

Harrisburg Area Geological Society
13th Annual Field Trip
Saturday, April 23, 1994

GEOLOGY OF THE LEBANON VALLEY and
THE WESTERN END of the
READING PRONG

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GUIDEBOOK

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INTRODUCTION

This field trip will take us west to east down the Lebanon Valley, a portion of the Great Valley of the Appalachians, to the western end of the Reading Prong, a possibly allochthonous massif of Precambrian gneisses overlain by the basal Cambrian Hardyston Quartzite.

We begin in the Borough of Palmyra, which has, for many years, been plagued by sinkholes. Bill Kochanov will show us some examples of locations where these karstic features have recurred, right up to recent months (STOP 1, in three parts).

From Palmyra, we will proceed to Cornwall Borough by way of the City of Lebanon, making a brief side excursion to see the Union Canal tunnel, a preserved remnant of the once extensive network of canals in Pennsylvania (STOP 2). Bill Jordan will conjure up visions of mules and canal boats for us here, as well as introducing us to the stratigraphy and structure of the Lebanon Valley sequence.

At Cornwall, we will tour the Cornwall Furnace museum and view the open pit and dump of what was at one time the largest iron mine in the United States (STOP 3). We also can see here how the intrusion of Mesozoic diabase into the carbonate rocks of the Lebanon Valley formed the magnetite ore. Gary Fleeger will be our geologic guide.

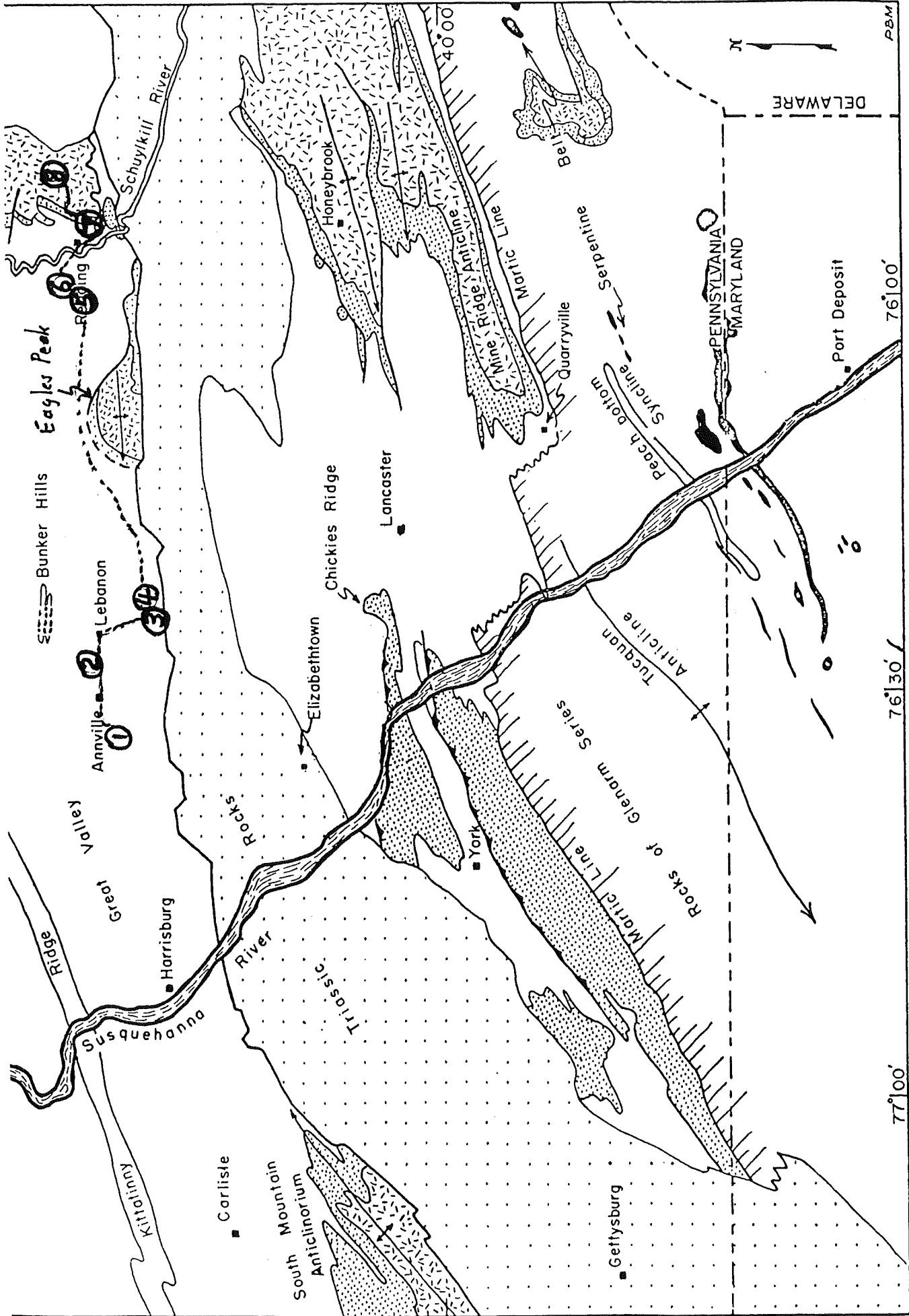
While we are at Cornwall, we will take the opportunity to see some fascinating examples of flexural-flow and passive folds in the Buffalo Springs Formation (STOP 4). Bill J. and Charlie Scharnberger will point out various features, but this will be a stop where everyone can get his or her "two-cents' worth" in.

From Cornwall, we continue eastward to Sinking Spring and lunch (buy your own, unless you packed it along), followed by a visit to the epicenter of the great Pennsylvania earthquake of '94 (STOP 5, in two parts). Charlie will let us in on what, or who, is at fault here.

Next, we will visit a location in Bern Township where a Triassic dike has intruded the Ontolaunee Formation, which is overlain by a slice of the Hamburg klippe (STOP 6). There will be a lot to see and talk about here.

Then we'll head for the summit of Mt. Penn, the Reading Pagoda, and an overview (if the weather cooperates) of five geologic terrains (STOP 7). We can also get a look at the Hardyston Quartzite here, and hear what Bill J. has to tell us about it.

Finally, we reach the basement of the Reading Prong at Antietam Lake, and can scratch our heads for a while at the complexity of the migmatites and gneisses exposed here (STOP 8).



0 5 10 Miles
 Modified from Stose & Stose, (1944)

ROAD LOG

Increment (miles)	Total	
0.0	0.0	Leave parking lot of Derrytown Mall, Route 743 south of U.S. 322, Hershey. Turn left.
0.3	0.3	Intersection with U.S. 322. Turn right.
0.6	0.9	Milton Hershey School.
2.2	3.1	Enter Cambelltown.
0.4	3.5	Palmyra Road. Turn left. (Street sign says "Lynmar Ave.")
0.3	3.8	Lingle Ave. Turn left just before the American Legion Post.
0.5	4.3	Road pavement badly broken up (as of 4/94). Is this damage karst-related?
0.5	4.8	Rockledge development on the left has had many problems with sinkholes.
0.6	5.4	Maple Ave. Turn right and park along the curb. Walk across Lingle Ave. to STOP 1 (Case #1). After viewing and discussing Case #1, continue east on Maple Ave.
0.7	6.1	Locust Ave. Turn left. Less than 0.1 miles to the north, turn right on Cherry St. Note the undulating character of Cherry St.
0.9	7.0	End of Cherry Street. Park and view Case #2. After finishing at Case #2 site, continue south on S. Duke St.
0.1	7.1	Maple Ave. Turn left.
0.4	7.5	Plaza Rd. Turn right.
0.1	7.6	301 Plaza Rd. Park along curb for Case #3. After finishing with Case #3, turn around and procede north on Plaza Rd.
0.2	7.8	U.S. 422. Turn right.

- 2.0 9.8 Main office of Wimpey Minerals on left. Wimpey owns and operates the quarries north of route 422. These quarries are long and narrow as they follow a narrow east-west outcrop belt of the Annville Limestone. A cross section of the nappe structure exposed in the Millard Quarry is shown on p. 29.
- 0.9 10.7 Cross Quittapahilla Creek. Enter Annville.
- 0.7 11.4 Bachman Rd. One-tenth mile to the south (right) is Quittie Park, which incorporates an abandoned quarry in the Epler Fm. Formerly, this quarry provided an excellent exposure of the complex nappe structures of the Lebanon Valley carbonates. Now, however, half of the high-wall exposure is covered by rubble and the other half is obscured by trees. Interesting structure can still be seen, especially during seasons when foliage is not present. At the time of this writing (4/94) the floor of the quarry was flooded to an extent that made access to the high wall difficult.
- 1.3 12.7 Entering Cleona.
- 1.7 14.4 25th Street. Turn left opposite Ebersole Honda.
- 0.8 15.2 Union Canal Park. Turn left and park in lot. STOP 2.
Turn right onto 25th St. and return to U. S. 422.
- 0.8 16.0 U. S. 422. Turn left.
- 0.8 16.8 Enter City of Lebanon.
- 0.5 17.3 Turn right in order to stay on U.S. 422.
- 0.2 17.5 Turn left to stay on U.S. 422.
- 0.2 17.7 PA Route 72. Turn right. Stay in left lane in order to take Cornwall Rd. ahead.
- 0.4 18.1 Continue straight onto Cornwall Rd. Do not follow Route 72 south.
- 2.3 20.4 Enter Cornwall Borough.
- 0.6 21.0 Bear left at intersection in order to stay on Cornwall Rd. Continue straight up the hill. Do not take Route 419 north.

- 0.8 21.8 Cornwall Furnace Museum. STOP 3. Turn left into parking lot. Admission fee for the museum is \$3.50 for adults, \$2.50 for seniors, and \$1.50 for children. Group rate is \$2.50. (Fee is included in the field trip registration.)
- After finishing at the museum, a 0.2 mi. drive south on the road east of the museum brings one to the open pit (right side) and the mine dump (left side). Another 0.2 mi. and one enters the Miners' Village. Road log resumes from the intersection near the entrance to the museum.
- Return on Cornwall Rd. in the direction from which you approached the museum.
- 0.7 22.5 PA Route 419 (Haeffer Ave.). Turn right.
- 0.6 23.1 Cherry Ave. Turn left.
- 0.1 23.2 Juniper Ave. Turn left.
- 0.1 23.3 STOP 4. Park in circle at the end of Juniper Ave. Walk a short distance to the abandoned RR grade and walk about 0.2 mi. north to exposures of the Buffalo Springs Fm.
- Return to Route 419 on Juniper and Cherry Aves.
- 0.2 23.5 PA Route 419. Turn left.
- 3.7 27.2 Buffalo Springs.
- 1.7 28.9 Route 419 joins Route 897. Enter Shaefferstown.
- 0.8 29.7 Turn left in order to stay on Route 419 north. High ground to the right of the road for the next several miles is underlain by the Martinsburg Fm., which seems to be in fault contact with the carbonates here because it rests directly on the Snitz Creek Fm.
- 3.0 32.7 Millbach Spring. To the right is Eagles Peak, a detached piece (klippe) of the Reading Prong. The scar on the side of the mountain is an abandoned Hardyston Quartzite quarry.
- 2.4 35.1 Enter Newmanstown.
- 2.2 37.3 Enter Womelsdorf.
- 0.2 37.5 W. High St. Turn right. Do not stay on 419.

- 0.7 38.2 U.S. 422. Turn right.
- 1.5 39.7 Enter Robesonia.
- 3.4 43.1 Wernersville. There is absolutely no truth to the rumor that the nickname of the High School's athletic teams is the "Neptunists."
- 3.0 46.1 Enter Sinking Spring. Be prepared to move into left lane in order to turn onto Mull Ave. ahead, if you are not stopping at one of the fine restuarants near the intersection of Mull and 422 for lunch. You have your choice of dining spots: Burger King or McDonald's.
- 1.0 47.1 Mull Ave. Turn left. (Or get onto Mull Ave. after leaving one of the restaurant parking lots.)
- 1.2 48.3 Snyder Rd. Turn right.
- 0.1 48.4 Bressler Dr. Turn left. Almost immediately, turn right on Burkey Dr. The vicinity of the intersection of Burkey Dr. and Evergreen Dr. was the area with the greatest density of damage reports following the January 15 earthquakes.
- 0.3 48.7 Valmont Ct. STOP 5a. Park along curb to see damage to pavement caused by the earthquake.
- Continue on Burkey Dr. Almost immediately, turn left on Gring Dr.
- 0.1 48.8 Clover Dr. Turn left. STOP 5b. Park to see another example of earthquake damage.
- Return to Gring Dr. and continue in same direction as before.
- 0.2 50.0 Broadcasting Rd. Turn left.
- 0.1 50.1 State Hill Rd. Turn left.
- 0.2 50.3 Patch across roadway shows location of earthquake damage to State Hill Rd.
- 0.2 50.5 Van Reed Rd. Turn right. State Hill Rd. is closed ahead because of a water main break apparently caused by a sinkhole, apparently caused by the earthquake. The Brenneman quarry can be seen to the left as one turns onto Van Reed Rd.

- 1.2 51.7 Enter the "Road to Nowhere."
- 0.5 52.2 Cross the Tulpehocken Creek.
- 0.8 53.0 Exit right at Route 183 south.
- 0.1 53.1 Top of exit ramp. Turn right and almost immediately, turn right again onto Van Reed Rd.
- 0.6 53.7 Must turn right; now on Blessing Lane.
- 0.1 53.8 Turn left in order to stay on Blessing Ln.
- 0.4 54.2 Just after sharp right turn in the road, pull into parking area on the left. STOP 6.
- Return the way you came to Route 183.
- 1.1 55.3 PA Route 183. Turn right.
- 1.2 56.5 Reading airport. Note Pagoda on the skyline of Mt. Penn ahead. Also, note quarry scar.
- 1.2 58.7 Enter City of Reading.
- 0.7 59.4 Cross Schuylkill River. Stay to right as you come off the bridge.
- 0.9 60.3 Route 183 (Schuylkill Ave.) curves left. After the curve, continue straight ahead onto Walnut St. Do not turn right to follow 183.
- 1.2 61.5 Thirteenth St. Cross 13th St., then almost immediately turn right onto Duryea Dr. (Follow red pagoda sign.) Climb Mr. Penn on Duryea Dr. switchbacks, following signs to the pagoda. In the early days of automobiling, this road was a favorite for races. The valley to your right is underlain by Lower Cambrian carbonates, probably the Buffalo Springs and Zook's Corner Fms., that are almost completely covered by colluvium. The hill across the valley is Neversink Mountain, another klippe of basement gneisses veneered by Hardyston Quartzite.
- 0.9 62.4 Turn left to complete climb to the pagoda.
- 0.2 62.6 Turn left around circle and park. STOP 7.
- Upon leaving the parking area, go counter-clockwise around the circle and procede northward on Skyline Drive.

- 0.8 63.4 Tower on right. The purpose and history of this structure is not known to the writer of these notes. It appears to be a water standpipe, but why would a standpipe be necessary when one is already at the highest point of elevation in the area?
- 0.9 64.3 List Rd. Turn right.
- 0.5 64.8 Angora Rd. Turn left.
- 2.1 66.9 Antietam Rd. Turn left and park on shoulder by the outcrop. STOP 8.

END OF FIELD TRIP.

To return to Hershey by the fastest route, turn around and go 2.2 miles south on Antietam Rd. (which becomes Carsonia Rd. and then 23rd St.) to Business Route U.S. 422. Turn LEFT (towards Pottsville) and go 2 miles to Neversink Rd. Turn right, following signs for U.S. 422 west. Take 422 back to Hershey.

ORDOVICIAN		CUMBERLAND VALLEY	LEBANON VALLEY	LEHIGH VALLEY	NORTHERN LANCASTER VALLEY	CENTRAL PENNSYLVANIA
Trentonian	Martinsburg Fm.*	"Martinsburg Fm.*"	Martinsburg Fm.	"cement rock"	Cocalico Fm.	Antes Sh.
	CHAMBERSBURG FM.	Hershey Fm.*	"cement rock"	"Cement ls."	? ? ? ? ?	Coburn Ls.
Black River	"Oranda" Fm.	Myerstown Fm.*	JACKSONBURG FM.	Ontelaunee	Myerstown Fm.	Salona Ls.
	Mercersburg Fm.	Annville Ls.*	BECKMANTOWN GP.	Epler Fm.	Hunter Ls.	Nealmont Ls.
Chazyan	Shippensburg Fm.	Ontelaunee Fm.*	Rickenbach Dol.	Rickenbach Dol.	Hatter Ls.	Hunter Ls.
	St. Paul Gp.*	Epler Fm.*	Stonehenge Ls.*	Allentown Fm. undivided	Loysburg Fm.	Hatter Ls.
Canadian	Pinesburg Station	Richland Fm.	BECKMANTOWN GP.	Leithsville Fm.	Annville Ls.	Loysburg Fm.
	Rockdale Run Fm.	Millbach Fm.	CONOCOCHAGUE GP.	Hardyston Qtzite	Ontelaunee Fm.	Bellefonte Dol.
Upper	Stonehenge Ls.	Schaefferstown Fm.	Leithsville Fm.	Gneisses	Epler Fm.	Axemann Ls.
	Staufferstown Fm.	Snitz Creek Fm.	Hardyston Qtzite	Gneisses	Stonehenge Ls.	Nittany Dol.
Middle	Shadygrove Fm.	Buffalo Springs Fm.*	Leithsville Fm.	Gneisses	Richland Fm.	Stonehenge Ls.
	Zullinger Fm.	concealed	Leithsville Fm.	Gneisses	Millbach Fm.	Larke Dol.
Lower	Big Springs Station	concealed	Leithsville Fm.	Gneisses	Snitz Creek Fm.	Mines Fm.
	Elbrook Fm.	Leithsville Fm.	Leithsville Fm.	Gneisses	Buffalo Springs Fm.	Gatesburg Fm.
Basement	Waynesboro Fm.	Hardyston Qtzite	Leithsville Fm.	Gneisses	Buffalo Springs Fm. or Elbrook Fm.	Warrior Fm.
	Tomstown Fm.	Hardyston Qtzite	Leithsville Fm.	Gneisses	? ? ? ? ?	Pleasant Hill Fm.
Basement	Antietam Ss.	Hardyston Qtzite	Leithsville Fm.	Gneisses	Leiger Dol.	Waynesboro Fm.
	Harpers Fm.	Hardyston Qtzite	Leithsville Fm.	Gneisses	Kintners Fm.	concealed
Basement	Weaverton Fm.	Hardyston Qtzite	Leithsville Fm.	Gneisses	Vintage Fm.	concealed
	Loudon Fm.	Hardyston Qtzite	Leithsville Fm.	Gneisses	Antietam Ss.	concealed
Basement	Volcanics	Hardyston Qtzite	Leithsville Fm.	Gneisses	Harpers Fm.	concealed
	Volcanics	Hardyston Qtzite	Leithsville Fm.	Gneisses	Chickies Fm.	concealed

Table 3.

* Designates formations outcropping in Dauphin County.

The Palmyra area has a long history of subsidence - related problems. During 1993 and early 1994 subsidence activity in the Palmyra area seemed to increase. Sinkholes became so common in the Borough of Palmyra that the residents began calling it "the sinkhole capital of Pennsylvania".

On today's trip we will examine three sites that are having subsidence problems. We will also examine one local outcrop.

General Geology

Most of the Borough of Palmyra is underlain by the Ordovician Epler Formation. The northerly part of town is underlain by the Ordovician Ontelaunee Formation (Attachment A).

The Epler is described by Geyer (1970) as being "...characterized by thick bedded, strongly laminated, finely crystalline limestone interbedded with medium to thick bedded, laminated, grayish-yellow weathering, crystalline dolomite...nodular chert is present and abundant..." The Ontelaunee Formation is described as "...a medium-dark-gray, very finely crystalline dolomite...dark-gray chert at the base is a conspicuous marker...weathers yellowish-gray with black shale partings between beds..."

The primary structural feature in the Lebanon Valley is a nappe system. Local structures are characterized by overturned bedding, folds that are approximately parallel to the regional strike (NE-SW), and joints that for the most part parallel strike and dip of bedding. No major faulting has been mapped in the Palmyra area (Geyer, 1970; Kochanov, 1988).

From a karst perspective, the Epler Formation is one of the top sinkhole producers in the eastern half of the Great Valley. Statistics compiled on the Epler show 676 sinkholes on record covering an area of 325 square kilometers (Kochanov, 1992). The distribution of sinkhole occurrences is skewed in urban areas. More sinkholes are reported when they occur in urban areas as opposed to those which may occur in the farmer's field. Factors which contribute to sinkhole formation, such as storm water drainage and failure of utility lines, are also more common to the urban setting. The actual number of sinkholes in the Epler could possibly be double the recorded number.

Karst Problems and Storm Water

The sinkhole occurrences we will examine in the Palmyra area can all be related to stormwater.

Where does the storm water go after a heavy rain? In the hydrologic cycle, water that has fallen as precipitation can move over the land surface, infiltrate through the soil, be taken up by vegetation, or evaporate. In urban areas, this water can run off roofs, down storm gutters, along streets, over parking lots, enter the ground by percolating through the soil or it can be directed towards a natural or artificial drainageway.

In a karst area, the natural plumbing system of drains and pipes lies beneath a relatively thin veneer of unconsolidated sediment. It is a dynamic give-and-take coexistence between the sediment, water, and the bedrock. In karst areas the subsurface drains serve as entryways for percolating water so that it can migrate through the fractures in the bedrock (the pipes) to the water table.

Often the karst drains are clogged with soil. But just like the clogged bathtub drain, water will still drain away but at a much slower rate. Over time the action of percolating water can flush open the karst drains. If the flushing mechanism results in a hole that breaches the land surface, then the feature is called a **sinkhole**. If the flushing mechanism causes the land surface to **sap** over time with **no** breach, then it results in a feature called a **surface depression**.

The storm-water-drainage problem is compounded in karst areas by the fact that development reduces the surface area available for rainwater to infiltrate naturally into the ground. A typical residential development with quarter-acre lots may reduce the natural ground surface by 25 percent whereas a shopping center may reduce it by 100 percent. If storm water, gathered over a specific area, is collected and directed into a karst area, the concentration of water may unplug existing karst drains.

In Palmyra, the main problem is where to send storm water runoff. If one drives along the streets of Palmyra you would note the lack of storm-water drains. For the most part, storm water is directed to areas outside of the Borough. The discharge points for the storm water often coincide with historically active sinkhole locations.

Another practice that was engaged in by the Borough was the installation of storm-water drains into existing sinkholes. The sinkholes are natural drains to begin with so it may appear logical to use them as storm-water drains. Unfortunately many of these types of drains have failed. The storm water that is directed into these drains often overwhelms the drains capacity causing backup and localized flooding. Nearby karst drains are often affected by this concentration of water with sinkholes resulting. The sinkhole problems at the east end of Palmyra on Cherry Street are

typical of this type of storm-water management.

Case #1

In April of 1992, reports of sinkholes were coming from residents of the 100 block of S. Lingle Avenue. Eight sinkholes have been recorded since the initial investigation.

The culprit appears to be a storm-water drainage pipe that runs beneath Lingle Ave. Storm water is collected by storm drains and transferred to the drain pipe. Storm water is then discharged to a drainageway where it is supposed to flow to a nearby intermittent stream. Over time the drainageway filled up with sediment and the pathway to the stream was cut off. At some point storm water flushed open existing karst drains and a number of sinkholes opened. The main sinkhole is located at the end of the drainageway. Other nearby sinkholes all appear to have some connection to this main sinkhole. Sinkholes encroached onto the property at 109 S. Lingle in several places, most notably in the carport adjacent to the house. The house was being put up for sale at the time of the sinkhole occurrences. Needless to say the property value decreased significantly, roughly \$20-30,000.

The call came to the Borough for assistance. The Borough replied that the sinkholes exist on land not owned by anyone. The last owner of the drainageway died in 1930. There were no heirs so the estate is closed with no other record of ownership. Since no one owns the drainageway strip, no one will repair the sinkholes for fear of assuming liability for damages to the 109 property. The property owner carried no sinkhole insurance.

Case #2

The Cherry Street section has had sinkhole problems dating back to the mid 1960's. Sinkholes have most notably affected the properties at 914 Cherry Street and 34 S. Duke Street.

At the 914 property, the final blow came in 1988 when eight sinkholes opened in roughly a 60 feet in diameter area. The house had severe structural damage with one of the sinkholes, about 15 feet in diameter, located in the basement of the house. The final solution was to move the house and garage away from the storm-water drain to the south by about 100 feet. The estimated cost to move the house was approximately \$20,000. The property was not covered by sinkhole insurance.

At the S. Duke Street property, which is across the street from the sinkhole storm drain, sinkholes opened in August of 1993 after a period of heavy rain. The main sinkhole was at the end of their driveway. The Borough

repaired the sinkhole and it re-opened about a month later. This time however, the Borough needed to gain access to the Duke Street property in order to make repairs. In Palmyra, the Borough is responsible for damages from curb to curb. Anything on private property is the property owners responsibility. So the property owners, in this case, would be responsible for paying for whatever damages outside the curb area (ie. sidewalk, driveway) the Borough caused in the repair of the sinkhole. This resulted in the property owner not allowing access to the Borough to repair the sinkhole. Such conflicts between private property owners and municipalities are common.

Case #3

The last case involves a partial solution to the storm-water problem in Palmyra. To help alleviate the problem, a storm-water drainage basin was constructed at the edge of town. The storm water would enter the basin, contain it and let it discharge slowly out drain pipes at one end of the facility.

The discharge area is a natural drainageway and has historically been an area of sinkhole occurrences. Sinkholes developed on the property at 301 Plaza Drive during spring of 1993. The sinkholes opened in the back yard, beneath the swimming pool, probably beneath the house, and in the front yard. Sinkholes also opened over the next few months on adjacent properties. The house on 301 Plaza Drive was condemned. Repairs were never initiated. The family living there had no sinkhole insurance.

Local residents have organized (CAUSE - Citizens Against Unfair Storm-water Erosion) and are filing suit against the Borough who they feel has compounded the sinkhole problems in the area by building the drainage basin.

Discussion

When discussing sinkholes the key ingredient is water. Aside from the rare case where the roof of a cave collapses causing a sinkhole, the majority of sinkholes in Pennsylvania are the result of the piping of sediment into karst drains by moving water over a period of time.

The cost of sinkhole repairs in Palmyra is staggering. A statistical summary for eight sinkholes from October 1991 to October 1993 for the Borough of Palmyra show an estimated total repair cost of \$871,000 (RETTEW Associates, Inc., 1993). It is interesting to note that six out of the eight sinkholes had previous repair records going back to the mid-1960's (Attachment B).

Solutions

In Palmyra, the major focus of the problem is on storm-water management. In October of 1993 the Borough of Palmyra held a meeting to discuss the sinkhole and stormwater issue. Those in attendance represented local, county, state and federal government agencies. The problems were defined and long-term solutions discussed.

What received most support was the plan to install a storm sewer system. However, as with most projects of this type, funding becomes a major issue. Estimates of \$10 million have been tossed about as the cost to install a piped storm-water drainage system for the Borough.

In March of 1994 the Borough received a proposal that will perform a stormwater management feasibility study, a quarry cone of depression investigation, and a PENNVEST application. The review of this proposal is ongoing as is the search for funding.

Note: The cone of depression investigation was initiated to determine if sinkhole occurrences and groundwater levels are or have been influenced by nearby limestone quarrying operations (possible source of money). PENNVEST is a state program that provides financial assistance to municipalities with sewage/stormwater problems.

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BOROUGH OF PALMYRA
SINKHOLE STATISTICS
 October 1991 to October 1993

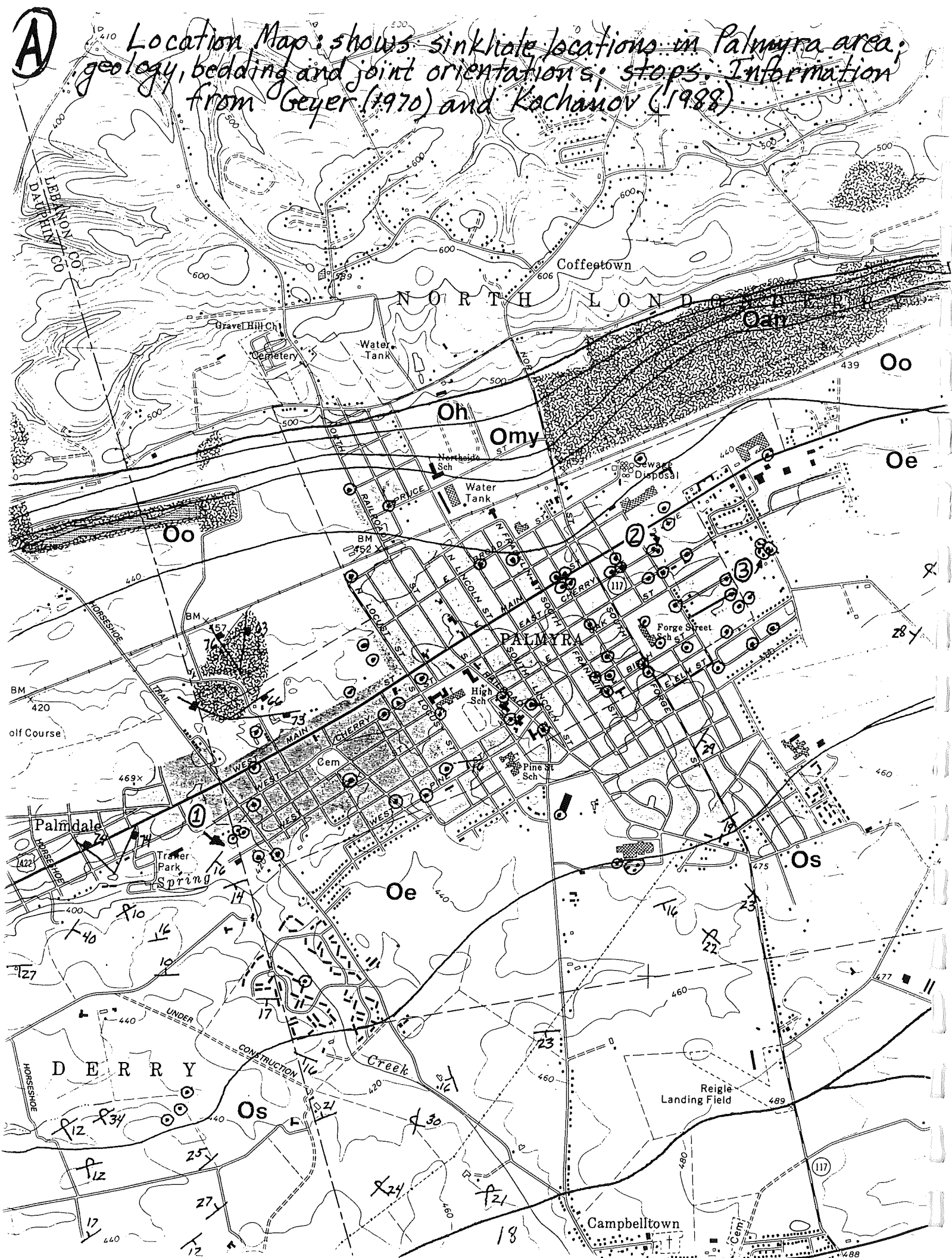
October 15, 1993

Location	Prior Repairs at this Location?	Approximate Date of Prior Repairs	Public or Private Cost Involvement (1991 - 1993)	Comments	Approximate Cost Distribution - 1991 - 1993 Repairs		TOTAL
					Public Share	Private Share	
1. Pine & Franklin Streets	YES	1965 to 1988	Public and private	Large storm sewer system installed	\$500,000.00	\$50,000.00	\$550,000.00
2. Birch and Forge Streets	YES	1975	Public and private	Storm sewers not feasible at this time	\$15,000.00	\$5,000.00	\$20,000.00
3. Forge Elementary School at concession stand	NO	-----	Public	Connection made to storm sewer system	\$15,000.00	-----	\$15,000.00
4. Forge Elementary School at Northwest corner	YES	1970 to 1989	Public	Storm sewer conveyance system installed	\$100,000.00	-----	\$100,000.00
5. 900 block of East Maple Street	YES	1968	Public and private	Storm sewers not feasible at this time	\$21,500.00	\$1,500.00	\$23,000.00
6. 900 block of East Cherry Street	YES	1975	Public	Storm sewers not feasible at this time	\$10,000.00	-----	\$10,000.00
7. 900-1000 block of East Main Street	YES	1965 to present	Public and private	Storm sewers not feasible at this time	\$1,500.00	\$1,500.00	\$3,000.00
8. 228 East Main Street	NO	-----	Private	Storm sewers not feasible at this time	-----	\$150,000.00 (Not yet repaired)	\$150,000.00
TOTALS					\$663,000.00	\$208,000.00	\$871,000.00

Compiled by RETTEW Associates, Inc.

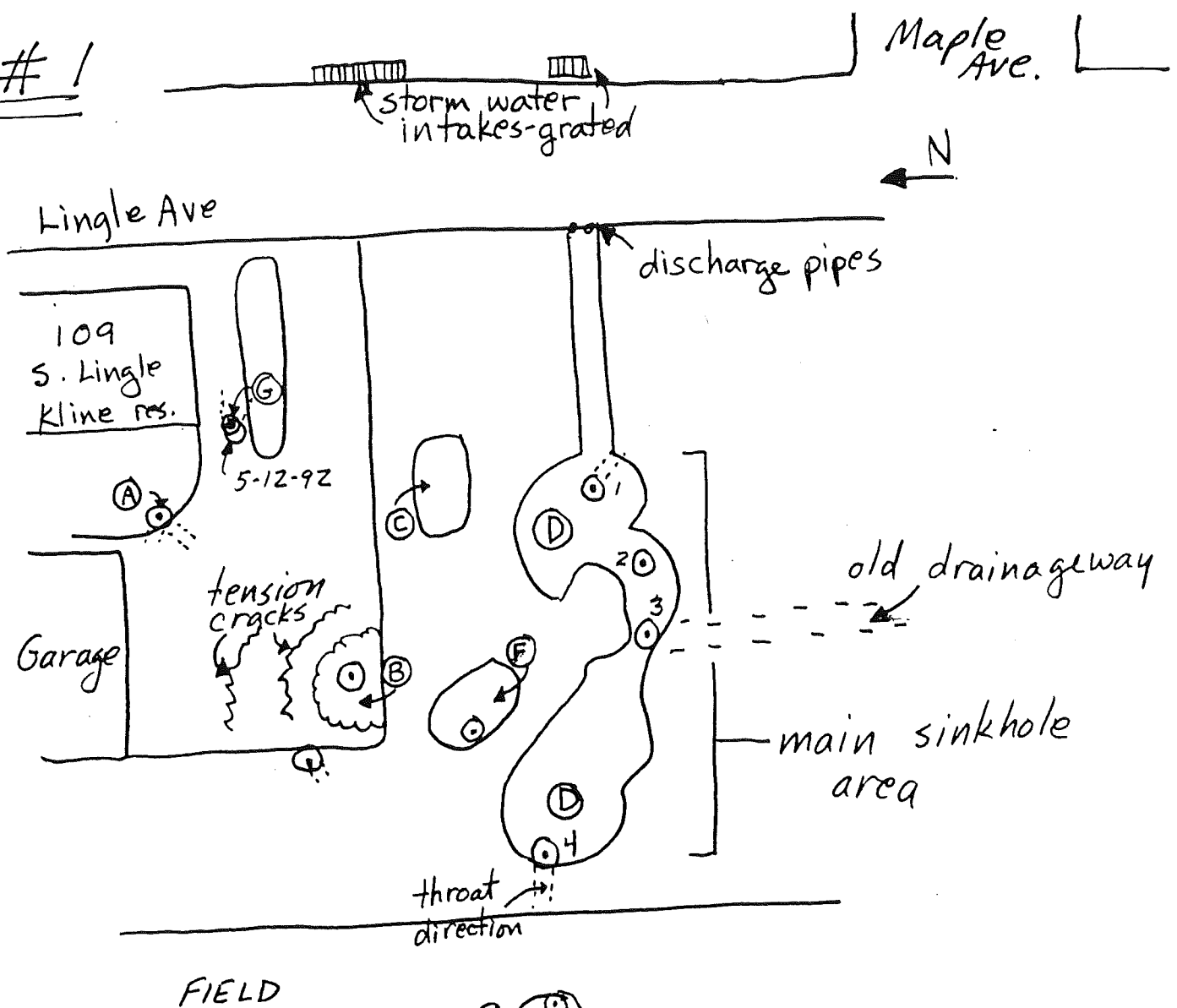
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Location Map: shows sinkhole locations in Palmyra area; geology, bedding and joint orientations; stops. Information from Geyer (1970) and Kochanov (1988)

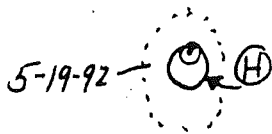


Case # 1

to
Pte. 422

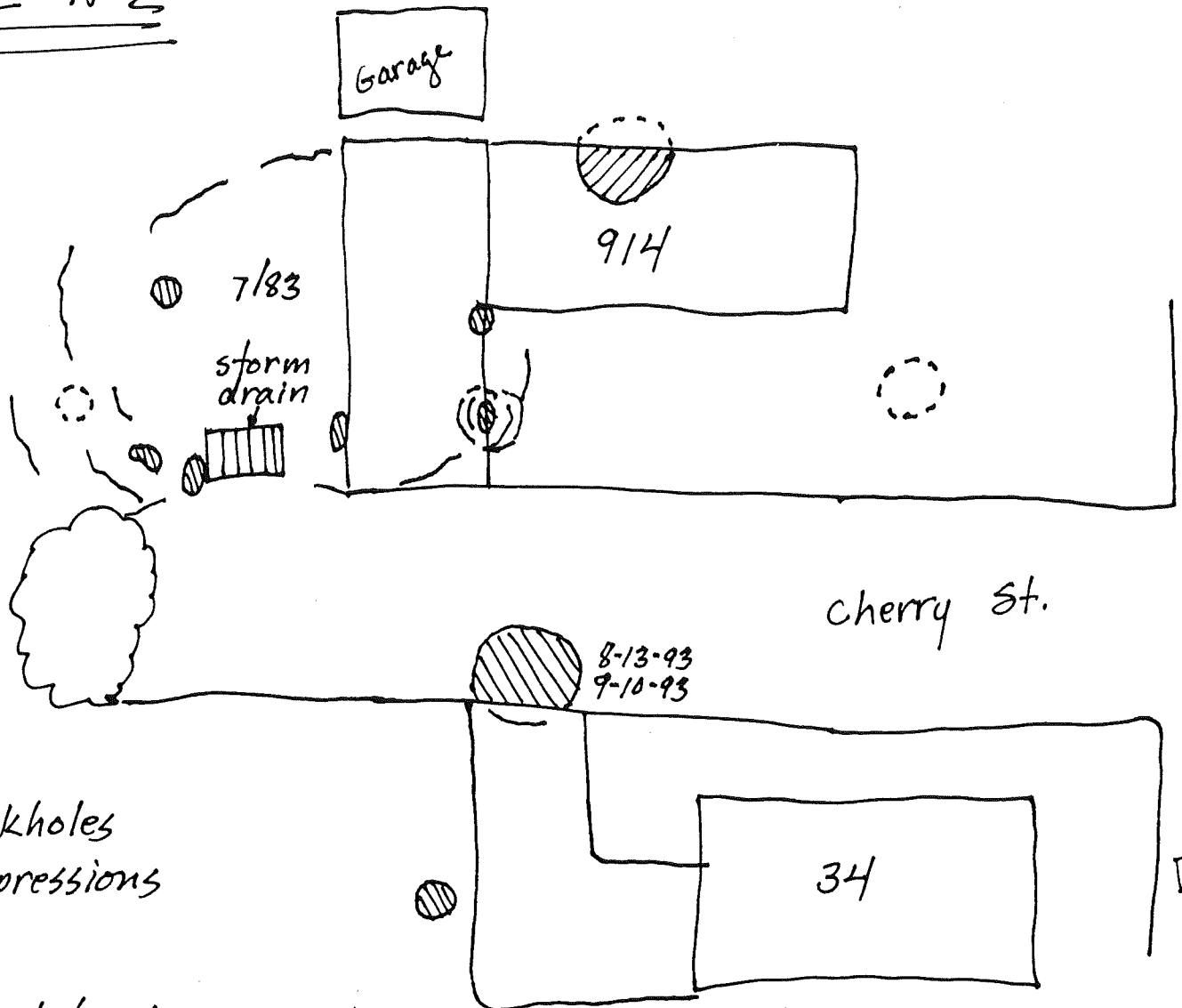


FIELD



sketch showing locations of subsidence areas at the Lingle Ave site. From PABS files. Not to scale

CASE # 2

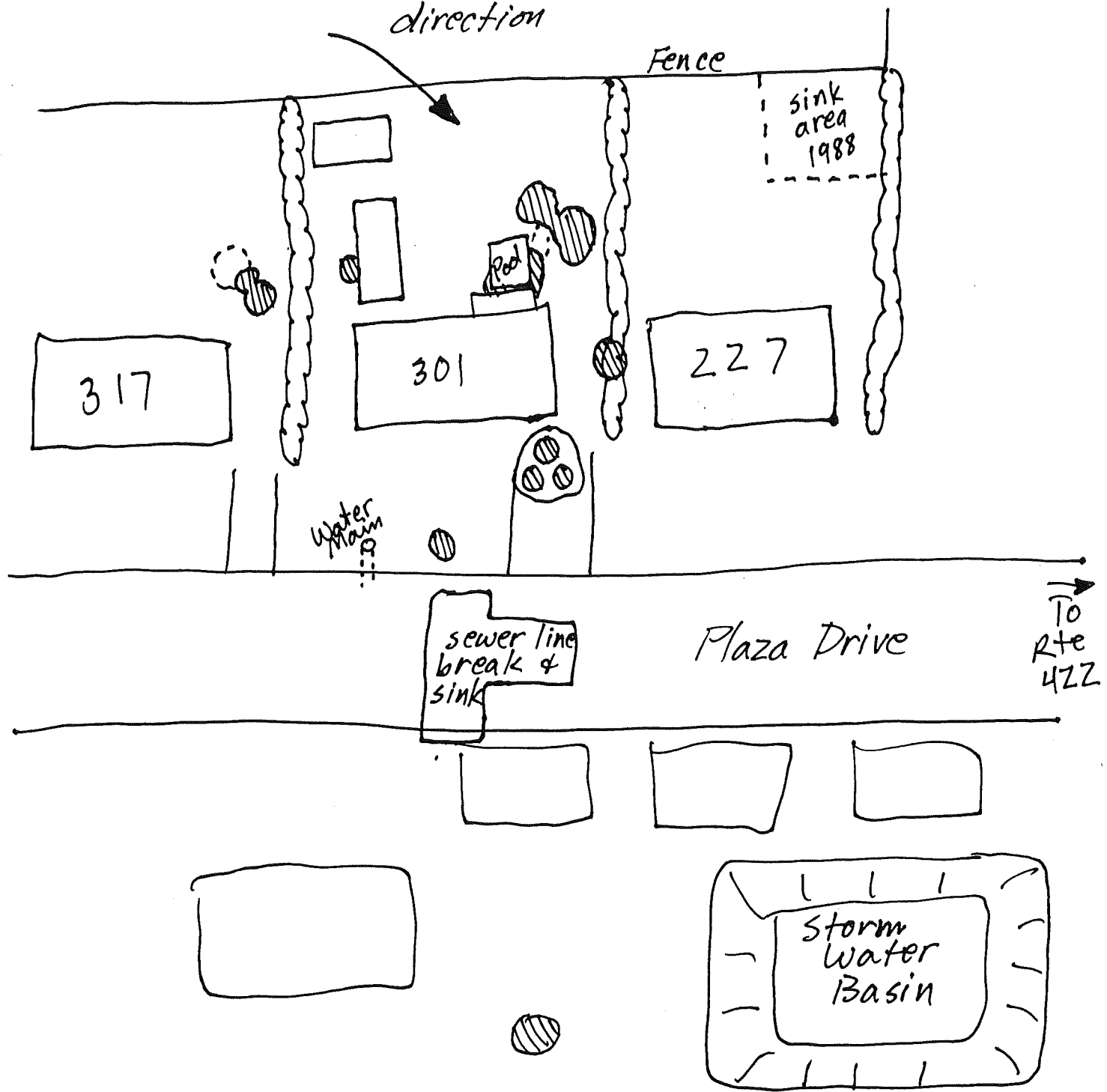


⊗ sinkholes
⊖ depressions

sketch showing locations of subsidence areas in the Cherry Street region of Palmyra. Info from PA Geological Survey files. Not to scale.

CASE #3

Water flow direction



Sketch showing location of subsidence areas in the Plaza Drive area. Info from PAGES files. Not to scale.

outcrop

THE UNION CANAL AND THE OLD TUNNEL, LEBANON, PA.

The Old Tunnel just north of Lebanon is the property of the Lebanon County Historical Society. It was not the first transportation tunnel built in the United States, but is the oldest surviving. It is 243 yards long, 18 ft. wide, and 14 ft. high. Boats were poled through the tunnel and the horses were walked over the top.

It all began in 1762, when trade was done by horseback from town to town. Discussion started in 1770 to construct a "navigation" between the Quittapahilla Creek, Lebanon, and the Tulpehocken Creek at Myerstown. In Philadelphia "The American Philosophical Society" started the study of canal building in Pennsylvania. After the Revolution the first major canal in the U.S. would be started in Lebanon. Robert Morris, friends, and others invested in the project in 1784. The company name given was "The Schuylkill and Susquehanna Navigation Company." It was Timothy Matlack, Free Quaker, Associator and Revolutionary Colonel, veteran of the early explorations into a canal possibility, and Secretary of the S. & S. Company, who outlined the plan of work started at Lebanon in 1792.

One acre and three perches of land were bought from Martin Light, used for drain or channel to carry water from his spring to the canal. It's almost a certainty that the S. & S. Canal extended to the vicinity of "Stoever's Dam." From here it would tap Clark's Creek. Stoever's Dam is on what was the Martin Light Farm, transferred to his sons in 1798. The water coming to the Canal they called from "Schott's Feeder." However in 1797 the S. & S. closed due to bankruptcy. In 1795 lotteries were held to regain more financing. The Union Canal Co. was incorporated in 1811.

Old Tunnel--In Lebanon there was a problem of connection between the eastern branch and the western branch of the Union Canal which followed the course of Swatara Creek to the north of the ridge. In 1826 work began. John B. Ives and Maley and Slaman were the contractors from the southern side and Thomas Moore & Co. from the northern side. When completed, the tunnel cost \$30,464.29 to construct. By June of 1827 the tunnel was completed. Construction was of sandstone and brick.

Summary of Canal--William Lehman, Resident Engineer of the Union Canal, faced tremendous responsibility. In his care would be 82 miles of canal, 95 locks, the water supply to keep the canal and locks filled and navigable. The canal was to be operative for a boating season of 250-270 days a year.

The Western Division started a few perches past Lock #1 West located beyond the Tunnel and along Clark's Creek to the Water Works. From there it followed the Swatara Creek to Portsmouth and Middletown on the Susquehanna. The Summit Level extended eastward from beyond Lock #1 West, through the Tunnel and along North Lebanon Borough, just beyond the present Narrows. The Eastern Division followed the Tulpehocken Creek to the Schuylkill River at Reading and was the Branch Feeder canal which went just northwest of Jonestown. By 1830 there would be 13 more locks and 20 more miles of canal reaching north to Pine Grove in Schuylkill County and a large dam built in the Swatara Gap above Lickdale. Two weigh locks were built at Reading and the Water Works.

The Union Canal was operative and an integral part of life in the Lebanon Valley for a span of 50 years. Information from "The Two Canals of Lebanon County" by Dean M. Aungst, published by the Lebanon County Historical Society.

Canals of the Lebanon Valley

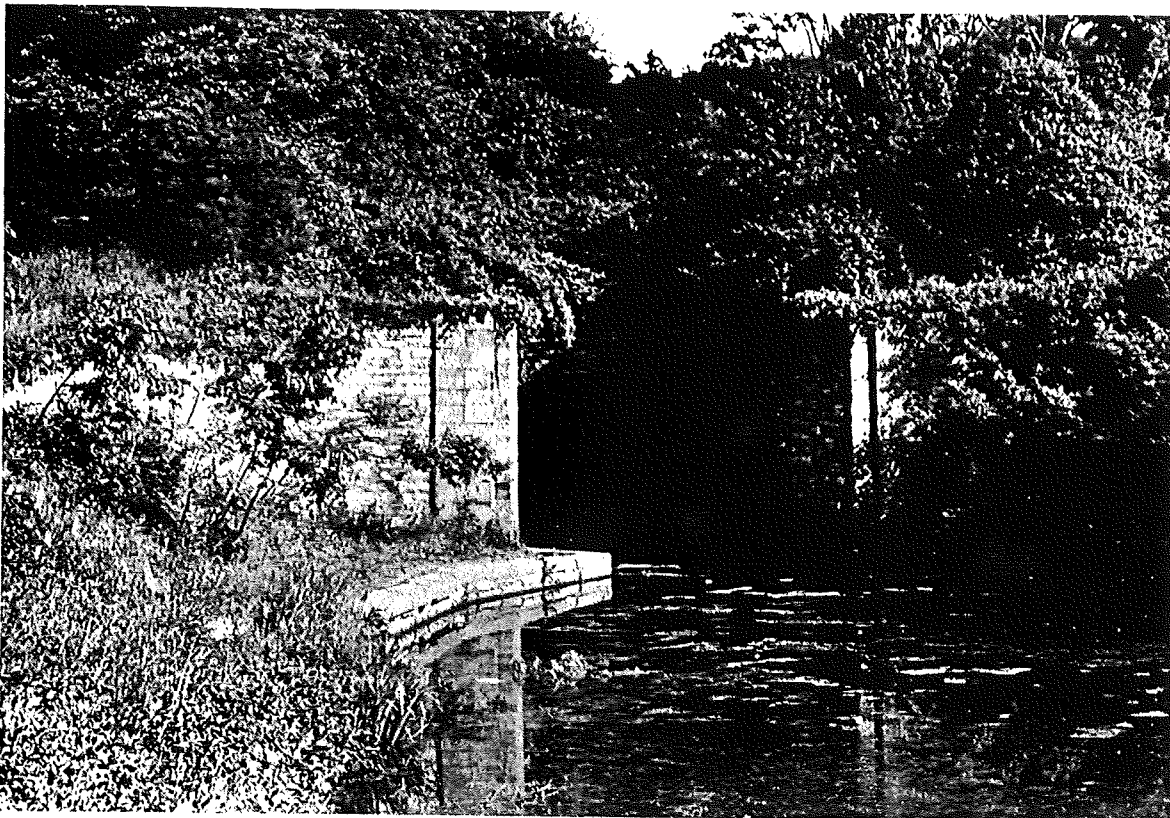
by William M. Jordan
Millersville State College

From: *Pa. Geology* 14/2
April 1983

Because the "Lebanon Valley" lies between the Susquehanna River on the west and the Schuylkill on the east it bears a number of place names dating from the 19th century halcyon days of America's great "canal era"; names like Union Deposit, Water Works, Leesport, and Port Clinton (the last north of the valley proper). Although these settlements are mostly vestiges of their former selves, they testify to the former importance of transportation and commerce provided by artificial waterways like the Union, Schuylkill, and Pennsylvania "Main Line" canals. It can even be argued that the canals influenced, indirectly perhaps, the geologic study of the region.

The importance of British canals in the history of geology and their role in the birth of stratigraphy is personified in the career of William Smith, as is well known (Phillips, 1844; Fuller, 1969). In Pennsylvania the case can be made that the "canal mania" resulting from the success of New York's Erie Canal, completed in 1825, and the resulting rash of "internal improvements" led to establishment of the short-lived (1836-1842) First Geological Survey of Pennsylvania, under Henry Darwin Rodgers (Jordan, 1979). The Second Pennsylvania Survey (1874-1889), under J. Peter Lesley, came when canals were well under the lengthening shadow of their spiritual descendant, the railroads, an ever expanding and eventually omnipresent transportation network. The final decline and abandonment of the canals closes-out the 19th century history of the Lebanon Valley, but the memory of canals lives on in the place names that they provided.

The main waterway serving the Lebanon Valley was the Union Canal, extending as the "Golden Link to the West" between the Schuylkill Canal at Reading to the state-owned Pennsylvania "Main Line" Canal at Middletown on the Susquehanna. Its route was the first (1762) to be surveyed, and the early works were visited several times by George Washington who had an entrepreneurial interest in canals because of his holdings on the Potomac (Aungst, 1966).



Several miles of canal, including locks, were constructed between 1792 and 1794 by the Schuylkill and Susquehanna Canal Company from Myerstown to a point near Lebanon. This financially troubled firm was reorganized and chartered by the state in 1811 as the Union Canal Company. Nine years later, in 1828, 80 miles of the completed canal were officially opened but for reasons of economy, which ultimately proved unfortunate, with "narrow locks" only 8½ feet wide by 75 feet long. Not until the immediate pre-Civil War period (1851-57) was enlargement of the locks to 17 by 90 feet undertaken in order to accommodate through-boats from the connecting canals, but 1857 also saw completion of the rival Lebanon Valley Railroad. Thus, despite the company's hopes, 1835 proved to be the Union Canal's best revenue year, based on the \$135,354 of tolls collected (Pawling, 1982).

The most famous engineering feature of the canal was, and still is, the summit level tunnel piercing the Martinsburg Formation in the divide between the drainages of the Tuplehocken and Swatara Creeks. This oldest surviving transportation tunnel in the United States, located and preserved in a park just east of Lebanon, was completed in 1826 with a length of 729 feet, but was shortened to 600 feet by the enlargement in the 1850's. The tunnel lacks a tow path, the boats being poled through by hand, while the mules were led over the crest on a path still visible today.

The major operating problem on the canal however, second only to the "narrow locks" as a deterrent to economic success, was the effect of porous carbonate bedrock on water levels beneath the summit level and eastward to beyond Myerstown. Elsewhere the canal is located mostly within the Martinsburg Formation. Engineering attempts to solve the dry-weather dilemma of repeated stranding of boats (lumber-laden barges would often tow their cargo behind in summer months; others had no recourse) included plank-lining several miles of trouble spots, a system of auxiliary reservoirs, and an arrangement to lift water from the Swatara Creek three miles away from the western end of the summit level. Two 40-foot water-wheels and two steam engines at the "Water Works" on the Swatara powered two pumping engines raising water 95 vertical feet to conduits connecting with the summit.

Also from this spot, a 22 mile "feeder canal" continued north along the Swatara to Pine Grove, well within the Ridge and Valley Province, where a 3.6 mile railroad, opened in 1833, gave access to the anthracite mines at Lorberry. This Pine Grove Feeder utilized, in part, slackwater navigation behind dams on the Swatara, but still had 14 locks and one aqueduct. The main Union Canal, in addition to its summit tunnel, had 92 lift locks constructed of Triassic red sandstone, and a total of 12 aqueducts.

The Schuylkill Canal, like the Pine Grove Feeder, was in large part a slackwater navigation from the coal fields near Pottsville to Philadelphia, via the river of the same name. Built in the interval between 1815 and 1827, its peak year of financial success was 1841 when revenues, mostly from the transport of anthracite, amounted to \$575,861 (Patton, 1982). In the same year the parallel and rival Philadelphia and Reading Railroad was completed.

To the west, the "Main Line" of the state-built and run Pennsylvania Canal System was started in 1826 at Harrisburg (McCullough and Leuba, 1973) but did not face railroad competition until 1850 when the Pennsylvania Railroad finished its own first link, from Harrisburg to Hollidaysburg. However it was the first to lose the economic battle, being sold to the competing railroad in 1857 (Shank, 1965). Ironically, the cause of failure was dependence on the canal's own railroad components, the Columbia and Philadelphia Railroad, and particularly the ingenious but inefficient trans-Allegheny Portage Railroad between Hollidaysburg and Johnstown. Both of these railroads and inclined plane systems were capable of carrying sections of canal boat overland, a clumsy method compared to all-rail transport (Jacobs, 1941).

The first of the Lebanon Valley canals to be abandoned was the Pine Grove Feeder, washed out by a flood on the Swatara in 1862, while the Union Canal itself went under in 1885. The Schuylkill Canal was sold to the Reading Railroad in 1870 which continued it in operation, but gradual coal and culm siltation of the Schuylkill resulted in incremental abandonment from 1872 until as late as 1931. Similarly, portions of the Pennsylvania Canal system were kept in operation by a subsidiary of the Pennsylvania Railroad, the Pennsylvania Canal Company, until final abandonment in 1903. Theodore Klein's 1901 classic report to the state Bureau of Railways on "The Canals of Pennsylvania and the System of Internal Improvements" describes the final stages of disintegration of a transportation network that had opened both the Lebanon Valley and the anthracite fields to the north to commerce, thus drawing the earliest systematic attention of geologists to the region.

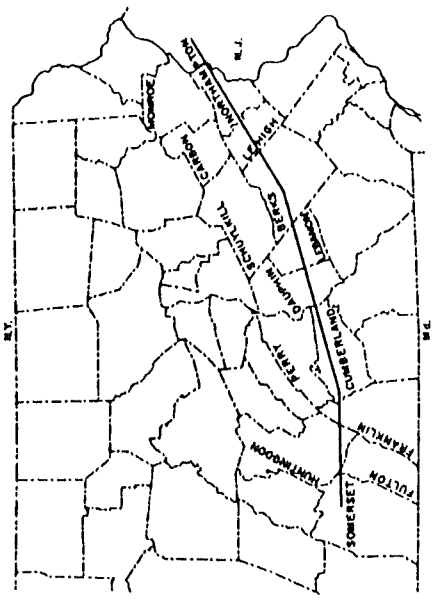
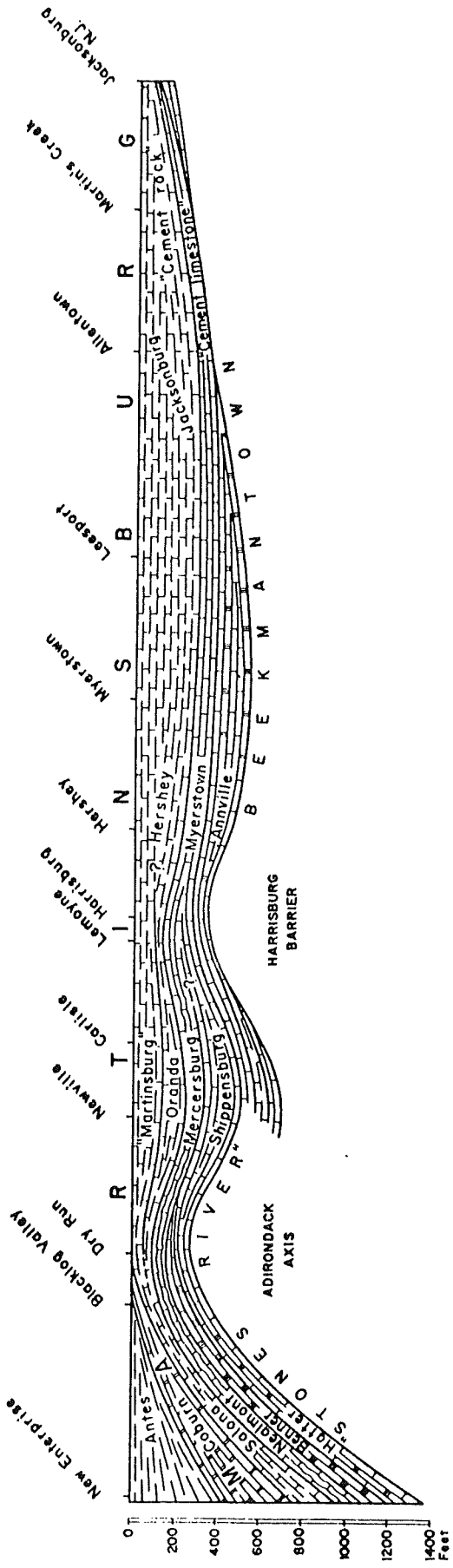
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CORRELATION TABLE OF MIDDLE ORDOVICIAN, CENTRAL PENNSYLVANIA TO NEW JERSEY

STANDARD		WEST OF ADIRONDACK AXIS	EAST OF ADIRONDACK AXIS	WEST OF HARRISBURG AXIS	EAST OF HARRISBURG AXIS	EASTERN PENNSYLVANIA	WESTERN NEW JERSEY	
M O N O L I T H I C	CINCINNATIAN	REEDSVILLE						
	Z I A N	GLOUCESTER	ANTES SH.	M	A	R	T	
		COLLINGSWOOD						
		COBOURG	COBURN IS.					
	A P I C	SHERMAN FALL	SALONA IS.	ORANDA IS.	ORANDA IS.	HERSHEY IS.	"CEMENT ROCK"	UPPER JACKSONBURG IS.
		KIRKFIELD	NEALMONT	MERCERSBURG IS.	MERCERSBURG IS.	MYERSTOWN IS.	"CEMENT LIMESTONE"	
		ROCKLAND	IS.					LOWER
	H A R T I C	CHAUMONT	BENNER					
		LOWVILLE	IS.					
		PAMELIA	HATTER IS.	SHIPPENSBURG	SHIPPENSBURG			
M O N O L I T H I C	CHAZY	LOYSBURG IS.	"STONES RIVER"	"STONES RIVER"	ANNVILLE IS.			
	BEEKMAN							
KITTATINNY								

Provisional correlation, after C. E. Prouty



Restored Section of the Annville-Hershey Interval

Figure 2

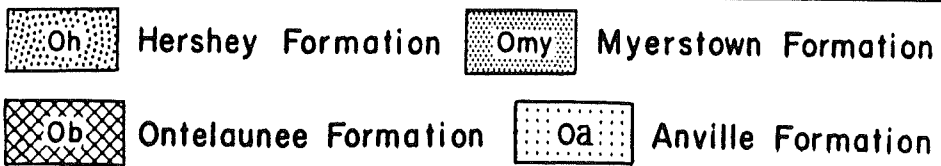
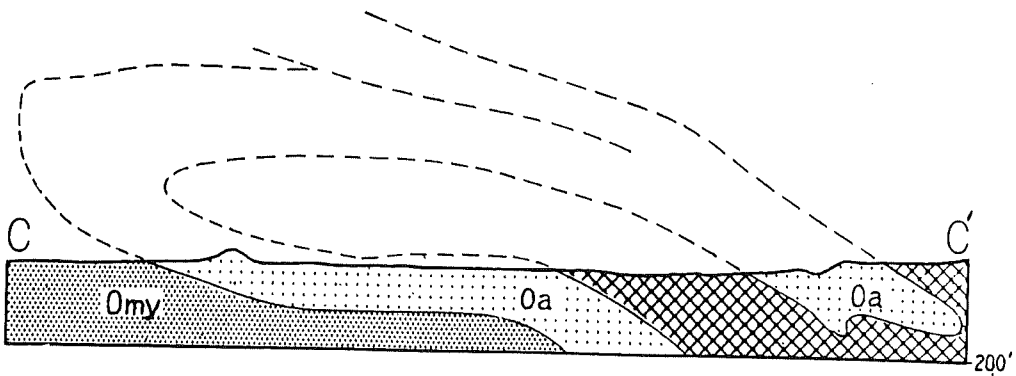
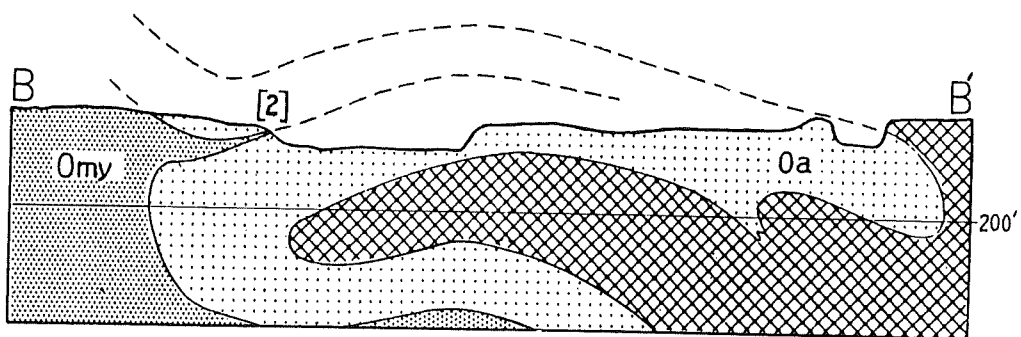
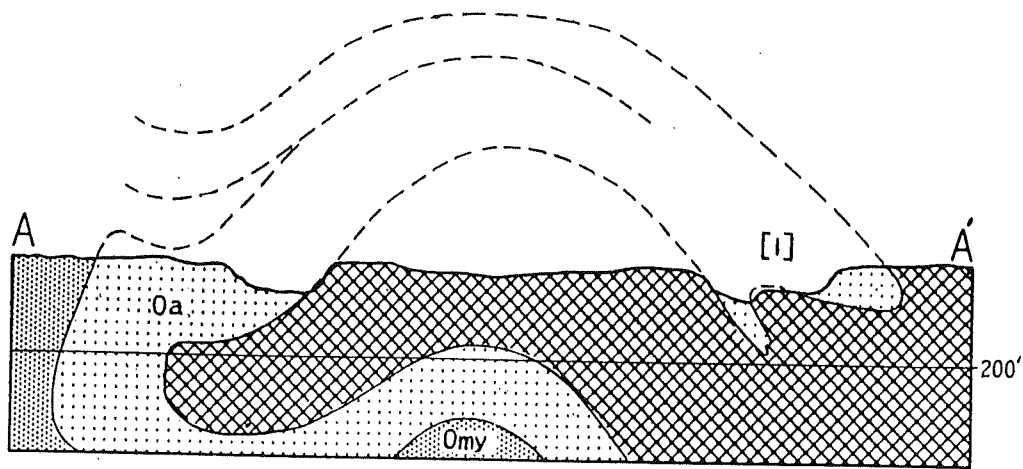
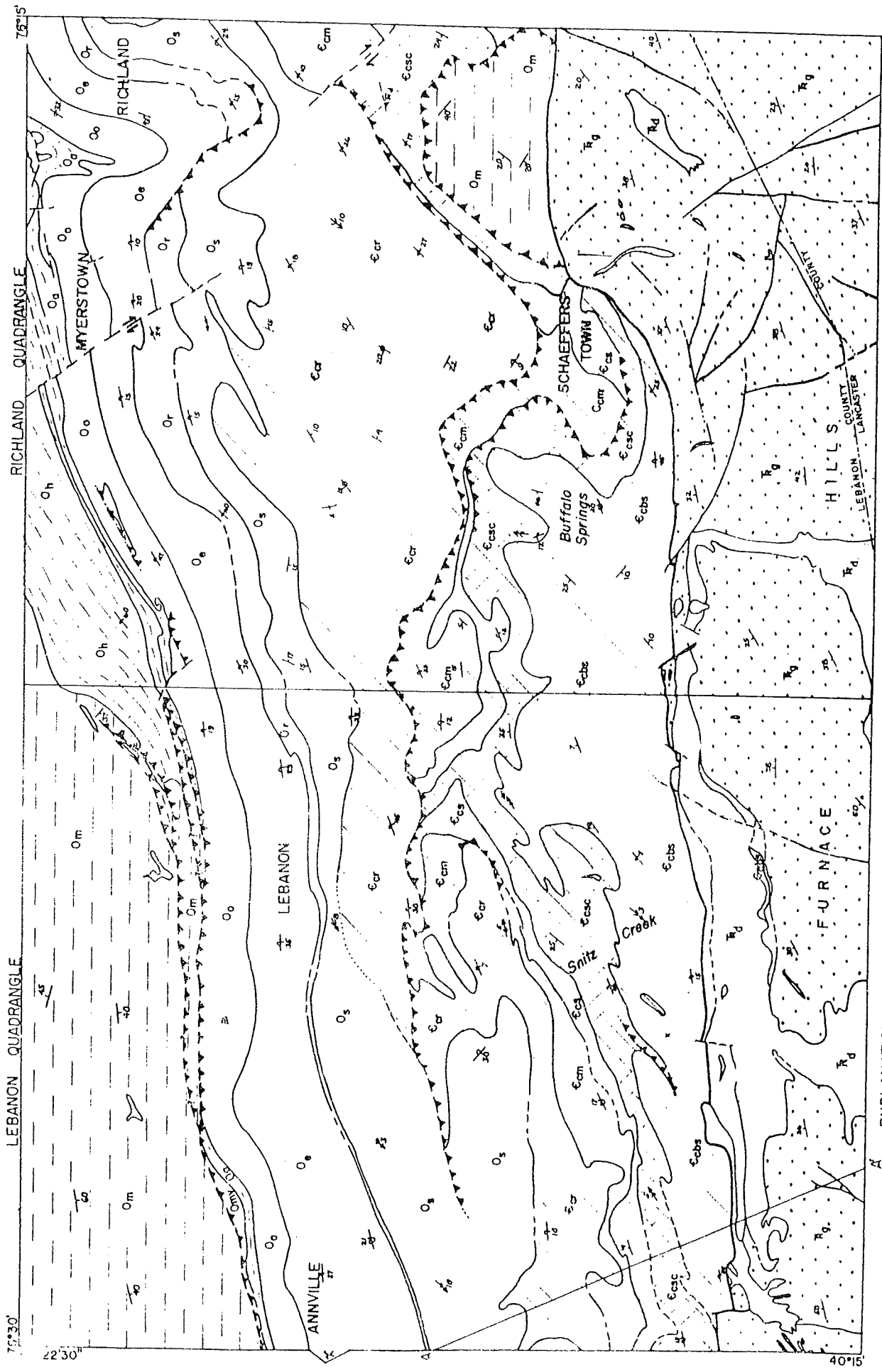


Figure 2. Cross sections at Millard Quarry.



GEOLOGIC MAP
OF THE
LEBANON & RICHLAND QUADRANGLES
 (After Grosz, Geogr. MacLaughlin & Moseley, 1958)

FIGURE 18
CROSS SECTION

EXPLANATION

	TRIASSIC Diabase		ANVILLE ls		CAMBRIAN CONOCOCHEAQUE FM: Richland mbr
	Gettysburg fm		BEEKMANTOWN GP:		Millbach mbr
	ORDOVICIAN Martinsburg fm		Ontelaunee fm		Schaefferstown mbr
	Hershey ls		Epler fm		Snitz Creek mbr
	Myerstown ls		Rickenbach fm		Buffalo Springs mbr
	Stonehenge fm				

Compiled by M.E. Koffman, 1960

Unless otherwise noted, the following description of the geology and mining history of Cornwall is summarized from Lapham and Gray (1972).

GEOLOGY OF CORNWALL

Paleozoic Stratigraphy and Deformation

Paleozoic stratigraphy directly connected with the origin of the Cornwall iron ore includes the Cambrian Buffalo Springs Formation and the Ordovician Martinsburg Formation (Figure 1).

The Buffalo Springs is the oldest of several Cambro-Ordovician carbonate units in the area. It is a white to pinkish-gray crystalline limestone with thin, shaly laminae, alternating with buff-weathering dolomite and magnesian limestone. All of the carbonates, including the Buffalo Springs, are intensely deformed and overturned to the north. They are part of the lower limb of a major recumbant anticlinal nappe formed during Taconic deformation. Several thrust slices, formed as a consequence of nappe formation, are also folded. The Buffalo Springs is thought to be the host limestone for the ore.

In the vicinity of Cornwall, the Martinsburg is contact metamorphosed by a Jurassic diabase sheet, to hornfels, known locally as the Mill Hill Slate and the Blue Conglomerate. The Mill Hill Slate is not a slate, but a laminated, calcareous, shaly hornfels. Likewise, the Blue Conglomerate is not a conglomerate, but a quartz-and-shale-fragment breccia. Because no similar breccia is found elsewhere in the Martinsburg, the Blue Conglomerate is thought to be at least partially tectonic in origin. The two hornfels interfinger and are in thrust contact with the overturned Buffalo Springs (Figure 2). This thrust involved considerable apparent displacement. Unlike the above thrust faults, the thrust between the hornfels and the Buffalo Springs is not folded. It is most likely younger than the other thrusts, either Acadian or Alleghanian in age.

Mesozoic Deposition and Diabase Emplacement

The Triassic Hammer Creek Formation was deposited from both north and south sources, possibly in an erosional Paleozoic limestone valley. The sediments were rotated to their present north dipping orientation.

During the early Jurassic, tholeiitic (olivine-poor) diabase magma was intruded into the Hammer Creek Formation. The location of diabase intrusion may have been locally influenced by the thrust between the Martinsburg and Buffalo Springs Formations. The diabase is part of a basin-shaped sheet with an outcrop pattern of 3 x 6 miles. Cornwall is located along the northern outcrop, where the diabase is about 1200 feet thick and dips about 40° south. The intrusion rafted part of the Buffalo Springs limestone and Martinsburg shale above the diabase (Figure 2). This portion of the Buffalo Springs would later be the main location of ore. Little ore has been found beneath the diabase at Cornwall. The Buffalo Springs limestone adjacent to the diabase sheet was contact metamorphosed, some recrystallized into marble. Diopside, actinolite, epidote, and garnet formed in the limestone from the heat of the diabase and the addition of some chemical elements from the final crystallization of the diabase. Contact metamorphism and metasomatism altered the adjacent Martinsburg to the two hornfels.

Diabase dikes later intruded through the diabase sheet and adjacent rocks. Throughout the area, no ore is associated with these dikes, but only with the earlier sheets.

Some normal faulting occurred after the emplacement and solidification of the diabase sheet. One of these faults probably served as a conduit through which the later ore bearing fluids migrated to the host Buffalo Springs limestone.

Ore Emplacement

Ore emplacement occurred after diabase emplacement as evidenced by ore replacement of small parts of the chilled zone of the diabase and ore in contraction cracks in the diabase. There are also some faults present which are post-diabase, but pre-ore.

The ore fluids probably originated from the same source as the diabase magma. They were probably introduced through the fault located between the eastern and western ore bodies (Figure 1). The fluids spread laterally from the feeder channel until a host rock of favorable composition was encountered. Limestone, assumed to be the Buffalo Springs, serves as the host rock for the vast majority of the ore (Figure 3). However, some diabase and hornfels have been replaced by ore minerals. Ore replacement of limestone favored the more "pure" layers. Shaly layers and dolomite beds are composed predominantly of gangue minerals. Magnetite, hematite, pyrite, chalcopyrite, actinolite, and chlorite formed by replacement of limestone and of previously formed diopside and actinolite.

In some places, particularly at the eastern ore body, the Mill Hill Slate and Blue Conglomerate acted as a caprock to the ore-bearing fluids and forms the hanging wall of the ore body. Elsewhere, ore is bounded by barren limestone, and limestone forms the hanging wall. The limestone lies between the ore and the overlying hornfels. This situation typically exists in the western ore body. The footwall of the ore bodies is everywhere composed of diabase.

The grade of the ore averaged 40 - 42% Fe. Iron was the only metal produced until 1920, except for veins of supergene enriched copper recovered in the early days. A magnetic separation-froth flotation plant was built in Lebanon to remove sulphides from the ore. Differential froth flotation made it possible to separate chalcopyrite from pyrite, making copper an important by-product. The copper sulfide concentrates averaged 25 - 30% copper. Gold and silver have also been produced from chalcopyrite, cobalt from pyrite, and sulfur from sulfides. The overburden was used for aggregate and fill (see below under Mineral Collecting). The cobalt, the only US production in the east, averaged 1% of the pyrite concentrate. 1700 oz. of gold were recovered in 1953. Iron ore was concentrated at Cornwall to increase its iron content before being transported to Lebanon. Concentrated ore pellets can be found along the abandoned railroad grade north of Cornwall.

MINING HISTORY

In the mid-1730s, Peter Grubb, a native of Delaware, was the first man to exploit the extensive resource of magnetite ore that outcropped at Big Hill, Middle Hill, and Grassy Hill. Cornwall was ultimately recognized as one of the most valuable ore deposits in the United States, continuing in operation until 1973 and producing not only 106 million tons of iron ore but also copper, cobalt, gold, and silver. It was the major source of iron ore in the US until the mines of the Mesabi range in Michigan were discovered.

The western ore body was discovered in outcrop in 1732 by Peter Grubb. He built the Cornwall Furnace in 1742 and 230 years of ore production commenced. Early miners included Hessian prisoners and slaves. Miners lived in three room houses in local miner's villages which preserve the area's architectural history. Middle income families lived in more four room houses near the villages. Mansions were located in removed sectors. Ore deposit ownership was split among as many as 96 owners until 1926 when Bethlehem Steel became the first sole owner since 1783.

The western ore body was mined only by open pit methods until an underground mine was opened in 1921. This mine was closed in 1940 so that ore could be mined by the cheaper open pit method. Underground mining resumed when the main open pit closed in 1953.

The subsurface eastern ore body, discovered in 1919 by a dip needle survey, was opened in 1927. Ore production was temporarily suspended during the depression and the mine filled with water. In 1936, it was dewatered and mining resumed in 1937. Mining reached a depth of 1225'.

The Elizabeth open pit produced from 1960-64. The East End open pit opened in 1964.

A small concentration of ore developed within diabase in the footwall, but was never mined. There are also occasional concentrations of ore veins in diabase. A small concentration below the diabase was mined at the Doner mine at Rexmont in the 1800s.

Although not expected, the closing of the mines came abruptly. In June of 1972, an electric pump failure caused by Hurricane Agnes resulted in the flooding of the underground mines. Because the ore was nearly exhausted, economics did not allow them to be dewatered. The flooding caused by Agnes moved the closing of the underground mines up by only a couple of years. The East End open pit was exhausted in 1973, ending over 230 years of production at the oldest continually operated mines in the western hemisphere.

The Cornwall ore deposits have been studied since 1858 (Lapham, 1972). The magnetite association with diabase is rare outside of Pennsylvania (Lapham, 1972) and was termed ore deposits of the Cornwall type by Spencer (1908).

MINERAL COLLECTING

This is a world famous mineral collecting locality. Across the road from the "Cornwall Banks" historical marker, are the dumps at the base of Big Hill. This was an excellent collecting site while the mines were in operation because freshly dumped material was available. When the mines closed, this area was closed to collecting. However, mine waste was used as fill material at an area along US 322 and along an unimproved secondary road, southeast of Cornwall (Geyer et al, 1976). Minerals can be collected at these two sites, shown in Geyer et al (1976). Ninety-five minerals are known to occur at Cornwall, 62 of which have been collected from waste dumps (Lapham & Gray, 1972).

CORNWALL'S FURNACES (from Fleeger and Strattan, 1992)

Peter Grubb first operated a bloomery in the mid-1730's. Grubb soon constructed Cornwall Furnace which was in blast in 1742 and 141 years of furnace operation commenced. The name "Cornwall" honors Grubb's father, born in Cornwall in the British Isles.

Cornwall was the seventh iron furnace in Pennsylvania. Its construction helped to expand the industrial "frontier" westward; the earlier Pennsylvania ironworks were located along Manatawny and French Creeks in what are now Berks and Chester Counties in southeastern Pennsylvania. Between 1786 and 1898 Robert Coleman purchased Cornwall Furnace and most of the mines from the Grubb heirs. Four generations of the Coleman family dominated the Cornwall iron empire until the end of the 19th century. The charcoal making process consumed adjacent woodlands at the rate of an acre per day; the furnace's annual output ranged from about 800 tons of iron in the 18th century to a peak of 1400 tons in 1844.

The Grubb buildings of 1742 were replaced in the 1790's. Major reconstruction occurring in 1856 - 57 resulted in the distinctive red sandstone Gothic Revival buildings that remain standing.

In the mid-1800's the American iron industry began to turn to anthracite as an alternative to the use of charcoal in smelting iron. In 1849 the first such furnace was built at Cornwall, 1/3 mile northeast of the charcoal furnace. Furnace No. 1 was in blast 1851 - 1898, and a second furnace built 1852 - 53 was in blast 1854 - 1898. Using coal at Cornwall required importing fuel from outside the area. A gently sloping route for horse- and mule-drawn wagons on a plank road from the Union Canal five miles north made the enterprise feasible. The construction of the Cornwall Railroad in 1855 contributed greatly to the expansion of Cornwall's iron industry.

Constructed on a grand scale and using up-to-date technology, the twin Burd Coleman and North Cornwall Furnaces were erected 1872 - 73 and put in blast in 1875. A second furnace was constructed at Burd Coleman in 1880, and the entire complex rebuilt 1884 - 85. At North Cornwall, the furnace was rebuilt in 1890 but not put back into blast until 1899. Both complexes closed c. 1918 and were demolished. Today, only workers' houses and office buildings testify that these magnificent complexes ever existed in Cornwall.

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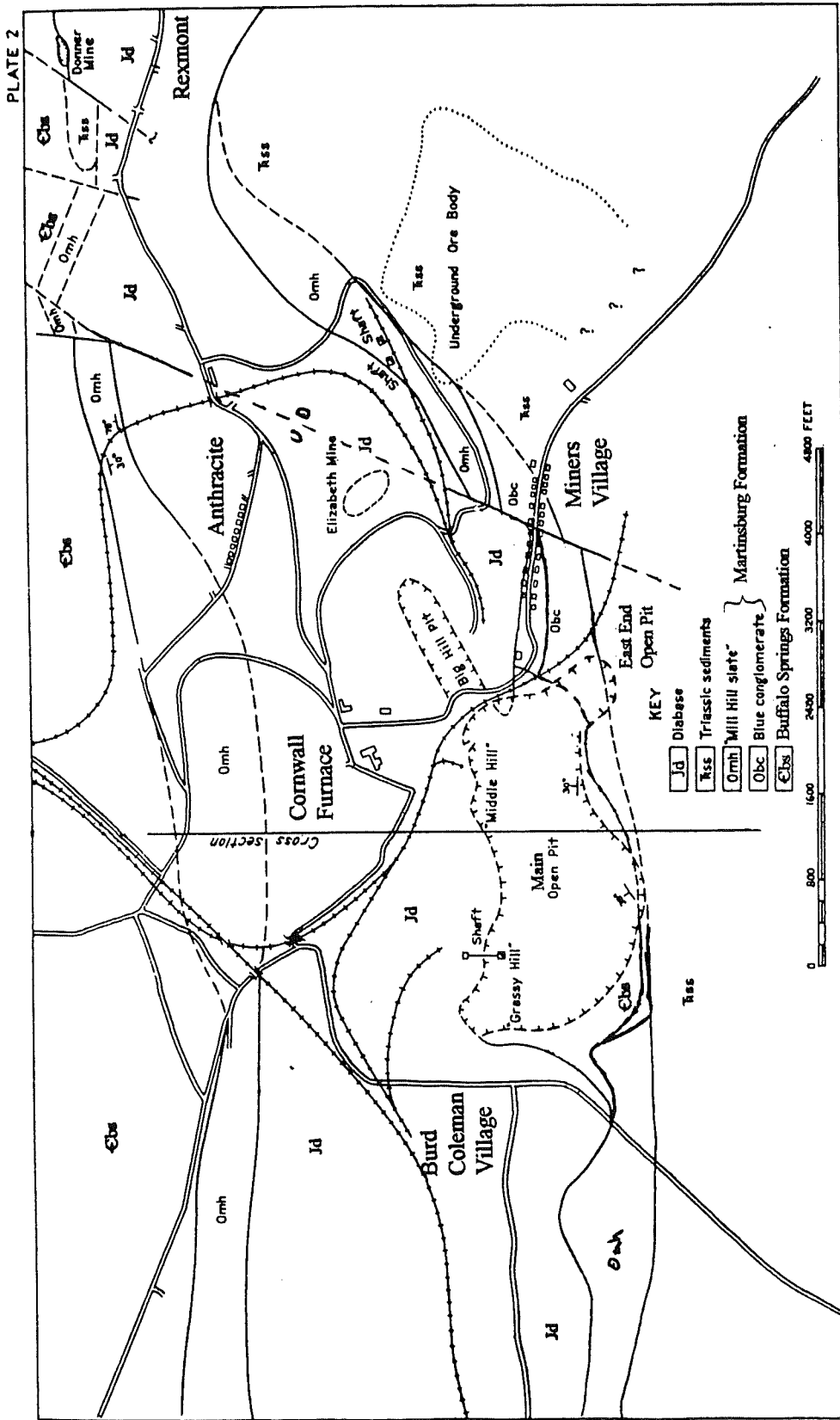
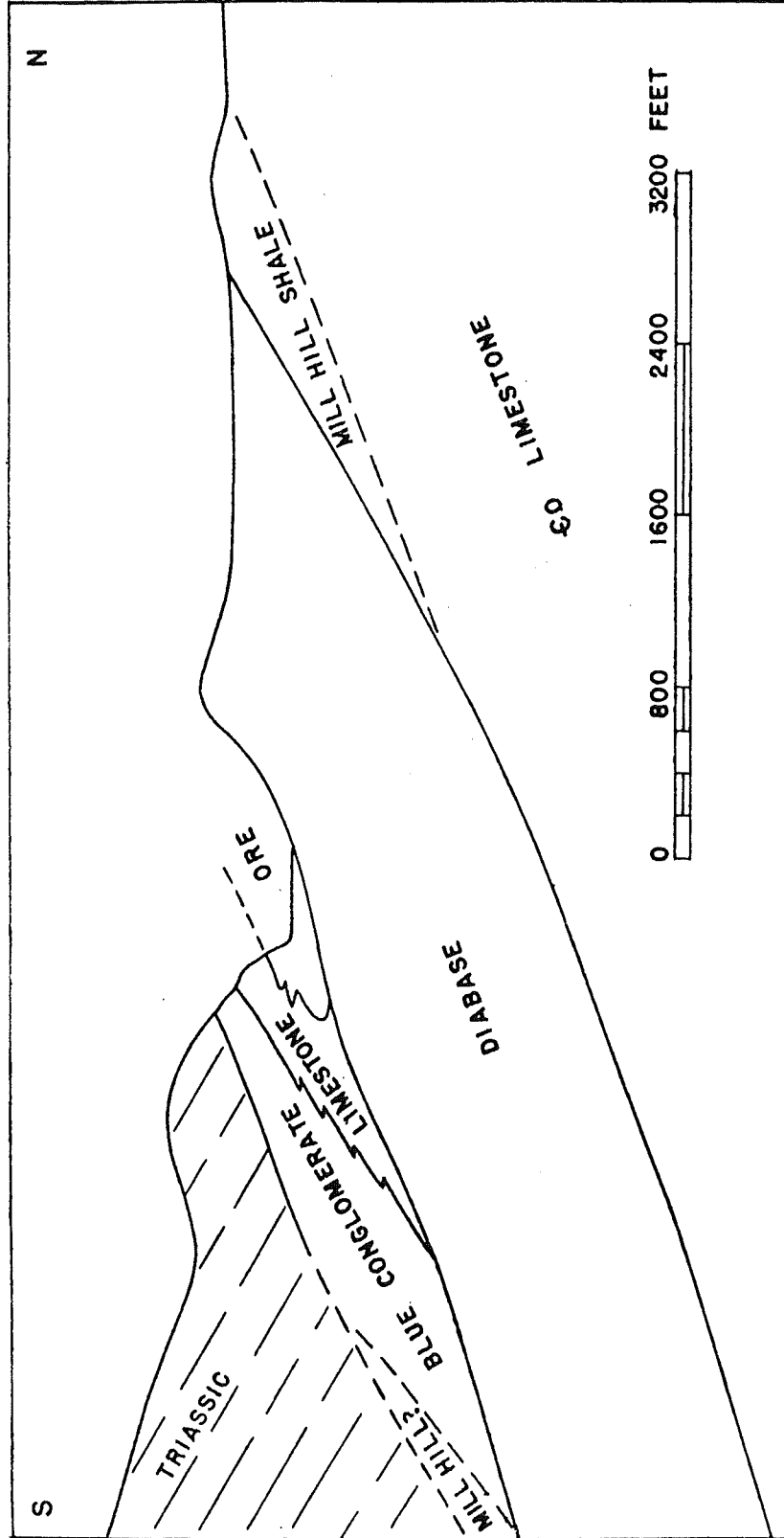
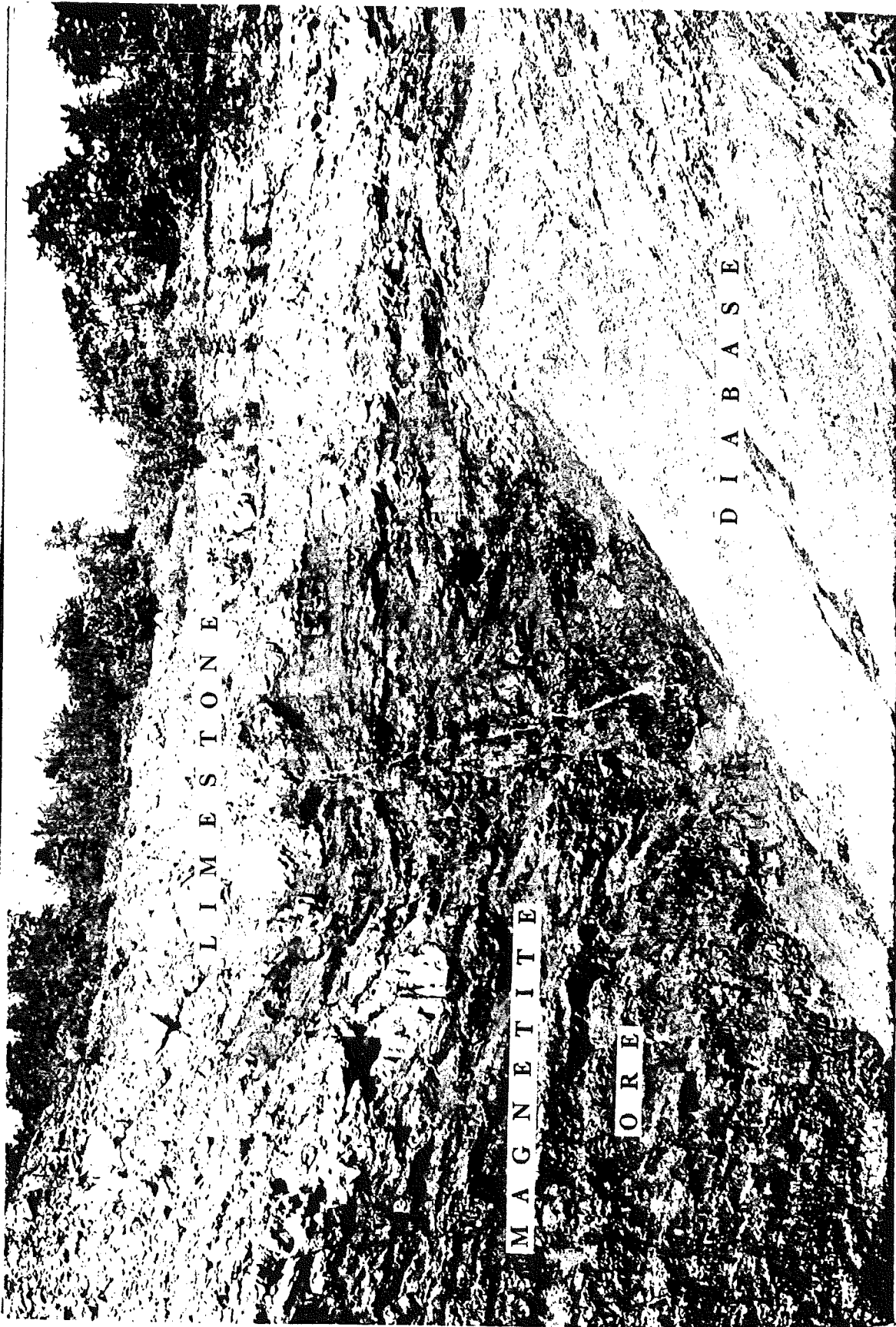


Figure 1 - Geologic map of the Cornwall area.

PLATE 3





L I M E S T O N E

M A G N E T I T E

O R E

D I A B A S E

Fig. 3

GUIDE
COR

DEPAF
TOPOGR

HISTORY OF THE CORNWALL IRON MINE

The iron ore mines at Cornwall are the oldest continuously operated mines in the Western Hemisphere. Iron ore is reported to have been discovered here by Peter Grubb in 1732. In 1742 a furnace was built near the deposits, and the ore has been worked continuously since that time. Through the first century or more of operations, ownership was very diverse, but in 1864 the Cornwall Ore Banks Company was formed consolidating 95 of the 96 holdings. In 1916 to 1921 Bethlehem Steel Company gradually acquired ownership of the Cornwall Ore Banks Company. In 1926 it purchased the Robeson Iron Company and for the first time the ownership of the entire area was in the hands of a single corporation.

The western orebody was worked entirely by open pit methods until 1921, when an inclined shaft was sunk near the western end of the open pit. From 1940 to 1953 operation was by open pit only. In 1953 underground mining was resumed as all of the ore that could be won by open pit methods had been removed.

The eastern orebody was not discovered until 1919, when it was located by a dip needle survey. Its discovery, however, had been forecast by Spencer (1908) who said, "All of this ground (from Miners Village) as far as the road leading from Rexmont to Overlook is regarded as likely to contain a continuation of the Cornwall ore bed." Two inclined shafts were sunk in the footwall of the eastern orebody in 1927 and 1928. Development in this orebody was halted due to the depression in 1931 before any significant ore had been produced. Mining was resumed in 1937.

With the exception of veins of supergene enriched copper recovered from the oxidized zone by selective mining in the early days, iron was the only metal recovered until shortly after 1920. At this time a combination magnetic separation-froth flotation plant was built in Lebanon to remove the sulphides from the ore to reduce its sulphur content. Differential froth flotation makes it possible to separate the chalcopyrite from the pyrite so that copper is now an important by-product. The pyrite concentrates contain about one percent of cobalt, and until recently Cornwall was the leading domestic producer of cobalt. Sulphur (sulphuric acid) is recovered in the roasting of the pyrite. Gold and silver in appreciable quantities (1700 oz. of Au in 1953) are derived from the refining of the copper. At present the mine is producing five metals and one non-metal. In addition, the limestone overburden removed from the pit is being crushed and sold for aggregate. The present production is around one million tons of ore per year. The grade of the ore averages 40-42% Fe. The magnetic concentrates contain about 62% Fe.

CORNWALL FURNACE
1742-1883

- Between 1740 and 1742, a charcoal furnace was built by Peter Grubb near Lebanon, Pa., close to three nearby ore hills. It was named the Cornwall Furnace, after the English mining county where Grubb's father was born. This furnace was in continuous operation for 140 years, from 1742 until February, 1883, when the last cast was made. The furnace proper is 32 ft. high with a 7 ft. bosh and a 3 ft. crucible. The charging hole is 17 in. in diameter. It was last rebuilt in 1856.
- Originally, the cold-air blast was supplied by a leather bellows 10 ft. long and 7 ft. wide, operated by a water wheel. In 1845 a steam engine was installed to furnish the power. A single-cylinder engine, with a 9ft. diameter flywheel, it developed 20 horsepower. Two boilers, each 21 ft. by 3 ft., were heated by hot gases from the stack, and generated the steam.
- The engine was geared to a 24 ft. diameter wooden wheel, mounted on a 13 1/2 ft. shaft. Wooden connecting rods operated pistons in two overhead tubs, each 6 ft. high and 6 ft. in diameter. The result was a cold blast with a pressure of 2 lb. per sq. in.
- Tin pipes of 8 in. diameter, leading from the top center of each tub, met in a box at a point midway between the two tubs. From here the air blast branched off in three directions, one branch going to each tuyere.

OPERATION

- Wood charcoal was used as fuel. It was manually pushed from the stock house in buggies and dumped into the furnace. A charcoal buggy consisted of a box 4 ft. long and 2 1/2 ft. deep, built over a pair of 34 in. diameter iron wheels. The buggies used for ore and limestone were much smaller.
- The charge consisted of one buggy of charcoal, one of limestone, and one of ore. In a 24 hour period, 18 to 20 charges were made. This produced 24 tons of iron a week. Compared to today's mighty blast furnaces, which can produce more than 14,000 tons a week, this total seems very small. At the time, however, it was considered eminently satisfactory.
- The charcoal ranged in size from 6 in. to 2 ft. long and averaged 4 in. in thickness. It took about 400 bushels of charcoal to produce a ton of iron for one cast, and it required about 50 minutes to melt the charge. The usual times for casting, or removing the molten metal from the furnace, were at noon and at midnight.
- When the keeper (furnace-tapper) was ready to tap the furnace, he blew a large horn. This was the signal for the tap-filler and his helper to come and help with the cast. Three tons was considered a large cast, while the average cast was about 2 tons. The man who broke the limestone (into small pieces about the size of a hen's egg) also filled the buggies with charcoal. When he had enough on hand for the night shift, he was allowed to go home, usually about noon. His starting time, however, was 4 o'clock in the morning.
- The "gutter" man removed the cinder and iron from the cast house. He made a trough of sand from the taphole of the furnace to the pig bed. This trough was aptly called the sow and the pig bed, her litter.

CHARCOAL

- The charcoal was made by charring green trees. First a pit was dug, 20 ft. in diameter and about 3 ft. deep. A large pole was planted in the center. Around it, cord wood was placed on end until the circle was filled. This was called a tier. Upon the first tier another was placed, and another, until there were four tiers high. Each tier was smaller in diameter than the preceding one, hence the pile took the shape of a cone. The wood was then covered with leaves and dirt. An opening was left at the bottom to start the fire. After the pile lighted, it was carefully watched, day and night, and any signs of flame were immediately smothered. It took from five to ten days to char the entire pile, depending on the type of wood, the prevailing weather conditions, and the skill of the burner.
- Every 24 hours, the furnace used approximately 840 bushels of charcoal, or about 21 cords of green wood. (One cord of wood produced 40 bushels of charcoal). One acre of 25 to 35 year old timber was required to produce this amount. In other words, for every day it was in blast, the average furnace consumed the equivalent of the timber from one acre of forest land.

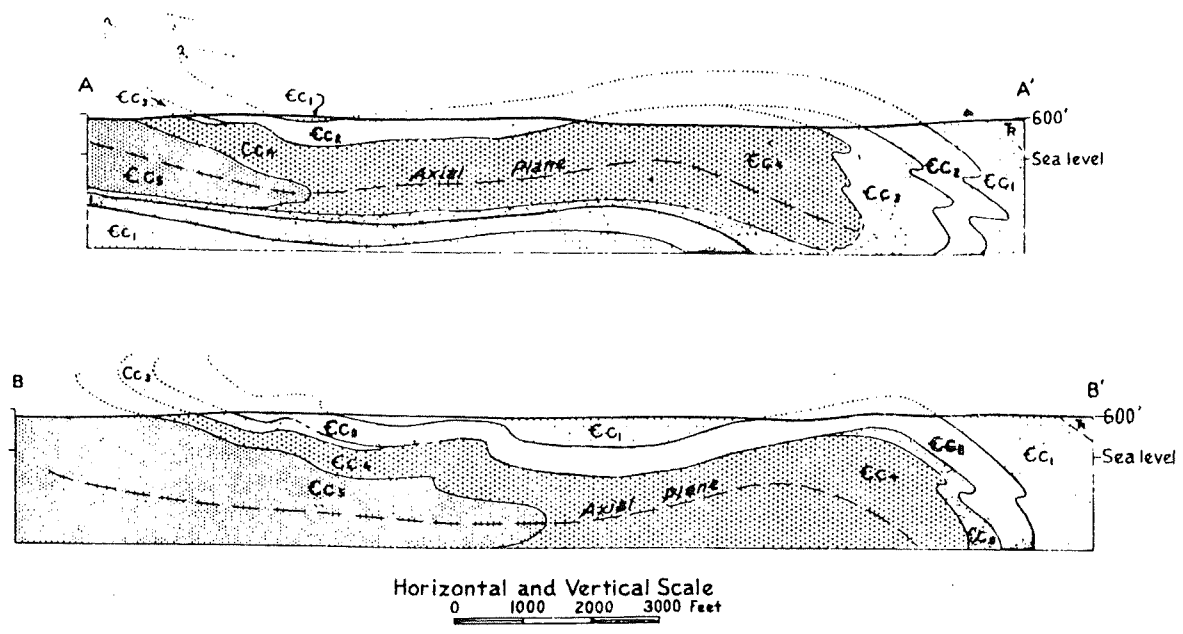


Plate 6. Cross sections, Buffalo Springs Area.

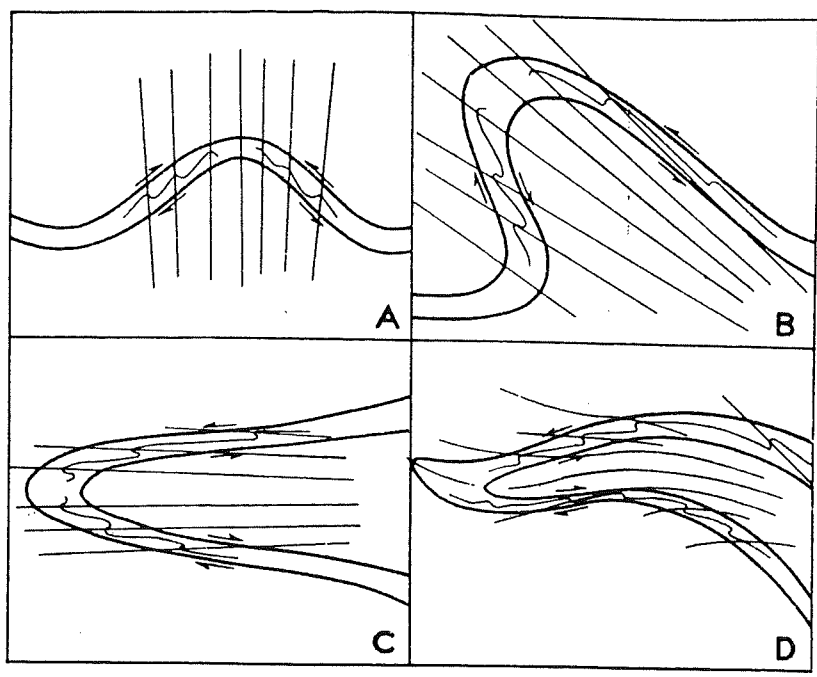
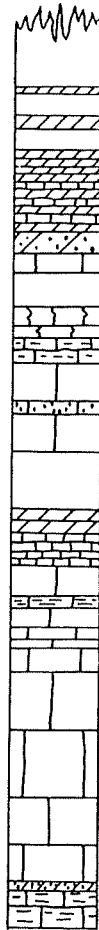
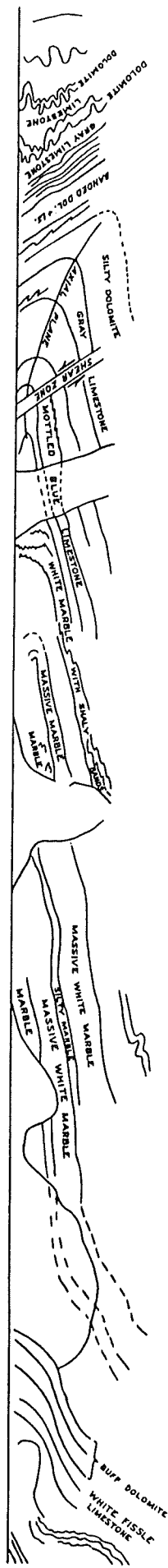
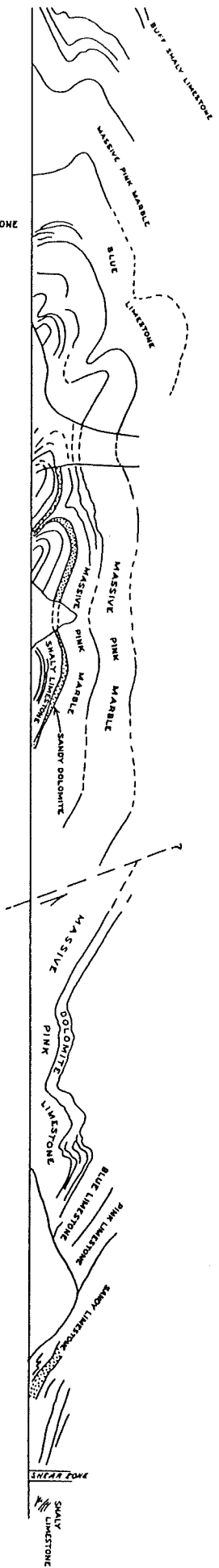
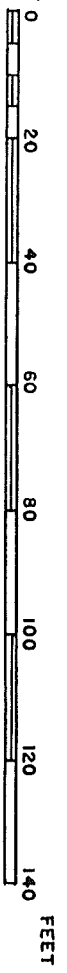


Plate 7. Diagrams illustrating bedding-cleavage relations in various types of folds.

PLATE 4



- LIMESTONE
- DOLOMITE
- GRAY LIMESTONE
- DOLOMITE
- GRAY LIMESTONE
- BUFF BANDED DOLOMITE
- INTERBANDED CREAMY DOLOMITE AND GRAY LIMESTONE
- SILTY GRAY DOLOMITE, WEATHERS CREAMY
- GRAY CRYSTALLINE LIMESTONE
- ?
- MOTTLED BLUE LIMESTONE
- WHITE MARBLE WITH SHALY BANDS,
RIBBED ON WEATHERED SURFACE
- MASSIVE WHITE MARBLE
- SILTY MARBLE, BUFF WEATHERING
- MASSIVE WHITE MARBLE
- COVERED
- BUFF DOLOMITE
- WHITE, FISSLE LIMESTONE
- BUFF SHALY LIMESTONE
- PINK CRYSTALLINE LIMESTONE, MASSIVE
- BLUE LIMESTONE, MASSIVE
- PINK CRYSTALLINE LIMESTONE, MASSIVE
- PINK CRYSTALLINE LIMESTONE, MASSIVE
- SANDY DOLOMITE
- SHALY LIMESTONE



RECENT SEISMICITY IN BERKS COUNTY

On the evening of January 15, 1994, residents of western Berks County experienced two earthquakes that were large for this region. The first shock, at 7:43 p.m. EST, had a measured Lg magnitude of 4.0; the Lg magnitude of the second quake, at 8:49 p.m. EST, was 4.6, making it the largest earthquake ever recorded with an epicenter in Pennsylvania. (Lg magnitude is found by measurement of the amplitude of the 1 Hz surface wave which is characteristic of eastern North American earthquakes. It is roughly equivalent to body-wave magnitude and hence often is designated m_b Lg.) These earthquakes were preceded by numerous foreshocks through the spring, summer and fall of 1993, beginning with an m_b Lg 2.8 event on May 10, and have been followed by numerous aftershocks.

The larger earthquake was felt in much of Lancaster County, and even as far away as Bethesda, Maryland; an isoseismal map and a map showing damage zones in the vicinity of the epicenter are found on the the page following the references. On the isoseismal map, the epicenter is marked by the zone of intensities VI-VII on the modified Mercalli scale. Intensity VII corresponds to damage that is "slight to moderate in well-built ordinary building." Types of damage included cracked foundations, cracked and dislodged bricks, especially from chimneys, broken windows, cracked pavements, much cracking and fall of interior plaster, and damage to household items that were thrown to the floor. The Berks County Emergency Management Agency estimates the dollar value of damage at \$2.6 million, which makes these the most damaging earthquakes in Pennsylvania history. The intensity VI zone in northeast Reading appears to be due to the presence of thick colluvium there, at the base of Mt. Penn.

The asymmetry of the intensity IV zone probably is real, though it could be an artifact of the data. Far more intensity reports were gathered from Lancaster County, southwest of the epicenter, than from areas to the north and east of the epicenter. The narrow isolated zone of intensity III in Maryland may not be continuous; it is based on only three reports. It is interesting, nonetheless, that this zone appears to follow the Fall Line.

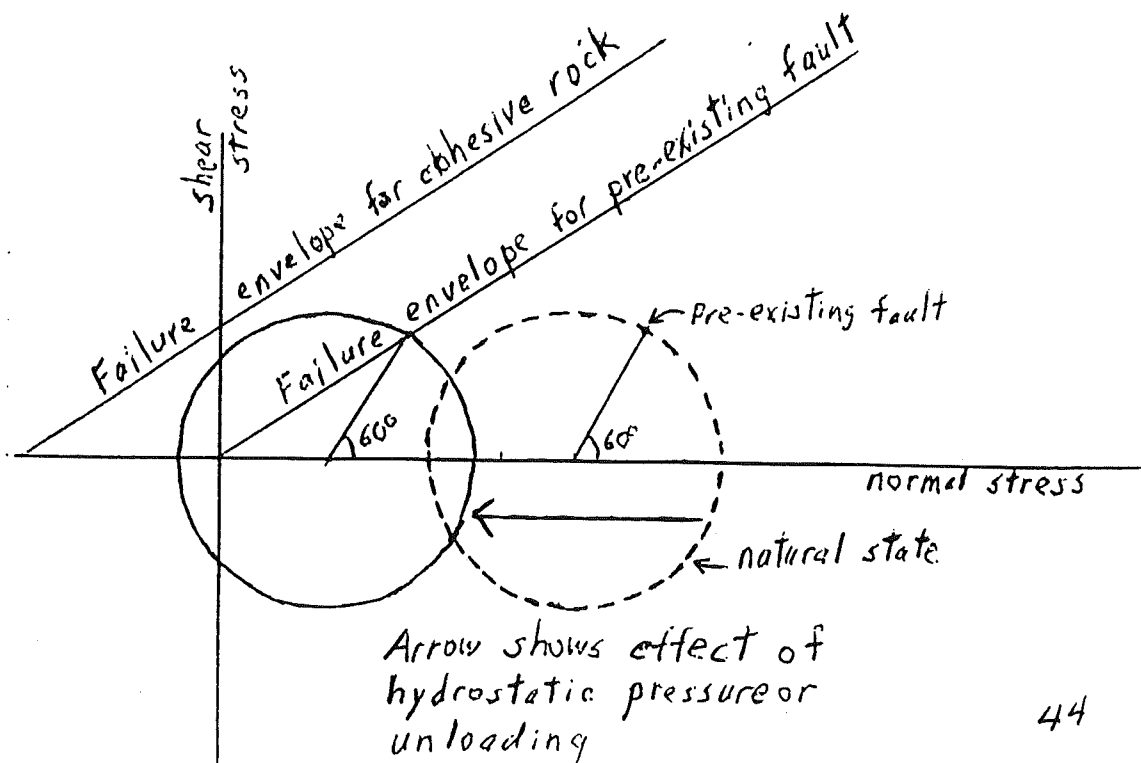
Despite the relatively high magnitude and high value of maximum intensity, the total felt area was relatively small. For example, the area of the intensity IV zone was only about one-tenth that of the 1984 Lancaster County earthquake. This phenomenon, as well as the large amount of damage, is consistent with the hypothesis that the Berks earthquakes had shallow hypocenters. An aftershock study, conducted by seismologists from Columbia University's Lamont-Doherty Earth Observatory, found that all aftershocks recorded during the two days following the main shocks had hypocenters less than 3 km.

One of the most interesting aspects of these earthquakes is the coincidence of the inferred epicenters with the Brenneman Quarry, located just to the southwest of the intersection of State Hill and

Van Reed Roads. The results of the aftershock study, shown as a map and cross section on the page following the isoseismal and damage maps, imply a fault plane striking southeast and dipping about 60 degrees to the southwest, i.e., directly under the quarry. The quarry had ceased mining and the pit had filled with water to a depth of about 30 feet above the quarry floor. Given the body of evidence that suggests a correlation between hydrostatic pressures in fault zones and seismicity (e.g., Gupta and Rajendran, 1986; Nicholson and others, 1988) it seems likely that these were induced earthquakes. Of course, the underlying condition of shear stress acting on a fault plane must have existed, and it is possible that the earthquake would have occurred eventually anyway.

Also of interest is the fact that a previous damaging earthquake had occurred in 1954. That event was felt most strongly in the Borough of Sinking Spring; however, the area between Sinking Spring and the quarry was not heavily developed in 1954, so it seems possible, though not well-established, that the epicenter of this earthquake also was coincident with the quarry. Because large-scale mining had just begun in 1954, the hypothesis in this case would be that unloading of the hanging wall had the effect of reducing the lithostatic stress at depth, thus inducing the earthquake.

The Mohr diagram below shows how either increase in hydrostatic pressure or unloading could induce the circle representing the two-dimensional state of stress to move the the left on the diagram until the point representing the stress on a pre-existing cohesionless fault plane intersects the failure envelope. This occurs before the stress circle intersects the failure envelope for cohesive rock. The diagram is based on the assumption of a fault plane with a 60 degree dip striking roughly perpendicular to the direction of maximum compressive stress. Inasmuch as regional measurements of near-surface crustal stress in the Northeast indicate maximum compression acting along a NE-SW axis (Zoback and Zoback, 1991), this seems to be a reasonable model.

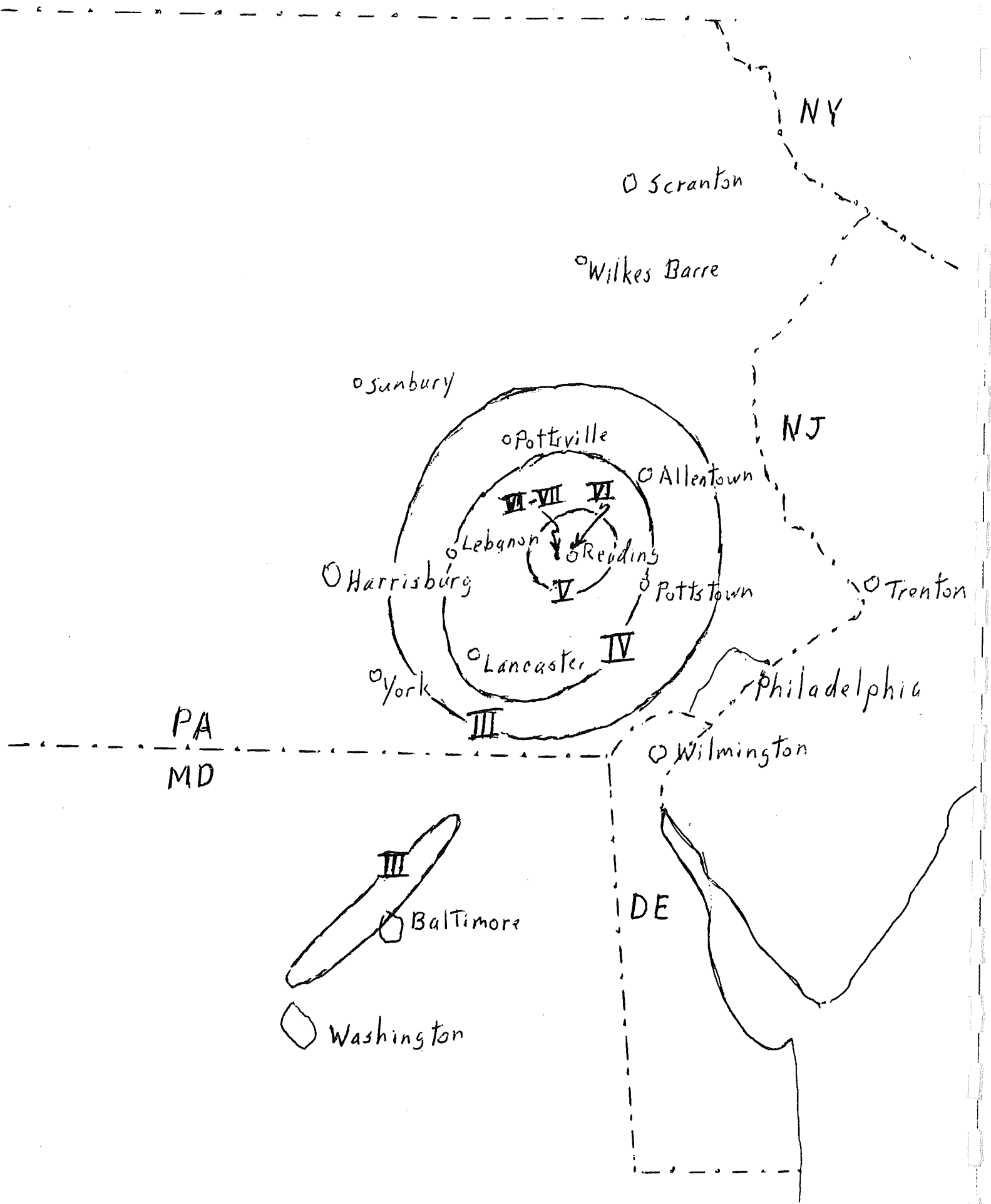


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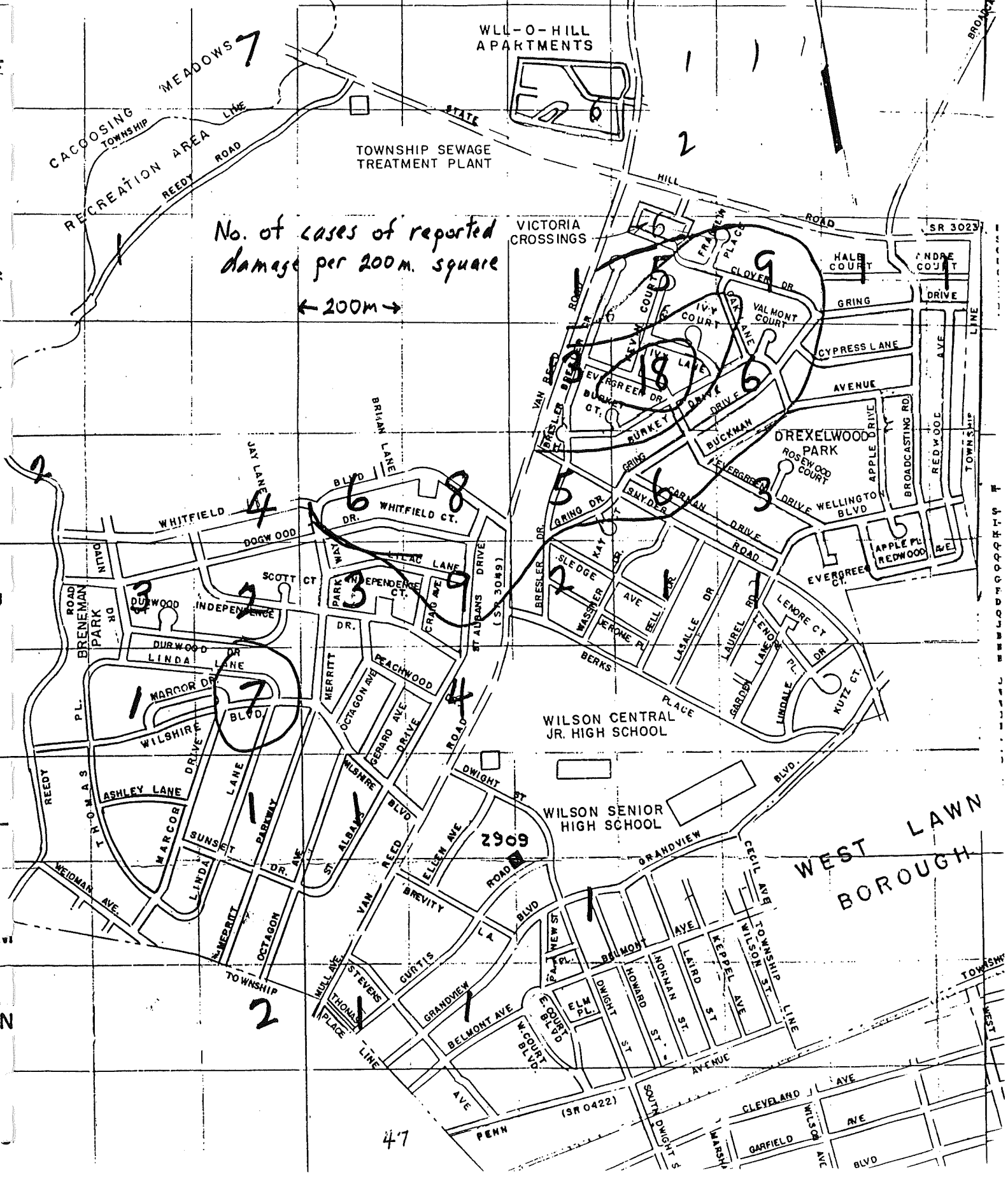
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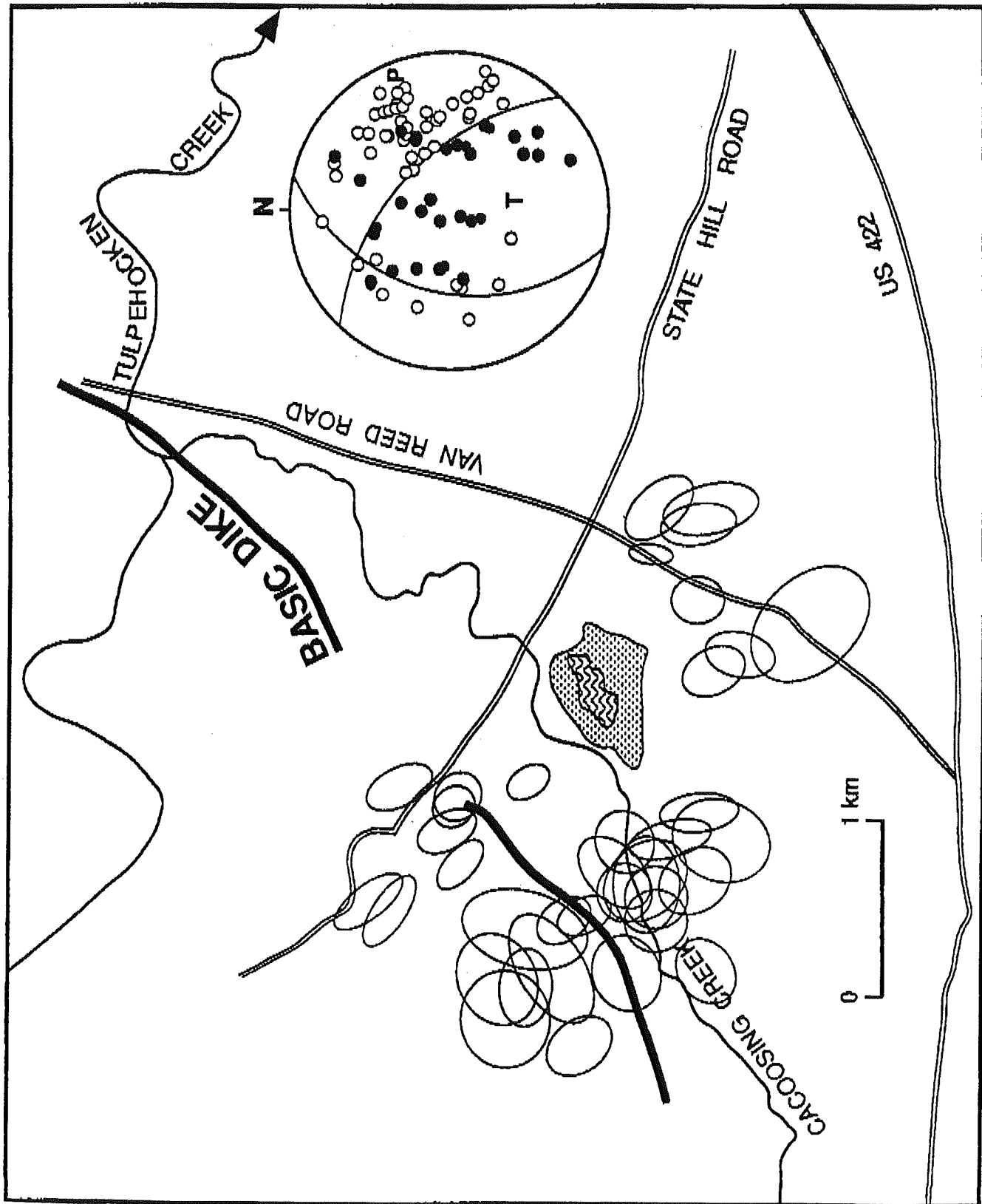
- B-14 Stone Hill Farms townhouses
- E-6 Will-O-Hill Apartments
- T-5 Wilson Townhouse Apartments
- G-7 Victoria Crossings Apartments
- J-2 Breneman Park
- F-2 Cacoosing Meadows Recreation Area
- B-13 Colony Park Playground
- S-7 Cornwall Terrace Playground
- I-8 Drexelwood Park
- R-8 Midvale Manor Playground
- P-9 Red Caboose Park



No. of cases of reported damage per 200m. square

← 200M →

WEST LAWN BOROUGH



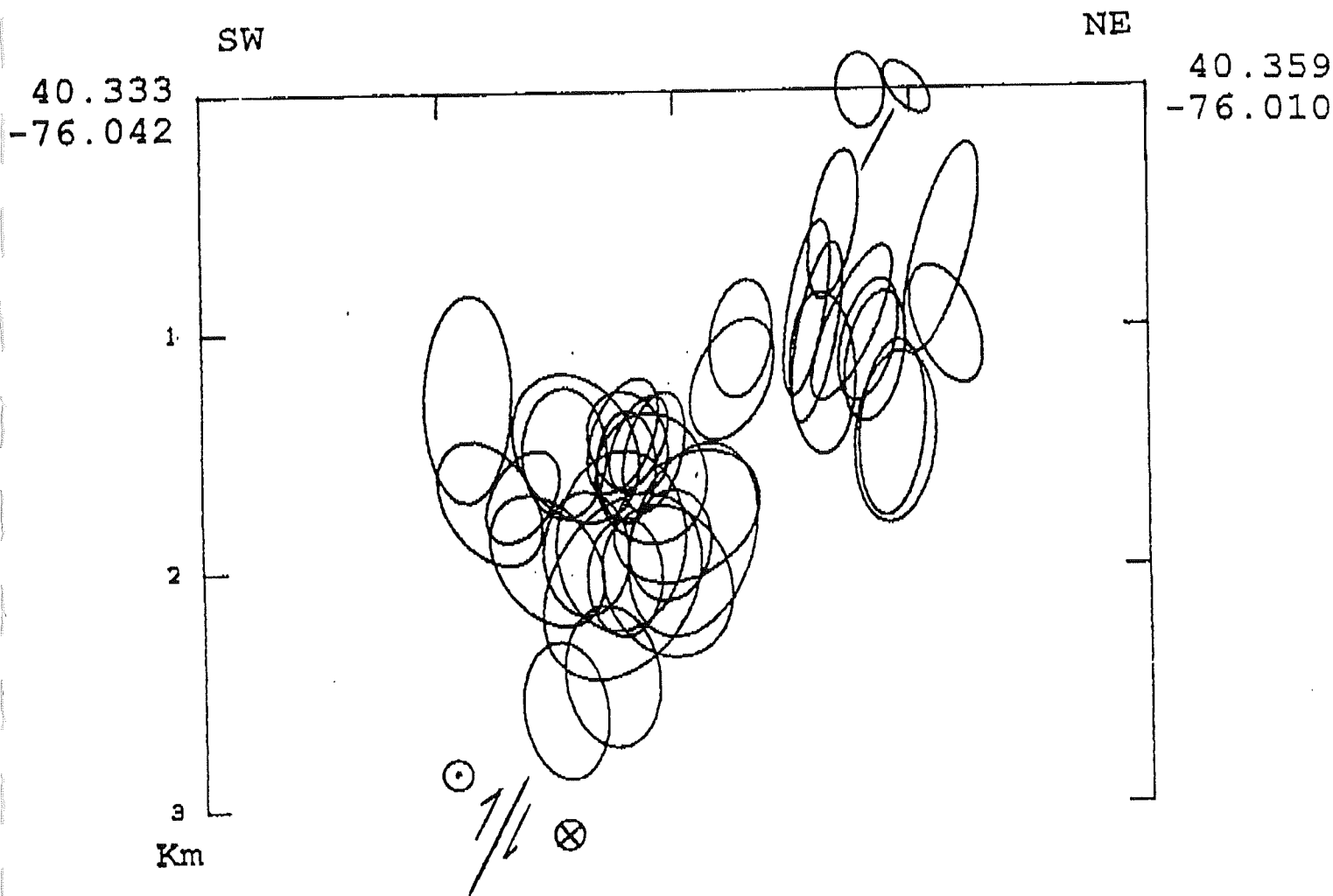


Figure 2. SW-NE cross section of earthquake aftershock locations from Figure 1. Pattern of hypocenters indicates the SW dipping plane is the fault plane.

BRIEF DESCRIPTION OF OUTCROPS ON THE NORTH SHORE OF
TULPEHOCKEN CREEK JUST BELOW ITS CONFLUENCE WITH
CACOOSING CREEK, BERN TOWNSHIP, BERKS COUNTY

The exposures here, along Blessing Lane and in an abandoned quarry, provide an opportunity for examination of three very different bodies of rock: 1) limestone of the Ordovician Ontolaunee Formation, 2) a Late Triassic or Early Jurassic diabase dike displaying spectacular horizontal columnar jointing, and 3) intensely folded and cleaved pelitic rocks of the Hamburg sequence.

The Ontolaunee Formation is exposed below road level near the canal towpath now used as a walking and cycling path. Clearly, there is a very abrupt contact between the Hamburg rocks (above) and the carbonate rock (below) just about at road level. MacLachlan (1983) describes the Ontolaunee Formation as follows: "Predominantly medium-dark-gray, finely crystalline dolomite in 30- to 60-cm (1- to 2-ft) beds. Massive to faintly laminated; weathers grayish yellow. Variably dolomitized beds of medium-gray limestone are abundant, especially in lower part of section. Dark-gray chert in beds up to 1 m (3 ft) is present at base. Thickness is 200 m (650ft)."

Very prominent in this exposure is a vertical diabase dike with horizontal columnar jointing. MacLachlan (1983) classifies this dike as York Haven type, meaning that it is a continental tholeiite. Note the holes left by paleomagnetists, sometimes known as paleomagicians, who have practiced their occult arts here.

The Hamburg rocks are exposed in outcrop along the north side of the road, just uphill from the parking area. MacLachlan (1983) has mapped the rocks here as part of Lithotectonic Unit 6, which he describes as follows: "Greenish-brown siltstone, claystone, and shale.... The age of this lithotectonic unit is indefinite, probably Early Ordovician. Rocks of this type occupy the sixth highest position in the allochthonous Hamburg sequence thrust slice complex north of this mapped area."

MacLachlan (1975) notes that the concept of a "Hamburg klippe" goes back to Stose and Jonas (1927). These rocks probably represent a clastic facies, in part equivalent in age to the Martinsburg Formation and in part older, that was emplaced above the Martinsburg and the carbonate rocks of the Great Valley during the Taconic orogeny. MacLachlan (1975) writes: "Contact relations between the Martinsburg Formation and elements of the Hamburg sequence have not been established through its full extent. In the Sinking Spring quadrangle, and probably at least throughout Berks County, Stose's Hamburg klippe appears to be a real entity in which a previously formed complex of early thrust slices was emplaced substantially as a unit in or on the Martinsburg Formation of the Lehigh Valley sequence prior to major deformation of the Irish Mountain nappe." The Irish Mountain nappe is the second of four major Paleozoic nappes which are thought to be present in the complex structure of the Great Valley.

Farther up the road, almost at the curve, is what appears to be an outcrop of Ontolaunee Fm. Curiously, the dike is not apparent in this upper exposure, but it may lie beneath the concealed zone between the Hamburg and Ontolaunee outcrops.

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ON TOP OF MT. PENN

Upon arriving at the crest of Mt. Penn, a visitor is greeted immediately by the surprising sight of a seven-story Japanese pagoda. Well, it would be surprising if one hadn't already seen its silhouette dominating the skyline from the city below. The story of the pagoda is a fascinating one. It was built in 1907-08 by James Matz and his son Charles for William Abott Whitman, a Reading politician and entrepreneur. Whitman claimed that the Pagoda was a copy of Nagoya Castle in Japan, but the design is more of a whimsical original, possibly thought up by Charles Matz, who had recently returned from the Far East. Whitman hoped to open a restaurant in the pagoda, but his application for a liquor license was denied. After the bank foreclosed on the property in 1910, it was bought by businessman Jonathan Mould and given to the citizens of Reading. During World War II, when anti-Japanese sentiment was running high, the pagoda narrowly escaped being razed by patriotic Readingites only because a pro-pagoda faction managed to convince everyone that the structure was Korean, not Japanese! Meanwhile, Nagoya Castle was leveled by American bombs. Today, the pagoda serves as a meeting place and observation tower, and as the premier symbol of Reading, after the railroad. (The information in this paragraph was taken from the article "East of Reading" by Alicia Rodriguez that appeared in the magazine Historic Preservation.)

On a clear day, the visitor to the summit of Mt. Penn can look out over five geologic provinces, counting the one he or she is standing on. These are, from south to north, the Triassic "Lowland" (hardly "low" here), the Great Valley, the Reading Prong, the Hamburg klippe, and the Ridge and Valley province.

Stose (1935) was the first to propose that the Reading Prong was allochthonous, a suggestion which led to a long and sometimes bitter dispute with Professor Benjamin Miller of Lehigh University. Today, the consensus seems to be that the Precambrian high-grade metamorphic and igneous rocks of the Reading highlands have indeed been thrust over the Paleozoic carbonates of the Great Valley. MacLachlan's (1973) cross-sections show basement rocks overlying the Paleozoic section on the Gring's Hill thrust, with the basal Cambrian Hardyston Quartzite, which nonconformably overlies the gneisses, overturned on the lower limbs of basement-cored, northward-verging recumbent folds.

The outcrops near the pagoda are of Hardyston Quartzite, apparently right-side-up at this locality. The Hardyston is described in the paper which follows this page, reproduced here by kind permission of the Rutgers University Press from Geology of Selected Areas in New Jersey and Eastern Pennsylvania and Guidebook of Excursions (S. Subitsky, ed.), 1969, a volume prepared for the G.S.A. meeting in Atlantic City that year. An abandoned quartzite quarry is located just below the pagoda.

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PETROLOGY AND ORIGIN OF THE HARDYSTON QUARTZITE (LOWER CAMBRIAN) IN EASTERN PENNSYLVANIA AND WESTERN NEW JERSEY¹

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ABSTRACT

The Hardyston Quartzite contains a varied lithic assemblage that consists principally of feldspathic sandstone, arkose, and orthoquartzite, with lesser quartz pebble conglomerate, silty shale, and, locally, jasper. The unit is about 100 feet thick and forms the base of the Paleozoic section in eastern Pennsylvania and western New Jersey, where it overlies Precambrian crystalline rocks of the Reading Prong and is in transitional contact with the superjacent Leithsville Formation of Early to Middle Cambrian age.

The textural fabric of the Hardyston is broadly graded. Discontinuous, lenticular beds of quartz pebble conglomerate and coarse, poorly sorted arkose are common in the lower part of the Hardyston. The upper part is composed of finer, better sorted arkosic sandstone, orthoquartzite, and silty shale.

Field and petrographic studies show that the Hardyston detritus was derived from a high-grade igneous and metamorphic terrane essentially similar to the Reading Prong. Mineralogy and textures indicate that the source was quite local, probably the Reading Prong itself.

The Hardyston probably is both alluvial and marine in origin. Poorly-sorted angular arkosic detrital material (represented by the lower part) formed an alluvial apron on the low-lying flank of a shield of Precambrian rocks (the Reading Prong). These deposits were partly reworked and augmented by better sorted orthoquartzitic marine

deposits (upper Hardyston) of an advancing Early Cambrian sea.

INTRODUCTION

The Hardyston Quartzite is about 100 feet thick and forms the base of the Paleozoic section in eastern Pennsylvania and western New Jersey, where it unconformably overlies Precambrian crystalline rocks of the Reading Prong. It has, of course, been recognized and mapped since the beginning of geologic work in the area, but all the early work and much of that done more recently, was concerned with problems of stratigraphic definition and mapping and the resultant structural and tectonic implications. Little attention has been given to the Hardyston as a unit of sedimentation that records important aspects of its history not normally available simply by mapping.

This paper summarizes briefly the current state of knowledge concerning the Hardyston, with particular emphasis on petrography and petrology. It results from some of the writer's recent work in the area. Most of the data were obtained from exposures in the Nazareth quadrangle, Pa. (fig. 1), and the quadrangles immediately east and south (Easton, Bloomsbury, Hellertown, and Riegelsville), but important localities in other quadrangles also were studied.

I am grateful to A. A. Drake, Jr., and R. B. Mixon, U. S. Geological Survey, for their very constructive technical reviews of this paper, and particularly to Drake, my coworker in this area, for several years of penetrating discussion of the structural, stratigraphic, and petrologic problems.

¹Publication authorized by the Director, U. S. Geological Survey.

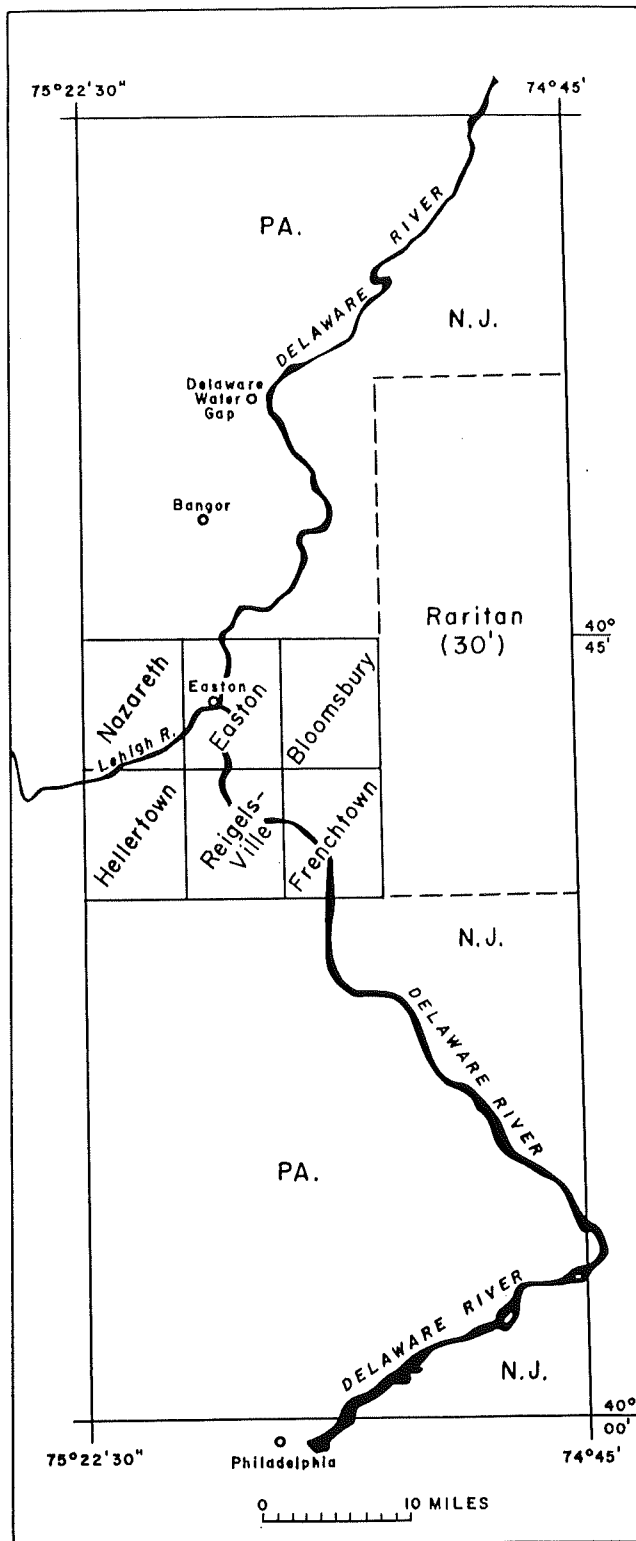


Figure 1. Location of area and quadrangles described in this report.

NAME

The Hardyston Quartzite was named for Hardistonville (Wolff and Brooks, 1898), a village near Franklin Furnace, Sussex County, N. J., where it is particularly well exposed. The name was shortened to Hardiston (Kümmel and Weller, 1901), the township name, which later was changed to Hardyston.

Formerly, the unit has been designated as Formation I of the lower Secondary rocks (Rogers, 1838), the Primal White Sandstone (Rogers, 1858), and the Potsdam sandstone (Prime, 1883). The discovery that the Potsdam sandstone in New York State (Van Ingen, 1902; Weller, 1903) was much younger than rocks called Potsdam in New Jersey and Pennsylvania led to the abandonment of the term in the latter areas.

DISTRIBUTION

The Hardyston Quartzite commonly is closely associated with Precambrian rocks, not only for obvious stratigraphic reasons but for structural reasons as well. Mapping in the area has shown that even where Precambrian rocks are allochthonous and far-traveled, the Hardyston usually is carried along. The same is rarely true for the younger carbonate rocks that overlie the Hardyston. Thus, Hardyston is exposed or present as float on one or both flanks of most of the Precambrian ridges in the area. Figure 2 summarizes the distribution of the Hardyston in the quadrangles on which the bulk of this report is based.

LITHOLOGY

The Hardyston Quartzite contains a rather varied assemblage of lithic types, principally feldspathic sandstone, arkose, and orthoquartzite, with lesser quartz-pebble conglomerate, silty shale, and, locally, jasper. Carbonate rocks occur in the Hardyston in New Jersey. There is a broad textural gradation within the Hardyston; conglomerate and coarse sandstone are more common at or near the base and shale is more common at or near the top. These are not generally mappable as stratigraphic subdivisions, however.

Arkose and feldspathic sandstone are light gray to very light gray and orthoquartzite is grayish orange-pink; all weather to moderate brown or moderate yellowish-brown (all rock-color designations determined from Rock-color chart (Goddard, 1948). Conglomerates are composed largely of iron-stained light- to dark-gray granules and pebbles of quartz and feldspar in a dark, poorly sorted, argillaceous matrix of finer quartz and feldspar.

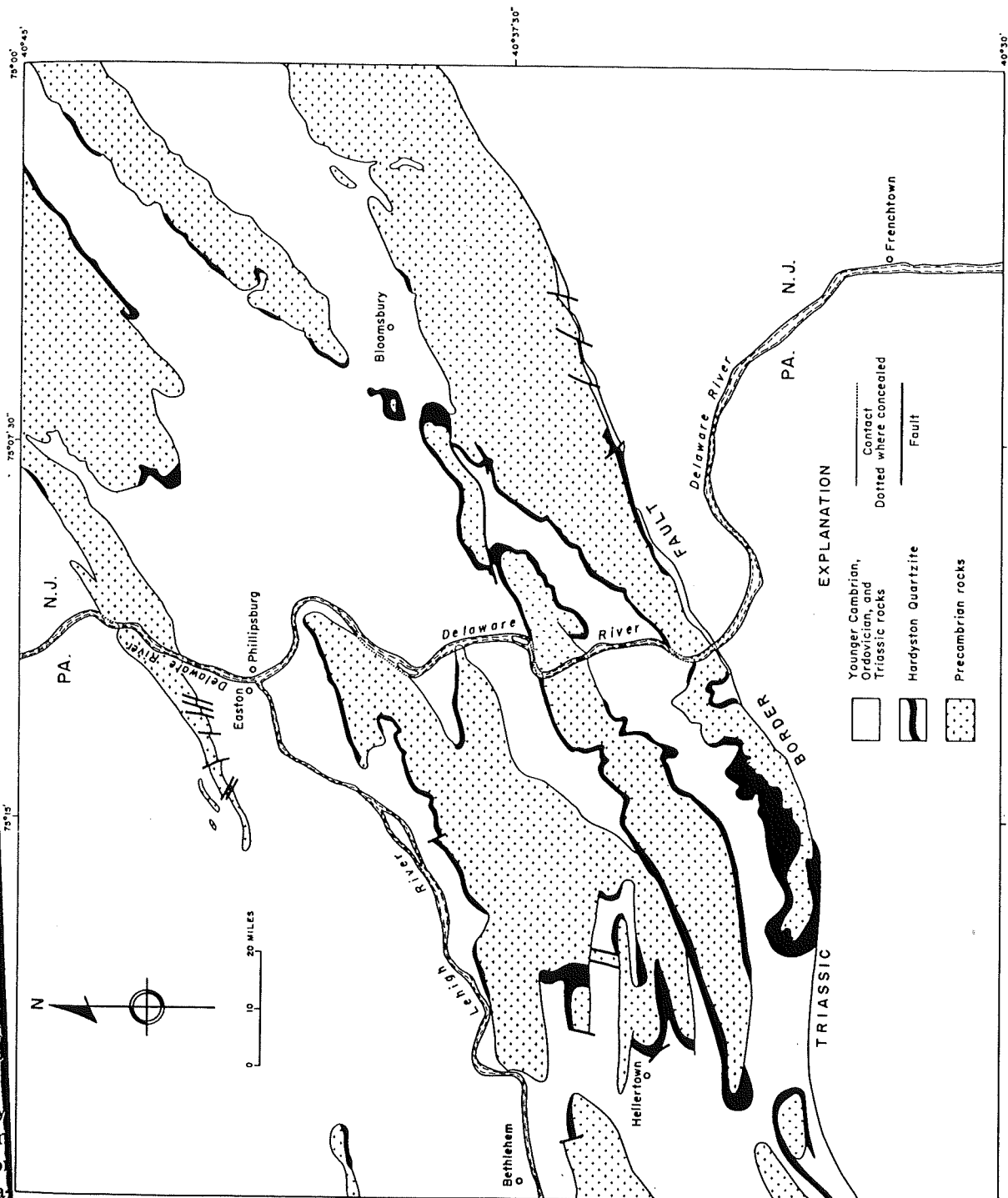


Figure 2. Generalized bedrock geologic map showing distribution of Hardyston Quartzite in part of eastern Pennsylvania and western New Jersey (in the quadrangles outlined in fig. 1). Data compiled from: Drake, 1967a, b; Drake and others, 1961, 1967; Miller and others, 1939, 1941; Willard and others, 1959 (Hellertown quadrangle); and J. M. Aaron, unpub. data (Nazareth quadrangle).

The granules and pebbles range in maximum diameter from 2 mm to 100 mm but most are less than 50 mm. They are subangular to subround, and the larger ones are platy to elongate. Shales are pale red or pale yellowish-brown, weather moderate yellowish-brown, and are silty and sandy. In all rock types, quartz grains are vitreous light to dark gray, but vitreous blue quartz is abundant locally. Pyrite is commonly a conspicuous constituent; it occurs as a fine "dust" (0.1 mm diam.) widely disseminated throughout individual hand specimens, or as larger (0.2 mm-0.5 mm) blebs and cubes.

Compositional stratification in sandstone and conglomerate typically ranges in thickness from 5 cm to 1.5 m, sometimes more, and in small exposures may be very difficult to locate. Stratification in all Hardyston rock types is irregular in thickness and rather discontinuous laterally, especially in the lower part. Cross-strata, small scale and planar, are present locally but the relative paucity of outcrops and the complexity of folding preclude meaningful systematic statistical study of them.

PETROGRAPHY

COMPOSITION

Modes, based on detailed examination of thin sections of representative Hardyston lithic types, are presented in table 1. Each mode represents ap-

proximately 400 counts. The total percentage of accessories is based on the point count, but the variety and relative abundance of these species is based on estimates by visual scan of the entire section and by examination of heavy-mineral separates from crushed rock.

Arkose and orthoquartzite are the end-member rock-types and all gradations exist between these rock-types, which have much the same character over the entire area.

MINERALOGY

Quartz. Quartz is the most abundant mineral in all Hardyston rock types, constituting from 33 to 80 percent of the rock (table 1). Most quartz is sand size and angular to subangular. Well-rounded quartz grains are rare.

Microscopic examination of thin sections reveals that almost without exception quartz in the Hardyston occurs as single grains with strongly undulose extinction (fig. 3A). The rare exceptions are composite grains with the same extinction. The predominance of this type of quartz strongly suggests that there was but a single source of the detrital quartz, most probably a high-grade metamorphic terrane. Moreover, in terms of microscopic morphology, the quartz in the Hardyston in no way differs from that of the several quartz-bearing gneisses and metamorphosed granitic

TABLE 1. MODES (VOLUME PERCENT) OF TYPICAL HARDYSTON ROCK TYPES

Field Number ¹	Arkose		Arkosic sandstone		Orthoquartzite	
	166-21	B-O-7-2	152-9	166-66	R-K ³ -32-C	166-48
Quartz	56.4	33.0	75.3	60.4	73.3	78.5
Potassium feldspar	20.4	15.0	10.3	12.0	3.3	1.0
Perthitic feldspars (all varieties)	4.8	16.7	4.7	4.8	—	1.3
Plagioclase	—	0.5	—	—	—	—
Silica cement	11.7	20.6	6.2	6.2	19.0	13.4
Clay and micromica	4.3	13.7	1.6	8.6	3.4	2.5
Accessories ²	2.4	0.5	1.9	8.0	1.0	3.3
Zircon	C	tr	tr	tr	tr	tr
Monazite	C	—	C	C	tr	tr
Sphene	tr	—	tr	tr	—	—
Tourmaline	tr	—	C	C	—	—
Garnet	—	tr	—	—	—	—
Rutile	—	—	tr	—	—	—
Topaz	—	—	tr	—	—	—
Hornblende	—	tr	—	—	—	—
Pyrite	tr	—	tr	C	tr	—
Magnetite	A	A	A	A	A	C
Limonite	C	C	C	C	—	C

¹ Nazareth quadrangle: 166-21, 152-9, 166-66, 166-48
 Bloomsbury quadrangle: B-O-7-2 (collected by A. A. Drake, Jr.)
 Reigelsville quadrangle: R-K³-32-C (collected by A. A. Drake, Jr.)

² Visual estimates of relative abundance of species in the detrital accessory fraction are limited as follows: A, 50 percent or greater; C, 10 to 50 percent; tr, 10 percent

rocks that underlie a major part of the Reading Prong in this area.

Feldspar. Feldspar is common to abundant in most of the Hardyston. The most abundant variety is potassium feldspar, mostly microcline with prominent grid twinning (fig. 3A). Feldspars having micropertthitic, mesopertthitic, or microantiperthitic structure are also common, and in some areas these collectively constitute the principal feldspar in the rock (for example B-O-7-2, table 1). Plagioclase, chiefly oligoclase, is rare.

All of the above minerals are common in the Precambrian rocks presently exposed in the Reading Prong. Surprisingly, however, plagioclase is much less abundant in the Hardyston than one might expect if the Reading Prong as it stands today were the ultimate source of the detritus, as plagioclase, chiefly albite-oligoclase-andesine, is quite abundant there. The dominant feldspars in the Hardyston are typical only of a small fraction of rocks in the Reading Prong. The predominance of the potassium feldspars must be due either to the relative unavailability of the plagioclase-bearing gneisses to erosion and transport, an unlikely possibility, or to the superior resistance and stability of the potassium feldspars. Differentiation of the latter sort is considered quite likely as there are clear examples of it in the coastal plain of New Jersey (J. P. Owens, oral commun., 1967). The possibility that the Reading Prong is not the source of the Hardyston detritus is considered highly unlikely in the light of other data to be presented.

The feldspar, like the quartz, is chiefly angular to subangular and most is of sand size not significantly different from the quartz. Although feldspars in transport should undergo a greater size reduction than quartz, the fact that quartz and feldspar are in the same size range in any given Hardyston sample is not significant because the feldspars probably were much larger initially (fig. 4D, for example).

The feldspars are fresh to moderately altered, but on the whole remarkably fresh. Alteration of microcline consists of patchy areas of dusty brown cloudiness or turbidity, which conventionally is ascribed to kaolinitization, but which also may be due to vacuolization or bubble formation (Folk, 1961). In no case, however, are microcline grains reduced to a mass of micromica or clay. The alteration is always of minor volumetric importance. Perthitic feldspars are altered differentially according to the composition of the exsolution lamellae (fig. 3B). Sodid lamellae are weakly to mod-

erately altered to sericite; the potassic lamellae are quite fresh or are altered weakly in the fashion described for microcline. Plagioclase is weakly to moderately altered to sericite.

Clay and micromica. Clays and micromica are minor constituents of the Hardyston, constituting less than 5 percent of the sandstones and as much as 50 percent of the shales. These minerals are predominantly sericite-illite, principally derived by weathering of feldspars in the source area, and secondarily by diagenetic alteration of feldspars after deposition. There is a significant correlation between feldspar and clay content (table 1).

Magnetite and limonite. Magnetite is the most abundant heavy accessory mineral; it composes from 35 to 95 percent (by volume) of the heavy fraction, but averages about 50 percent of that fraction. Limonite, used here for poorly crystalline hydrated iron oxides of uncertain identity, is commonly associated with magnetite. Both occur as irregularly shaped grains and rare euhedral and subhedral crystals in the finer fraction of the sandstones and conglomerates. Limonite also occurs, though rarely, as very round opaque grains from 0.5 to 1 mm in diameter, and both the enclosing sand grains and the round limonite grains are very well sorted. These could possibly be pseudomorphs after glauconite as glauconite readily oxidizes under subaerial conditions. The magnetite is detrital, but much of the limonite is authigenic.

Pyrite. Pyrite is present in conspicuous amounts in some Hardyston sandstones but volumetrically it is a minor constituent. It occurs as cubes and irregularly shaped grains widely scattered throughout the sediment. Undoubtedly it is authigenic in origin.

Monazite. Monazite, an unusually common accessory in the Hardyston, is second in abundance only to magnetite and limonite. It occurs as colorless to pale yellow, angular to subround, subequant to slightly elongate sand- and silt-size grains. Subhedral and euhedral detrital grains are not at all uncommon (fig. 3D).

Although monazite is quite resistant to chemical destruction (Pettijohn, 1957), it is not notably resistant to abrasion (Friese, 1931; Cozzens, 1931). The angular, subhedral, and euhedral detrital grains suggest an extremely local source. Monazite is a common accessory in granites and pegma-



A



B

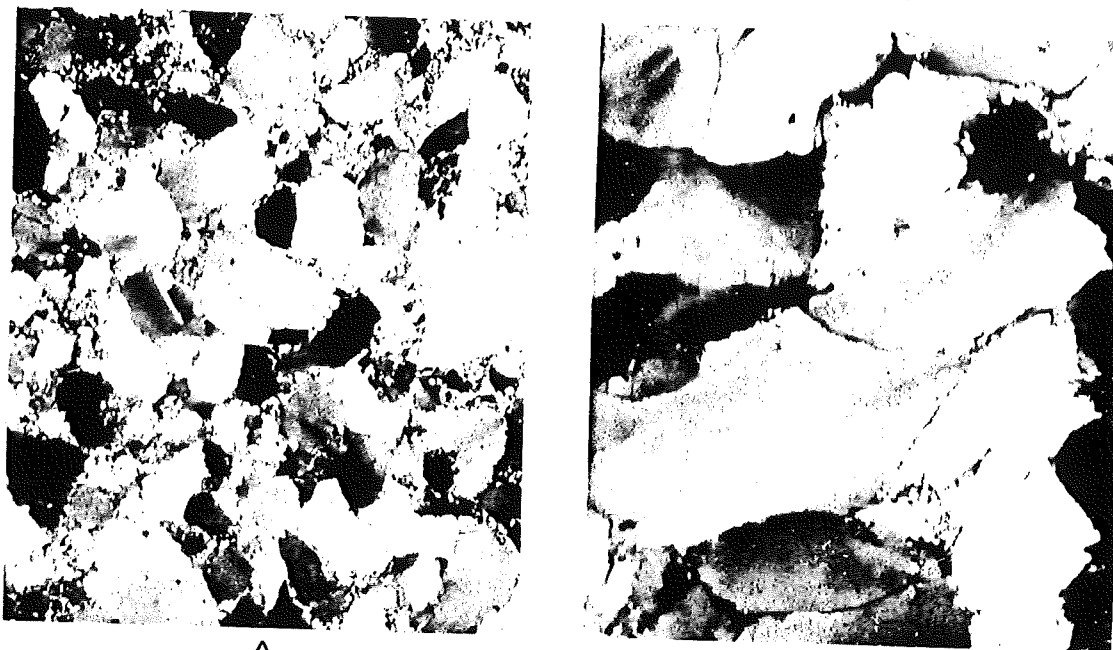


C



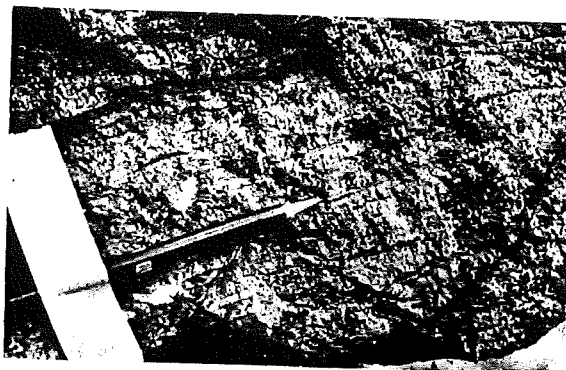
D

Figure 3. Photomicrographs showing some petrographic features of the Hardyston Quartzite. A, Arkose with quartz showing undulose extinction (q) and microcline (mi). Crossed polarizers, $\times 100$. B, Differentially weathered detrital mesoperthite grain. Lighter lamellae are potassium feldspar, darker are altered sodic feldspar. Crossed polarizers, $\times 100$. C, Authigenic feldspar overgrowth on detrital feldspar grain. Crossed polarizers, $\times 100$. D, Euhedral (above) and subhedral detrital monazite grains (m) with angular quartz grains. Crossed polarizers, $\times 100$.

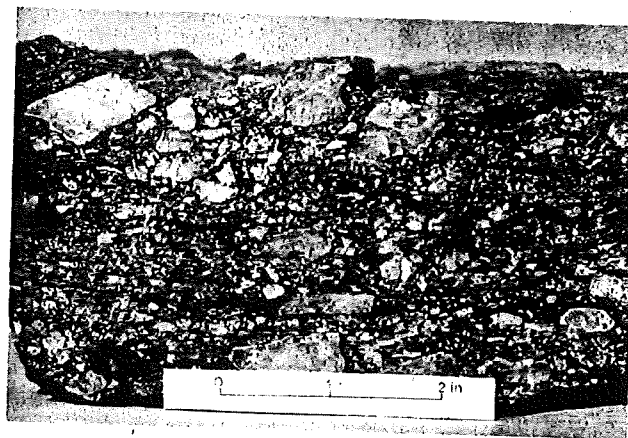


A

B



C



D

Figure 4. Photomicrographs and photographs of Hardyston Quartzite. A, moderately sorted, subangular to subround quartz and feldspar grains in clay and silica cement. Note nature and variety of grain-to-grain contacts and compare with figure 4B. Crossed polarizers, $\times 30$. B, Orthoquartzite showing sutured grain boundaries. Crossed polarizers, $\times 30$. C, *Scolithus* tubes in orthoquartzite. Pencil points to well-developed tube emerging from plane of outcrop. D, Typical conglomerate from lower part of Hardyston. Large clasts are potassium feldspar.

tites, both of which occur in the Reading Prong. Moreover, the prong is known to have at least one monazite-rich belt several miles long and several hundred feet wide within the gneissic terrane in New Jersey (A. A. Drake, Jr., oral commun., 1967); therefore, a local source for the monazite in the Hardyston is all the more probable.

Zircon. Trace amounts of zircon occur throughout the Hardyston. The grains are small (0.125–0.05 mm), colorless, extremely well rounded (in marked contrast to the monazite), and contain very few inclusions. Very probably the zircon is multicyclic and was derived from older metasedimentary rocks similar to those of the Reading Prong, the Canadian Shield, or even the Piedmont rocks to the east.

Tourmaline. Common in some specimens, virtually absent from others, tourmaline occurs in subequant to elongate, angular to rounded grains of medium to fine sand. The grains are strongly pleochroic but the colors are variable; typically, they range from very pale brownish-yellow to pale green (E) and from dark brownish-green to dark green (O). Neither inclusions nor zoning is present; the grains are clear. These color varieties would appear to be part of the dravite (Mg-rich)-schorlite (Fe-rich) series that occurs in granitic and metamorphic or metasomatic rocks (Deere and others, 1966). In the Reading Prong tourmaline is present in some gneisses and granites, and in Precambrian pegmatites.

Other accessories. Garnet, hornblende, rutile, sphene, and topaz are found in trace amounts in some heavy separates of the crushed rock. They

are very rarely seen in thin section and are not common enough to generalize or discuss their optical properties or occurrence.

TEXTURE

The microscopic textural fabric of most Hardyston specimens is generally homogeneous. The commoner exceptions are streaks and stringers of magnetite, clay, or mica, and larger grains of quartz and feldspar.

The degree of compaction or tectonic compression is indicated by the nature of grain-to-grain contacts. Most contacts range from straight to concavo-convex, suggestive of minor to moderate pressure solution (Adams, 1964). However, the entire range of possibilities, from sand grains "floating" in silica or clay cement to highly sutured grains, is present at one place or another in the Hardyston (figs. 4A, B).

Grain enlargement by secondary overgrowth on quartz and feldspar is common (fig. 3C). The material forming the overgrowths presumably is the result of diagenetic precipitation but it is no less conceivable that it was generated by pressure solution. Some of the most striking overgrowths, particularly on feldspar, occur in samples with abundant highly sutured grain boundaries. Abraded overgrowths have not been observed in the Hardyston.

Results of grain-size analyses using the microscope and sieve-size conversion methods developed by Friedman (1958; 1962) are summarized for four representative samples (table 2). Grain-size frequency distributions were determined by measuring the apparent long axes of grains in a thin-section and converting this apparent size to the equivalent sieve size according to Friedman's

TABLE 2. SUMMARY OF TEXTURAL PARAMETERS OF TYPICAL HARDYSTON ROCK TYPES

Field No.	Arkose 166-21	Arkosic sandstone 152-9	R-K ³ -32-C Orthoquartzite	166-48
Mean grain size (mm)	0.34 Medium sand	0.7 Coarse sand	0.37 Medium sand	0.5 Medium-coarse sand
Sorting	Poor	Very poor	Moderate	Moderate-well
Standard deviation (ϕ)	1.21	2.2	0.79	0.53
Skewness	Coarse	Strongly coarse	Nearly symmetrical	Fine
	(-0.23)	(-0.32)	(0.07)	(0.23)
Kurtosis	Very platykurtic	Platykurtic	Leptokurtic	Leptokurtic
	(0.61)	(0.72)	(1.20)	(1.25)
Textural maturity	Submature	Submature	Mature	Mature
Grain shape	Very angular	Angular	Subangular to subround	Subangular

regression equation. The highly indurated character of all Hardyston rock-types precludes grain-size analysis by more conventional means. Thin sections with abundant sutured grain boundaries were excluded from the size analyses. The moment measures, determined graphically according to the methods of Folk (1961), are the statistical parameters used to summarize the frequency distributions.

Grain shape, a complex function of original shape, internal anisotropy, composition, directional properties, and depositional history, was determined on quartz and feldspar in the Hardyston by estimation and comparison with the roundness scale of Powers (1953). Results are summarized in table 2. Roundness ranges from very angular to subrounded, but most sand-size grains are subangular to angular. Roundness sorting is fair to good, and there is no apparent variation in roundness with composition. Shapes (sphericity) do vary with composition, however, because feldspar grains commonly are bounded by cleavage surfaces.

Textural maturity (Folk, 1961) is a function of degree of winnowing (clay content), rounding, and sorting. Hardyston rock types range from immature (greater than 5 percent clay and fine mica) to mature (less than 5 percent clay, well sorted but not well rounded). The Hardyston, however, is most typically submature (less than 5 percent clay, but grains poorly sorted and poorly rounded).

The textural properties described above tend to vary with stratigraphic position. In general, detrital grains are coarser and more poorly sorted in the lower part of the unit. This is only a generality however, and cannot be used to determine the stratigraphic position ("upper" or "lower") of an isolated outcrop.

STRATIGRAPHIC RELATIONS

The Hardyston Quartzite unconformably overlies Precambrian crystalline rocks. The contact is seldom exposed, and a mapper usually must infer its presence and location from float.

Locally, in this area, the Hardyston-Precambrian contact is marked by a deposit of light-green cryptocrystalline material that has been called pinite (Miller and others, 1939; Virgin, 1956), a fine mixture of muscovite with some serpentine or chlorite mineral and iron oxides. Although this material has been interpreted as a metamorphosed remnant of a residual soil developed on underlying gneiss (Miller and others, 1939; Virgin, 1956), more probably it is simply a mylonite or shear zone at the Hardyston-Precambrian interface.

The contact with the superjacent Leithsville Formation is transitional through a series of silty and shaly beds. This contact is also very poorly exposed and commonly faulted. As with the Precambrian contact, the geologist is forced to muster all of his regional biases and intuition in order to locate it with precision.

THICKNESS

There is much uncertainty concerning the thickness of the Hardyston in eastern Pennsylvania and western New Jersey; outcrops are scarce, long sections are nonexistent, and contacts are commonly faulted.

In the Delaware Valley the Hardyston is reported to be as much as 200 feet thick (Johnson and Willard, 1957). Miller (1939) reported a range of 0-200 feet in the Lehigh Valley. Mapping and construction of geologic cross-sections by Drake (1967), Drake and others (1967) and by the writer (unpub. data, Nazareth quadrangle) support a thickness of no more than 100 feet in these quadrangles. A section 45 feet thick was measured at low water in the Delaware River in the Riegelsville quadrangle (see Drake, this volume).

In the many areas where the Hardyston is reported as missing from its stratigraphic position, faulting is undoubtedly responsible. There is no unequivocal field evidence to support erosion or nondeposition in these cases.

Regionally, the Hardyston thickens considerably southwestward along the Reading Prong. Buckwalter (1963) reports a thickness of 600-800 feet in the Womelsdorf quadrangle, at the extreme southwest end of the prong.

AGE

No fossils of conclusive chronologic significance have been found in what is currently mapped as Hardyston in eastern Pennsylvania. The only "fossil" in that area is *Scolithus linearis* (fig. 4C), found at a few localities in the Lehigh Valley. The taxonomic history of *Scolithus* is so diverse and its paleontologic significance so obscure that any interpretations based on it are questionable indeed. There are even opinions to the effect that what has been called *Scolithus* in some areas, including the type area at Chickies Rock, near Columbia, Pa., is not biogenic at all, but tectonic!

Olenellus thompsoni has been found in considerable numbers in calcareous beds of upper Hardyston at three localities in the Raritan quadrangle (fig. 1), New Jersey (Weller, 1903; Bayley and others, 1914). On this basis the Hardyston in

eastern Pennsylvania is considered to be Early Cambrian in age.

CORRELATION

In eastern Pennsylvania and adjacent New Jersey the Hardyston directly overlies the Precambrian igneous and metamorphic complex (table 3). It would appear, therefore, to correlate physically with the Hellam Conglomerate Member of the Chickies Quartzite of southeastern Pennsylvania, with the Weverton Sandstone and Loudoun Formation of south-central Pennsylvania and adjacent Maryland and Virginia, and with the Poughquag Quartzite of southeastern New York. All these units are basal clastics in roughly equivalent stratigraphic sections.

In contrast to this apparent physical correlation is the location of the lowest *Olenellus* horizon within the stratigraphic section at the above localities. This horizon is in the upper part of the Hardyston and Poughquag in New Jersey and New York, respectively, but southwestward to central Pennsylvania, Maryland, and northern Virginia, it is progressively 1,200 to 2,600 feet stratigraphically higher, in the Antietam Quartzite. Paleontologically, therefore, the upper part of the Hardyston would appear to be correlative with the Antietam.

What is the significance of this apparent paradox? Is there any more compelling reason to consider

the Hardyston necessarily coeval with the Antietam rather than with the Chickies and Weverton? What is the significance of the wandering *Olenellus*? How does the Hardyston fit into the regional stratigraphic picture of the middle Appalachians? An answer to these questions must be based on considerations of the probable origin of these units in terms of Early Cambrian stratigraphy, geography, and tectonics.

ORIGIN OF THE HARDYSTON QUARTZITE

The Cambrian stratigraphic sequences and lithostratigraphic correlations in the middle Appalachians are, for the most part, rather well known (table 3). However, strong and ever-mounting evidence of very complicated structural relations and tectonic history of these rocks greatly hampers attempts to produce an integrated system- and process-oriented sedimentation picture.

Recent work in the Great Valley by the U. S. Geological Survey (Drake, 1967a, b; Drake and others, 1967; J. M. Aaron unpub. data) and the Pennsylvania Geological Survey (Field Conference of Pennsylvania Geologists, 1966) has shown convincingly that much of the Cambrian and Ordovician sequence between the Susquehanna and Delaware Rivers is regionally inverted and allochthonous. These rocks are involved in large-scale nappes and are displaced westward, probably

TABLE 3. CORRELATION OF CAMBRIAN FORMATIONS IN THE EASTON AREA, PA.-N. J., AND NEIGHBORING AREAS

Age	Cumberland Valley, Pa. (Field Conf. Pa. Geologists, 1966) Autochthonous	Reading area, Pa. (Geyer and others, 1963) Allochthonous	Easton area, Pa.-N. J. (Drake, 1967a) Allochthonous	Eastern New York (Broughton and others, 1962) Allochthonous
Late Cambrian	Conococheague Group 2,150 feet	Conococheague Group 2,000 feet	Allentown Dolomite 1,700 feet	Stockbridge Group 4,000 feet
	Elbrook Formation 3,000 feet	Buffalo Springs Formation 1,000 feet		
Middle Cambrian	Waynesboro Formation 1,000 feet	Leithsville Formation 1,000 feet	Leithsville Formation 1,000 feet	
	Tomstown Formation 1,000-2,000 feet			
Early Cambrian	Antietam Sandstone 500-800 feet	Hardyston Formation 250-600 feet	Hardyston Quartzite 100 feet	Poughquag Orthoquartzite 250 feet
	Harpers Formation 2,750 feet			
	Weverton Sandstone 1,250 feet			
Precambrian	Volcanic rock	Gneiss	Gneiss	Gneiss

by as much as 35 miles. In contrast, rocks of similar age and gross character in the Cumberland Valley section of the Great Valley, west of South Mountain and southwest from the Susquehanna River, are autochthonous (Field Conference of Pennsylvania Geologists, 1966). Thus tectonic events have juxtaposed initially widely separated parts of the depositional basin, telescoping the original facies relations and obscuring the depositional strike. Whatever relation, if any, exists between the ancient predeformation facies boundaries and the present regional strike of the rocks is totally unknown. Thus, it is extremely difficult at this time to frame the origin of the Hardyston Quartzite in very meaningful paleogeographic terms.

Consideration of the physical and mineralogic properties of the Hardyston (table 4) does not necessarily lead to a unique solution regarding the origin of the detrital material and its environment of deposition. Ancient, complex, poorly exposed units of this sort, including its relatives throughout the Appalachians, do not have entirely convenient analogies among modern sediments. Modern sediments abound with cases in which the application of the interpretative principles that are conventionally applied to ancient rocks would produce conclusions that are diametrically opposite to what we know to be true by direct observation, i.e., interpretations of wind, water current, climate, source, etc. It is much easier, obviously, to understand sediment properties, types, and dispersal patterns when most of the controlling variables are reasonably well known. The reverse path, from sediment properties to the controlling variables, is infinitely more difficult, correspondingly more

speculative, and less reliable. Some reasonable generalizations, however, can be made about the Hardyston, and there are some possible implications which must await further work.

The detrital mineralogy of the Hardyston rather strongly indicates that the ultimate source of the material was a high grade metamorphic and igneous terrane essentially similar to the Precambrian rocks currently exposed in the Reading Prong. The textures of the Hardyston suggest that the source of the detritus was quite local, because even the detrital grains that should have undergone fairly rapid physical modification are little altered, i.e., little rounded and nonspherical. Indeed many crystal faces and forms are still preserved.

All the tangible evidence and the absence of any evidence to the contrary indicate that Hardyston detritus was transported and deposited in water. That at least the upper part of the Hardyston is marine is indicated by the very well-washed, well-sorted sands, the possible glauconite, and the presence of marine fossils in calcareous beds. The poorly-sorted, poorly-washed, laterally and vertically variable, unfossiliferous arkosic sandstones and conglomerates of the lower Hardyston may well be alluvial, however. The paleogeographic picture thus envisioned is one of an Early Cambrian sea gradually inundating the low-lying flank of a shield of Precambrian rocks, which were thinly veneered by a broad apron of alluvial deposits. The encroaching sea reworked the upper part of the alluvial material. Subsequent deposits (upper part of Hardyston) were better sorted, better washed, finer (as the shoreline became more distant), and less variable.

The presence of relatively fresh feldspars in the Hardyston raises some interesting questions about the climate and relief in the source area. It may indicate that the relief was great enough to allow streams to breach the mantle of weathered rock (if there was any), thereby exposing fresh rock to vigorous stream action. Although the lack of strongly altered feldspars of the same initial composition as the fresh would argue against this, there is the possibility that the altered material was virtually destroyed in transport. One clue as to the relief on the basement complex is found in the Blue Ridge of northern Virginia, near Luray, where the Catoclin Formation of Reed (1955) (upper Precambrian or Lower Cambrian volcanic rocks) rests on a granitic basement having a relief of as much as 1,000 feet. Presumably the geomorphic history of the basement complex in north-

TABLE 4. SUMMARY OF PROPERTIES OF HARDYSTON QUARTZITE

Composition: Mineralogy is very similar to subjacent Precambrian rocks, which are probable ultimate source. Quartz and microcline are principal minerals. Cement is both chemical and detrital. Faunal remains are absent to scarce and restricted. Little argillaceous material except in upper part. Authigenic limonite, pyrite, feldspar, and quartz.

Texture: Sorting is poor to moderate in lower part, moderate to good in upper. Rounding is fair to poor. Sand sizes predominate in all mineral species. Highly variable from outcrop to outcrop and from bed to bed.

Sedimentary structures: Crossbedded; exposures too poor to judge abundance reliably; no data on orientation. *Scolithus*(?) burrows in well washed sands. Beds tend to be lenticular and discontinuous, with erosional scour.

Internal organization: Irregularly asymmetric, with grain size decreasing stratigraphically upward. Conglomerates common in lower part.

Contacts and associated lithologies: Nonconformable basal contact. Upper contact transitional into silty shales and carbonates.

ern Virginia was not too significantly different from that of the basement in eastern Pennsylvania, but this is questionable. Another possibility is that the local climate simply was too dry or too cold to support chemical weathering; or perhaps climatic variations were seasonal and extreme, and whatever clays and micromicas formed in a given wet season were spalled away, along with fresh rock, by physical extremes in a thermally variable dry season, and washed away by the next round of torrential rains. If the latter were true, however, claystones ought to be more common throughout the Hardyston rather than virtually confined to the transitional zone with the overlying Leithsville. Or perhaps the clays were transported out of the immediate depositional area of the upper Hardyston by marine currents and were deposited farther from the shore.

Although the location of the source and the sediment dispersal patterns from it are more obscure than its petrologic nature, in all probability the Hardyston detritus came from a westerly or north-westerly direction, specifically a more extensively exposed Canadian Shield. Indeed, some paleogeographic reconstructions of the Early Cambrian (for example Lochman, 1956) place the shield well into eastern Pennsylvania even after partial marine submergence. Moreover, the Precambrian rocks of the Reading Prong itself probably were once part of the shield as the rocks of the prong are quite similar to those of the Grenville province of Canada and New York, and the Adirondacks, as noted by Engle (1956).

Studies of crossbedding in the Weverton Sandstone (Whitaker, 1955) and the Chickies Quartzite (A. Hohl, unpub. data, 1964), both at least partial equivalents of the Hardyston, indicate a westward source for these sediments. Both studies show paleocurrent azimuths trending east and southeast. Unfortunately neither has much to conclude about the probable origin of these units. Both are unfossiliferous and in both the variability of crossbedding orientations is rather low (75 percent of Whitaker's Weverton orientations are within 30° either side of due east), suggestive of an alluvial origin (Potter and Pettijohn, 1963). The plausible possible marine environments (beaches, bars, tidal basins, shallow-water marine) ought to produce either bimodal or more variable orientations (Pettijohn and others, 1965).

Other than the deposits of possible alluvial origin, the character, distribution, and age of the lowest Cambrian clastic rocks in eastern and central North America clearly record a westward-moving

marine transgression. The basal Cambrian sequence from southeastern Pennsylvania to southeastern New York is Early Cambrian (Howell, 1956; Fisher, 1956). In the Nittany Valley of central Pennsylvania, the oldest known Cambrian is the Waynesboro Formation of Swartz (1948) of Middle Cambrian age, which is believed to have a westward source (Rodgers, 1956). Along the southeastern flank of the Adirondack Precambrian mass and throughout the eastern and northern interior of the United States the earliest Paleozoic clastic rocks are Late Cambrian (Fisher, 1956; Lochman-Balk, 1956; Bell and others, 1956). Thus, the ubiquitous Cambrian clastic rocks basal to the Paleozoic in the eastern United States are time transgressive and decrease in age and thickness northward and westward. The Upper Cambrian clastic rocks of the central and eastern interior are viewed broadly as facies equivalents of the coeval shales and carbonate rocks of the eastern states, then far removed from shorelines and sources of coarse clastic sediment.

On a local scale, the Hardyston and Leithsville should not necessarily be considered in strictly "layer-cake" terms. They may indeed be partly contemporaneous facies equivalents, being no more than different parts of one and the same transgressive carbonate-orthoquartzite system. At any given Hardyston locality the superjacent Leithsville would, of course, be younger, with the contemporaneous Hardyston-equivalent Leithsville lying somewhat to the east. The transitional contact between these units and the presence of calcareous beds and scattered interbedded carbonate rocks in the upper part of the Hardyston are consistent with this interpretation.

SUMMARY AND CONCLUSIONS

Mineralogy and texture indicate that the Hardyston Quartzite is of essentially local derivation with both alluvial and marine aspects. The alluvial material is in the lower part of the unit and is poorly sorted, poorly rounded, feldspathic, conglomeratic, highly variable both laterally and vertically, and unfossiliferous. It originated as an alluvial mantle on the seaward flank of a Precambrian terrane of probable moderate relief. The upper part of the Hardyston is dominantly of shallow marine origin and is moderately to well-sorted, better rounded, cleaner, finer, less feldspathic, locally calcareous, contains *Olenellus*, and grades up into the overlying Leithsville Formation (dirty dolomite). The upper Hardyston and the Leithsville (along with the Antietam Quartzite-Tomstown

Formation) may be partly contemporaneous facies equivalents in a transgressive carbonate-orthoquartzite sedimentary system. Thus the Hardyston may be genetically related to both the Antietam (marine transgression) and the Weverton-Chickies (alluvium on Precambrian terrane).

Undoubtedly these inferences and speculations are simplified answers to old and complex questions. Although the outcrops are sparse and the data commonly are ambiguous, it is hoped, at the very least, that these problems will be pursued further until the pivotal evidence is found and critically evaluated.

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BASEMENT EXPOSURE AT ANTIETAM RESERVOIR

Now the hard rockers can have their day. This magnificent roadcut exposes Precambrian rocks of the Reading Prong. MacLachlan (1983) lists five varieties of basement rock in the Reading and Birdsboro quadrangles: 1) pegmatite, 2) quartz diorite gneiss, 3) granitic gneiss, 4) hornblende gneiss (including some pyroxene-rich varieties), and 5) graphitic gneiss. He notes that these rocks commonly occur as migmatites and closely interbanded gneisses. A transition occurs within this exposure from darker, hornblende gneiss migmatite at the north end, to lighter, granitic gneiss at the south end of the roadcut. In previous visits to this location, it has seemed to me (CKS) that if one views the southern portion of the cut from across the road, the suggestion of a synformal structure can be seen. But maybe this is just the result of an over-active imagination. What do you think? A good example of a fault surface with nearly horizontal slickenlines is present in the northern portion of the exposure.

Buckwalter (1975) describes these basement rocks in some detail and concludes that most, if not all, of the gneisses, except the granitic gneiss, are of metasedimentary origin. The granitic gneisses most likely have formed by granitization of the more mafic varieties.

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