shows that the N 70° E, 37° NW attitude of bedding is continuous across the main building area without any interference of displacement oriented in a non-parallel fashion to the bedding attitude.

Likewise, displacement striking parallel to bedding does not occur beneath the Reactor Building, as substantiated by the Geologic Cross Section Through the Reactor Building, Exhibit 3.

Subsequent detailed mapping of the Reactor Building foundation rock system during the final excavation process validated earlier subsurface projections.

From the studies conducted, it was concluded that the site is not deleteriously affected by faulting, and further, that regional tectonic elements are inactive and present no threat to the structural integrity of local geology.

3.0 Soils

TMI is composed of fluvially stratified, sub-rounded to rounded, sand and gravel, containing varying amounts of silt, clay, fine coal detritus, and occasional lenses of clean sand. Density values range from loose to very dense, as established by Standard Penetration Tests. Boulders are present at depth and are mainly confined to the lower portion of the soil zone on the north end of the island. Depth of soil is relatively constant at about 20 feet in the vicinity of the plant site.

Two general soil units comprise the island:

1. Overlying rock is a lower layer of coarse sand and gravel which, at the north end of the island, contains numerous boulders and cobbles and ranges from medium-dense to very dense.

2. Above the coarse sand and gravel is a layer of loose to medium-dense, fine-grained granular material which varies from a fine silty sand and gravel on the northern third of the island to a very stiff, clayey silt on the south end of the island.

In the main building area the elevation of bedrock occurs at about elevation 276 feet. This rock surface is overlain by the lower layer of sand and gravel with N values in excess of 30 BPF up to elevation 286. This in turn is overlain by approximately 10 feet of plus 20 BPF sand and gravel.

Unit weights of the sand and gravel from the main building area are about 119.5 for the 20 BPF material and 115.0 for the 30 BPF material, with water contents of the order of 6% and 8%, respectively. Average minimum and maximum density values were determined to be 109 and 132 PCF, respectively.

4.0 Groundwater

Groundwater occurs under water table conditions. The water table reaches its maximum elevation at the highest topographic point in the center of the island and falls off toward both the east and west shores. A variation of only about 5 feet occurs from either side to the center producing a gradient of approximately 0.6% toward the river.

At 20 observation points in and surrounding the plant area, water levels occurred generally at a depth in excess of 15 feet and ranged from 14 to 19 feet. The groundwater level occurred at a maximum of 6.2 feet above the top of rock with less than 1 foot of head existing above the soil-rock interface at one point of observation.

TMI groundwater levels are controlled by the stage of the Susquehanna River. Since a positive head exists on the island, any movement of groundwater from the plant site is toward either channel of the river. The river acts as a natural boundary, limiting the dispersal of groundwater from the island to the river.

Three types of tests were run to establish permeability of unconsolidated material. Data acquired from a pumping-out test on the eastern side of the island indicated permeability to be on the order of 10^{-2} cm./sec. Permeability of unsaturated soil was determined by a falling head test to be 10^{-3} cm./sec. Laboratory permeability coefficients obtained on sand and gravel samples from three test pits in the Reactor Building area ranged from 2.79×10^{-3} at 12.0 feet to 1.58×10^{-2} at 4.0 feet.

5.0 Foundation Considerations

TMI subsurface conditions are favorable for safe, economic foundation design. Maximum thickness of the uniformly dense to very dense sand and gravel occurs at the north end of the island, which optimized use of these dense soils as bearing materials and provided a greater opportunity to work above the groundwater table. A plant built on the south end of the island would have involved expensive rock excavations, dewatering costs, and variable rock competency as implied by a seismic refraction survey.

5.1 Soils

There is a high degree of uniformity of density and of soil types at the selected plant location, within the upper silty sand layer and the lower sand and gravel layer. Both layers are capable of supporting foundation loads which will greatly increase with increasing depth. The actual bearing capacity of each soil layer is dependent upon the depth, size, and spacing of footings.

Figure 1, based upon Terzaghi and Peck (1964)*, shows the increase in recommended bearing capacity with depth for a footing of width equal to 10 feet. According to Meyerhof (1965)**, no decrease in bearing capacity was made for footings influenced by the water table.

Studies were also devoted to an analysis of the behavior of these granular soils under cyclic loading resulting from the design earthquake. It was concluded that for the site soils and foundation loadings, the expected maximum differential settlement between footings founded on rock, and those founded in the dense sand and gravel 12 feet above rock would be less than one-quarter inch.

5.2 Rock

For planning purposes, sound rock was assumed to be represented by a seismic velocity of 10,000 ft./sec., which would possess an assumed bearing capacity equal to 30 kips per square foot.

Later laboratory tests of BX rock cores established unconfined compressive strengths of greater than 80 TSF for representative sandstone cores. This high value was not considered to be representative of the in situ bearing capacity of the shale members, due primarily to the abundance of fossilized slickensides, the dipping strata, and the secondary discontinuities (joints) in the foundation rock system. In addition, examination of exposed rock cuts and drill cores showed that shaly members of the rock system rapidly slaked when dried and subsequently became soft clay seams following dewatering.

Therefore, because of deleterious effects of the above factors, original and seemingly conservative assumptions were realistic.

Because of these factors it was recommended that high differential loading not be placed on, or close to the top of weathered or unweathered rock.

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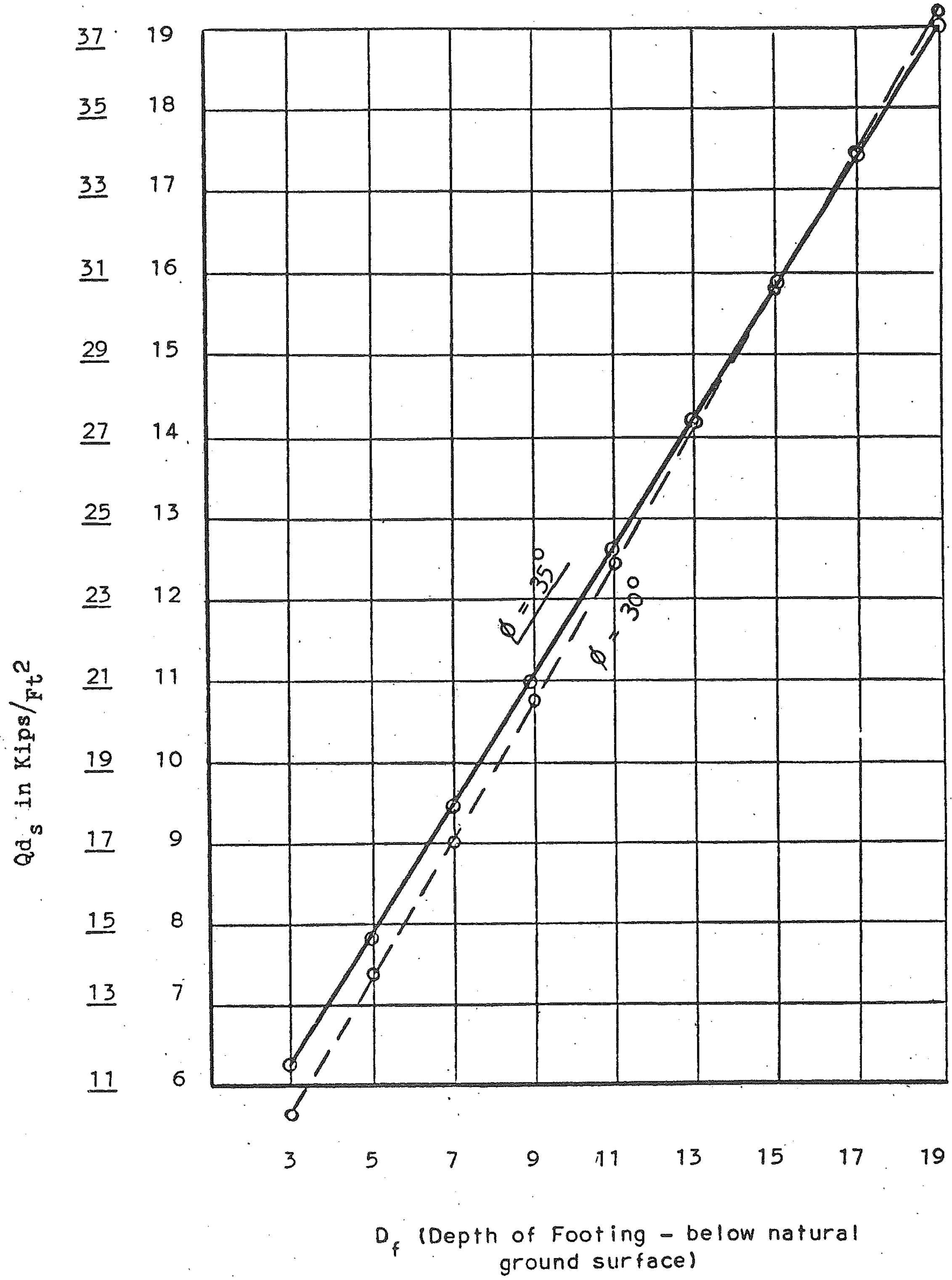
* Terzaghi and Peck (1964), Soil Mechanics in Engineering Practice, J. Wiley and Sons, P. 169-173.

** Meyerhof, G.G. (1965), "Shallow Foundations," ASCE, Journal of Soil Mechanics & Foundation Engineering, March, 1965



Recommended Bearing Capacity of Square Footings on Granular Soil
Three Mile Island Nuclear Station

Figure 4.

Heaviest foundation loading is below 15 KSF; therefore, additional quantitative determinations of the strength parameters of the foundation rock system were not warranted.

5.3 Groundwater

Groundwater studies showed that the water table occurred from elevation 279 to 282 and increased in elevation with distance from the river. It was further concluded that fluctuations of the Susquehanna would be only partially attenuated because of the high permeability of the granular soils.

It was therefore recommended that, since flood studies indicated that the 50-year design flood could raise the river to more than 15 feet above its normal 277 foot elevation, foundation design parameters include forces due to hydrostatic uplift.

It was originally thought that a permanent deep well system could accomplish the required dewatering for construction, serve as a controlling mechanism for rising groundwater during floods, and serve as a potable water supply. Because positive protection of surface structures against floods was required, and it was possible to construct such dikes far enough away from the building area that even the high soil permeabilities would not permit abnormal hydrostatic uplifts to develop during the design flood, hydrostatic uplift control was unnecessary.

Dewatering of excavations was satisfactorily accomplished by sumping.

EXHIBIT 1

REPRESENTATIVE STRATIGRAPHIC COLUMN

AS TYPIFIED BY BORING RB-3NX

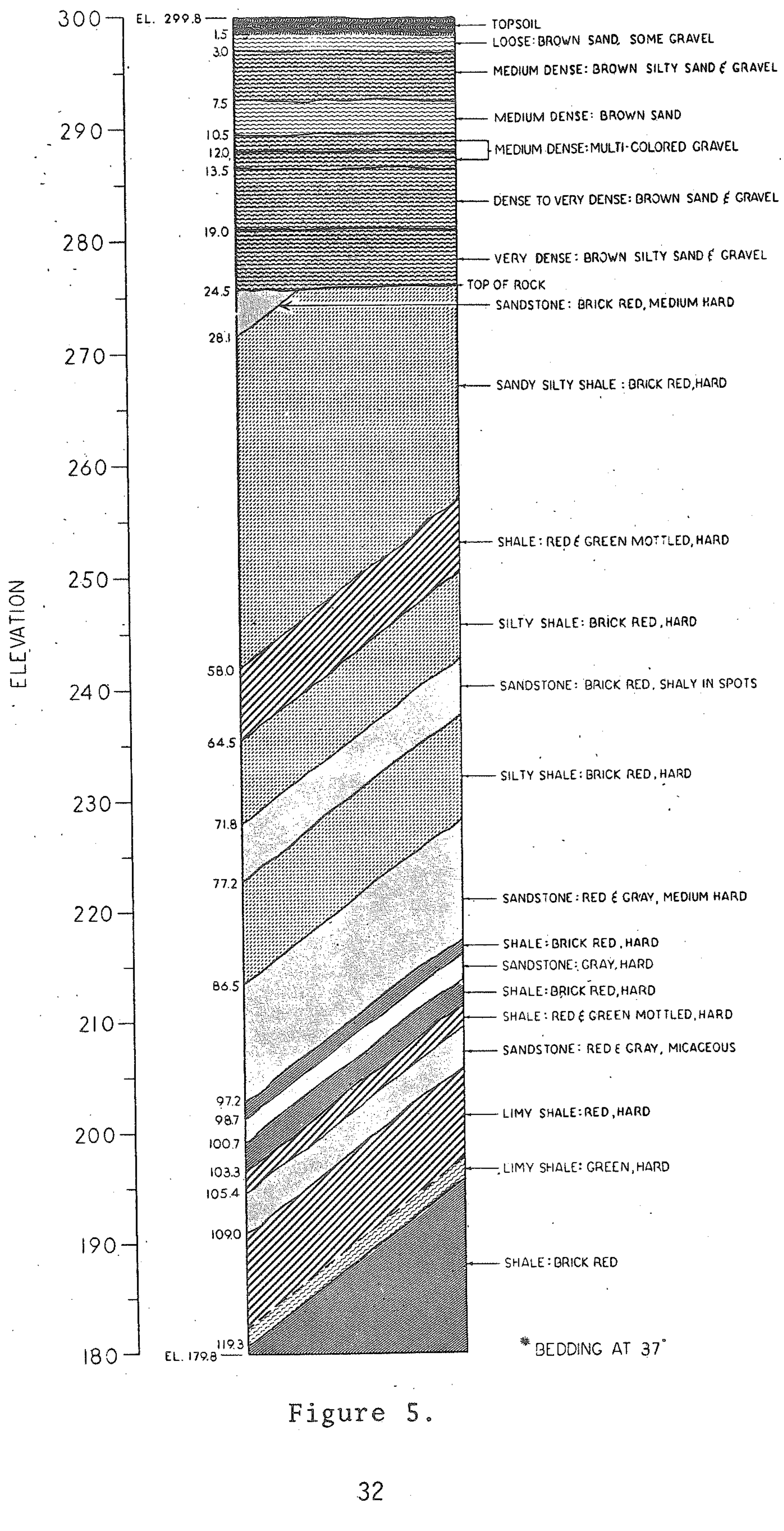
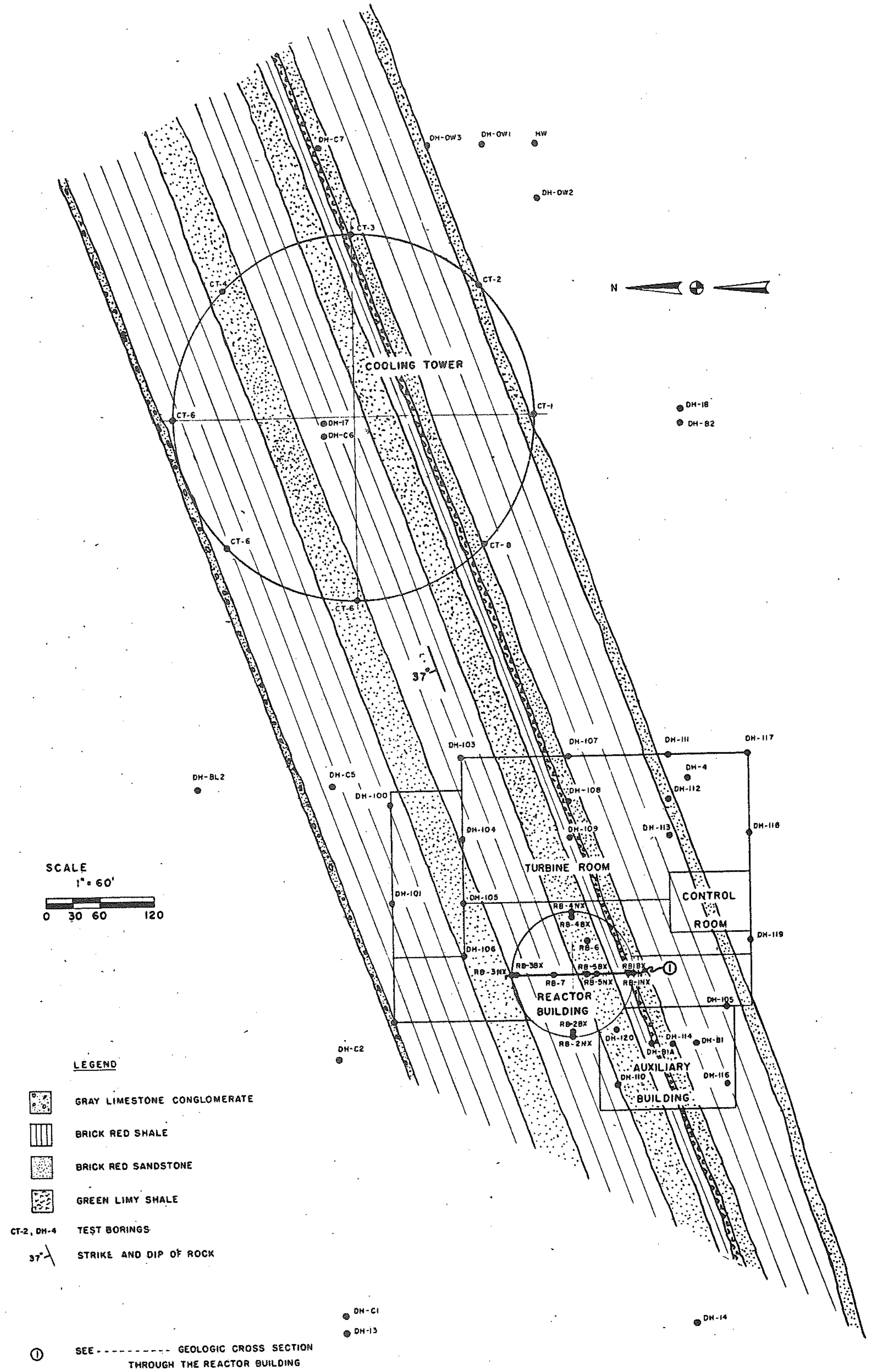


Figure 5.

EXHIBIT 2



GEOLOGIC MAP OF THE BEDROCK SURFACE
THREE MILE ISLAND NUCLEAR STATION

Figure 6.

EXHIBIT 3

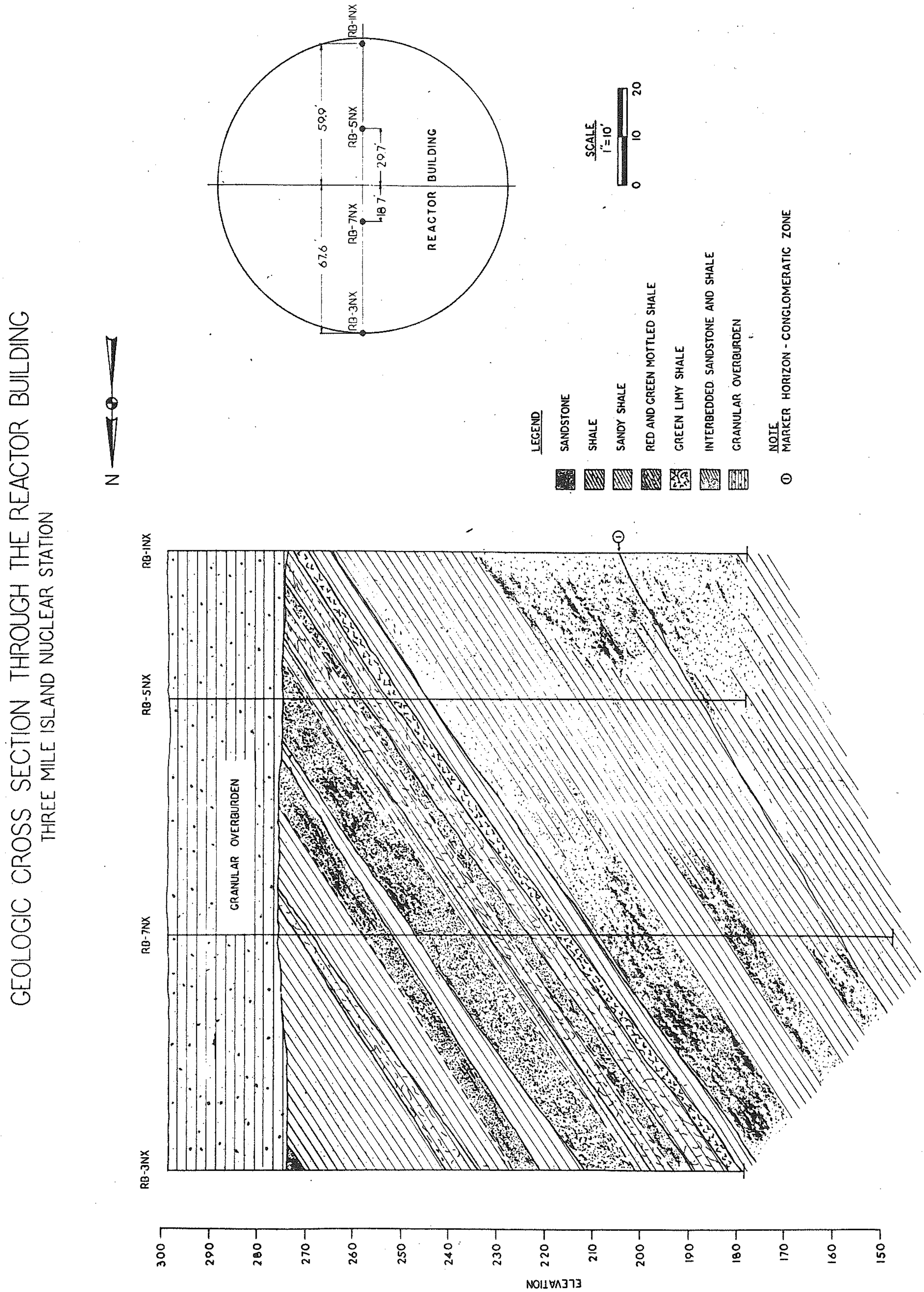


Figure 7.

EXIT north end of parking lot.

0.1 15.0 TURN LEFT onto PA 441 South.

2.4 17.4 On right is access road to PA Fish Commission Falmouth Access area. This is an option stop. Drive 0.1 mile to north end of parking lot. Potholes in diabase still are exposed along bank of the Susquehanna River when water is low. Best procedure is to walk north along river observing rocks and potholes as far as the second metal power line where potholes are the largest and best developed. Return to the parking lot is simplest along a trail just toward the river from the railroad track. Total walking distance is about 1 mile.

1.0 18.4 Mill on left made of diabase with Triassic sandstone corners.

1.0 19.4 Travelling across dissected terrace level of unknown age.

1.3 20.7 Limestone outcrop in field on left is near contact with Triassic rocks to north.

3.0 23.7 Ridge across the river on the right is of lower Cambrian clastics.

4.9 28.6 Pull off into small pull off area immediately beyond south end of bridge. Do not park in driveway to small white building.

Stop 5. Chickies Rock - 60 minutes

Charles Scharnberger and Glenn Thompson

Leave parking area and CONTINUE south on PA 441. Road goes up hill through long exposure of Chickies.

Figure 8. Noel Potter and Bill Sevon stand in potholes typical of those found near Susquehanna River at optional stop, Falmouth. Many of the potholes are nearly six feet deep and several feet in diameter.

CHICKIES ROCK

Chickies Rock is a promontory of quartzite which rises 200 feet above the east bank of the Susquehanna River just south of the town of Marietta and just north of Columbia. The rock has been a popular spot for picnicing, hiking and climbing for generations. The top could be reached by trolley at one time. The nineteenth-century naturalist and philologist Samuel Haldeman lived at the north end of the rock, at the place where we gain access to the face. Haldeman corresponded with Charles Darwin concerning the distribution of American flora and fauna and it is reported that Darwin considered him absolutely authoritative. Remains of the foundation of Haldeman's house can be seen, as well as the trace of the Pennsylvania Main Line Canal. Today, ownership of the rock is divided between the Lancaster Conservancy and the Marietta Water Company; both parties are committed to preserving the area for public enjoyment and education.

Chickies Rock is the type locality for both the Chickies Formation and the problematical trace fossil Scolithus linearis, first described by Haldeman. The predominantly clean quartzite, interbedded with phyllite in places, probably represents a beach and near-shore environment. It is conventional to assign a Lower Cambrian age to the Chickies Formation, but this is not certain. It does underlie all other sedimentary strata and overlies meta-volcanic rocks unconformably. These older rocks are not exposed at Chickies Rock, but can be seen at Accomac, on the west side of the river.

Scolithus appears as cylindrical tubes, circular in cross section and perpendicular to bedding where undeformed, but generally showing the effects of strain. These tubes are apparently burrows of some primitive invertebrate, probably a worm. They make useful markers for detailed structural studies of the kind undertaken by Wise (1960a,b).

The face of Chickies Rock is developed perpendicular to the axis of a large, eastward plunging anticline. This structure forms a prominent ridge which extends east to Rohrerstown, where the Chickies and overlying Harpers and

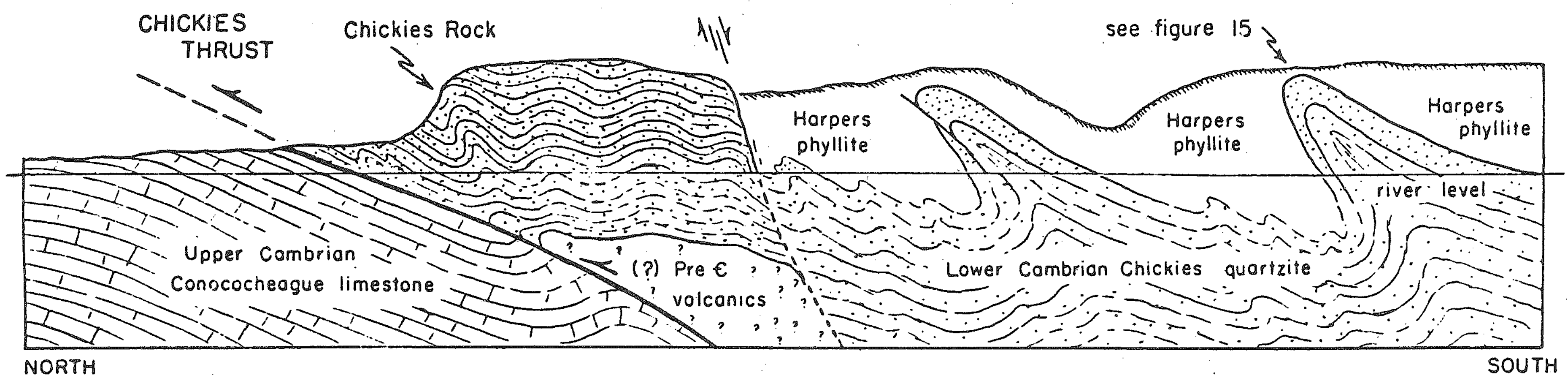
Antietam Formations plunge beneath younger carbonates and shales. The face of the rock is thus essentially parallel to an AC joint set. The present face is not entirely natural, having been modified when the railroad was built.

The north limb of the Chickies Anticline is steeper than the south, and on the north the quartzite appears to have been thrust over the younger carbonates. An interesting point is that the anticline does not continue across the river. On the shore opposite Chickies Rock, the beds are dipping steeply and uniformly to the south.

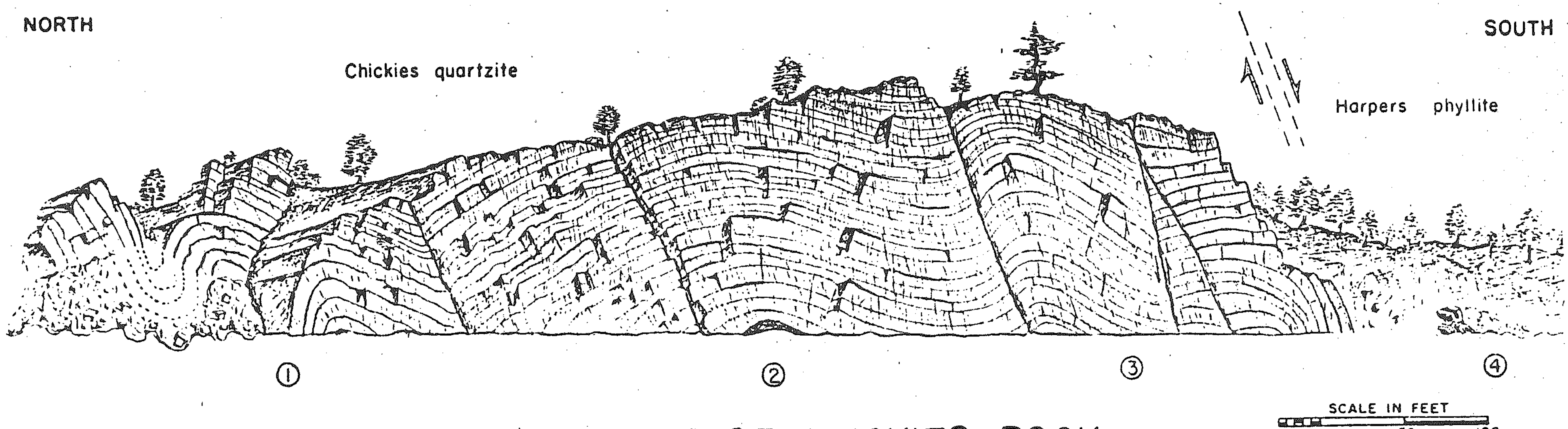
Excellent examples of various structural features can be found at Chickies Rock. There are many small faults and second-order folds, including a particularly interesting reclined synform at Location 4 on Figure . There is a well-developed fracture cleavage which can be seen to fan across folds at Locations 1 and 2. Primary ripple marks occur on bedding surfaces near Location 1. The intersection of bedding with cleavage can be measured in many places; this lineation should be parallel to the fold axis in cylindrical folds. At Location 3, the difference in orientation of the cleavages of the quartzite and the phyllite could be interpreted as "cleavage refraction". Wise (1960b) concluded that the cleavage had been rotated during folding as the result of flexural slip between beds. He also invoked shear in the plane of fracture cleavage as well as shear in the AC plane to explain the origin of the fold. It is interesting to speculate on the mechanical state of the rock at the time of folding.

Another point worth thinking about is why the Susquehanna River turns abruptly south at this point to cut through the resistant quartzite. Only a few miles farther east it could flow around the nose of the anticline through carbonates.

More information about the structural geology of Chickies Rock, and of this part of the Pennsylvania Piedmont, may be found in Freedman and others (1964).



SKETCH OF THE CHICKIES RIDGE FOLD AND THRUST ZONE
AS EXPOSED IN THE BLUFFS OF THE SUSQUEHANNA RIVER



Location: along the Susquehanna River,
Lancaster County, Pennsylvania

THE FACE OF CHICKIES ROCK

1951
By D. U. Wise

Figure 9. Sketch of Chickies Rock exposure, east bank of Susquehanna River, near Columbia, by D. V. Wise.

0.5	30.1	TURN LEFT onto entrance ramp for U. S. Route 30 West. Proceed on U. S. Routh 30 West across Susquehanna River. View to right up river of Chickies Rock.
2.2	32.3	EXIT RIGHT to PA 462, Wrightsville.
0.3	32.6	TURN LEFT onto paved road to Wrightsville.
0.8	33.4	STOP sign at PA 462. CONTINUE straight ahead onto Cool Creek Road. Golf course on right.
1.5	34.9	TURN RIGHT to Sam S. Lewis State Park on Mt. Pisgah Road.
0.5	35.4	TURN LEFT into Sam S. Lewis State Park.
0.1	35.5	Park in parking lot.

Stop 6 and lunch - 1 hour, 15 minutes

Bill Sevon

SAMUEL S. LEWIS STATE PARK

Samuel S. Lewis State Park consists of 75 acres at the top of Mt. Pisgah 2 miles south of Wrightsville. Mt. Pisgah (elevation 865 feet) is the high point on a series of prominent hills bordering the south side of the York Valley and extending 12 miles southwestward from the Susquehanna River. These hills are formed on a broad, fault-bounded anticlinal belt of black slate, quartzite, and conglomerate known collectively as the Chickies Formation (Cambrian). Some of Mt. Pisgah is composed of black slate, but the crest is upheld by the more resistant conglomerates which come to the surface here. Good outcrops of the slate occur in the deep roadcut on Mt. Pisgah Road northeast of the park entrance (see Road Log). A poor outcrop of weathered slate occurs as a small parking lot downhill to the south of the picnic pavillion. Moderate outcrops of the conglomerate, the Hellam Member, occur in the woods at the crest of Mt. Pisgah, but a better exposure is in the woods south of the road downhill from the picnic pavillion. These outcrops show a light gray, quartz pebble conglomerate with pebbles generally less than one inch in diameter, vague crossbedding, and flattening and elongation of some pebbles as a result of intense deformation. Numerous quartz veins cut through the conglomerate.

On a clear day the view from the top of Mt. Pisgah is impressive and encompasses several hundred square miles to the north, east, and south. The accompanying panoramic sketch locates some of the things seen from the field just east of the picnic pavillion. The following itemization starts looking north and moves to the east and then south.

1. The valley north of Mt. Pisgah is the York Valley which is underlain by Ordovician-Cambrian carbonates. The valley is generally one to two miles wide and extends southwestward from the Susquehanna River at Wrightsville 28 miles to Hanover.

2. To the north of the York Valley are the Hellam Hills which are a rocky belt of wooded hills developed mainly on the Cambrian Chickies and Antietam quartzites and Harpers phyllites. Some Precambrian volcanics also occur.

3. Round Top occurs southwest of a sharp bend in the Susquehanna River and is underlain by Cambrian quartzites.

4. Chickies Rock is the location of Stop 4 on this trip.

5. Chickies Ridge is a narrow ridge of Chickies quartzite which extends eastward a short distance.

6. Columbia sits on the extension of the York Valley and is underlain by limestones.

7. The foreground hills with houses and school buildings are the continuation of Mt. Pisgah and are underlain by the less resistant Chickies slate. This ridge is cut by the Susquehanna River and east of the river the ridge is called the Manor Hills.

8. The Conestoga Valley is the large limestone valley of Lancaster County and is developed on the Ordovician-Cambrian Conestoga Limestone. The York Valley is the westward extension of this valley.

9. Turkey Hill is a prominent schist hill which marks the north end of the narrow gorge cut by the Susquehanna River into the Piedmont Upland underlain by the Wissahickon Formation. At this point the Susquehanna narrows from a width of about 1.5 miles to less than 0.75 mile.

10. The Safe Harbor Dam marks the approximate axis of the Westminster anticline hypothesized by Campbell (1933). The relatively flat-appearing upland surface seen to the left of the Susquehanna River and developed on the Wissahickon presumably represents the dissected remnants of a warped Harrisburg peneplain.

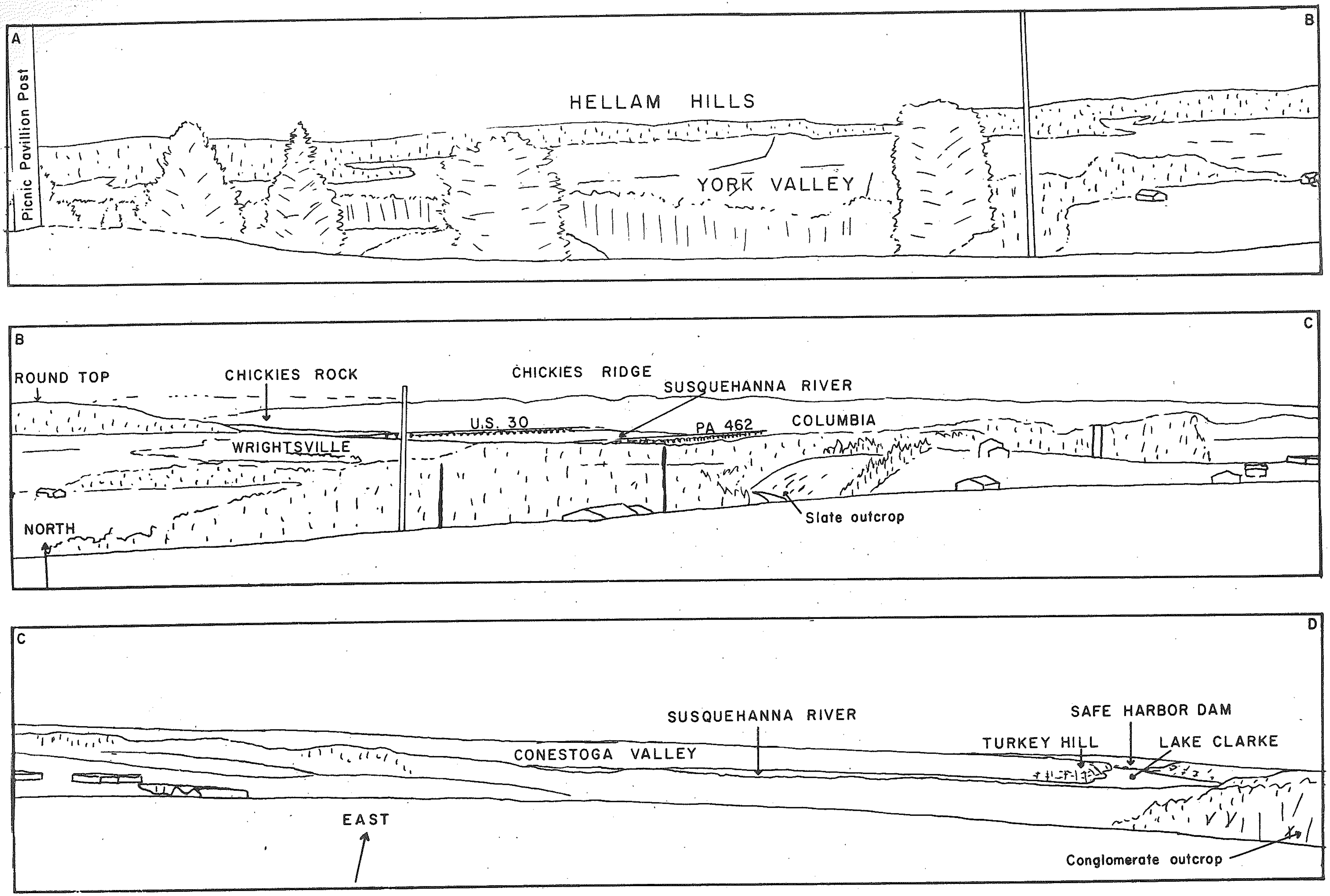


Figure 10.

Panoramic view from the top of Mt. Pisgah at Samuel S. Lewis State Park. View site is in the open field immediately east of the picnic pavillion.

		LEAVE parking lot - either retrace route to Mt. Pisgah Road (Road Log does this) or drive through park if exit gate is open.
0.1	35.6	TURN RIGHT onto Mt. Pisgah Road and retrace route to U. S. 30.
0.3	35.9	Outcrop of phylitte on right.
0.2	36.1	TURN LEFT onto Cool Creek Road
1.5	37.6	STOP sign at PA 462. CONTINUE straight ahead.
0.6	38.2	TURN RIGHT onto U. S. Route 30 East.
1.5	39.7	EXIT RIGHT to PA 441.
0.1	40.8	STOP sign. TURN RIGHT to PA 441.
0.2	41.0	STOP sign. TURN RIGHT onto PA 441 North in Columbia.
3.9	44.9	STOP light. TURN RIGHT onto PA 743 North.
4.9	49.8	TURN LEFT on Stone Mill Drive.
0.3	50.1	TURN LEFT on Rutts Road and Stone Mill Drive. Rutts Road turns left ahead. Go straight on Stone Mill Drive.
1.6	51.7	Pass through cut in diabase dike.
0.1	51.8	PULL OFF in parking area by roadside at shop.

Stop 7. Warren Aungst Farm - 1 hour

Glenn Thompson

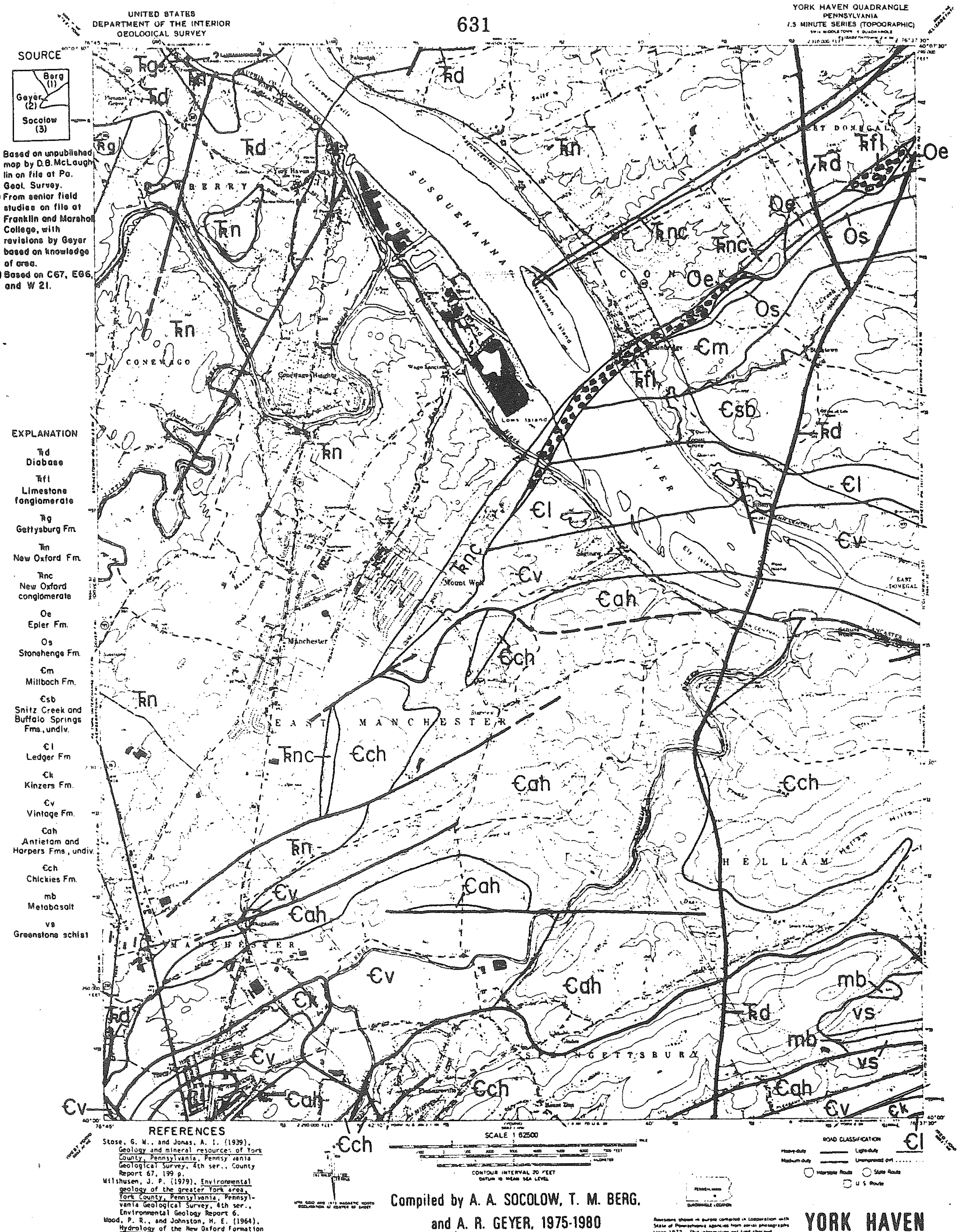


Figure 11. Location map for Fanglomerates

TRIASSIC BRECCIAS AND CONGLOMERATES

The Newark-Gettysburg Basin is generally recognized today as a Late Triassic rift structure genetically associated with the opening of the Atlantic Ocean. As such it is similar to the Connecticut and Culpepper Basins and other rifts now buried beneath Coastal Plain sediments. Although these basins frequently display borders bounded by normal faults, some margins are simple hinge lines dipping into downwarps of a pre-Triassic surface.

Sediments deposited in these basins, known collectively as the Newark group, consist of immature arkoses, silt and shale red beds and a variety of coarse conglomerates. Enclosed fossils of land plants, freshwater fish and reptiles offer added evidence that the Newark group represents a continental, perhaps intermontane, environment. This scenario suggests local sources for all clastics, an interpretation consistent with observations of textural aspects.

Typically the sediments dip toward faulted borders where maximum thickness is developed. Early investigators (Stose, Stose and Bascom) have suggested thicknesses exceeding 20,000 feet in the local basin. In addition to clastic infilling, the strata have been somewhat disrupted by igneous intrusions and subsequent minor faulting.

The field trip will visit one site, the Aungst farm, to examine a special coarse conglomerate unit. Primarily a limestone breccia, the "Donegal marble" also contains scattered quartz pebbles interstitially filled with a red clay-silt matrix. The name "Donegal marble" is a misnomer applied by the Aungst's in association with a commercial venture. The rock is variously hard enough to cut and polish, and through techniques developed by the Harrisburg Marble Company the material is fashioned into table tops, book ends and other ornaments enhanced by natural esthetic qualities.

The deposit is representative of that type termed "fanglomerate" (Stose, 1932). In his study of Adams County, Pa., Stose concluded the deposits were "remnants of a thick alluvial cone of coarse unsorted material derived from a gorge in the mountains on the west..., and may properly be called a fanglomerate." A cusp in the up-dip side of the local outcrop favors a mere pre-Triassic valley filling. Glaeser (1966) analyzed the entire set of basin conglomerates especially in terms of particle composition. His conclusions were in support of local provenance.

The outcrop seen on this trip is basal to the Newark group. It exhibits a narrow discontinuous pattern trending southwest along strike crossing the Susquehanna River and extending about one-half mile into York County. Bedding attitude measurements, N60°E, 32°NW (McLaughlin, 1960), are similar to those of the overlying Triassic sediments. The local section, however, lies with a marked angular unconformity upon a beveled surface of early Paleozoic carbonates. Local water well drilling on the Aungst farm penetrated the carbonate surface at 75 feet. A neighbor drilled 120 feet without penetration (Aungst, personal comm.).

About two miles southwest of the site solutional activity in the unit has created Red Hill Cave. The cavity is a single strike passage some 60 feet long (Brison and Reich, 1974). It represents the fact that weathering and erosion are actively reducing the unit from some former greater size. Alan Geyer (personal comm.) has confirmed the reduction north of the basin by observing similar deposits in sinkholes near Hummelstown. These are at least one-quarter mile from the present basin deposit border. Stose (1932) also reported fanglomerate fills in solution cavities on the upper surface of underlying limestones near York Springs.

<u>On site topics for discussion</u>:

1. Stratification characteristics
2. Textural aspects: rounding, sorting, orientation
3. Origin of matrix
4. Age relations compared to fanglomerates along northern border of basin
5. Was there a "Schooley surface" supporting the Susquehanna River?
6. Why so hard? (Nearby basal clastics are quite friable.)

TURN AROUND and proceed on Stone Mill Drive.

0.1 51.9 TURN LEFT onto Miller Road.

0.2 52.1 Cross small creek. Outcrops of Triassic conglomerate on left. Outcrops of Triassic sandstone ahead on right.

0.7 52.8 STOP sign at T intersection. TURN RIGHT onto Bainbridge Road (PA 241). As route enters Elizabethtown, Masonic Home will be on left. Pass under stone bridge. PA 241 will turn left. CONTINUE STRAIGHT on Bainbridge Road.

2.4 55.2 STOP light. TURN RIGHT onto PA 230, South Market Street.

1.0 56.2 BEAR RIGHT at Y in road onto Anchor Road. PA 230 goes to the left.

0.7 56.9 Triassic-carbonate contact about here.

0.2 57.1 Immediately after passing under stone bridge proceed straight ahead into Rheems Quarry.

Stop 8. Rheems Quarry - 1 hour

Rodger Faill

STOP NO. 8
RHEEMS QUARRY

The quarry at Rheems has become a classic site illustrating the recument fold style and associated structures that are characteristic of the carbonate rocks belonging to the Lebanon Valley nappe, in both northern Lancaster County and in the Lebanon Valley to the north.

The quarry is 3½kilometers southeast of Elizabethtown, just west of Rheems (Figure 8-1). It is located within the outcrop belt of the Epler Formation. Immediately to the north is the southeastern unconformable margin of the Gettysburg Mesozoic basin, which separates the carbonate rocks of Lancaster Valley from those in Lebanon Valley.

The quarry is owned and operated by Union Quarries, Inc.

Regional Setting

The Lebanon Valley nappe is a complexly folded and faulted recumbent fold of large proportions. It extends along the Great Valley for more than 100 km from west of Harrisburg to east of Reading; and it reaches across the regional structural grain for 50 km from the Great Valley north of Lebanon southward well into the Piedmont terrane south of Lancaster. Its root lies somewhere in the Piedmont and it was formed during the Middle Ordovician Taconic orogeny as a large recumbent structure pushing its way northward into the Martinsburg depositional basin. The rocks range in age from the Early Cambrian Chickies Formation to the Middle Ordovician Martinsburg Formation. The rocks are for the most part in the lower limb of the nappe, and so are largely overturned. Within the immediate vicinity of the quarry, the rocks are Ordovician carbonates (Epler Formation); and the beds dip mostly southward, becoming younger in age to the north (Fig. 8-1). Although the nappe has been modified, mostly by faults, by the Late Paleozoic Alleghanian deformation, the structures in the quarry are almost entirely of Taconic age.

Being in the lower limb of the Lebanon Valley nappe, these beds have undergone considerable horizontal transport to the north. The folds, boudins and slickensides that commonly occur in such tectonic settings are present in outcrops elsewhere in this vicinity, but they are particularly well exposed within this quarry at Rheems.

Overall Structure Within the Quarry

Two major structures are present in the quarry. On the east wall (Fig. 8-2) is a recumbent anticline and syncline pair. On the west wall, folds are absent--only a fairly homogeneous south dip of bedding is present. The relationship between the two was worked out by Wise (1958, 1960) as follows. The folds on the east wall plunge eastward at 5 to 15 degrees, a relationship that can be best seen along the north quarry wall. Thus, the rocks across the quarry floor and on the west wall are structurally below the folds. The rather large extent of the "unfolded" beds indicates that recumbent folding on a small scale (east wall) does not pervade the overturned limb of the nappe. Yet the occurrence of such folds elsewhere in this valley shows that this type of small folding is common.

Two aspects of these recumbent folds are worth noting. First, the axial surfaces are nearly horizontal, dipping very gently to the south. Despite some irregularity in the axial surfaces, they retain an approximately constant separation of 5 to 8 meters across the entire east face. These folds tend to be quite angular, with narrow hinges and relatively planar limbs (e.g., State A, Fig. 8-2). Yet the fold profiles vary considerably from layer to layer, and in places the folds are nearly concentric (Station B).

Secondly, no evidence of depositional tops of beds have been found in this quarry, so whether the rocks become younger to the north or south cannot be determined directly. However, as Wise points out, considering the northward transport of the nappe, anticlines are produced in rock masses that have moved further than the adjacent rock masses. In this sense, synclines occur in the rocks that are retarded relative to the northward movement. From this argument, the fold that is convex toward the north must be anticlinal, and the southward convex fold is synclinal.

It follows in this kinematic model that, with the anticlinal hinge moving northward relative to the underlying synclinal hinge, the overturned fold limb between these two hinges became increasingly lengthened. In effect, this fold limb was a zone of simple shear, a large flow zone with northward movement parallel to the axial surfaces. This movement is consistent with the lower limb kinematics of a northward moving nappe. Similarly, the entire west wall occupies a shear zone, which accounts in part for the overturned attitude of the beds, and for the small scale structures, the boudins and vein fillings.

Smaller Scale Features

The carbonate sequence of this part of the Epler Formation consists of limestone containing interbeds of dolomite. Although both are carbonates, the two lithologies behave quite differently under the same conditions of stress, temperature, and time. Limestones, composed primarily of calcite, utilize the numerous slip systems of the calcite crystal and deform in a moderately ductile manner. Dolomite crystals, on the other hand, do not have the same slip mechanisms available for deformation, and thus dolomite beds behave in a more brittle fashion. This contrast in material behavior is responsible for the various smaller scale structures common in this quarry.

Bed thickness in fold hinges - The dolomite beds tend to preserve a constant bed normal thickness around fold hinges because of their relatively brittle behavior. In contrast, the more ductile limestones have flowed in the hinges at some places, resulting in small to large increases in bed normal thickness in the fold hinges. A particularly good example of this is in the center of the east wall, above the first bench (Station B), where an abrupt change in fold profile from angular to nearly concentric is present.

Boudinage - This "necking" of beds is common throughout the quarry, occurring almost exclusively in the overturned dolomite beds. Again, the contrast in material behavior is responsible for this structure. The more brittle dolomite beds, being less able to flow, tend to separate by fracturing when they are extended parallel to bedding. (Some flow does occur in the dolomite, but it is concentrated in the "necks".) The adjacent limestone beds, being more ductile, then flow into the space vacated by the necking and separating dolomitic boudins. The boudins occur only in the overturned beds below the anticlinal hinges, and not at all in the beds in the fold limb above the anticlinal hinges. This reflects the extension in the overturned beds by the northward movements in the nappe. The intervening zones (fold limbs) were not subjected to this movement, and thus the boudins were not developed in the vertical to right-side-up beds in these zones. Boudins are particularly well developed at Stations D and E.

Fractures and veins - Fractures which opened during folding were developed almost exclusively in the dolomite beds, reflecting their more brittle behavior. These early fractures can be distinguished from later ones by the fact that they were

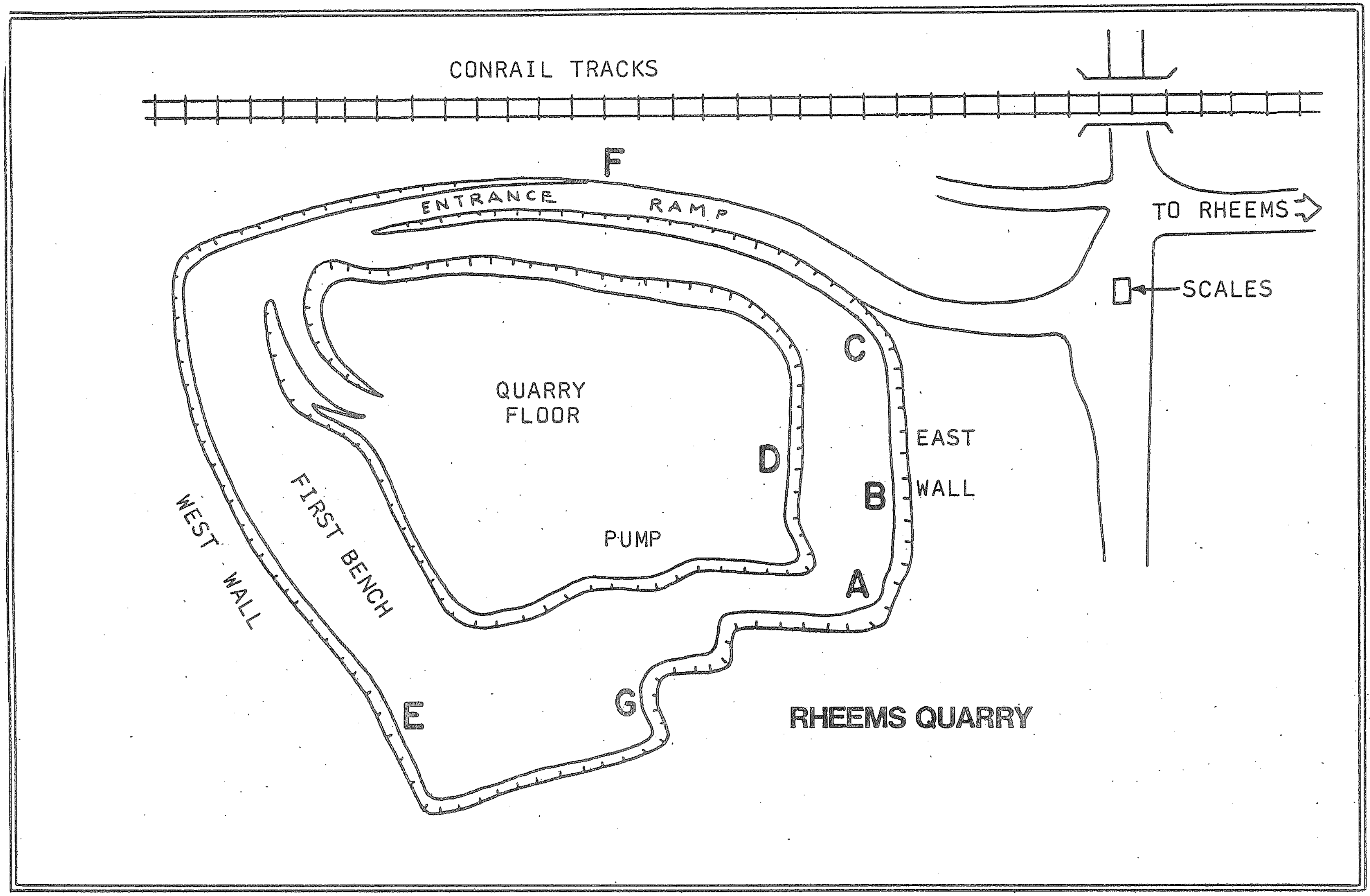


FIGURE 12. GENERALIZED MAP OF RHEEMS QUARRY, SHOWING LOCATIONS OF STATIONS AND OTHER FEATURES MENTIONED IN THE TEXT.

filled with white calcite (veins), deposited from solution as the fractures formed and widened. These filled fractures are common in the overturned beds that were extended as part of the northward movement, and the amount of vein filling (reflecting the amount of separation) greatly exceeds those in the right-side-up beds. These fractures are parallel to the fold axes, and tend to be perpendicular to the beds. The vein filled fractures probably developed later than the boudins for the following reasons: 1) they are not deformed by the formation of the boudins; and 2) rocks tend to become more brittle with increasing strain--hence the limestone could not flow into the fractures as easily. These vein filled fractures are common throughout the quarry, but are best developed in association with the boudins at Station E.

Slickensides - Flow was an important, if not dominant, mode of deformation in these rocks, but it was not the only mode. Abundant slickenlines on bedding surfaces attest to slip on these surfaces, particularly in the folds (flexural slip folding), being a significant process that contributed to the total deformation. Slickenlines are particularly well exposed in the folds above the ramp along the north wall (Station F).

Faults - Faults are present in this quarry, and occur in two principal orientations--parallel and perpendicular to the fold trends. At Station G, a steeply north dipping east-west fault cuts part of a fold, but neither the sense of displacement nor the amount of offset were determined. A steeply west dipping fault trending north-south appears in the highwall just south of the pump near Station A. The apparent offset is 2 m down on the west side, but slickenlines on the fault surface plunge only 10 to 15 degrees to the south. This indicates that the movement was primarily strike-slip, and thus much more than 2 m to produce the offset observed. A possible extension of this fault appears in the north wall, near Station C, but here the slickenlines plunge steeply (obliquely) to the northwest. Apparently, these fault movements (later than the folding) represent some rather complex movements in the late stages of deformation. Or, some of these faults may have formed during the subsequent Alleghanian orogeny.

Minor disharmonic folds - Considering the amount of flow and transport these rocks have undergone, it is remarkable that the folds have maintained as consistent a geometry as they have. The principal exception to this occurs at Station C. Here, in part of the right-side-up limb to the north of the concentric fold geometry, the beds seem to be anomalously thick, perhaps by flow or by duplication. In addition, several small recumbent folds, detached from one another, attest to discordent movements in this part of the quarry.

		Leave Rheems Quarry. TURN RIGHT onto West Harrisburg Avenue towards the Village of Rheems.
0.6	57.7	TURN LEFT onto Colebrook Road.
0.2	57.9	STOP light. CONTINUE straight ahead across PA 230 to Clover Leaf Road.
1.0	58.9	TURN LEFT onto PA 283 West.
14.3	73.2	BEAR RIGHT to Interstate 283 North.
2.6	75.8	TAKE CENTER LANE to Interstate 83 North (left lane to Harrisburg; right lane to U. S. 322 East).
3.9	79.7	BEAR LEFT to Interstate 81 South and U. S. 322 West.
2.3	82.0	BEAR RIGHT to U. S. 22 East and PA 230 South and Cameron Street. STAY IN LEFT LANE after leaving I-81 South.
1.2	83.2	STOP light. TURN RIGHT onto Industrial Road.
0.2	83.4	TURN RIGHT to HACC Campus.
0.2	83.6	BEAR RIGHT TO east parking lot.
0.2	83.8	END of Trip.

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