

GUIDEBOOK

33rd Field Conference Of Pennsylvania Geologists



Harrisburg, Pa.

October 4th and 5th, 1968

Guidebook for the
33rd Annual Field Conference of Pennsylvania Geologists

THE GEOLOGY OF MINERAL DEPOSITS IN SOUTH-CENTRAL PENNSYLVANIA

October 4th and 5th, 1968
Pennsylvania Geological Survey
Harrisburg, Pennsylvania

Leaders - Ernst Cloos, Jacob Freedman, Gilbert Hole, Karl Hoover,
John Hosterman, Arnold Nelson, Samuel Sims, and Donald Wise

Cooperating Companies - Bethlehem Mines Corporation, Raymond Bender
& Son, J. M. Eshelman & Son, Inc., GAF Corporation, Philadelphia
Clay Products Company, and Thomasville Stone and Lime Company

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Arthur A. Socolow, State Geologist

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THE GEOLOGY OF MINERAL DEPOSITS IN
SOUTH-CENTRAL PENNSYLVANIA

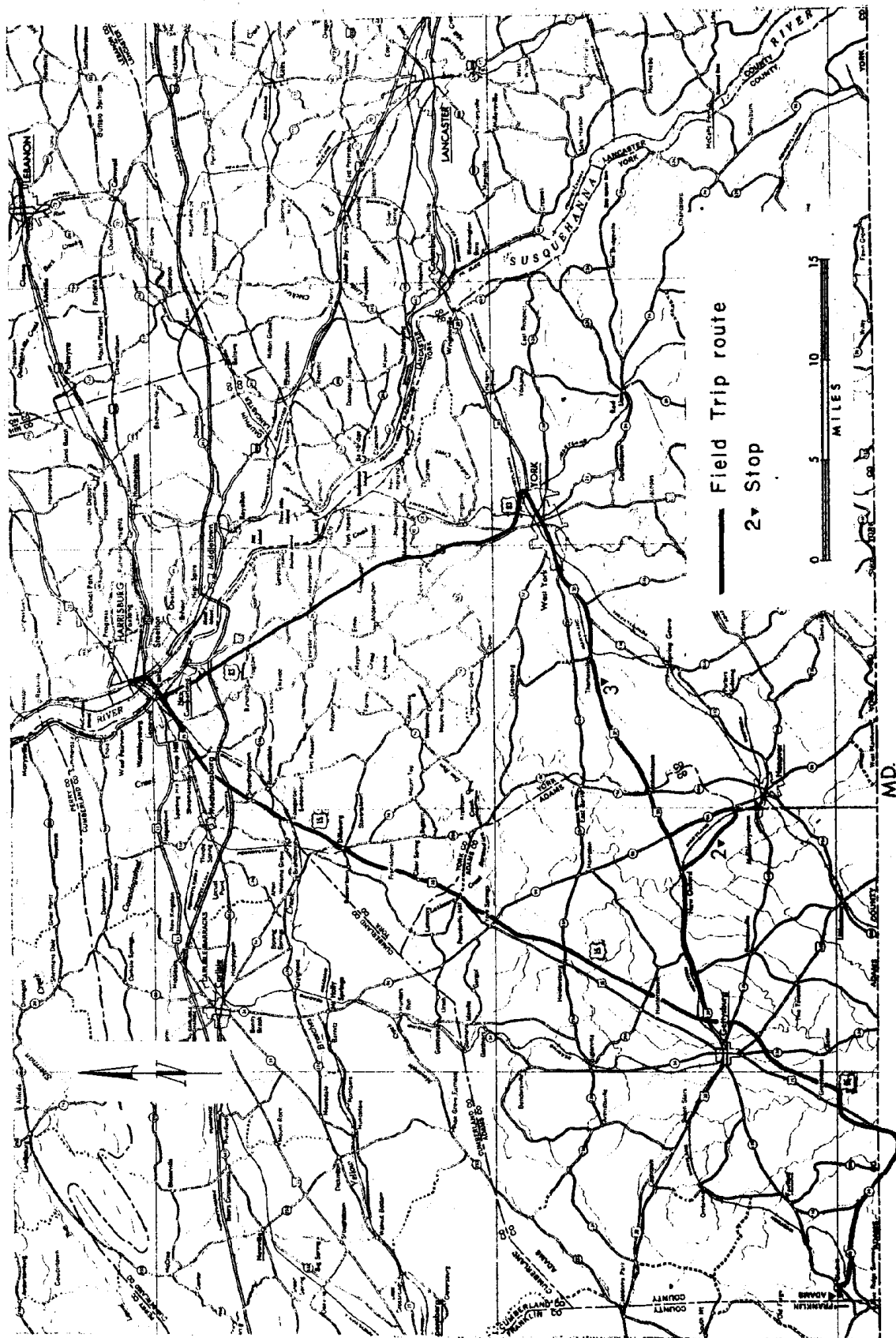
Introduction

The Thirty-Third Field Conference of Pennsylvania Geologists is intended to demonstrate the inter-relationships of complex structure and stratigraphy with the practical, economic utilization of mineral resources in south-central Pennsylvania. This is a region which is blessed with important industrial minerals and where the utilization of those minerals makes a major contribution to the local economy. It is important to recognize, however, that the occurrence of these mineral deposits and the very nature of the extraction procedures are determined by the structure, stratigraphy, and geologic history of the formations of the area. Thus, the results of academic research are related to the practical needs of man - and the result is Economic Geology.

Acknowledgments

The success of this guidebook and of the field trip is due largely to the efforts of the authors and guides who, as a result of long research and experience at each locality, have been able to highlight the significant geological features. Thus, appreciation and acknowledgment are extended to Ernst Cloos, Jacob Freedman, Gilbert Hole, Karl Hoover, John Hosterman, Arnold Nelson, Samuel Sims, and Donald Wise.

The companies whose properties are being visited have been exceedingly cooperative in not only granting permission to enter their operations, but also in generously furnishing technical data, necessary equipment, and guides. Sincere appreciation is extended to Bethlehem Mines Corporation, Raymond Bender & Son, J. M. Eshelman & Son, Inc., GAF Corporation, Philadelphia Clay Products Company, and Thomasville Stone & Lime Company.



ROAD LOG - FIRST DAY
Friday, October 4, 1968

Mileage

- 0.0 HARRISBURGER HOTEL
Buses will load in front of hotel along North Third Street;
DEPARTURE: 8:00 A. M.
Proceed south along Third Street.
- 0.2 Turn RIGHT (west) onto Chestnut Street.
- 0.4 Turn LEFT (south) onto Front Street. KEEP IN MIDDLE LANE to
enter the YORK RAMP of Interstate 83.
- 1.0 YORK RAMP of Interstate 83. CAUTION: there is no acceleration
strip onto Interstate 83-enter with care. You are headed
west along Interstate 83-Harrisburg Expressway.
- 2.3 York, Pa. Exit. Continue west on the Harrisburg Expressway.
- 4.6 U. S. Rt. 15 South, Gettysburg Exit. Leave Harrisburg
Expressway by this exit and proceed south toward Gettysburg,
Pa.
- 7.9 PENNSYLVANIA TURNPIKE Entrance.
- 14.3 Pa. Rt. 74.
- 31.3 Pa. Rt. 394 CAUTION: U. S. Rt. 15 changes from a four-lane
divided highway to a two-lane undivided highway.
- 34.4 U.S. Rt. 30.
- 45.5 PENNSYLVANIA-MARYLAND boundary.
- 46.0 Turn RIGHT (west) onto Business U.S. Rt. 15.
- 47.1 Turn RIGHT (west) onto Md. Rt. 97 at square of Emmitsburg,
Md.
- 48.7 MARYLAND-PENNSYLVANIA boundary. Route number changes from
Md. Rt. 97 to Pa. Rt. 16.
- 50.2 CONTINUE west on Pa. Rt. 16. Pa. Rt. 116 bears off to right
and continues north.
- 53.3 LEAVE Pa. Rt. 16 at Texaco Station on left (Culvert across
Pa. Rt. 16) by turning RIGHT and proceed west on old Pa. Rt. 16.
- 55.1 STOP #1: Charmian Roofing Granules Plant Industrial Products
Division, GAF Corporation. Entrance to quarry road.
7½ Topo.: Blue Ridge Summit, Iron Springs

GAF CORPORATION QUARRIES
CHARMIAN, PENNSYLVANIA

Arnold Nelson
GAF Corporation

Rock from several GAF Corporation quarries in the area forms the base material stone that is ceramic coated to make artificially colored roofing granules. The granules are used to surface asphalt-base roofing to prevent deterioration, cracking, water penetration and to provide homeowners with a fire-resistant and esthetically attractive roof. The technology is complex and has been developed only after many years of intensive research.

Greenstone Quarry

The Greenstone Quarry is located on a ridge between "Wildcat Rocks" and "Pine Mountain", on the Iron Springs 7 $\frac{1}{2}$ ' topographic quadrangle, Pennsylvania (Figure 4). The rock from this quarry is used in the manufacture of artificially colored roofing granules at the corporation's nearby granule manufacturing plant. The stone has the physical characteristics necessary in meeting the exacting specifications required for top-grade base granular material for artificial coloring. The rock must be essentially nonporous, as uniform as possible in color and texture, resistant to weathering, and compatible with the coloring process.

The typical metabasalt (greenstone) of the area is a greenish-gray to dark-greenish-gray, uniformly aphanitic to fine-grained rock. Amygdaloidal and porphyritic metabasalts are also present. The amygdaloidal rock contains colorless to milky white, circular to irregular-shaped amygdules. Feldspar, epidote, quartz, or chlorite usually fill the amygdules. Locally two of these minerals may fill an amygdale. Quartz and epidote combine to form epidosite, a uniform fine- to medium-grained, granular rock whose dusky yellow-green to moderately yellow-green color is distinctive. The epidosite,

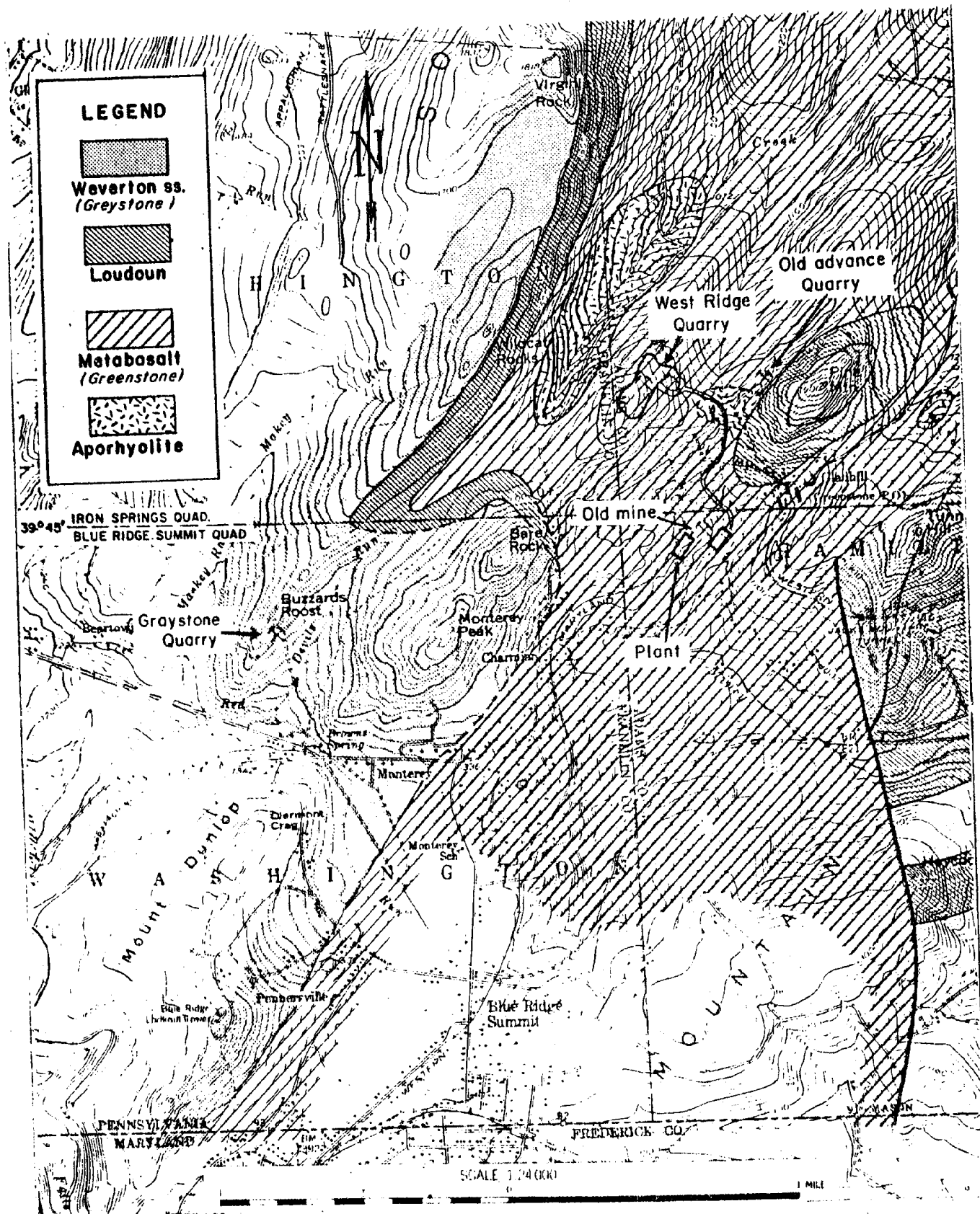


Figure 4 - Location map for GAF Corporation quarries at Charmian, Pennsylvania.

In the form of large, irregular pods, lenses, veins, and oval knots, occurs within the metabasalt. The contact with the metabasalt may either be sharp or gradational. In many places the veins and lenticular bodies of this rock occur along the regional cleavage. Closely spaced fractures within the epidosite and normal to the regional cleavage may be filled by quartz associated with an asbestiform amphibole.

A combined study of mineralogy and textures of these rocks indicates that they were originally basalts, and subsequently metamorphosed to a greenschist facies. It is part of a complex of altered Precambrian volcanic rocks commonly referred to as the Catoclin Formation. Calcite is rare but in some places forms the amygdules. Small amounts of native copper associated with azurite, malachite, chalcocite, and cuprite are found in the quarry.

The greenstone strikes northeast-southwest, but the dip is unknown. The visible structure in the quarry is a southeast dipping regional flow cleavage. The regional cleavage and joints are the dominant planar structures. Primary flow structure, columnar jointing, and pillow structures have not been recognized in the metabasalt of the quarry.

Fauth (1968, p. 54) reports the dominant secondary structure in the South Mountain area is a flow cleavage (regional axial plane). This cleavage (S_1) is the ab plane or plane of movement, and maintains a consistent northeast strike, moderate southeasterly dip, and position parallel to the axial planes of bedding folds.

The present greenstone quarry was opened in 1964 and currently is worked from two levels. Local fracture zones are encountered. These present problems in quarry development because of alteration of the rock along the fractures.

Rock previously used was from a quarry on the west side of Pine Mountain but quarrying at this site ceased when contact with the sandstone phase of the overlying Loudoun Formation was encountered. A slope mine opened in 1925 had been the source of stone before quarrying operations located on Pine Mountain. Other quarries predate the slope mine.

Graystone Quarry (Non-Operating)

The GAF Corporation Graystone Quarry is located on a knoll known as "Buzzards Roost," north of Pa. Rt. 16. The quarry is located on the Blue Ridge Summit, Maryland-Pennsylvania, 7 $\frac{1}{2}$ ' topographic quadrangle.

The rock quarried at this site is the Weverton Formation, Lower Cambrian age. The lithologies common to this formation are gray and purplish feldspathic sandstones, quartzites, and conglomerates. The only lithology of economic value for use as a roofing granule raw material is the tough, hard, fairly uniform quartzite unit which because of its resistance to weathering and erosion is commonly found cropping out along the high ridges.

The chief impurities in the roofing-granule quality quartzite are muscovite and chlorite. Minor amounts of epidote, hematite, ilmonite, zircon, and ilmenite are normally incorporated in the rock.

The structure of the rock in the quarry is a series of similar folds. The anticlines are asymmetrical, overturned to the northwest, and cut by strike faults dipping 40-50° SE. The fold axis trends S 35-40° W and the plunge is roughly 10-15° in a S 40° W direction (Figure 5).

The earliest reported investigation on the geology of the South Mountain region of Pennsylvania was in 1858 by H. D. Rogers. The more recent investigations have been by G. W. Stose (1932) and G. W. Stose and F. Bascom (1929). John L. Fauth is currently mapping the volcanics and associated sedimentary rock in the South Mountain region of Pennsylvania.

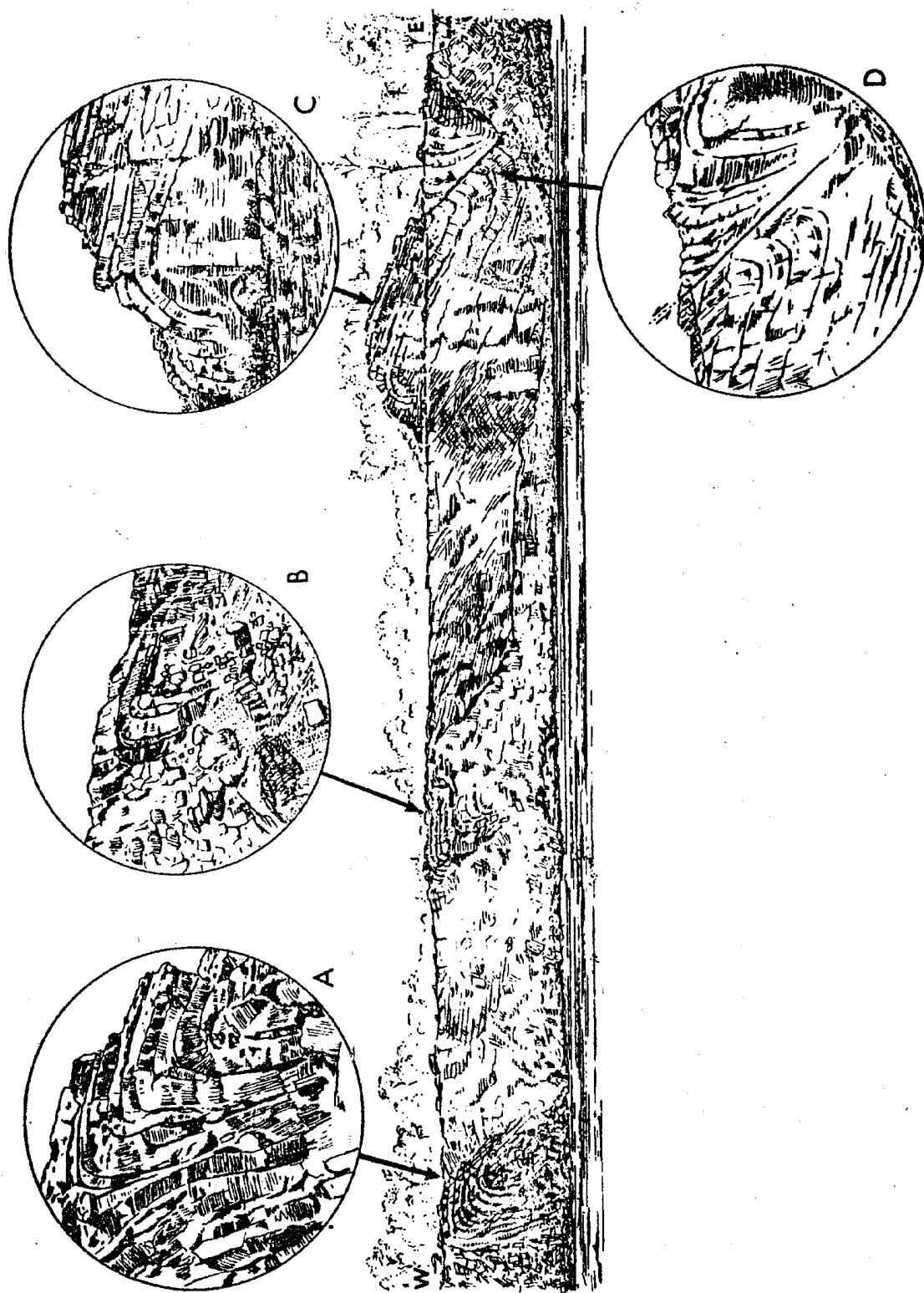


Figure 5 - Sketch of structural features in the Graystone Quarry at Charmian, Pennsylvania.

Mileage

- 55.1 RETRACE ROAD LOG to the intersection of U.S. Rt. 15 with U.S. Rt. 30.
- 75.8 Turn RIGHT (east) onto U.S. Rt. 30.
- 83.3 New Oxford, Pa. Turn RIGHT (south) at square onto Hanover Street. (Hanover-New Oxford Road).
- 86.0 STOP #2: Bethlehem Mines Corporation, Hanover Quarry. Entrance to property is approximately 500 ft. west of Bittinger, Pa. railroad crossing.
7 $\frac{1}{2}$ Topo.: McSherrystown

GEOLOGY OF THE HANOVER QUARRY
HANOVER, PENNSYLVANIA

Gilbert L. Hole
Bethlehem Steel Corporation

The Hanover Quarry of the Bethlehem Mines Corporation is located in eastern Adams County, about 3 miles northwest of the city of Hanover and 12 miles east of Gettysburg.

According to the usual physiographic classification, the area is located in the Piedmont physiographic province of the Appalachian Highlands. The sedimentary rocks in the quarry area are all of Lower Cambrian and Ordovician age with the exception of red Triassic sediments which overlap the older sediments on the west and north. Some outcrops of Precambrian metabasalt can be seen in the core of the Pigeon Hills a few miles northeast of the present quarry operations, but the main mass of the Pigeon Hills is Chickies quartzite and conglomerate of Cambrian age. Antietam (Cambrian) sandstone has been thrust over younger carbonate rocks in this area, but much has been removed through erosion and exposures are rare.

The quarrying operations are developed in the Ledger Formation, the youngest of three formations which as a group comprise the Tomstown dolomite of late Lower Cambrian age. The others are the Kinzers shale and Vintage

dolomite. The Kinzers shale lies immediately below the Ledger and in general forms the footwall of the quarry. The Vintage Formation immediately below the Kinzers shale is an impure dolomite that is not quarried although there is a considerable quantity available.

The Conestoga limestone of Lower Ordovician age overlies the Ledger and again this is not quarried for metallurgical stone. Figure 6 shows a simplified columnar section of the Hanover quarry.

The Ledger Formation is composed mainly of fairly pure beds of inter-layered dolomite and limestone. However, there are high silica layers or zones which are quarried for commercial stone rather than metallurgical stone. The dolomite is medium grained, light gray to buff in color, and often contains stringers, or small veinlets of calcite. The limestone is fine grained, medium to dark gray for the most part, and occurs in beds which vary in grade from virtually pure calcium carbonate to an impure rock containing several percentage points of silica. In places, particularly near the Kinzers shale contact at the footwall, pure thin-bedded limestone is interbedded with shaly layers giving an overall rock of high silica and low strength that is not especially desirable for either metallurgical or commercial stone. In general, the limestone beds occur in the lower portion of the Ledger Formation and often very pure stone is found in direct contact with the shale.

Other impurities in the rock are iron and alumina but they are never of sufficient quantity in the metallurgical stone to constitute a problem. Sulphur is practically absent in the high-grade stone, but pyrite has been noted occasionally in drill core.

A typical analysis of the best grade of dolomite is 0.6 percent SiO_2 and 44.00 percent MgCO_3 . The best grade limestone is 0.80 percent

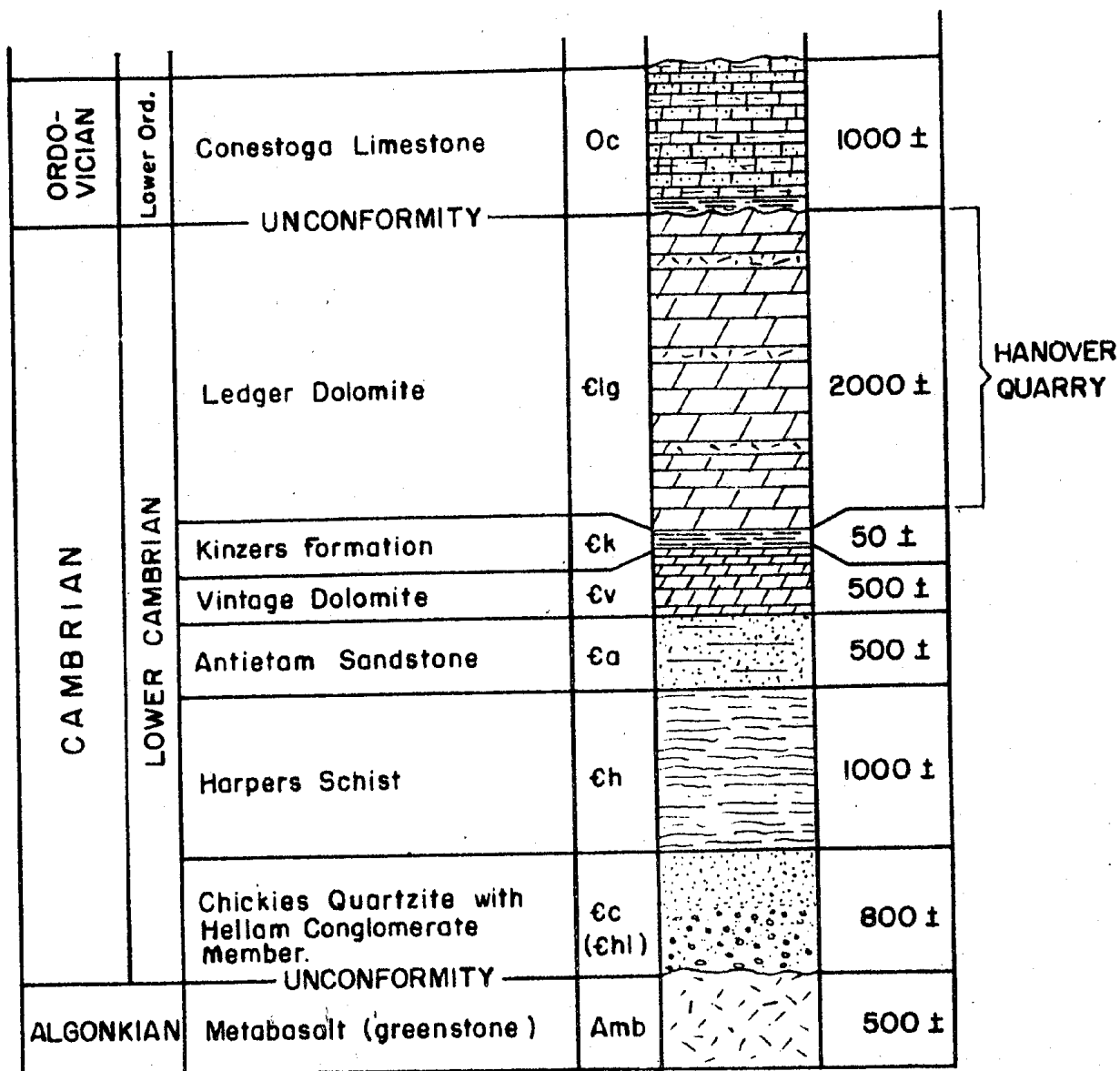


Figure 6 - Columnar section of the Hanover Quarry area (Stose and Bascom, 1929).

SiO_2 and 5.00 percent MgCO_3 . There is a large reserve of rock of both types in the range of 1.00-3.00 percent SiO_2 , and stone shipped as regular blast furnace feed runs about 1.50 percent SiO_2 and 35.00 percent MgCO_3 . A high-grade dolomite sinter sand is produced from dolomite fines, while the lime plant accepts a feed in the range of 0.80-1.00 percent SiO_2 and 6.00-12.00 percent MgCO_3 .

The structural geology of the area is highly complex and has not been completely explained. Outcrops are sparse in the unquarried areas, so field mapping has been of little value. In the quarries the faces show many unusual structural features, but bedding is often very difficult to define and in fact cannot be seen at all along long stretches.

Faulting has been extremely strong throughout the area and it seems that almost every type of fault ever described can be found in the quarry. The lithologic contacts are occasionally delineated by these faults. The fault zones have provided water courses through the rock. The upper levels are marked by mud and clay, disintegrated rock, and cavities, which cause considerable trouble to the quarry operations. Numerous sink holes developed when quarry operations commenced in the West Plant area. All of these were found along fault zones. Some sink holes reached a depth of 50 feet or more and were quite cavernous. Certain areas of the present quarry present such difficulties for drilling and blasting that they have temporarily been bypassed but eventually the stone and mud will have to be moved.

In a general way, the Ledger Formation strikes northeast throughout the quarry area and dips steeply to the northwest. There are many exceptions, however, as one can see by making a casual trip through the various cuts. There is some evidence of complete over-turning of beds in

places, and the appearance of wedges or slices of Kinzer shale stratigraphically far above the normal contact zone adds to the complexity.

Exploration is done by diamond drilling. Since 1948 over 500 holes totaling almost 150,000 feet have been drilled throughout the entire area. Each 5-foot core run constitutes a sample and the core is regularly analyzed for SiO_2 , Fe_2O_3 , Al_2O_3 , CaCO_3 , MgCO_3 , and occasionally for S. All geologic cross sections and maps have been developed from the chemical analyses of cores, using structural features when they appear and can be deciphered. As the quarry has developed, additional drilling has been done near the areas of operation so that more reliable information is at hand. Blast-hole cuttings are analyzed and plotted on a daily basis and the results are correlated with exploration data.

The major use of stone is for metallurgical purposes, mainly regular blast furnace flux stone which is shipped to Bethlehem's steel plant at Sparrows Point, Maryland. The versatility of the operation and the various types of stone available permit the production of numerous other products as well:

Sinter Flux
Rice Flux
Limestone for Quicklime
Commercial Stone
Screenings

Open Hearth Flux
Sinter Feed
Sand
Ag-Lime

Total production in 1967 was slightly over 4,000,000 tons from the West Plant quarry. Since the main quarry was opened in 1956, 19,800,000 tons of stone have been processed, and during the same time about 1,200,000 tons of shale and mud have been removed. This gives some idea of the difficulties of quarrying this highly faulted, cavernous ground. As lower levels are developed, the problems of mud and caverns will diminish, but not disappear.

Mileage

- 86.0 Return to entrance to Bethlehem Mines Corp. property.
Turn RIGHT (east) on Hanover - New Oxford Road and cross
Western Maryland RR tracks (CAUTION).
- 86.3 Turn HALF-LEFT (bear northeast) onto Appler Road. Note
quarry on left.
- 86.6 Turn LEFT (north) onto Pa. Rt. 94. Note quarries on each
side of road.
- 88.9 Turn RIGHT (east) onto U.S. Rt. 30 (Cross Keys, Pa.).
- 91.3 Abbottstown, Pa.
- 98.5 Lincoln Stone Producers Quarry on south side of U.S. Rt. 30.
- 98.6 Turn RIGHT (south) onto Biesecker Road.
- 99.0 STOP #3: Thomasville Stone & Lime Company. Enter on right
(west) side of road between laboratory and garage - plant
office building.
7 $\frac{1}{2}$ Topo.: West York

THOMASVILLE STONE AND LIME COMPANY THOMASVILLE, PENNSYLVANIA

Ernst Cloos
Geologist, Thomasville Stone & Lime Company
Professor Emeritus, The Johns Hopkins University

Location

Thomasville is 7 miles west of York, Pennsylvania, south of U.S.
30 (Lincoln Highway). The large quarries and mines are owned by the
Thomasville Stone and Lime Company.

Source of Information

A large amount of information has been amassed during over 30 years
of the development of the Thomasville property. Quarry and mine exposures
and nearly 300 core-drill holes were examined and maps and sections have

been constructed. A more detailed report on the geology and history of the property is in preparation.

The Stratigraphic Column

The following column evolved during the development of the property and is based on practical considerations. It can easily be recognized in drill cores and mine workings and is mappable in the field. All units belong to the Kinzers and Vintage Formations.

Table 1. -- Stratigraphic column for the Thomasville quarry

Top not exposed (probably Conestoga limestone)	
Upper dolomites and limestones, well bedded	at least 350 feet determined in drill cores
"Top Black"	20-40 feet
Upper Thomasville breccia	50-300 feet
"Bottom black"	20-30 feet
Lower Thomasville breccia	Up to 300 feet
Phyllite	?
Vintage dolomite with <u>Salterella</u> near top	determined at least 200 feet

The upper dolomites and limestones are thickly bedded and light, with several thin greenish or black shale seams. Some breccia layers are common. They are quarried for crushed stone.

The "Top Black" is a black dolomitic limestone with graphite which leaves a black scum when samples are digested in acid. As a key horizon it is most valuable and can readily be identified in drill cores and outcrops.

The "Upper Thomasville breccia" consists of several layers which are frequently interrupted and cannot be traced easily. Huge blocks reach the size of houses or larger and can be white, very pure limestone, oolitic blocks or gray-banded limestone; in a matrix of small-fragment breccia with units down to cubic inches in diameter. The overall chemical composition is rather uniform and most favorable. Recognition of components from drill core fragments is difficult, although some layers can be traced between drill holes for short distances.

Dolomite occurs in two forms: as dolomitization, mainly on fractures and as primary dolomite sand which can be traced across distances. Sand grains are perfectly rounded and up to $\frac{1}{4}$ inch in diameter.

At some places two breccia layers are separated by a gray laminated unit.

The breccia is very spectacular and of limited extent but occurs in the entire Thomasville property.

The "Bottom Black" is a well-bedded unit of silty limestone with 20 percent or more insolubles and like the "Top Black" is a distinct key bed. The "Bottom Black" is locally exposed but quarrying and mining has so far been limited mainly to the overlying sequence of rock.

The "lower Thomasville section" is partly breccia, partly mottled limestone, and some well-bedded white limestone. On the average it is slightly higher in insolubles.

The phyllite has been encountered at the base of the section in many drill holes and is exposed along a fault zone in the western portion of the property. Here it is the boundary between the Kinzers and Vintage Formations. Its thickness has not been determined but is probably several hundred feet. Flat lying it caps several hills to the west and south of the quarries.

The Vintage dolomite is well exposed in the crushed stone quarry operation to the west of the phyllite fault zone. Here it is a thick, mostly dark dolomite with a uniform north dip. Near the top occurs Salterella in profusion (see Stop 1, Figure 7).

Distribution of portions of the section is conditioned by the shape of the quarry and the use of the layers at different times for various purposes.

Figure 7 is not a geologic map which would be most complicated and meaningless due to the artificial outcrop pattern. The map is a route map for orientation.

In general the Thomasville area is a broad anticline, plunging a few degrees to the east with its crest running through the center of the property. Operations are essentially in its center and down the dip of the two gently dipping flanks.

The anticline is modified considerably by faulting (see Structures).

Structures

Bedding is plainly seen in all formations except the breccia beds. Cleavage is elusive but well shown as axial plane cleavage of small folds dipping south. Small fragments in breccias are elongated and subparallel and oolites are slightly deformed. Small folds are common in gray laminated limestone layers.

Most prominent are faults. They occur as cross faults at an angle of almost 90 degrees to the fold axes and strike fault zones which may be up to 50 feet wide.

Cross faults are at many places such clean cuts that they are hard to see in the absence of displaced key beds. At some localities they are

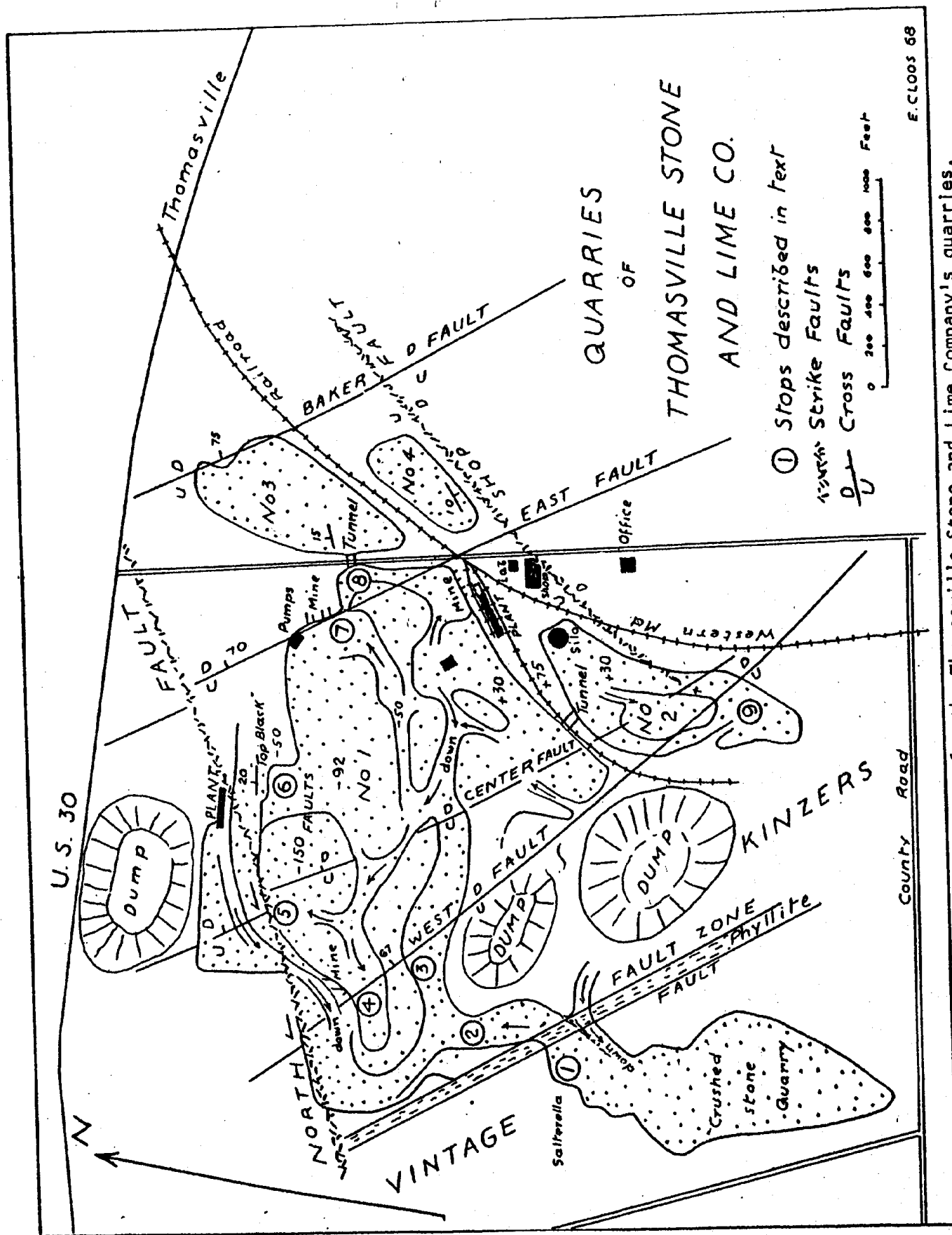


Figure 7 - Route map for the Thomasville Stone and Lime Company's quarries.

accompanied by brecciation and infiltration of red mud, red stain, or dolomitization.

Strike faults are more or less open zones, very muddy, and cavernous with abundant carbonate crystal growths. Two major strike fault zones are shown in Figure 7.

Displacements on cross faults are down on the east side. Average dip slip is 50 feet. On strike faults the dip slip is about 60 feet to the south on the "shop fault" and left lateral about 70 feet on the north fault. Strike faults offset cross faults at several places. However their mutual relation is not always clear.

In addition there are innumerable small faults. Some normal faults and small grabens are very well exposed on the east wall of the -150 and -92 levels. They are due to the downbending along the north fault.

Additional details are noted in the "descriptions of stops" section.

Economics

The total production of the Thomasville quarries averages 2 million tons of stone, of which about 900,000 tons are chemical stone and over 1 million is crushed stone produced by Lincoln Stone Company located on the Thomasville property.

The chemical stone is used in the manufacture of steel, glass, and cement, and as agricultural lime and industrial filler. Sixty percent of the Thomasville production is mined in extended mining operations.

Description of Stops (Figure 7)

WARNING: Loose rocks in quarry faces!! Watch for falling rocks and do not kick loose rocks down the slope - people below!!

Stops are shown in Figure 7.

Stop 1: North face of "crushed stone" quarry. Dark-gray Vintage dolomite, well bedded, some beds show Salterella. Dip about 10-20 degrees north.

East of stop 1, fault zone with phyllite. The phyllite is caught between two faults, one throws Vintage against phyllite, the other phyllite against lower Thomasville section. Normally the phyllite is between lower Thomasville and Vintage but much thicker. Note bedding in phyllite dips gently. Slickensiding and dislocation is conspicuous. Normal thickness of phyllite is unknown.

Walk to Stop 2: In canyon of lower Thomasville section. Light breccia with small components, white limestone, mottled light limestone. Gentle north dip.

Walk to Stop 3: At stop 3 in south wall, west fault displaces lower Thomasville limestone against upper Thomasville section. The fault is red, shows small accessory faults and dip slip is at least 70 feet here. The eastern block is above Bottom Black, the western block below Bottom Black. From here good view of north face and west fault. It can also be traced up the north wall to surface and seen that the west fault is offset on north fault which appears as a yellow zone. In the north face the Top Black is cut off on the fault and thrown against upper Thomasville light limestones on the west side.

Board bus for stop 4.

Stop 4: West fault throws upper Thomasville section above "Bottom Black" against lower Thomasville. Lower section well exposed in that portion of quarry. Fault shows breccia, red infiltration of probably Triassic mud,

and details of fault. East of fault is the entrance to new mine.

Walk to Stop 5: At stop 5 north fault zone is well exposed. Drilling has shown this zone to be about 30 feet thick. Note striation, muddy zone, and accessory faults in east wall due to downbending and extension of the beds. A graben has dropped between two blocks and the south-dipping faults have been rotated into gentle dips.

Board bus for stop 6.

Stop 6: At stop 6 Top Black - graphitic limestone exposed in face cut by white calcite veins with slickensided surfaces. Faults in east face of several kinds, muddy zones with crystal growth, and normal faults in extension zones.

Board bus for stop 7.

Stop 7: East face at -100 level. Next to pumping station and mine entrances. Huge white blocks in breccia, oriented blocks at mine entrance. "Bottom Black" just south of right entrance shows north dip well. Cleavage indicated by block orientation, dips south.

Board bus for stop 8.

Stop 8: East face of first level at entrance to tunnel into No. 3 quarry.

Dark-gray banded limestone shows numerous small asymmetrically overturned folds above Thomasville breccia, with well-oriented fragments that show cleavage. Some fragments are full of small dolomite pebbles and sand grains. Walk to east side of tunnel and note the fragment orientation below gray banded limestone above. To the east, in the east face of the quarry another cross fault is seen, and also some flexures and folds in limestone.

Board bus for No. 2 quarry and stop 9.

Stop 9: In No. 2 quarry are exposed fault surfaces and the south dipping limb of the Thomasville anticline.

The west fault of stops 3 and 4 cuts across the west face of No. 2 quarry and displaces Bottom Black against upper Thomasville limestones. The center fault is shown in north face of No. 2 quarry and as a large smooth rodded surface in the south corner of the quarry. Rodding suggests horizontal displacement components. A large block of Top Black has dropped to quarry level in the south wall between center and west faults.

Mileage

- 99.0 Return to entrance of Thomasville Stone & Lime Co. property. Turn LEFT (north) on Biesecker Road.
- 99.4 Turn RIGHT (east) on U. S. Rt. 30.
- 105.6 Proceed east on U. S. Rt. 30 - West Market Street. At Carlisle Street, York, Pa. U. S. Rt. 30 becomes one-way east. STAY IN MIDDLE LANE.
- 106.7 Turn LEFT (north) on Duke Street or Business Interstate 83. This point is one block east of city square (Market Street and George Street). Follow Interstate 83 North signs.
- 107.0 Turn LEFT on North Street.
- 107.1 Turn RIGHT on North George Street. STAY IN RIGHT-HAND LANE.
- 108.9 Turn RIGHT onto Interstate 83 North-Harrisburg ramp.
- 125.7 PENNSYLVANIA TURNPIKE.
- 127.8 Follow Interstate 83 North-Harrisburg by remaining in right-hand lane and bearing right.
- 129.2 Bear RIGHT onto Second Street Exit ramp.
- 130.3 Turn RIGHT (east) off Second Street onto Pine Street.
- 130.4 Turn RIGHT (south) onto North Third Street.
- 130.5 HARRISBURGER HOTEL.

NOTES

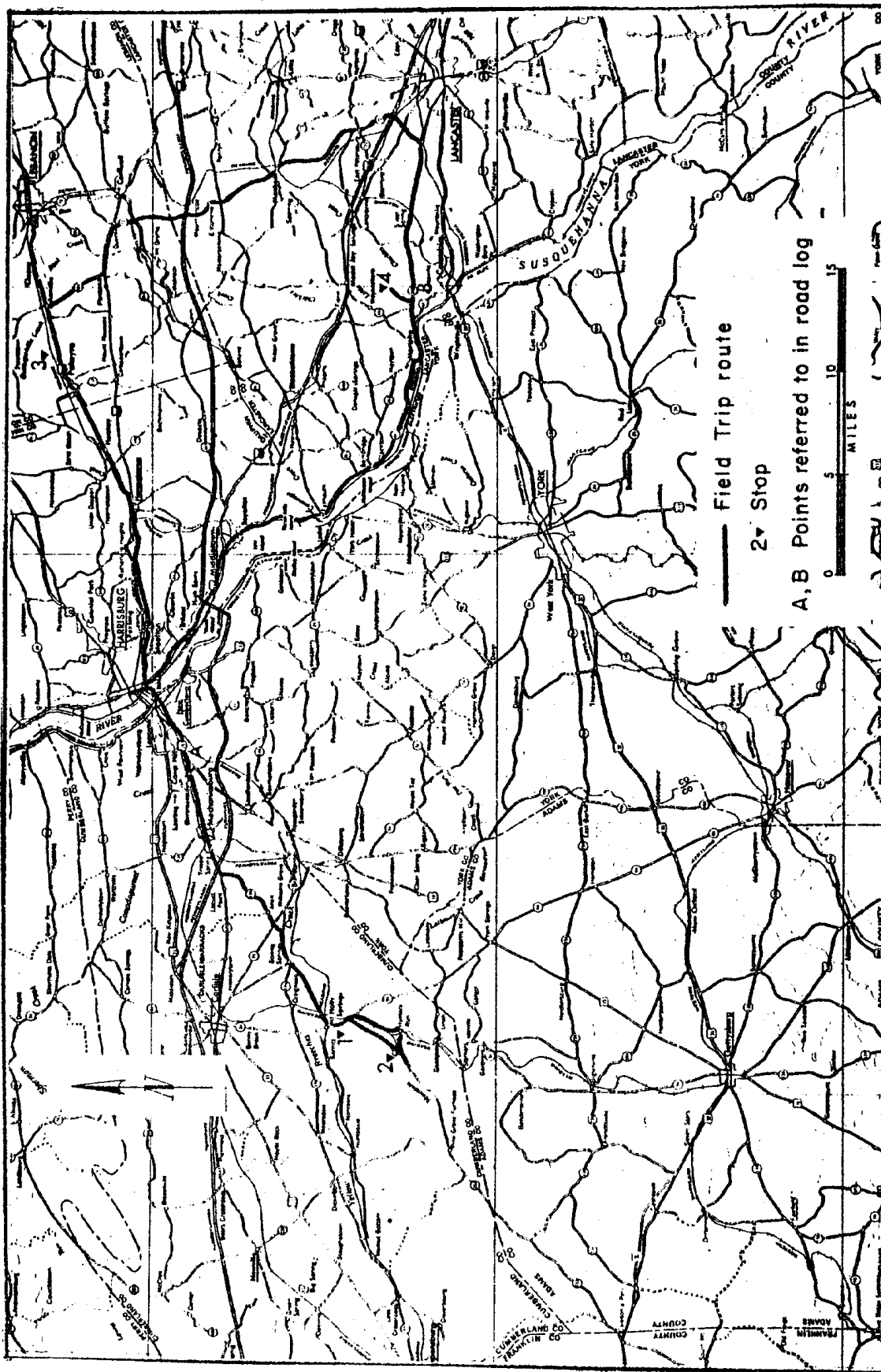


Figure 8 - Location map for stops - second day.

ROAD LOG - SECOND DAY
Saturday, October 5, 1968

Mileage

- 0.0 HARRISBURGER HOTEL
Buses will load on North Third Street.
DEPARTURE: 8:00 A. M.
Proceed south on Third Street.
- 0.2 Turn RIGHT (west) on Chestnut Street.
- 0.4 Turn LEFT on Front Street. KEEP IN MIDDLE LANE in order to enter YORK RAMP of Interstate 83.
CAUTION: Entrance to Interstate 83 has no acceleration strip.
- 1.0 YORK RAMP entrance to Interstate 83 - Harrisburg Expressway.
- 2.3 York, Pa. Exit for Interstate 83. Continue west on the Harrisburg Expressway toward Camp Hill, Pa. At Camp Hill, U. S. Rt. 11W joins the Harrisburg Expressway.
- 5.6 Turn RIGHT and leave the Harrisburg Expressway - U. S. Rt. 11 at the Pa. Rt. 641 - Trindle Rd. Exit. Continue west on Pa. Rt. 641 - Trindle Rd. through Mechanicsburg.
- 5.8 Intersection of St. Johns Rd. (POINT "A").
- 11.1 Turn LEFT (south) off Pa. Rt. 641 onto Pa. Rt. 174.
- 15.0 Junction Pa. Rt. 74. CAUTION: Stop sign, continue south on Pa. Rt. 174.
- 17.0 Boiling Springs, Pa. Observe springs on left (east) side of road.
- 17.1 Turn LEFT (east) off Pa. Rt. 174 onto Walnut Street. Esso Station in southeast quadrant.
- 20.5 Hempt Brothers sand and gravel operation.
- 21.5 Turn LEFT (south) onto Pa. Rt. 34 in Mt. Holly Springs, Pa.
- 22.0 Turn RIGHT (west) onto West Pine Street.
- 22.4 Bear LEFT on left prong of the "Y" road.
- 23.2 Turn LEFT onto Mt. View Rd. White frame church building on right approximately half a city block beyond Mt. View Rd. Intersection.
- 23.6 STOP #1: RAYMOND BENDER & SON Sandstone Quarry.
7½' Topo.: Mt. Holly Springs.

BENDER'S QUARRY
MT. HOLLY SPRINGS, PENNSYLVANIA

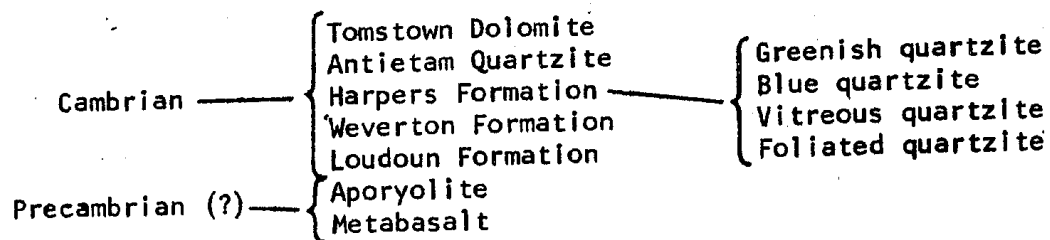
Jacob Freedman
Franklin & Marshall College

The Mt. Holly Springs quadrangle lies in a critical area in the Appalachians, and solutions of its problems are keys to the problems of the Blue Ridge, and the Great Valley (Figure 9). The following are the principal problems:

1. Sedimentary facies changes between the Piedmont and Blue Ridge,
2. Structural relationship of the Blue Ridge to the nappes in the Great Valley,
3. The Blue Ridge in the Appalachian curvature.

Regional Geology - Stratigraphy

Rocks ranging in age from late Precambrian to Lower Cambrian underlie the Blue Ridge Mountains. These are as follows (Freedman, 1967 p. 8):



In the Great Valley, Tomstown Dolomite apparently rests conformably on Antietam Quartzite or is overthrust around the mountains and in intermontane valleys. Northward the strata become younger as follows: Tomstown Dolomite, Waynesboro Formation, Elbrook Formation, Conococheague Formation, Beekmantown Group, St. Paul Group, Chambersburg Formation, and Martinsburg Formation.

The principal stratigraphic problem at Bender's Quarry is the correlation of the rocks with the Antietam Formation. Stose (1953) mapped the Antietam Quartzite wrapping completely around Mt. Holly overlying the

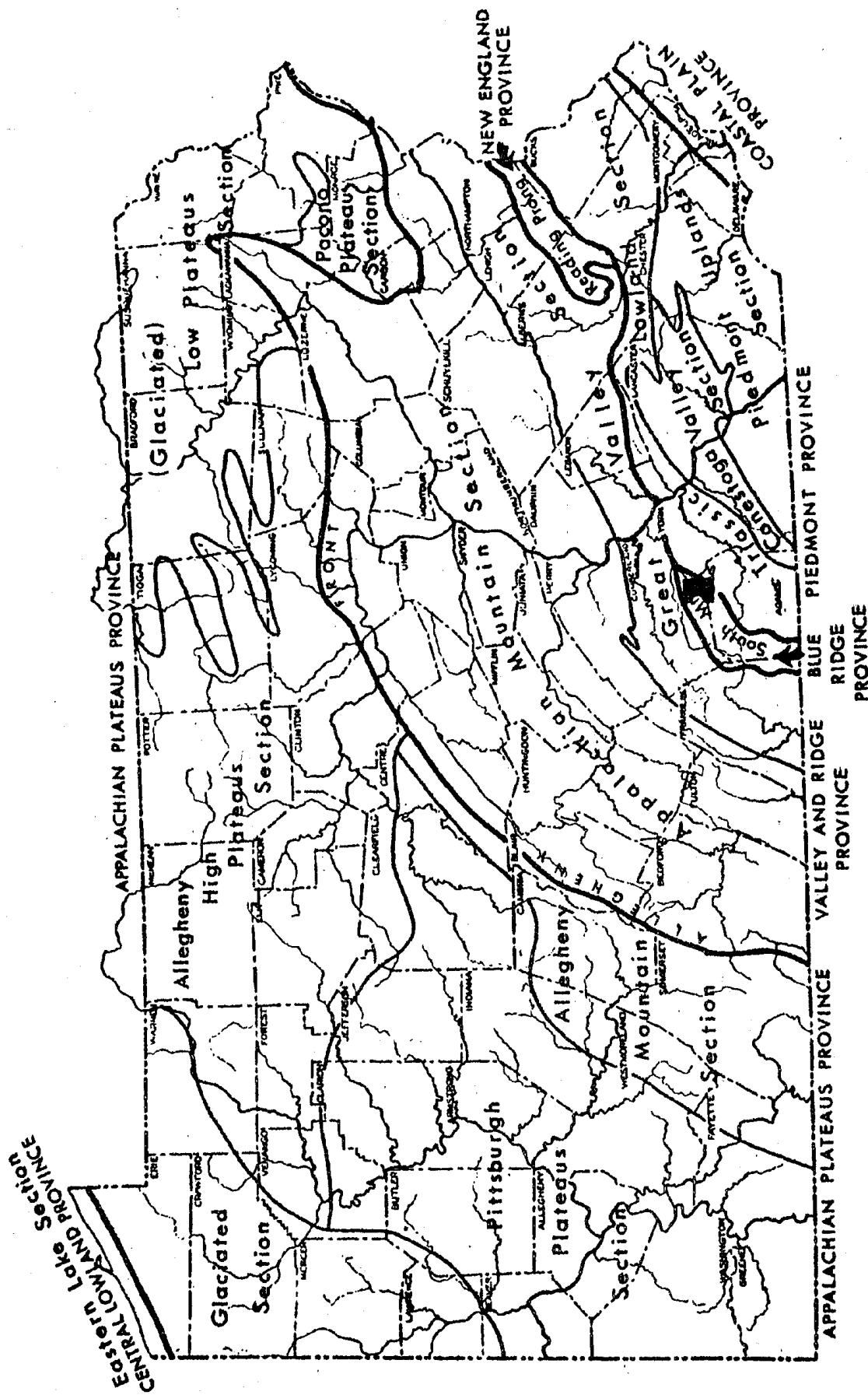


Figure 9 - Location of the Mt. Holly Springs 7½-minute quadrangle.

Montalto Quartzite Member of the Harpers Formation and underlying the Tomstown Dolomite. Subdivision of the Montalto quartzite permitted restricting the Antietam Quartzite to the northwest slope and the nose of Mt. Holly (Plate 1 of the Mt. Holly Springs quadrangle, Freedman, 1967).

The clean quartzites of the Antietam Quartzite are typical miogeosynclinal sediments (Figure 10). These and underlying and overlying rocks thin eastward and southward (Stose and Bascom, 1929, and Hohl, A., 1964) suggesting that the sediments were derived from a westward cratonic source (Kay, 1954).

The contrast in the lithology of the Antietam Quartzite in the Blue Ridge Mountains and the Piedmont around Lancaster County also suggests a deeper sea eastward or a lower lying continental land mass. In Lancaster County, the Antietam lithology is quartz-mica schist and micaceous quartzite indicating an original muddy sand sediment. In the Blue Ridge, it is a clean quartz sand with numerous Skolithos indicating a near-shore character. This is similar in appearance to the Chickies Quartzite lower in the section in Lancaster County. Could this mean that the shore of the Chickies sea transgressed westward and reached the Blue Ridge by Antietam time? Or did the two seas so similar in character occur at the two different times?

Structural Geology

The northern part of the Blue Ridge Mountains forms a culmination and a salient and is wider than the Blue Ridge locally further south (Figure 11). The culmination is due to the up-folding of the oldest rocks in the Blue Ridge of Pennsylvania, the Precambrian (?) volcanic metabasalts and aporhyolites. The salient marks the great arcuate bending of the Appalachian chain from a $N15^{\circ}-20^{\circ}E$ in Maryland to a $N60^{\circ}-70^{\circ}E$ in Pennsyl-

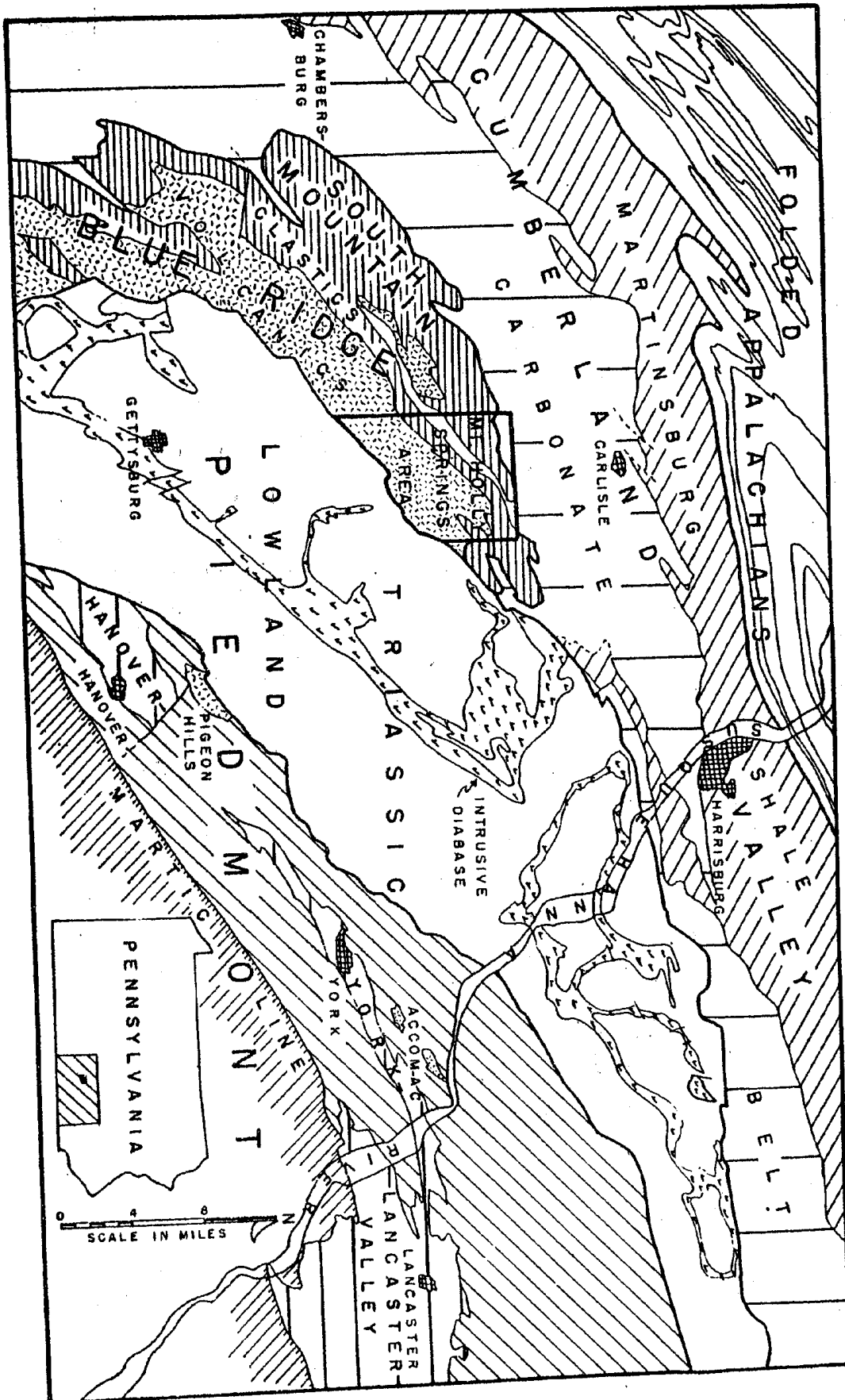


Figure 11 - Regional geologic setting of the Mt. Holly Springs area.

Isometric Fence Diagram Of Lower Cambrian Clastics

Southeastern Pennsylvania

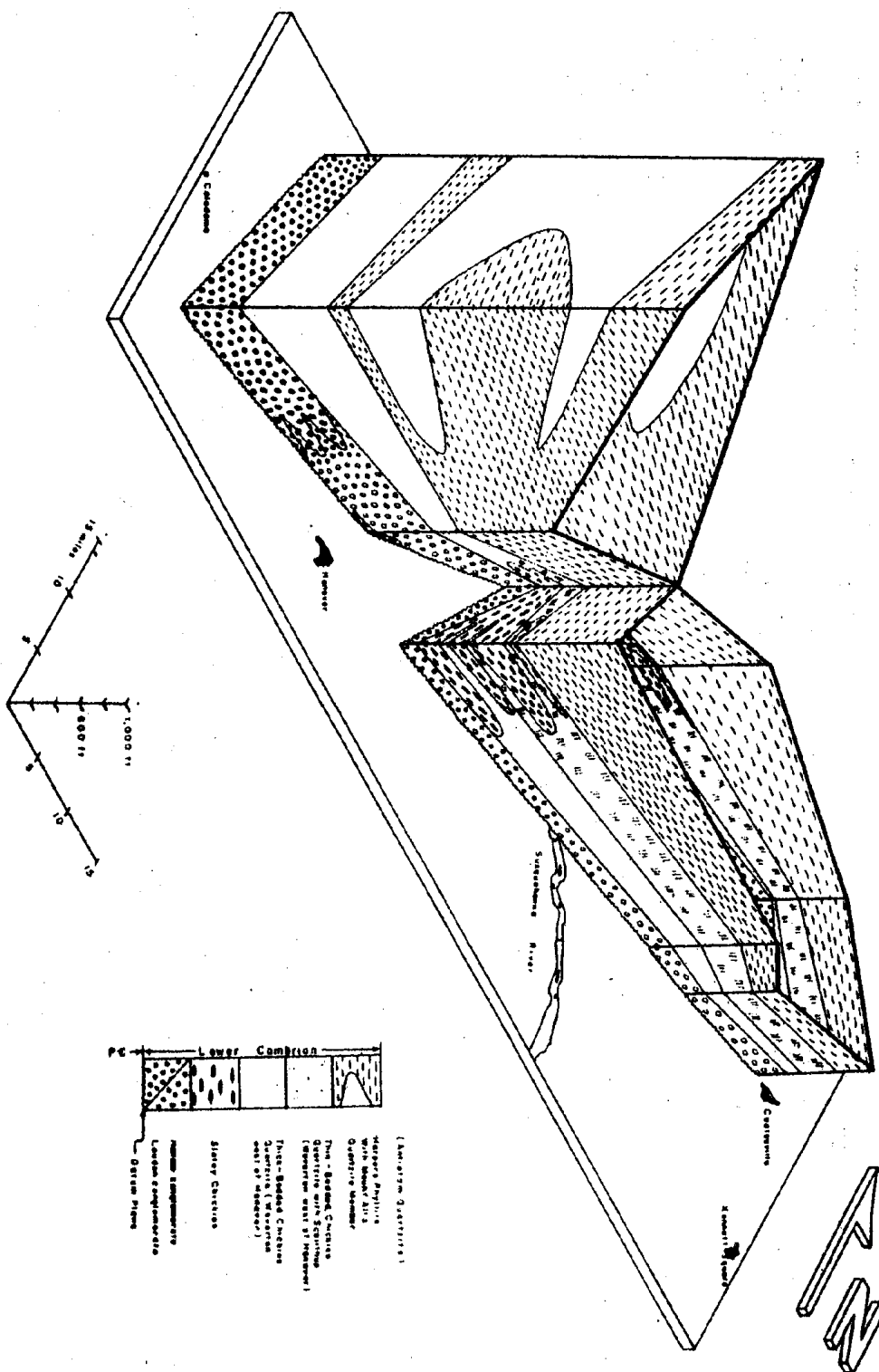


Figure 10 - Isometric fence diagram of Lower Cambrian clastics in southeastern Pennsylvania (Hohl, 1964).

vania. The curvature may have been caused by rotation around a vertical axis or by a right-lateral offset (Drake and Woodward, 1963). The cause or origin of a rotation around a vertical axis is not known. The right-lateral offset has been reputed to the Cornwall-Kelvin basement fault at the 40° north parallel. This is an east-west fault which could be the cause of New England and Long Island being shoved about 100 miles east of the rest of the United States. It may also have caused the string of Kelvin seamounts 400 miles out to sea east of New York, and the separation of the Reading prong of the New England province from the northeast end of the Blue Ridge.

No one has been able to define an acceptable line of the Kelvin-Cornwall fault as it conveniently disappears under Triassic sediments in Bucks County. If a fault does offset the nose of the Blue Ridge Mountains, possible splays from it could be tied into the faults in the Mt. Holly Springs area.

A study of lineations relating to tectonic transport and curvature of the Appalachians is presently being conducted at Franklin and Marshall College. This study indicates one set of uniformly striking lineations starting southwest of Susquehanna River and another set from there eastward. It has not yet been determined whether these were formed contemporaneously.

Location

Bender's Sand Quarry is located in Dickinson Township, Cumberland County, Pennsylvania, on the northwest slope of Mt. Holly near the northeast end of the Blue Ridge physiographic province.

Physiography

The view northwest from Bender's Quarry is spectacular. Standing on

Mt. Holly near the northeast end of the Blue Ridge Mountains, you are looking across the Great Valley to the first mountain, Kittatinny or Blue Mountain, in the Folded Appalachians or Ridge and Valley physiographic province' (Figure 11).

Bender's Quarry is shown on the colored geologic map (Freedman, 1967) by an elliptical gray area in the Antietam Quartzite at one of the wider areas of the Blue Ridge. Cloos (1950) attributed thicker portions of the Blue Ridge to additional folds, rather than thrusts. Another contributing cause could be thrusting or strike-slip movement of blocks similar to the movement along Cold Spring Run fault. The Bender's Quarry anticline is one of numerous minor folds on the South Mountain anticlinorium that contributed to its greater width.

The Bender's Quarry sand pit is based on the greater leaching of the cementing silica in the fault zone along the crest of the anticlinal ridge. Seven benches were worked at the approximate following elevations:

No. 1- (top)	1215'
2	1195'
3	1175'
4	1160'
5	1145'
6	1110'
7	1050'

The Bender's Quarry anticline is doubly plunging but at the quarry it has a steeply dipping axial plane and plunges northwest at a gentle angle. The axis of the anticline is marked by a steep fault essentially parallel to the axial plane. The attitude of the limbs of the anticline change away from the axis, gently dipping near it, getting steeper away

from it. On the lower northwest slope, the steepest dip recorded was 79°NW., asymmetric but not overturned.

Features to Observe

1. Antietam Quartzite is a fine-grained to coarse-grained, well to poorly sorted rock, thin-to-thick-bedded, with local cross-bedding, laminations and numerous Skolithos.
2. Locally Skolithos is dragged into sigmoid shapes by differential slippage on bedding, (well developed on bench #1).
3. Lineation of Skolithos at an angle to bedding deformed from original perpendicularity by bedding-plane slippage.
4. Leaching of Antietam Quartzite to the point where outcrops are extremely scarce and is locally 40 to 50 feet deep.
5. Shear zones along the crestal fault marked by fracture cleavage, clay gouge, chloritic layers, and limonitic and manganese oxide staining (bench #4 particularly).
6. Joints are dominantly steeply dipping both northwest and southeast but make a girdle fanning the anticline (equal area net of joints, Figure 12).
7. Follow the crestal fault from top of the quarry to the bottom bench.
8. Syncline south of peak in an abandoned sand pit.

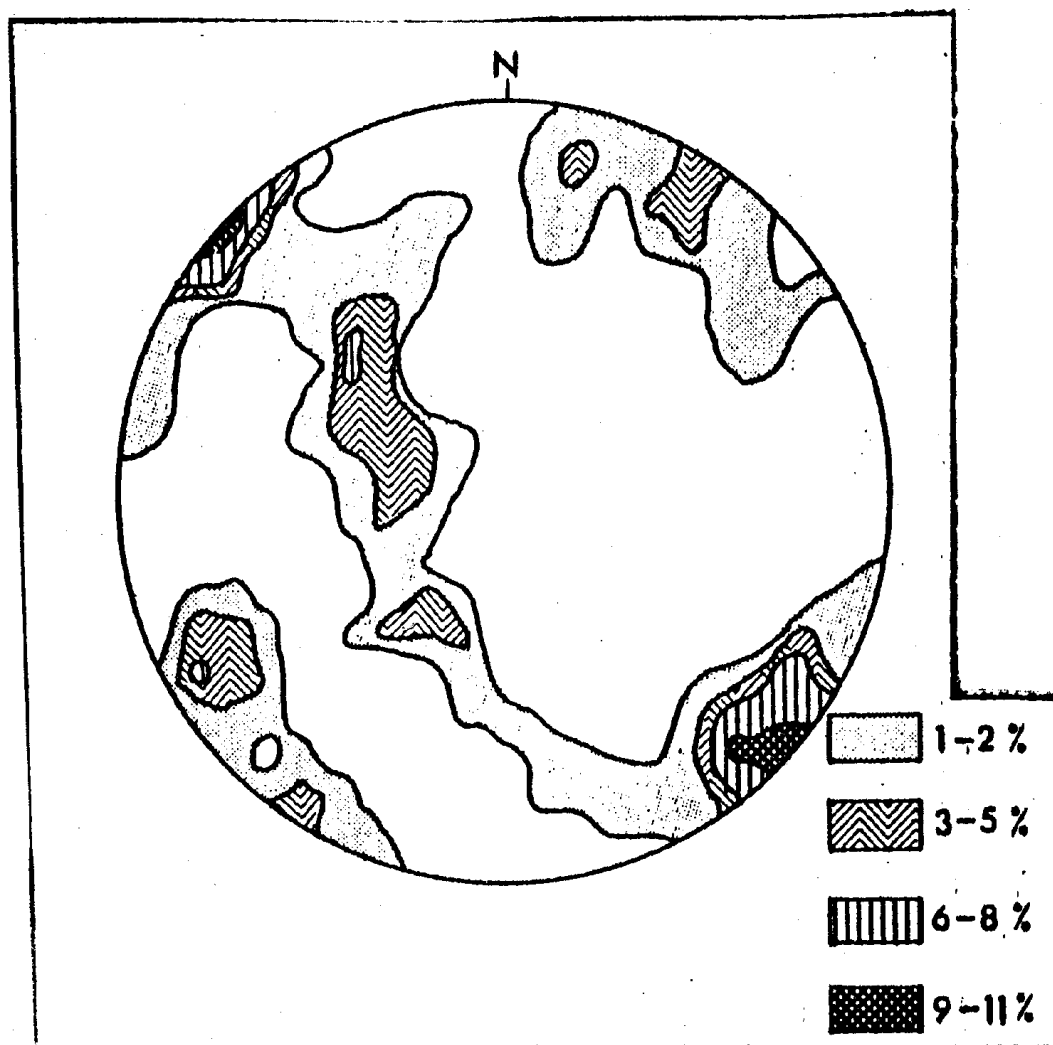


Figure 12 - Equal area net of 100 joints in Antietam Quartzite, Bender's Quarry on NW side of Mt. Holly.

Evidence at Bender's Quarry on the Development of South Mountain by Thrusting over the Tomstown Dolomite

Mt. Holly is surrounded on three sides (NW, NE, and SE) by Tomstown Dolomite. One interpretation for the development of South Mountain is that it has been thrust en masse and overlies the Tomstown Dolomite as well the sole of the thrust and near the recumbent folding.

The breccia outcrops lower on the northwest slope of Mt. Holly about 4,000 feet west of Bender's Quarry. This breccia is composed of white quartzitic angular fragments up to about 1 inch in diameter, tightly cemented by limonite and silica. The fragments show little or no orientation typical of a shear zone and may represent a sedimentary breccia. However, similar, less well-cemented and structureless breccias are typical at the base of the enormous Pulaski thrust, Pulaski County, Virginia. The breccia near the base of Mt. Holly is near where a breccia should be for a thrust interpretation. In addition breccia float was observed along Cold Spring Run Valley.

The steep axial plane and right-side-up asymmetry of the northwest limb of the Bender's Quarry anticline does not fit an overthrust theory. However, the observed steepening of dip, the lower one goes, may continue into recumbency with depth.

There seems to be some thrusting along the north slope of Mt. Holly - enough to suggest that all of South Mountain may be overthrust?

Mileage

- 25.2 RETURN to intersection of West Pine Street and Pa. Rt. 34. Proceed south on Pa. Rt. 34.
- 26.0 CAUTION: Blind railroad crossing.
- 26.1 CONTINUE southwest on Pa. Rt. 34 at its intersection with Pa. Rt. 94.
- 28.1 Summit Industries milling plant on west side of road.
- 28.1 Turn HALF-RIGHT onto macadam road.
- 28.7 Turn RIGHT (west) at "T" road.
- 29.1 Turn RIGHT (north) onto Philadelphia Clay Products Company road. Tagg Run Store on left side of road.

STOP #2
PHILADELPHIA CLAY PRODUCTS COMPANY. Note: Many of the
highwall slopes are unstable.
7½' Topo.: Mt. Holly Springs.

WHITE CLAY DEPOSITS NEAR MT. HOLLY SPRINGS,
CUMBERLAND COUNTY, PENNSYLVANIA*

John W. Hosterman
U. S. Geological Survey
Beltsville, Maryland

History of the Deposits

In the vicinity of Mt. Holly Springs, as many as five white clay deposits have been in operation during the past 75 years. Only one of these deposits remains in operation at present, the Philadelphia Clay Company's Mt. Holly Springs Quarry.

White clay deposits in the South Mountain area have been mined intermittently since about 1890, but no accurate production data are available. The clay was probably first recognized in the mid-1800's by prospectors looking for iron ore. Between 1890 and 1910, there were at least five companies in the area mining clay. Four of these companies had facilities for beneficiating the clay which was then sold to the paper mills for use as a paper filler. One company, in Mt. Holly Springs, used the raw clay for making cream to light-buff brick (Stose, 1907, p. 330). By 1930, however, only two companies were mining clay. The Philadelphia Clay Company had a 100-ton daily capacity mill for washing and drying clay. The Medusa Portland Cement Company was mining and shipping raw clay for use as a whitener in portland cement (Lehighton, 1934, p. 13). In 1967,

* Publication authorized by the Director, U. S. Geological Survey.

the Philadelphia Clay Company was the only producer of clay. This company, with modern earth-moving equipment, changed from underground mining to open-pit mining and is currently producing about 40,000 tons of raw clay a year. The clay is trucked to York and is used in making hydraulic white cement.

Geology of the Philadelphia Clay Company's Clay Deposit

All of the clay deposits in the Mt. Holly Springs area undoubtedly have the same geologic environment. The deposits are in the phyllite member of the Tomstown Formation in the area of this report, and all of the deposits are about the same distance from the quartzite of the Montalto Member. Although Stose (1953) shows this contact to be normal, evidence in the Philadelphia clay pit, which is the only one accessible for study, indicates that it is a fault contact. This fault is probably the principal reason for the formation of these deposits.

The white clay deposit of the Philadelphia Clay Company is lens shaped, measuring approximately 200 feet in width at its maximum breadth and 1,600 feet in length (Figure 13); its vertical extent at depth is unknown. The northern boundary of the deposit, where it is in fault contact with the quartzite of the Montalto Member, is sharp and straight. The southern boundary is gradational; the white clay grades into yellow, pink, red, and brown silty clay. This varicolored silty clay, which is about 200 feet wide, grades into grayish-green to light-gray phyllite and calcite-veined limy phyllite of the Tomstown Formation.

Two auger holes were drilled in the floor of the pit (Figure 13). Auger hole 2 penetrated white clay for its entire length of 150 feet. Auger hole 1 encountered white clay for a depth of 80 feet before penetrating variegated silty clay. By connecting the variegated silty clay

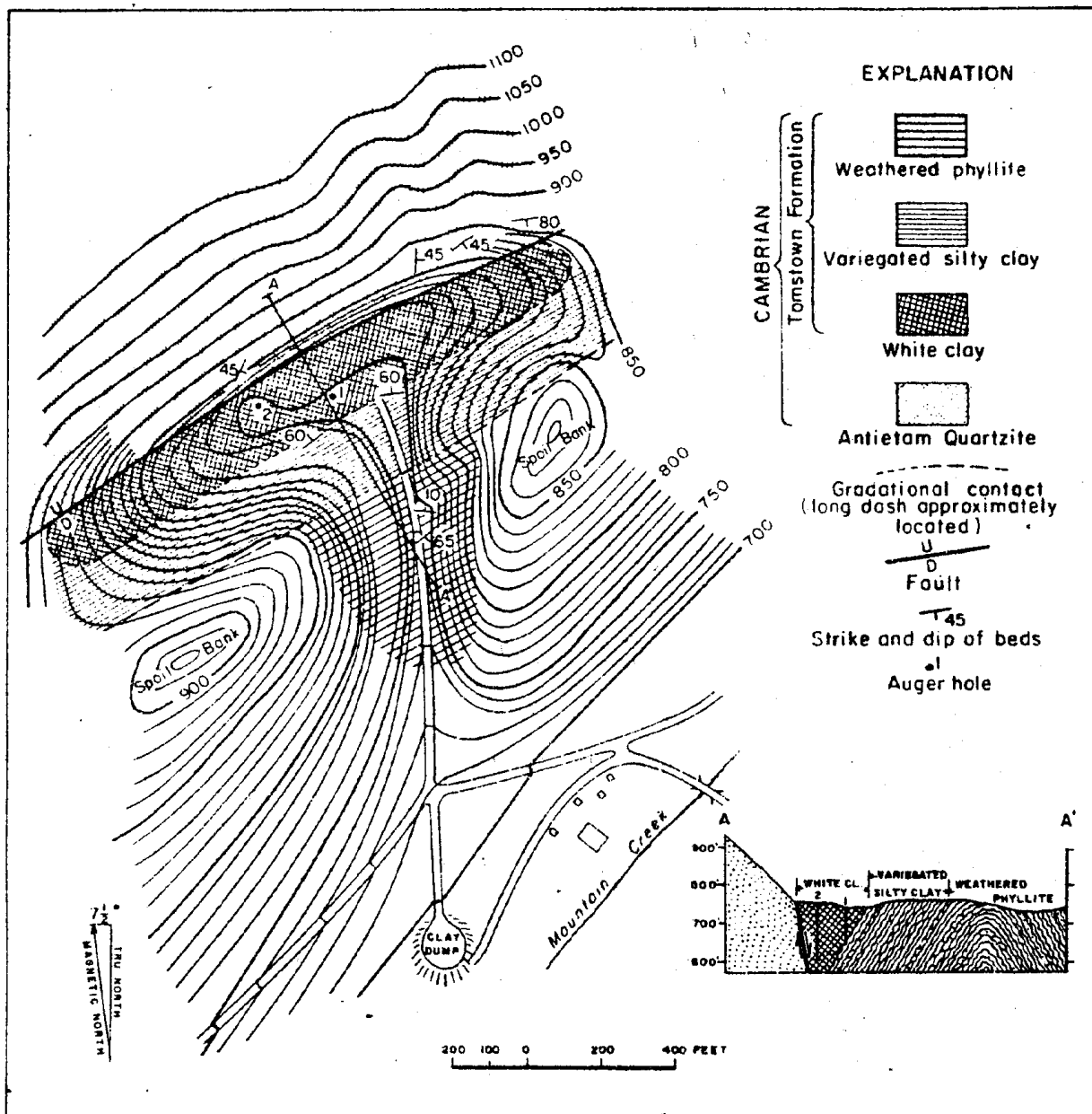


Figure 13 - Geologic map of the white clay deposit owned by the Philadelphia Clay Company near Mt. Holly Springs, Cumberland County, Pennsylvania.

contact with the same contact at a depth of 80 feet in auger hole 1 (Figure 13), it is seen that this contact has an approximate dip of 60° . This contact does not follow the bedding, except locally. Assuming that the contact between the white clay and the variegated clay dips 60° NW., the white clay deposit probably wedges out against the steeply dipping fault contact at about 300 feet below the level of the pit floor (See section AA', Figure 13). The Antietam Quartzite dips 45° to 80° SE. along the southeast-facing steep slope of South Mountain. Bedding in the white clay is not distinguishable because open-pit mining has not exposed clay that was not disturbed by previous underground mining. Adjacent to the white clay, the variegated silty clay, although very contorted, has an average dip of 60° to the north. This can be seen by following the thin sandy beds. The haulage way exposed an anticline in the somewhat weathered Tomstown about 350 feet south of the white clay.

Mineralogy and Chemistry of the Deposit

The white clay, variegated silty clay, and weathered phyllite show progressive differences in particle-size content, clay-mineral ratio, and SiO_2 and Fe_2O_3 content (based on X-ray fluorescence analyses, Table 2). In the white clay, sand and silt decrease and clay increases slightly with depth; at a depth of 100 feet below the pit floor the clay content increases to 72 percent, and at a depth of 150 feet the clay content is 74 percent. The sand and silt fractions of the white clay are composed chiefly of quartz and trace amounts of muscovite, hematite, and limonite. The sand and silt fractions of the variegated silty clay are composed of fine-grained quartz with hematite and limonite. The sand and silt fractions of the slightly weathered phyllite are composed of fine-grained quartz with a little muscovite, biotite, and magnetite. Some of the phyllite contains limy beds and calcite veins.

Table 2. -- Particle-size, clay-mineral ratios, and SiO_2 , Al_2O_3 and Fe_2O_3 content of samples

from the Philadelphia Clay Company's Mt. Holly Springs Quarry

	No. of samples	Sand Silt Clay		Clay-mineral ratios		SiO_2 Al_2O_3 Fe_2O_3		
		(in weight percent)		Kaolinite	Illite	Montmorillonite	(in weight percent)	
White clay	30	6	24	70	9	1	--	71 19 0.4
Variegated silty clay	3	5	34	61	8	2	tr	66 19 2.2
Weathered phyllite	5	7	33	60	1	7	2	56 18 6.3

Hosterman (in press) describes how the samples were prepared for determining the partial chemical composition by X-ray fluorescence methods. The method is not as accurate as the wet-chemical method, however, it was found to be accurate to within 10 percent of the amount of oxide present. This means that if a sample was found to contain 20 percent Al_2O_3 , it was accurate to within 2 $\pm$ percent. Rose and others (1962, 1964) have described more complicated sample preparation procedures that give more accurate results.

The SiO_2 content in the rocks at the surface decreases from the white clay through the variegated silty clay to the weathered phyllite, whereas, both the Fe_2O_3 and K_2O content increase; the Al_2O_3 content varies only a few percent without any discernible trend, except a slight decrease from the variegated silty clay into the weathered phyllite; and the TiO_2 content remains constant (Figure 14). In addition to these chemical variations, the following mineralogical changes also take place; kaolinite is most abundant in the white clay and least abundant in the phyllite; illite is least abundant in the white clay and most abundant in the phyllite. The differences in chemical and mineralogical composition may be due to weathering, but they may also be due to differences in lithology. The Al_2O_3 content does not change very much due to either weathering or bulk lithology, because the abundance of Al_2O_3 in natural-occurring illite can be almost as high as it is in kaolinite (Grim, 1953, p. 272).

The nature and attitude of the southern boundary of the white clay deposit were determined from the chemical and mineralogical data obtained from auger hole 1. The vertical hole (Figure 15) was drilled within the white clay deposit, approximately 60 feet from the contact with the

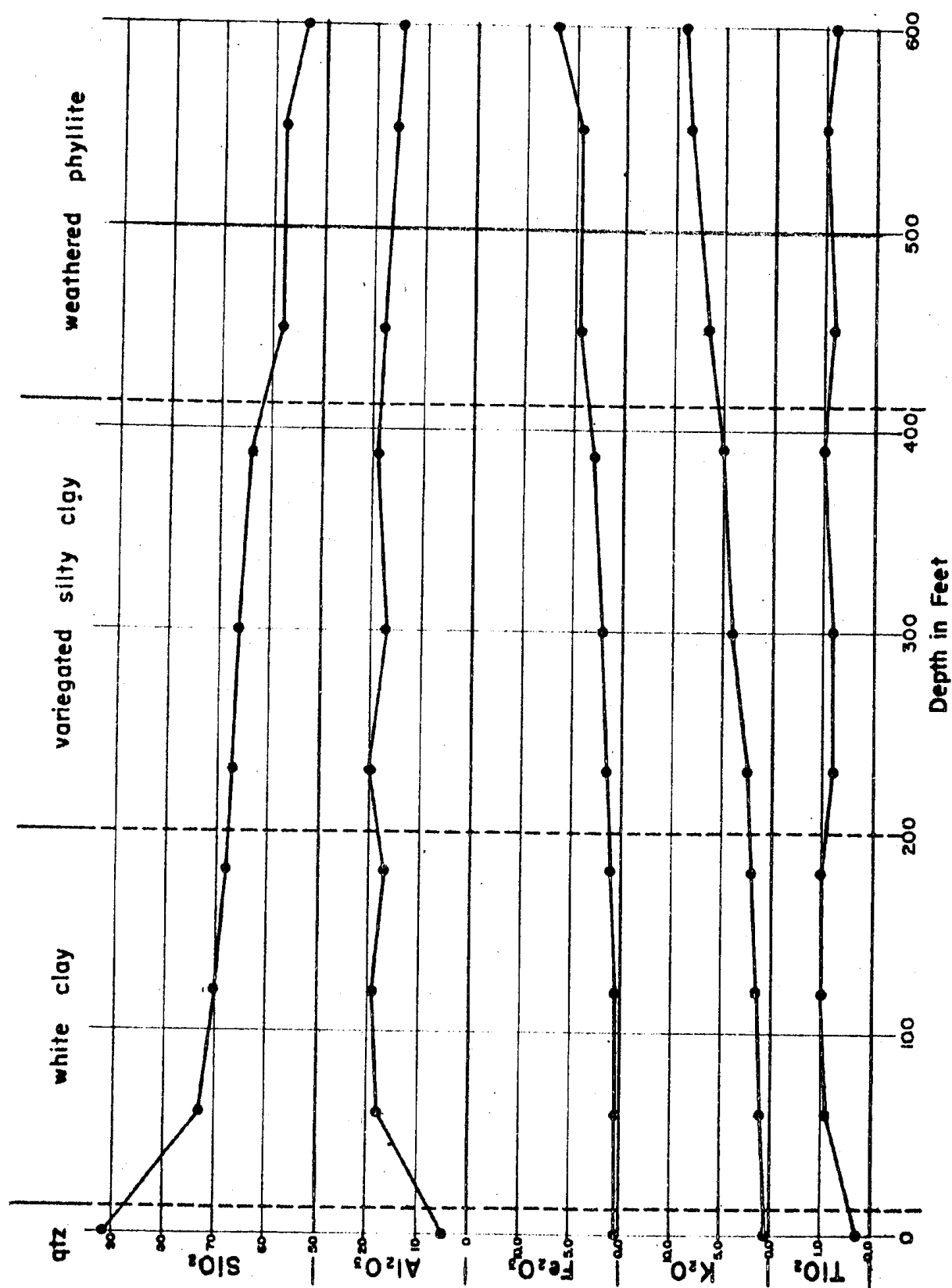


Figure 14 - Chemical differences between surface samples of quartzite, white clay, variegated silty clay, and weathered phyllite. Chemical analyses by X-ray fluorescence. See Figure 13 for location of samples.

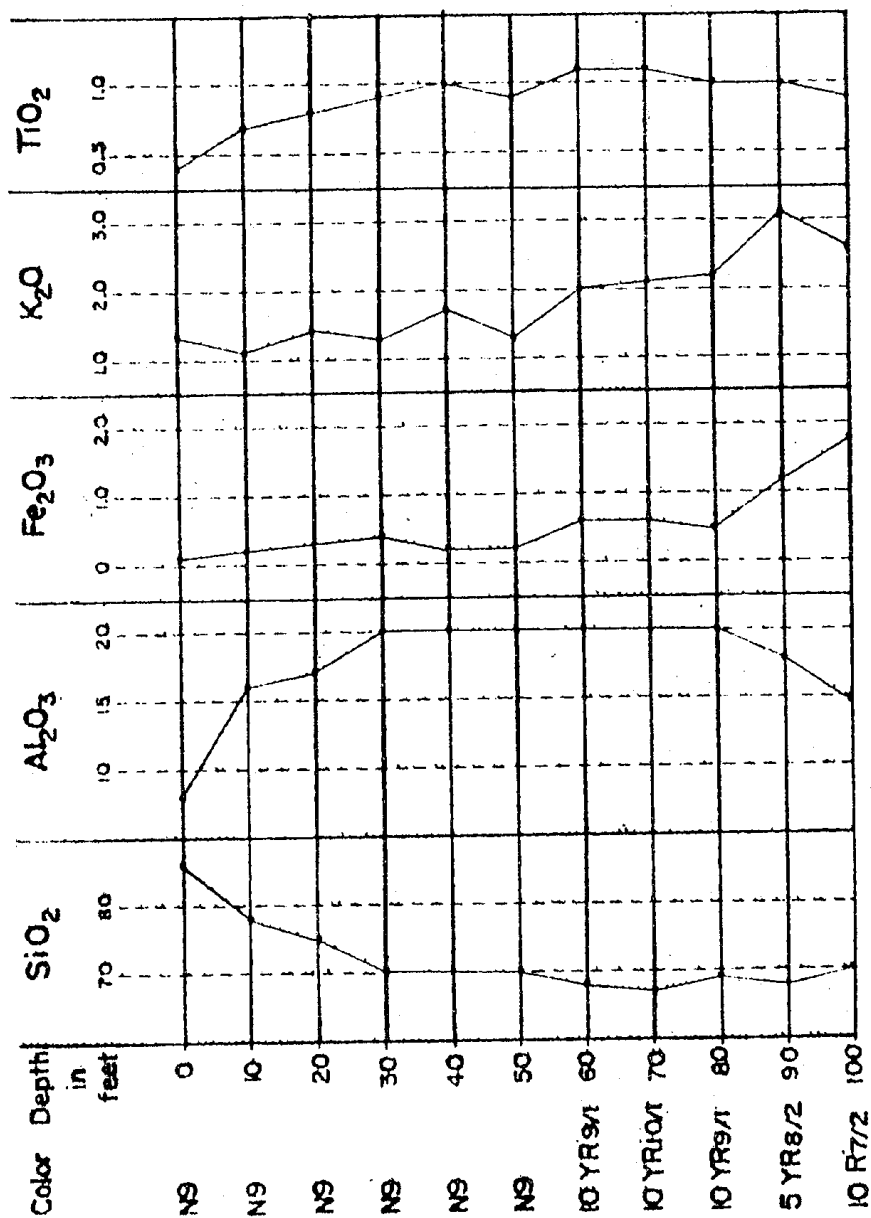


Figure 15 - Chemical and color changes of the white clay with depth in auger hole 1. Chemical analyses by X-ray fluorescence. Colors determined from "Rock-color chart" (Goddard and others, 1948).

variegated silty clay (Figure 13). The high SiO_2 and low Al_2O_3 content of the first sample is due to contamination from both quartzite and the variegated silty clay washed into the clay pit from the nearby spoil bank. The samples taken at depths of 10 and 20 feet are slightly higher in silt content than the average white clay, and, therefore, the SiO_2 content is higher and the Al_2O_3 content is lower than the average grade white clay. At a depth of 80 feet, the hole penetrated variegated silty clay. The boundary between the two clays is placed where there is a marked color change from white (N9) and yellowish white (10YR9/1) to weak orange pink (5YR8/2 and 10R7/2). At this boundary, there is a marked decrease in the Al_2O_3 content and an increase in the Fe_2O_3 and K_2O content as compared to the 50 feet of white clay above it. The SiO_2 content, however, remains fairly constant, indicating that there is no increase in the amount of sand and silt present. In addition, mineralogical changes at the boundary involve an increase in illite and a decrease in kaolinite. The kaolinite-illite ratio above 80 feet is 9:1 and below is 8:2. Traces of alunite were observed between 30 and 80 feet. These color, chemical, and mineralogical changes at a depth of 80 feet indicate that the white clay-variegated silty clay contact dips approximately 60° to the north.

The chemical and mineralogical data obtained from auger hole 2 indicate that the Philadelphia Clay Company clay deposit was not formed exclusively by weathering processes. Auger hole 2 was drilled vertically in white clay approximately 145 feet from the variegated silty clay contact (Figure 13). The high SiO_2 and low Al_2O_3 content (Figure 16) of the surface samples is possibly due to quartz contamination resulting from blasting and stripping of the Antietam Quartzite on the mountain slope above

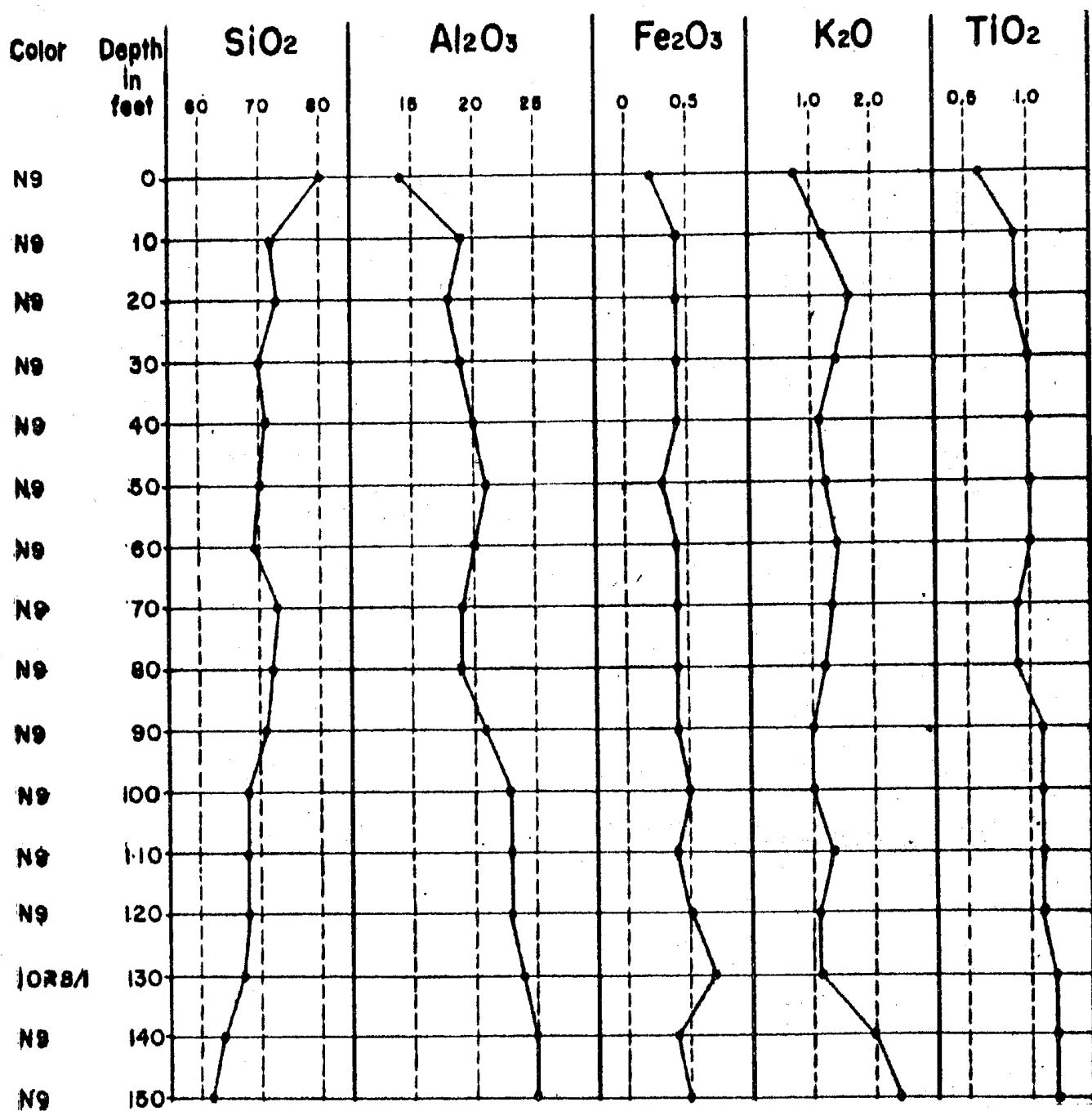


Figure 16 - Chemical and color changes of the white clay with depth in auger hole 2. Chemical analyses by X-ray fluorescence.

the clay pit. From 10 to 150 feet, SiO_2 decreases from 72 to 62 percent, Al_2O_3 increases from 18 to 25 percent, Fe_2O_3 and TiO_2 are relatively constant, and K_2O is constant down to 130 feet but increases from 1:1 to 2.4 percent below 130 feet. The kaolinite-illite ratio is greater than 9:1, and the color, except for one sample, is white (M9) in all of the 16 samples examined. Alunite occurs in trace amounts from depths of 40 to 130 feet and in slightly more than trace amounts from 130 to 150 feet. The only observed change in bulk lithology of the white clay from 10 to 150 feet is an increase in clay content from 70 to 74 percent; the silt content decreases from 25 to 21 percent; and the sand content is 5 percent throughout. Thus, the 5 percent increase in the amount of clay does not account for the almost 33 percent increase in Al_2O_3 content. The steady increase of Al_2O_3 with depth and the striking complementary decrease in SiO_2 cannot be attributed solely to differences in lithology. This increase in Al_2O_3 with depth and the striking complementary decrease in SiO_2 cannot be attributed solely to differences in lithology. This increase in Al_2O_3 content with depth, however, is opposite to changes normally observed in a weathering profile (Hosterman, 1960, p. 13).

The clay deposits in the vicinity of Mt. Holly Springs could have been formed as residual clay or as hydrothermal clay deposits. Stose (1907, p. 323) was first to propose an origin due to weathering. Chemical and mineralogical evidence presented in this paper, however, suggest that these clay deposits were formed, at least in part, by hydrothermal alteration.

The surface relations suggest that the white clay deposit is a residuum formed from weathering of an argillaceous sediment. Surface waters with a high oxygen content drained from the mountain slope and penetrated

the phyllite along fractures created by faulting and along bedding planes. Iron and potassium were leached from the phyllite so that illite was altered to kaolinite. The ions were carried away in solution leaving a residual deposit of white kaolinitic clay. The iron, derived from the illite but chiefly from magnetite, was precipitated from solution when the slightly acid ground water permeated the sandy carbonate beds of the Tomstown Formation. Thus, the iron ore deposits in this area, mined during the mid-19th century, were formed by supergene enrichment and are probably similar in origin to those in Virginia described by Lesure (1957, p. 98). A capping of gravel derived from the Antietam Quartzite protected these white clay deposits from erosion during the development of the Mountain Creek valley.

I believe these clay deposits formed by hydrothermal alteration modified by later weathering or katamorphic alteration. The occurrence of alunite, a low-temperature hydrothermal mineral (Parker, 1954, p. 42), in minor amounts has been confirmed by X-ray diffraction methods, differential thermal analysis, and by electron microscope examination (Figure 17). Hydrothermal alteration, indicated by the presence of alunite and increase in Al_2O_3 content, is more prevalent at depth than at the surface. The fault zone bordering the clay deposit provided a passageway for ascending hydrothermal solutions.

The chemical analysis, particularly the Al_2O_3 content of auger hole 2 (Figure 16), supports a hydrothermal origin and does not support the theory that the white clay was formed exclusively as a residuum due to katamorphic alteration. In most weathering environments involving katamorphic alteration, SiO_2 , Fe_2O_3 and K_2O are leached, whereas, Al_2O_3 increases gradationally upward from the parent material to the residual.



Figure 17 - Electron photomicrograph of kaolinite aggregate (top) and alunite crystal (bottom) in clay sample from the 40- to 50-foot interval of auger hole 1. Photograph by E. J. Dwornik, U. S. Geological Survey.

product. If the white clay is considered the final product, the variegated silty clay, the intermediate weathered product, and the phyllite, the parent material, then there has been normal leaching of Fe_2O_3 and K_2O both laterally and vertically, but the SiO_2 and Al_2O_3 content are the reverse of a normal weathering profile. In auger hole 2, the silt content decreases with depth from 25 to 20 percent; this could account for most of the decrease in SiO_2 content which is 72 percent at a depth of 10 feet and 67 percent at 130 feet (Figure 16). Conversely, however, the increase

with depth in the amount of clay from 70 to 74 percent does not account for the increase in Al_2O_3 content from 18 percent at a depth of 10 feet to 25 percent at 150 feet. This represents a 5 percent increase in clay and a 33 percent increase in Al_2O_3 . Alunite, $(K,Na)Al_3(OH)_6(SO_4)_2$, accounts for only part of this increase because it occurs only in trace amounts. The additional Al_2O_3 content could be attributed to the presence of allophane. Allophane is amorphous and cannot be detected by X-ray; it is also almost impossible to identify by differential thermal analysis in the presence of kaolinite. Kaolinite, the most abundant mineral present, can be formed by either hydrothermal alteration or by katamorphic alteration.

The chemical and mineralogical evidence indicate that the white clay deposits near Mt. Holly Springs were probably formed by hydrothermal alteration. The surface features, the presence of supergene iron ore deposits, and the weathered phyllite indicate that katamorphic alteration occurred after hydrothermal alteration.

Mileage

- 29.1 Return to entrance of Philadelphia Clay Products Co. property. Turn LEFT (east) on public road.
- 30.0 CAUTION: Blind railroad crossing.
- 30.1 Turn LEFT (north) onto Pa. Rt. 34, continue into Mt. Holly Springs and retrace route thru Boiling Springs to St. Johns Road & Pa. Rt. 641 - Trindle Road (POINT "A").
- 49.8 St. Johns Road (POINT "A") continue east on Pa. Rt. 641 - Trindle Road.
- 50.0 Turn RIGHT onto ramp to U. S. Rt. 11 - Harrisburg Expressway and continue east through Harrisburg.
- 54.3 Susquehanna River.
- 56.7 Hempt Brothers Paxton Quarry on right, (south).

- 58.0 Intersection of Interstate 83 and Pa. Rt. 283 and U. S. Rt. 322. CONTINUE EAST on U. S. Rt. 322.
- 62.5 Swatara Creek & Union Canal.
- 64.6 Intersection of U. S. Rt. 322 and U. S. Rt. 422. U. S. Rt. 422 trends east-northeast into Hershey, Pa. FOLLOW U. S. Rt. 422.
- 67.1 Junction Pa. Rt. 743 in center of Hershey, Pa.
- 70.3 Palmyra, Pa.
- 71.8 Western end of Bethlehem Steel Corp., Millard Quarry. Runs eastward parallel to U. S. Rt. 422 for approximately a mile.
- 73.3 STOP #3
BETHLEHEM STEEL CORPORATION, MILLARD STONE DIVISION office.
Turn LEFT (north) off U. S. Rt. 422 onto public road and enter company parking lot on left (west) side of road.
7½' Topo.: Palmyra

MILLARD QUARRY
ANNVILLE, PENNSYLVANIA

Samuel J. Sims
Bethlehem Steel Corporation

Introduction

The Millard Quarry, formerly the H. E. Millard Lime & Stone Company before its acquisition by Bethlehem Steel in 1966, produces lime and metallurgical limestone from the high-calcium Anville Formation. The Millard Quarry consists of several quarries, both active and abandoned, located in the Lebanon Valley in Lebanon and Dauphin counties, Pennsylvania. At present four quarries are in operation. Three of them - Palmyra, Anville West, and Anville East - produce high-calcium limestone and some commercial stone as part of the stripping operation. The Palmyra South Quarry produces only commercial stone. The Anville East Quarry is operated on a lease basis by Fiala, Inc., and the Palmyra Quarry is

scheduled for reduced production. The main operation is therefore at the Annville West Quarry.

An exploration program was initiated by Bethlehem shortly after acquiring Millard Quarry. The program consisted primarily of diamond drilling and also geologic mapping in order to determine more accurately the reserves of high-calcium limestone.

Stratigraphy

The Annville Formation is Middle Ordovician in age and overlies in apparent conformity the Ontelaunee Formation of the lower Middle Ordovician Beekmantown Group (MacLachlan, 1967, p. 34). The Annville is in turn overlain disconformably by the upper Middle Ordovician Myerstown Formation (MacLachlan, 1967, p. 54). Figure 18 shows the position of the Annville Formation in the Ordovician stratigraphic column of the Lebanon Valley. Structurally, the Annville Formation is on the overturned north

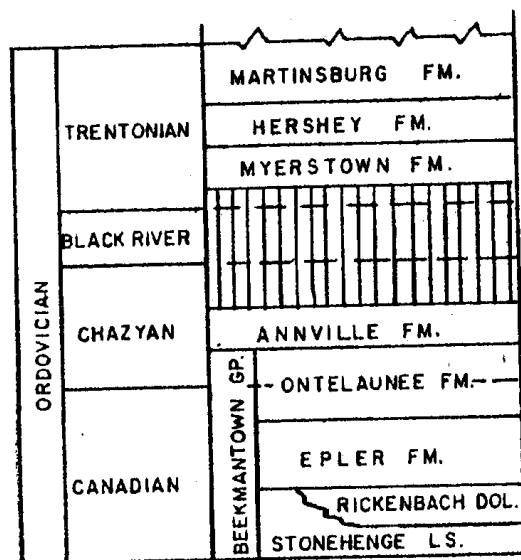


Figure 18 - Stratigraphic column of Ordovician rocks in the Lebanon Valley.
Taken from MacLachlan, 1967, p. 11.

limb of a complex regional anticline (Gray, 1952, p. 5), so that the older Ontelaunee Formation forms the hanging wall and the younger Myerstown Formation the footwall of the Annville Formation (Figure 19). Several publications treat the stratigraphy, structure, and distribution of the Annville Formation (See Gray, 1951 and 1952; Prouty, 1959; and MacLachlan, 1967); this report is only concerned with the Annville Formation as it occurs at the Millard Quarry.

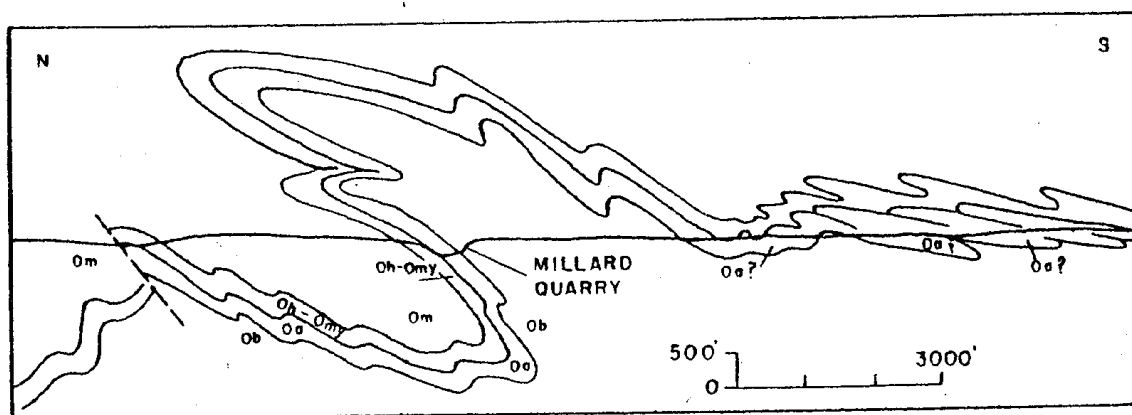


Figure 19 - Hypothetical regional structure section through the Millard Quarry. (Taken from Gray, 1962, p. 6.) Om - Martinsburg Formation, Oh-Omy - Hershey-Myerstown Formations, Oa - Annville Formation, and Ob - Beekmantown Group.

Myerstown Formation

The Myerstown Formation at and near the contact with the Annville Formation is graphitic, thinly layered, dark-gray to black limestone with scattered fine-grained blebs of white calcite. Drill core samples break easily along graphitic partings which typically have slickensides. Core samples characteristically show a cataclastic texture with shear folds, boudinage, and augen structures. The Myerstown is cut by thin calcite veinlets and in places by quartz veinlets. Pyrite crystals are not uncommon. Surface samples of Myerstown Formation weather to a dense blue-gray rock that is similar in appearance to weathered Annville Formation.

Because the Myerstown Formation was penetrated by drill holes only in the first 10-12 feet adjacent to the Annville Formation, the chemical analyses from the drill holes are not representative of the entire formation. The average analyses from drill holes are:

<u>SiO₂</u>	<u>R₂O₃</u>	<u>CaCO₃</u>	<u>MgCO₃</u>	<u>S</u>
5.57	2.22	86.0	3.6	.210

Annville Formation

The Annville Formation is a high-calcium limestone that was given formal status as a mappable rock unit by Prouty (1959), although the terms Annville stone and Annville limestone have been in use in both a commercial and a geologic sense for a long time. Surface exposures at Millard Quarry are limited to scattered outcrops in the wooded areas near the intersection of Forge Road and the railroad and the extreme eastern end of the Annville East Quarry. Otherwise all exposures are in the quarries.

The type section selected by Prouty (1959, p. 6) is in the Palmyra Quarry, probably near the underground crusher and measures 180.5 feet thick. However, the Annville Formation is variable in thickness. In the 26 drill holes that penetrate both top and bottom of the formation, the thickness ranges from 144 feet to 286 feet and averages 192 feet.

The contact between the Annville Formation and the older Ontelaunee Formation is conformable but locally has been deformed. In many drill holes the contact is sharp and well defined, typically by a stylolite. In 13 of the drill holes, the contact zone between Annville and Ontelaunee rocks is marked by from one to three alternating layers of limestone and dolomite, each layer ranging in thickness from less than 1 foot to 5 feet. The contact is placed at the base of the last dolomite layer so as to include no contaminants in the Annville limestone.

The contact with the younger Myerstown Formation is disconformable and typically marked by a surface of shearing with conspicuous slickensides and coarse crystals of calcite. In some places the contact is stylolitic and sharp. In other places the locus of shearing is not coincident with the lithologic contact, but is always very close to the contact. The age relations of the two formations indicate a hiatus between Annville and Myerstown rocks (MacLachlan, 1967, p. 56).

The Annville Formation is a massive high-calcium limestone quite uniform in both lithology and chemistry throughout the Millard Quarry area. It is finely crystalline, ranges from white to light-gray to blue-gray to dark bluish-gray and weathers to white-gray. The rock consists of a mosaic of equigranular to elongate interlocking grains of calcite with scattered zones of coarser recrystallized calcite. The groundmass calcite ranges in size from about 0.005 mm up to 0.05 mm and averages about 0.01 mm. Coarse recrystallized calcite ranges up to 1.0 mm and tends to occur in thin lenses or in blebs, typically on fold hinges. Miner impurities are quartz, pyrite, and clay plus carbonaceous material - perhaps graphite.

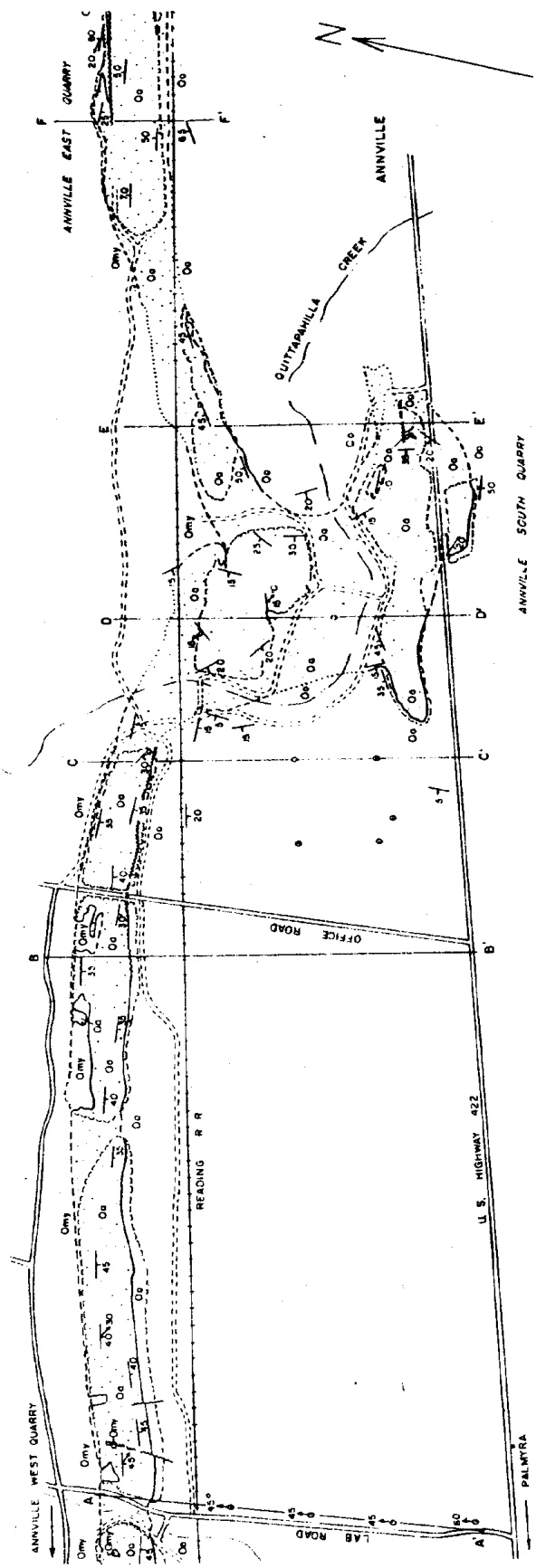
Stylolites are conspicuous in the limestone, especially on smooth core surfaces, and are about 0.01 mm thick. They are not regularly spaced and may range from ten or more to the inch to none. Besides stylolites, the limestone has thin parallel bands or lamellae of slightly darker hue caused by finely disseminated clay and/or carbonaceous material. The bands range from stylolite thickness up to 1 inch or more and from quite distinct to very faint. In general they are about 1 mm thick and moderately conspicuous. These lamellae of disseminated clay probably define original beds. They weather out more readily than the pure calcite

and form thin troughs on the weathered surfaces of the Annville Formation and are therefore one of the main causes of the characteristic fluted weathering of the Annville Formation (Gray, 1952, p. 3; Prouty, 1959, p. 7).

The Annville Formation is locally altered beneath the surface where associated with cavities. This alteration is mainly by solution of intergranular grain contacts which produces a friable creamy-white rock. The most conspicuous location of this granular limestone is in the Annville South area (Figure 20).

Calcite veinlets cut the Annville in varying amounts. The veinlets are white, typically 1 mm to 2 mm thick, steeply dipping, and composed of coarsely crystalline calcite. It was noted that where veinlets are abundant in the limestone, so are stylolites. It was also noted that stylolites are younger than veinlets and cut across them.

In general, the Annville Formation consists of groundmass calcite with a few scattered stylolites and disseminated clay bands and some lenses and thin layers of recrystallized calcite. No systematic variation in the Annville was noted except very near the two contacts. The first few feet away from the Ontelaunee Formation is characterized by layers and lenses of darker limestone in the normal light-gray rock. The lenticular character of the darker portions is probably a result of plastic deformation - slippage or flowage of the more plastic limestone along the contact with more brittle dolomite and with the lenses representing interfingers of dolomitic limestone at the contact that were rolled during deformation. Approaching the Myerstown contact, the last 5 to 10 feet of Annville Formation is marked by an increase in clayey or carbonaceous material imparting a darker hue to the rock and causing a semi-fissile parting.



EXPLANATION

- CONTACT
- DIP AND STRIKE SHOWING LINEATION
- FAULT
- QUARRY OUTLINE
- A- A STRUCTURE SECTION
- DDH SHOWING INCLINATION
- MYERSTOWN FM.
- ANNVILLE FM.
- ONTELAUNEE FM.

GEOLOGIC MAP OF THE ANNVILLE FORMATION MILLARD QUARRY ANNVILLE, PA.

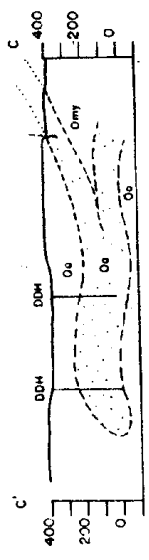
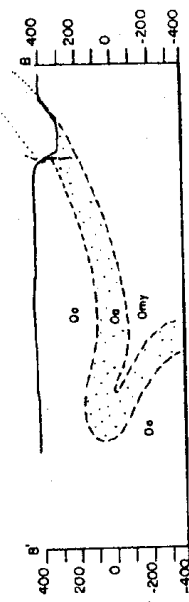
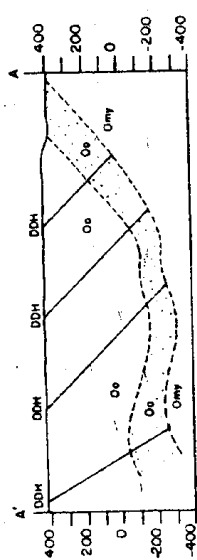
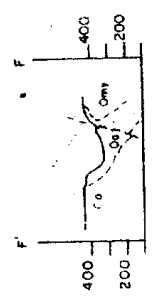
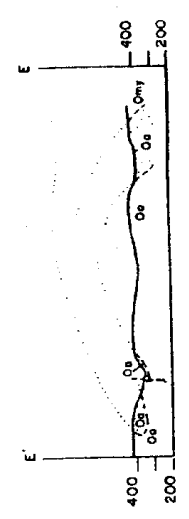
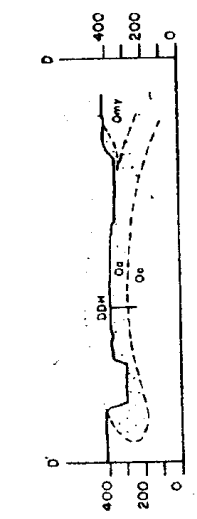


Figure 20 - Geologic map and structure sections of the eastern part of the Millard Quarry.

The average analyses of all drill cores of the Annville Formation are:

<u>SiO₂</u>	<u>R₂O₃</u>	<u>CaCO₃</u>	<u>MgCO₃</u>	<u>S</u>
0.81	0.68	96.6	1.6	0.022

Ontelaunee Formation

The uppermost Beekmantown Group dolomite is the Ontelaunee Formation, reported to be about 800 feet thick by MacLachlan (1967, p. 33) near the Palmyra Quarry. Therefore, all the holes drilled at Annville and Palmyra would have penetrated only Ontelaunee dolomite. The Ontelaunee is important at Millard because it is the hanging wall and must be stripped for open pit operations and will be the roof rock for any future underground operations. It is also sold as a commercial stone.

The Ontelaunee Formation is a dense, gray to dark-gray (locally black), finely crystalline dolomite with scattered layers and lenses of light gray limestone which resemble the Annville Limestone. A distinctive fetid odor is noted on freshly broken surfaces. Faint layering is visible on drill core surfaces and in places resembles graded micro-bedding. Characteristic of the Ontelaunee are well-developed stylolites with concentrations of carbonaceous material or graphite. The stylolites are younger than the other features and cut across them. The dolomite is brittle, deforming by fracturing rather than flowage. On smooth core surfaces a mottled texture is apparent, probably the result of brecciation during deformation. Limestone layers in dolomite are typically 2 feet or less thick and show an intense plastic deformation. Dolomitic limestone and calcareous dolomite are noted in places as distinct layers. Wherever limestone is present, the degree of deformation is markedly increased.

Dolomite is cut by many fractures, some of which are filled with white crystalline calcite and typically lined with minor quartz. Joints and stylolite partings combined impart a blocky fracture pattern to the dolomite.

The average chemical analyses of all dolomite samples from the drill core show the following compositions:

<u>SiO₂</u>	<u>R₂O₃</u>	<u>CaCO₃</u>	<u>MgCO₃</u>	<u>S</u>
2.39	1.40	60.6	34.7	.078

Structure

The type of geologic structure at the Millard Quarry is best illustrated by a sketch of a hypothetical cross section from Gray (1952, p. 6) showing the relationship of the beds exposed in the quarry to the regional structure (Figure 19). The Annville Formation exposed in the Millard Quarry is shown on the overturned north limit of a complex anticlinorium. Because the outcrop pattern of the Annville Limestone is regular over a long distance with no major strike changes, Gray (1952, p. 6) concluded that there was no regional plunge to the anticlinorium. Locally the outcrop pattern is complicated by smaller folds as at Millardsville, the Calcite Company quarries near Myerstown, and at the Annville South area (Gray, 1952, Pl. 1). Drilling at Millard has helped define the structure more closely and it can be shown that, at least at the Millard Quarry, the folding plunges about 6° to the west.

The main structural feature at Millard is the complicated fold exposed in the Annville South area (Figure 20). With the exception of scattered faults and minor folds, the main part of the Annville Formation at Millard can be considered as an overturned homoclinal bed dipping between 40° and 50° and striking about N 75° E, with an average thickness of about 200 feet but which pinches and swells both along the strike and the dip.

The fold exposed at Annville South is interpreted as a recumbent isoclinal flowage fold that is folded about an axis that plunges S 72° W at about 6°, nearly parallel to the trend of the Annville Formation. Towards the west, the fold is interpreted as becoming less and less recumbent until at the Lab Road (Figure 20, Section AA') it is a gentle, nearly symmetrical, fold. This is a different interpretation than that given by Gray (1952). He likewise interprets the Annville South area as the nose of a recumbent fold which plunges westward towards Annville South from the east, but which then reverses plunge and rises towards the west. That is, the crest of the recumbent fold is synclinal about a general north-south axis and only the trough of the syncline intercepts the ground surface at Annville South. The drilling, however, showed that the recumbent fold crest is not synclinal but plunges continuously westward.

The importance of the above structural interpretation is evident when it is considered that the prime area for future underground mining is between the Lab Road and the Office Road. The interpretation of a plunging fold beneath this area would not only result in more stone, but in shallower depths than would the interpretation of the fold rising above this area. It will, of course, require more drilling to accurately locate the fold.

The Annville Formation has been plastically deformed so that bedding planes within the formation are for the most part hard to see. On weathered surfaces bedding planes defined by clayey layers weather more rapidly resulting in a fluted appearance. However, stylolites and foliation planes may also produce the same appearance, so it is not easy to determine true bedding. On fresh surfaces minute differences in color define bedding. Foliation, which is defined by layers of more coarsely recryst-

tallized calcite which weather out more rapidly than fine-grained calcite, is mainly parallel to bedding but locally is divergent. Lineations are defined by fine crenulations on bedding or foliation planes but are not too common in the Annville Formation at Millard Quarry. The few measurements made show a general southwest trend and are not apparently related to the isoclinal folding. The lineations may be smear lineations and represent direction of transport during deformation as reported by MacLachlan (1967, p. 92).

Small-scale flowage folds are evident in many locations in the quarry and are defined by the clayey layers in the limestone. In one location a foliation impressed at a lower angle to original bedding was observed where weathering has produced layers of different relief which define both the foliation and the beds. The foliation is probably axial plane and formed in response to deformation at the time of folding.

The difference in competency or response to deformation between Annville and Beekmantown rocks is well illustrated by the faults which offset the hanging wall of the quarry but which die out as they cross the Annville and grade to folds at the footwall, or in places, die out with no effect on the footwall. Joints are more prevalent and regular in the dolomite than in the limestone where joints are less well defined.

The hanging wall faults have a general northerly strike, dip steeply either east or west, and typically have normal movement with offsets up to 50 feet, but in most cases less. Some hanging wall faults, however, show strike-slip movement while others show oblique-slip movement.

In the eastern part of the area are several faults which strike parallel to nearly parallel with the strike of the Annville Formation, but which cut across the dip. These faults tend to be located near the

contacts between either hanging or footwall rocks and are probably associated with the folding, most likely where rate of failure plastically was not enough to keep up with rate of deformation. A strike fault forms the northern edge of the Annville East Quarry.

Production

The annual production at Millard Quarry is about 1,200,000 tons of limestone and 250,000 tons of commercial stone (Ontelaunee Formation dolomite). Four kilns produce about 220,000 tons of lime per year; this production will increase as soon as an additional kiln, now under construction, is completed. The following products are produced by the Millard Quarry:

- Lime
- Hydrated Lime
- Metallurgical Limestone
- Sinter Flux
- Limestone Sand
- Limestone Screenings
- Pulverized Limestone
- Agricultural Limestone
- Commercial Stone

Reserves of high-calcium limestone from open pit operations are sufficient for over 20 years more production. In addition, reserves of limestone exploitable by underground mining are large enough to insure a source of lime and limestone for a very long time.

Mileage

- 73.3 Return to Bethlehem Steel Corporation, Millard Stone Division Office parking lot and proceed to turn LEFT (east) onto U. S. Rt. 422 and continue eastward.
- 73.8 Fiala, Inc., quarry north of U. S. Rt. 422 Annville, Pa. Turn RIGHT (south) onto Pa. Rt. 934.
- 78.0 Turn LEFT (east) onto U. S. Rt. 322.
- 80.0 Pa. Rt. 72 enters from the north and continues eastward with U. S. Rt. 322. KEEP IN LEFT LANE to continue on Pa. Rt. 72.

- 81.5 U. S. Rt. 322 bears off to right. CONTINUE on Pa. Rt. 72.
- 83.4 PENNSYLVANIA TURNPIKE entrance.
- 89.0 Manheim, Pa.
- 92.3 Binkley & Ober, Inc. quarry on right (west) side of highway.
- 95.0 Intersection of U. S. Rt. 230.
- 95.6 Turn RIGHT (west) onto U. S. Rt. 30 bypass.
- 99.1 Turn RIGHT off U. S. Rt. 30 bypass onto Centerville Road exit.
- 99.7 In Centerville, Pa., turn LEFT (west) onto Pa. Rt. 23.
- 102.8 Turn RIGHT (north) onto Prospect Road. Farmdale School building located in northwest quadrant (POINT "B" see Figure 8).
- 104.5 Turn RIGHT (east) onto Quarry Road.
- 104.7 STOPE #4
ESHLEMAN'S Quarry.
7½' Topo.: Columbia East.

ESHELMAN'S QUARRY
LANDISVILLE, PENNSYLVANIA

D. U. Wise and J. Freedman
Franklin and Marshall College

J. R. Henderson
McMaster University

The Basic Problem

Eshelman's Quarry (Figure 21) is located in a zone of anomalous warping of cleavages (Figure 22) which defines an abrupt southwestern edge to a large region of nappe structures in northern Lancaster County and in the Great Valley (including Annville Quarry area). The problem to be considered here is the mechanism(s) by which a major nappe region terminates along strike. Fold axes here are neither parallel nor perpen-

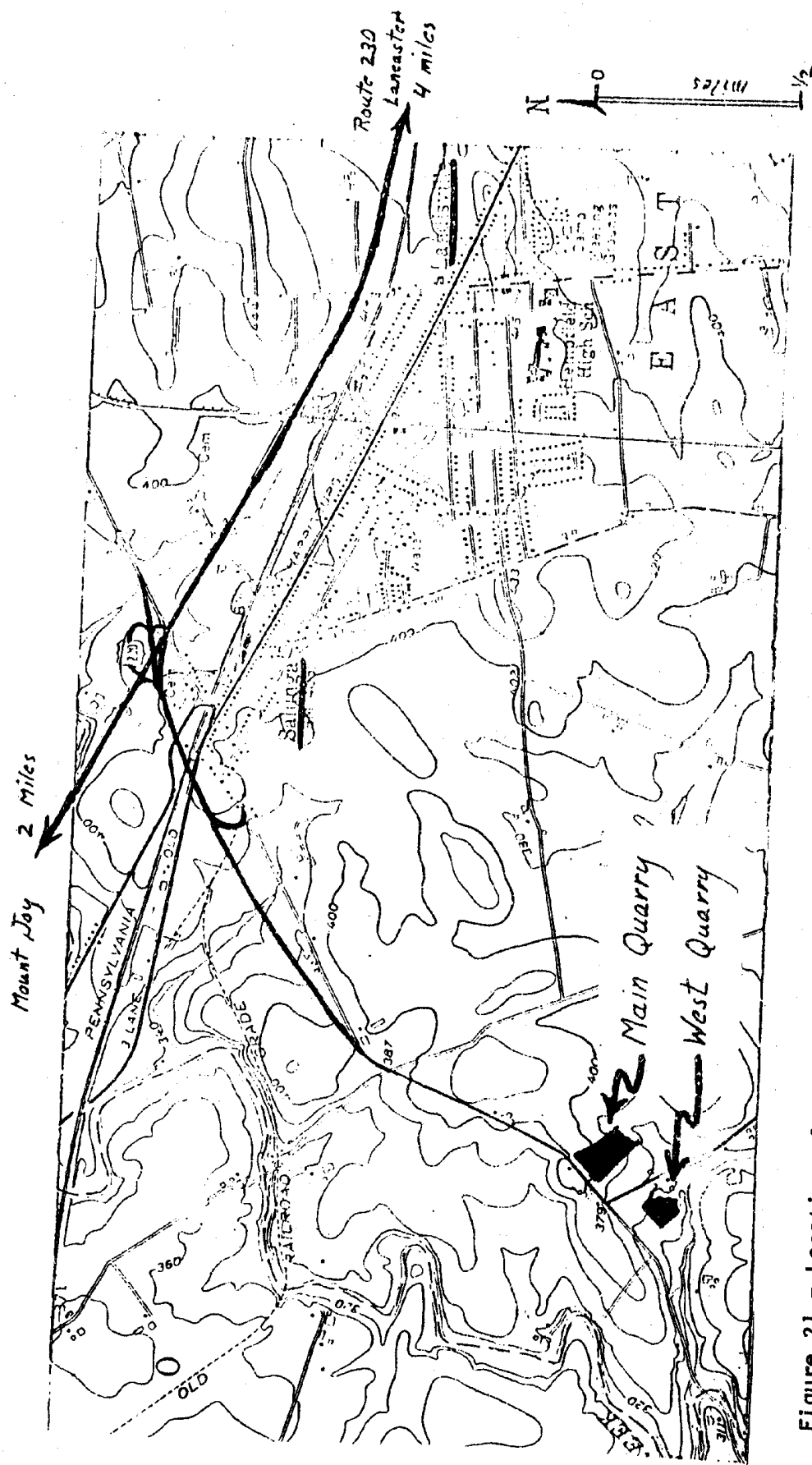


Figure 21. - Location of Eshelman's Quarry, 5 miles west of Lancaster. Permission to enter should be obtained at quarry office or by phoning 215-898-2277.

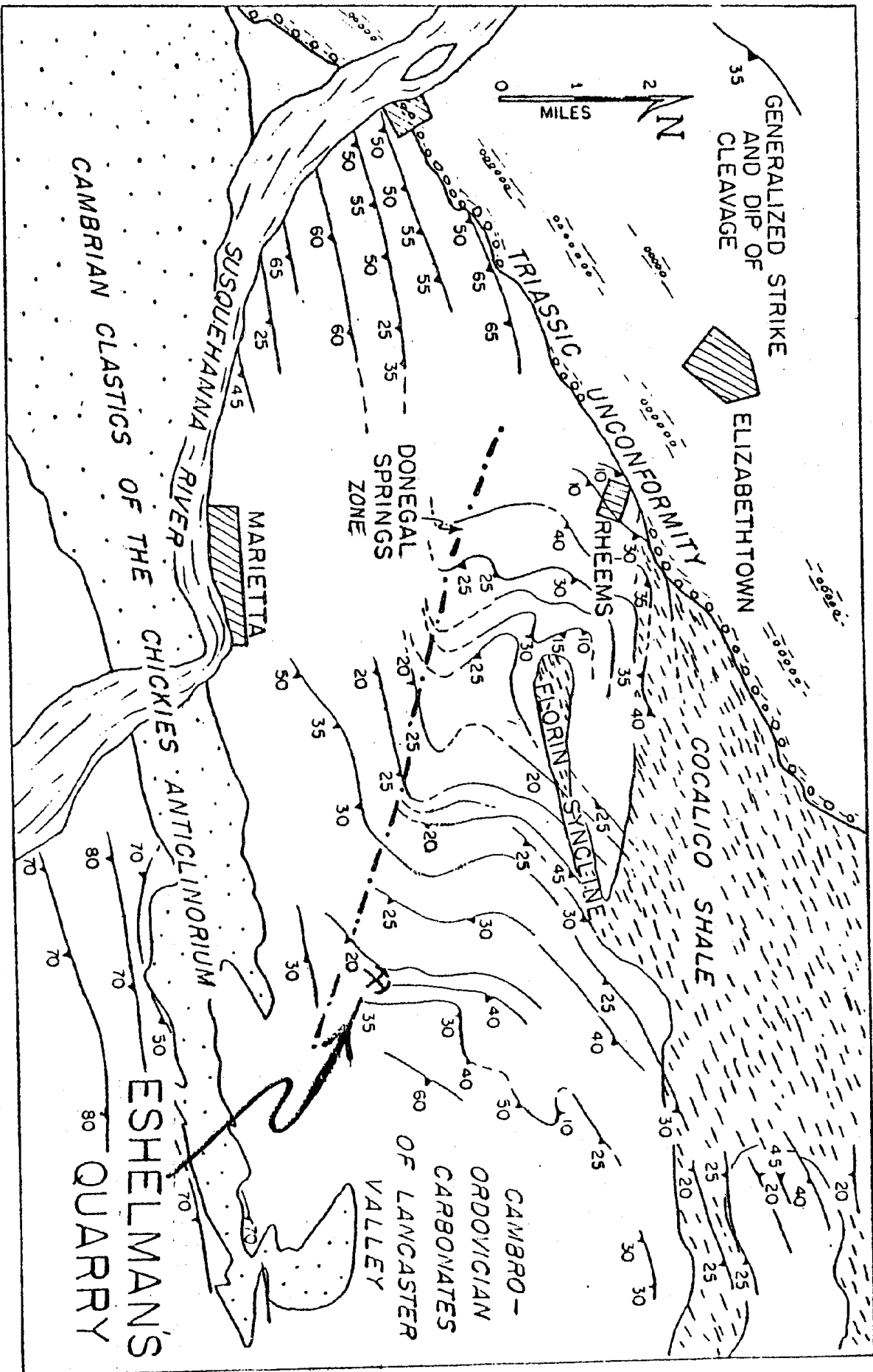


Figure 22 - Disruption of flow cleavage along the Donegal Springs zone which bounds nappe structures to the northeast against non-nappe folds to the southwest (from Skerlec and Wise, 1968).

dicular to tectonic "a" and may pose some problems for some schemes of tectonic terminology.

The Donegal Springs Disturbed Zone

The Donegal Springs disturbed zone (Figure 22) is a 2 mile wide west-northwest trending area of strongly curved cleavages and axial planes (Skerlec and Wise, 1968). It marks an abrupt southern termination of the nappe and recumbent flowage domain of northern Lancaster County. Recumbent structures of the type exposed at Rheems Quarry (Figure 22, and Wise, 1960 Guidebook) are common north of the zone whereas open folds with steeply dipping axial planes and little or no overturning are common south of the zone.

The entire region, including the zone and the areas on either side, records a pervasive parallel tectonic transport of N30-40W as indicated by stretched ooids, amygdules, bedding and cleavage plane slickensides and smears (Figure 23). Fold axes in the nappes and en echelon folds in the Chickies anticlinorium are all roughly perpendicular to this regional transport direction. The Donegal Springs disturbed zone strikes at about 45° to the regional transport direction and at about 30° to the Chickies anticlinorium (Figure 22). In other words, its strike relationship to other structures is not obvious. However, to the east-southeast it projects into a strange hook of the Cambrian clastics on the edge of the Chickies structure, sometimes interpreted as a thrust sheet. To the west-northwest it disappears beneath the Triassic unconformity. If projected beyond the Triassic, it would intersect the end of the South Mountain uplift at a location where Cloos's (1947) oolite elongation directions seem to show a break in pattern.

Within the zone, fold axes are quite discontinuous. Mapping by

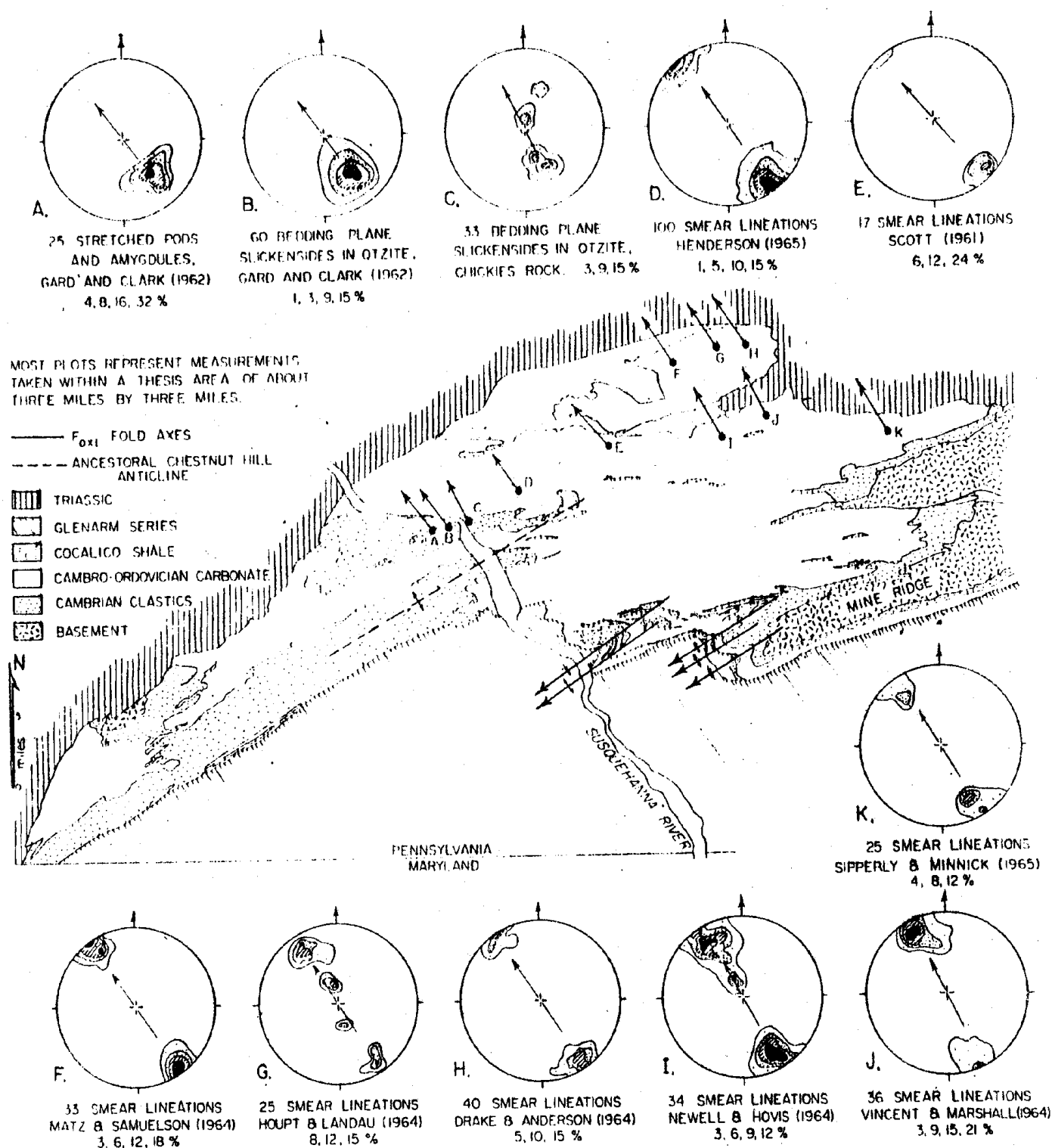


Figure 23 - Tectonic transport directions in the nappe and adjacent structures south of the Triassic as indicated by stretched ooids, smear lineations, etc. Location D includes Eshelman's Quarry.

Henderson (1965) (Figures 24 and 25) and by Grauch and Robelen (1966) shows a pattern of fold axial traces as derived from lithology bearing little relationship to the flow cleavage planes sweeping across them in broad arcs. This is nicely illustrated in Henderson's block diagram (Figure 25). The diagram also includes general trends of fold axes which curve around to parallel the direction of tectonic transport in the formational boundaries forming the Eshelman's Quarry re-entrant (Figure 24).

The Eshelman's Quarry re-entrant (Figure 24) is interpreted by Henderson on the basis of plunge of fold axes and local bedding cleavage relations as fundamentally an area of overturned Millbach units arched into an antiform (Figure 25) with its axis parallel to tectonic transport but curving around northwest to become more nearly parallel with the Donegal Springs disturbed zone. (The quarry itself is right-side up, just at the south edge of the overturned region.)

Cleavages are not simply arched across the antiform of the Eshelman's Quarry re-entrant but instead (Figure 24) strike subparallel with it and dip at moderate angles to the northeast. The cleavage pattern indeed sweeps around to south dips similar to the rest of the zone, but this sweep occurs approximately a mile southwest of the re-entrant defined by the formational contacts (Figure 24). The sweep is in effect, an antiform in the southeastward dipping cleavage, an antiform which can be traced along the Donegal Springs zone (Figure 22) and can be projected southeast to a similar curve in the boundary of the Cambrian clastics. At the northeast edge of Figure 24, the cleavages begin to sweep into a synform which also can be traced for some distance parallel to the zone (Figure 22) and can be projected into the end of the Cambrian clastics.

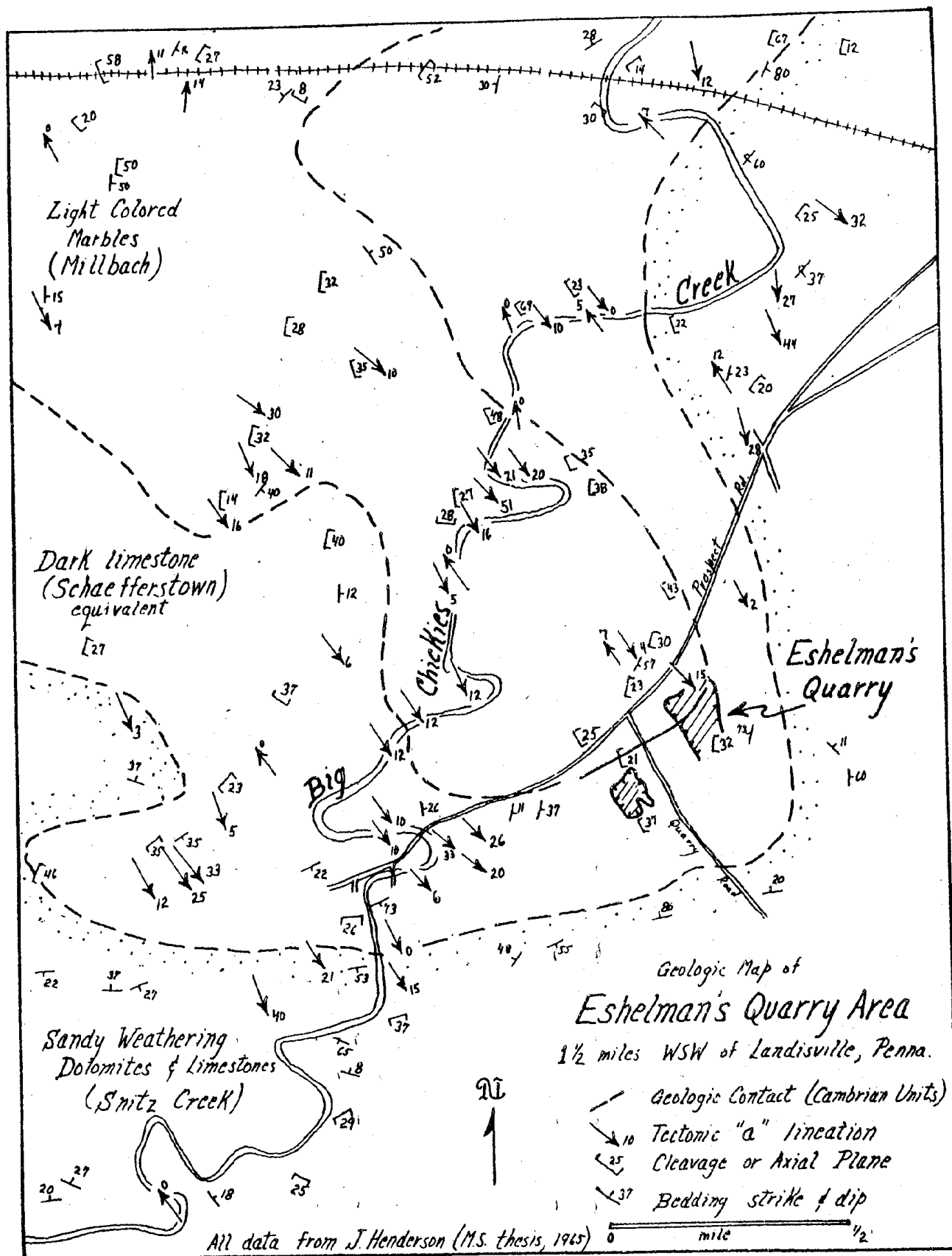


Figure 24 - Geologic map of Eshelman's Quarry re-entrant. Note that formational contacts curve around much more sharply than the flow cleavage.

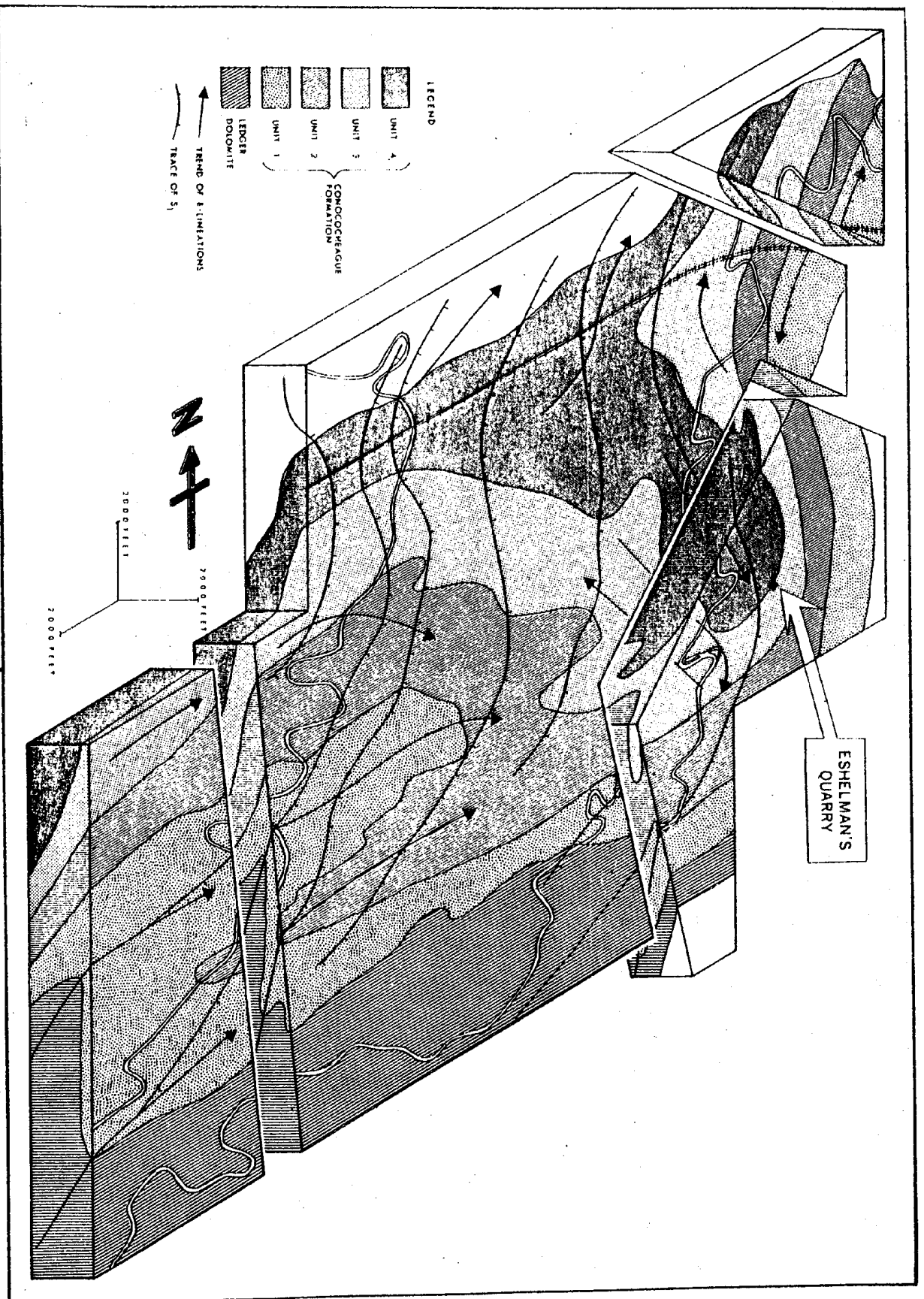


Figure 25 - Block diagram of the Eshelman's Quarry-Big Chickies Creek area. Note that the cleavage (S) traces curve around in relative independence of axial traces of the folds. (Diagram by J. Henderson, 1965).

The Quarry Geology

The geologic exposures (as of 1968) in Eshelman's Quarry are illustrated in Figure 26. The inactive west quarry is water filled but still offers views of rather spectacular cascades of recumbent folds piled one on another. The active east quarry has many local folds but is essentially right-side up and north dipping.

Lithologically the quarry is in a unit composed largely of dark limestones. Sandy weathering dolomites of the Cambrian Snitz Creek - Buffalo Springs Formation lie just to the south and light marbles of the Millbach Formation just to the north. The quarry could be regarded as being located in a southern equivalent of the Schaefferstown Formation as done in this article or it could be included with the Snitz Creek - Buffalo Springs unit as mapped by Meisler and Becher (1968).

Structure of the quarry is quite deceptive. The two main walls obliquely intersect analogous north limbs of two different anticlines separated by a broad syncline which is visible in the north wall. The result is that the east and west walls look similar in fold pattern and seem to permit units (especially the olive ones of Figure 26) to be matched across from wall to wall in simple fashion. The clue that something is wrong with this interpretation is that the simple matching would necessitate fold axes striking N60E but all the measured axes and strike and dips indicate a fold system striking N10-20E. Construction of a section at right angles to the strike (Top, Figure 26) eliminates the illusion created by apparent dips in the oblique quarry walls.

The gross strike of units is about N60E parallel with the north wall and quite different from the strike of the slightly plunging fold axes. These relationships between gross strike of units versus strike of axial

planes and fold axes are more readily understandable when the quarry detail is examined in light of the re-entrant geometry of Figure 24,

The problem is further complicated by the direction of transport being at acute angles to the fold axes and roughly parallel with the north-northwest quarry elongation. The smearings on bedding and cleavage can be seen on the stripped surfaces at the top of the north and northeast walls and in magnificent outcrops in the pasture behind (north of) the restored schoolhouse across the road from the north face.

Considerable strike-slip faulting is evident along the quarry walls, many of which are developed along the faults. Much of the faulting is subparallel to the transport direction but the brittle behavior must largely if not totally postdate the flow-fold period. Locally fault breccias and some fluorite occur along the faults and associated fissures. Movement senses indicated by slickensides (Figure 24) do not give any apparent preference for right or left lateral displacement. The faults, all of relatively minor displacement, may help explain some of the problem of anomalous gross strike in the quarry but seem to be of too late an age and too local development to explain the general pattern of irregular fold geometry of the re-entrant itself.

In the water-filled west quarry even more spectacular piling of nearly recumbent fold on fold is visible. The fold axes trend northeasterly and axial planes dip east as in the east quarry.

Points of Interest - Eshelman's Quarry (Locations on Figure 26)

1. Match olive units across east quarry to get N60E general strike. Contrast with north-northeast trend of fold axes. Fit in with broad syncline in north wall and general geometry of the re-entrant of Figure 24.

2. Possible collection of samples of small hand specimen folds and of fluorite or slickenside specimens.
3. Examine extent of late-stage strike-slip faults. Examine breccia.
4. Examine excellent smear lineations on bedding and cleavage top of north wall and behind schoolhouse across the street.
5. Examine spectacular folding in walls of water-filled west quarry. (Go down ramp to do this.)
6. Extra -- Abandoned quarry half a mile to southwest along Prospect Road at Big Chickies Creek is a real hash with lots of calcite and irregular structures. Also railroad cut at Salunga (dangerous) near the Route 230 cloverleaf (1 mile NNE) shows many sedimentary structures and the transition from right-side up to overturned beds.

Tectonic Interpretation

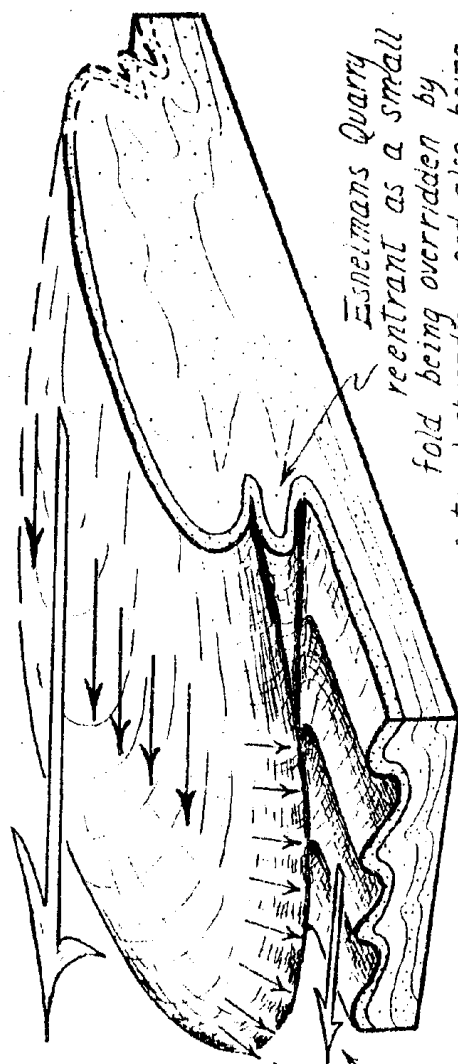
The Eshelman's Quarry re-entrant and the Donegal Springs disturbed zone are interpreted (Figure 27) as edge effects of a greatly thickened nappe region located to the east and north. Parallel northwestward transport was taking place throughout the area but was much more extensive in the thickened region. Reasons for this localized extra movement and thickening might include:

- A. Nappe movement through a structural low between the end of Chickies Ridge and the Welsh Mountains.
- B. Nappes and thrusts overriding the depositional edge of the Cocalico (Martinsburg) Shale and hence providing lubrication for greater movement on the region with shale at depth.

Main Direction of
Nappe Flow
(N 30-40 W)

Sideward
spreading

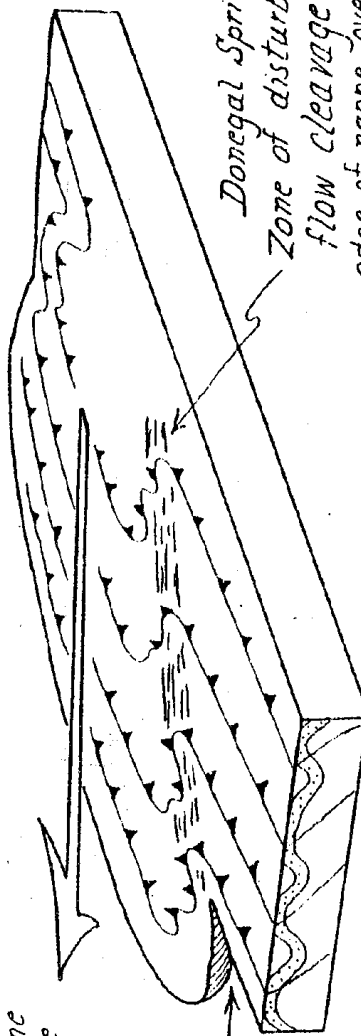
Parallel
transport
adjacent to
main nappe



Esnelmans Quarry
reentrant as a small
fold being overridden by
lateral spreading and also being
smeared forward along with the
transport of the main nappe.

Flow cleavage pushed
forward in zone
of main nappe
transport

Florian syncline in
under-limb
of nappe



Donegal Springs
Zone of disturbed
flow cleavage at
edge of nappe over flow

D. W. H. - 1906

Figure 27 - Interpretation of the origin of the Donegal Springs disturbed zone and Esnelman's Quarry re-entrant in terms of nappe transport and distortion of flow cleavage patterns.

C. Patterns of differential subsidence to the northwest and/or differential uplift to the southeast.

D. Thinner original stratigraphic column over the region of lesser movement.

Whatever the underlying reasons, the greater load and forward (N30W) movement of the nappe region pushed the flow cleavage forward and depressed it to create the pattern of Figure 22. Upwellings along the edges of the advancing nappe mass which created local antiforms like the Eshelman quarry re-entrant streamed out parallel to the direction of transport (Figure 27). Gravitational spreading and shifting of the mass laterally created changed loads forcing new flow patterns on early stage folds. The result was the observed semi-independence of flow cleavage and axial traces in the disturbed zone. Fold axes were twisted around by local differential movement to bear little relationship to being parallel to either tectonic "a" or "b". Henderson (in press) discusses sawed rock slabs which strongly indicate this passive rotation of the fold axes by differential forward advance parallel to oolites in the same flow plane. Fold axes trending into the Donegal Springs disturbed zone (such as the Florin syncline of Figure 22) were strongly warped, forced to plunge out, or else were never developed because the infolding of tight synclines ceases along the zone. This is suggested in the bottom of Figure 27. The early or older Chickies thrust fault (Figure 22) was warped around into a pattern mimicking the curving cleavage planes by the differential depression and forward movement.

This study of the mechanics of termination of Lancaster County nappe structures is still in progress. Similar zones of sharp disturbance of flow cleavage extend to the east from East Petersburg through Brownstown.

These are approximately at the southern edge of nappe overturning but unlike the Donegal Springs zones they are marked by steeply dipping secondary cleavages associated with the disruption of the main flow cleavage.

Mileage

- 106.6 Retrace route to POINT "B" and continue west on Pa. Rt. 23.
- 110.7 Turn RIGHT (northwest) onto Pa. Rt. 441 and 743.
- 112.4 Pa. Rt. 743 turn RIGHT (north) continue west on Pa. Rt. 441.
- 118.8 Junction Pa. Rt. 241.
- 125.5 Royalton, Pa.
- 126.2 Turn RIGHT (north) onto Union St., Middletown, Pa. Continue on Pa. Rt. 441. Note: Underpass is 11' 6" high and north side slope out of underpass is steeper than south slope.
- 126.7 Turn LEFT (west) onto U. S. Rt. 230.
- 130.2 Turn RIGHT (north) onto Pa. Rt. 283.
- 130.6 PENNSYLVANIA TURNPIKE entrance.
- 132.3 Intersection of Pa. Rt. 441.
- 133.4 Intersection of Pa. Rt. 283, U. S. Rt. 322, and Interstate 83. APPROACH intersection in LEFT HAND LANE.
- 133.4 Turn LEFT (west) onto Interstate 83.
- 136.4 Bear RIGHT (north) Exit 23 (Second St.)
- 137.5 Turn RIGHT (east) onto Pine Street.
- 137.6 Turn RIGHT (south) onto North Third St.
- 137.7 HARRISBURGER HOTEL.

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