# Geochemical Prospecting for Zinc, Lead, Copper, and Silver, Lancaster Valley, Southeastern Pennsylvania

GEOLOGICAL SURVEY BULLETIN 1314-C

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*By* JACOB FREEDMAN

CONTRIBUTIONS TO GEOCHEMISTRY

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*A search for geochemical anomalies and a study of dispersion patterns of zinc, lead, copper, and silver in the Lancaster area*

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[Plates are in pocket]

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# GEOCHEMICAL PROSPECTING FOR ZINC, LEAD, COPPER, AND SILVER, LANCASTER VALLEY, SOUTHEASTERN PENNSYLVANIA

By JACOB FREEDMAN

**ABSTRACT**

The objectives of geochemical prospecting during 1966 and 1967 in the Lancaster Valley of southeastern Pennsylvania were (1) to search for geochemical anomalies of zinc, lead, copper, and silver near old mines and prospects, (2) to study the dispersion patterns of metals, (3) to determine whether anomalous geochemical patterns indicate larger exploration targets than do the geological surface features present in the vicinity of mines and prospects, and (4) to determine whether dispersion patterns could provide information on underlying structures in areas of no outcrop.

The Lancaster area is underlain predominantly by carbonate rocks that have been disrupted by imbricate thrusting and folded into nappes. The rocks are mainly of early Paleozoic age, but locally there are Triassic sedimentary rocks and intrusive diabasic dikes. A thick podsolized, residual immature to mature soil profile has developed above bedrock; consequently the bedrock is poorly exposed.

A geochemical reconnaissance was made of eight 7½-minute quadrangles near Lancaster. Two old mines, the Bamford zinc mine and Pequea silver mine, and the Gap prospect were sampled in detail. Samples from the three areas are anomalous in metal content.

At the Bamford zinc mine the ore minerals occur in Ledger Dolomite in two brecciated, steeply dipping beds 12 feet and 14–18 feet thick; these beds have been explored in several mine workings and shallow prospect pits. Near the surface, sphalerite and small amounts of galena have been oxidized to smithsonite, hemimorphite, cerussite, anglesite, and aurichalcite(?). Anomalous metal values in soils, rocks, and stream sediments from the area reach a maximum of 30,000 ppm (parts per million) zinc and 1,000 ppm each of lead and copper. The geochemical dispersion pattern is similar to that of plunging folds and suggests stratigraphic control of ore deposition.

At the Pequea silver mine, galena and minor quantities of sphalerite and chalcopyrite occur in quartz veins that range in width from veinlets to 6 feet. The veins are almost entirely in the Vintage Dolomite near and along the contact of the overlying black carbonaceous phyllite of the Conestoga Limestone. Near the surface, the primary ore minerals are oxidized to cerussite, anglesite, calamine, aurichalcite (?), and vauquelinite (?). The lead-zinc distribution pattern is characterized by isolated anomalies with values that reach a maximum of 1,700 ppm lead and 860 ppm zinc.

The vicinity of the Gap prospect is underlain by white sheared marble of the Vintage Dolomite and schistose quartzite of questionable affiliation. Chalcopyrite, sphalerite, and galena grains occur along vertical cleavage planes of these folded rocks. More extensive mineralization is indicated by anomalies in which values of zinc reach a maximum of 4,230 ppm and those of copper, 115 ppm.

Geochemical prospecting for silver in the Lancaster Valley can best be done by analyzing soil samples for the indicator elements, zinc, lead, and copper.

# INTRODUCTION

## PURPOSE AND SCOPE

This project was designed to search for geochemical anomalies of lead, zinc, copper, and silver in the Lancaster Valley of southeastern Pennsylvania. Principal attention was directed to the vicinities of the Bamford zinc mine and the Pequea silver mine, and to a prospect near Gap. Distribution patterns of geochemical anomalies found in these areas were studied to determine whether they indicate a greater extent of potentially mineralized ground than is indicated by other geological features. The relation of the distribution patterns to underlying rock units and geologic structures also was studied. Other mineralized occurrences were investigated, and a search was made for geochemical anomalies in previously unexplored soil-covered areas.

The geochemical exploration consisted essentially of collecting and analyzing samples of soil, rocks, and stream sediments. The exploration program was confined to the area shown in figure 1.

## FIELDWORK

Geochemical work in the area was initiated by G. E. McKelvey while a student at Franklin and Marshall College in the spring of 1966 (G. E. McKelvey, unpub. data). He collected 150 samples in the Gap area which were analyzed for copper and zinc by atomic absorption spectrophotometry at the U.S. Geological Survey. The writer started to work on the project in the eight 7½-minute quadrangles in June 1966. Fieldwork, collecting samples, and studying the geology of critical areas were continued through the summer and fall of 1966 and the spring of 1967. R. I. Grauch, on a student project during the summer of 1966, collected 205 samples and studied the geology of the Bamford area.

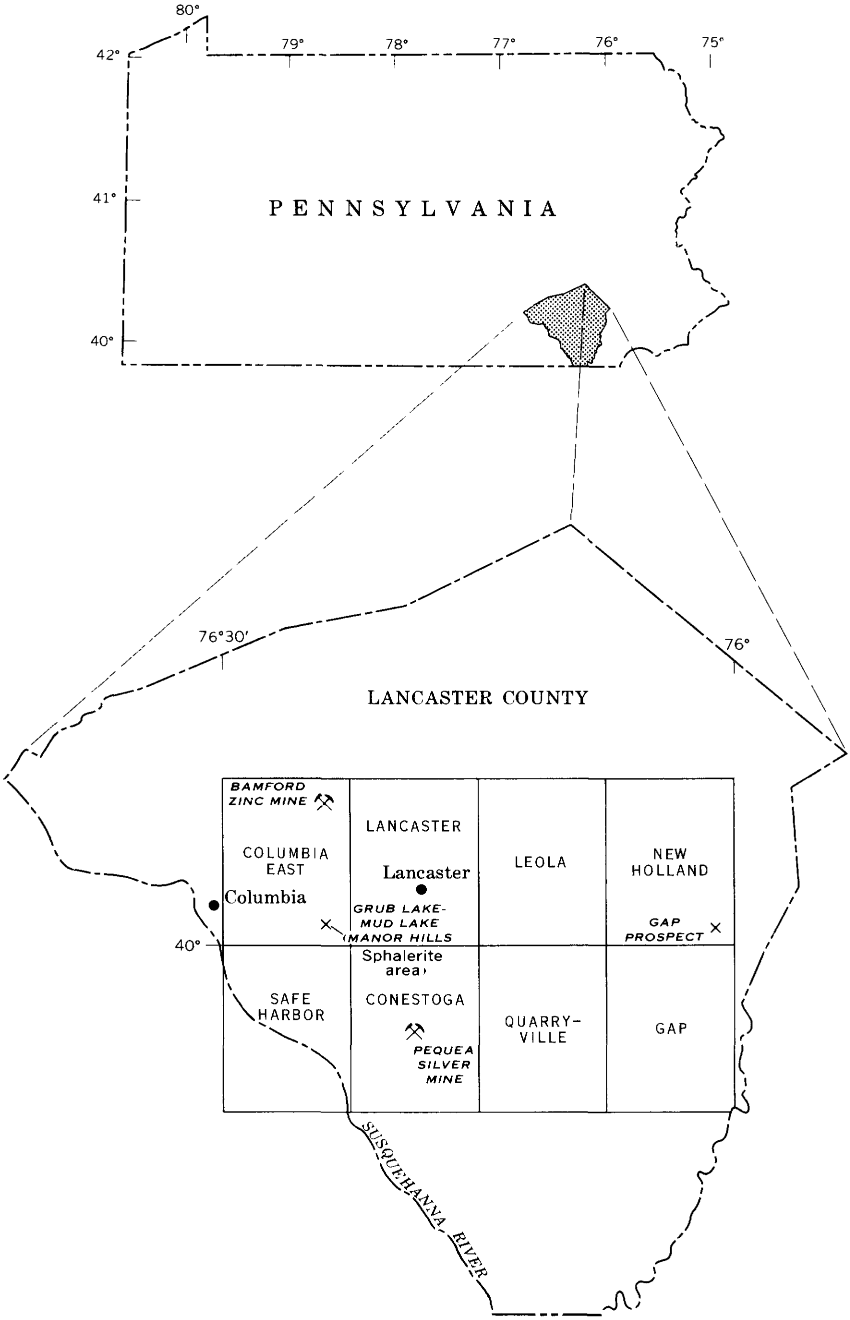


FIGURE 1.—Location of the eight 7½-minute quadrangles traversed and the principal mines and prospects studied.

## ACKNOWLEDGMENTS

The writer is indebted to a number of academic and professional colleagues. Allen V. Heyl, of the U.S. Geological Survey, stimulated my interest in the local mineral deposits and helped to evaluate the field data. Thor Kiilsgaard and Frank Canney, of the U.S. Geological Survey, were helpful in discussing the problems of the project. D. U. Wise, of the Geology Department, Franklin and Marshall College, discussed with the writer many details of the geology and supplied additional geologic data.

Analyses were made mainly at the U.S. Geological Survey, Washington, D.C. F. S. Grimaldi and F. J. Flanagan were most cooperative in making arrangements for and supplying analyses of samples. W. B. Crandell, J. L. Harris, P. J. Aruscavage, J. W. Budinsky, J. C. Chandler, C. L. Burton, G. J. Daniels, F. O. Simon, Leonard Shapiro, and M. M. Schnepfe, analysts, and Kam Wo Leong, A. W. Helz and Irving May, ran analyses on the numerous samples.

Appreciation is extended to the innumerable property owners for allowing the writer and his colleagues to work on their lands.

J. L. Warner, of Franklin and Marshall College, composed a computer program for analyzing the field and laboratory data. Walter Martin, computer technician of the IBM 1130 at Franklin and Marshall College, ran the program to provide data for the frequency curves. Helmuth Wedow, of the U.S. Geological Survey, analyzed the data and prepared the histograms shown on the various illustrations.

## PREVIOUS STUDIES

The abundant literature on the geology of Lancaster Valley, Pa., includes many reports on the Bamford zinc mine and on the Pequea silver mine. Very little information has been written, however, on the numerous smaller lead-zinc prospects in the valley.

Previous investigations of the Bamford area span the period from 1845, when a fence builder turned up lumps of ore in a post hole, to the present. Genth (1875) visited the Bamford zinc mine and identified minerals. Frazer (1880) visited the mine in July 1876 during its productive stage. In addition to checking surface and mine exposures, he described the mine workings and the plant and quoted average daily production figures. He also obtained a sketch of the mine from E. Gybbon Spilsbury, superintendent of the mine from 1875 to 1877. Landis (1904) outlined the progressive events in the finding, development, and demise of the mine. Brown and Ehrenfeld (1913) listed the minerals at the mine and Siebenthal (1919) gave mine production figures from 1873 to 1876 inclusive. Gordon (1922) identified minerals at the mine, and Miller (1924) reviewed the mine's history and production.

Jonas and Stose (1930) mapped the geology of the area. Mosier (1948) described four diamond-drill holes put down at the Bamford zinc mine by the U.S. Bureau of Mines, and Arnold L. Brokaw (unpub. data, 1947) logged the drill core. Cannon (1947) found species of vegetation that were tolerant of large quantities of zinc and found other species that were stunted by excess zinc in the soil. She also sampled waters in nearby streams for heavy-metal content. Minerals at the Bamford zinc mine were listed by Beck (1952), and Carey (1959) made a detailed study of the numerous soil types in Lancaster County. Robert S. Kier (unpub. data, 1965) concluded that the local red soils in Lancaster County were formed during a previous warmer climate. Dahlberg and Keith (1966) studied the distribution of trace elements in stream sediments in southeastern Pennsylvania.

R. I. Grauch (unpub. data, 1966) investigated the geology and collected soil and stream-sediment samples at and in the vicinity of the Bamford zinc mine. Meisler and Becher (1966) reported on the hydrology and quality of waters in the carbonate rocks of the Lancaster 15-minute quadrangle and prepared a geologic map of the quadrangle at a scale of 1:24,000 (Meisler and Becher. 1968, 1970). Keith, Cruft, and Dahlberg (1967) sampled stream sediments throughout southeastern Pennsylvania for trace metals.

Eckman (1927) and Price (1947) presented historical information on the Pequea silver mine. The mine was mapped by Foose (1947) and Wise and Kauffman (in Field Conference of Pennsylvania Geologists, 1960).

The geology of the Gap area was mapped by Jonas and Stose (1926). The Gap area prospect was discovered by W. B. Satterthwaite and R. E. Wright (unpub. data, 1958) during their investigation of the vicinity, and the geology was restudied by Steven Curran and John Gucwa (unpub. data, 1967).

Sphalerite in the Manor Hills area was reported by Jonas and Stose (1930). J. W. Kauffman and R. H. Lowright (unpub. data, 1962) restudied the geology and reported sphalerite in one of their rock samples.

## GEOLOGY

### REGIONAL SETTING

Lancaster County can be divided into three geologic terranes.

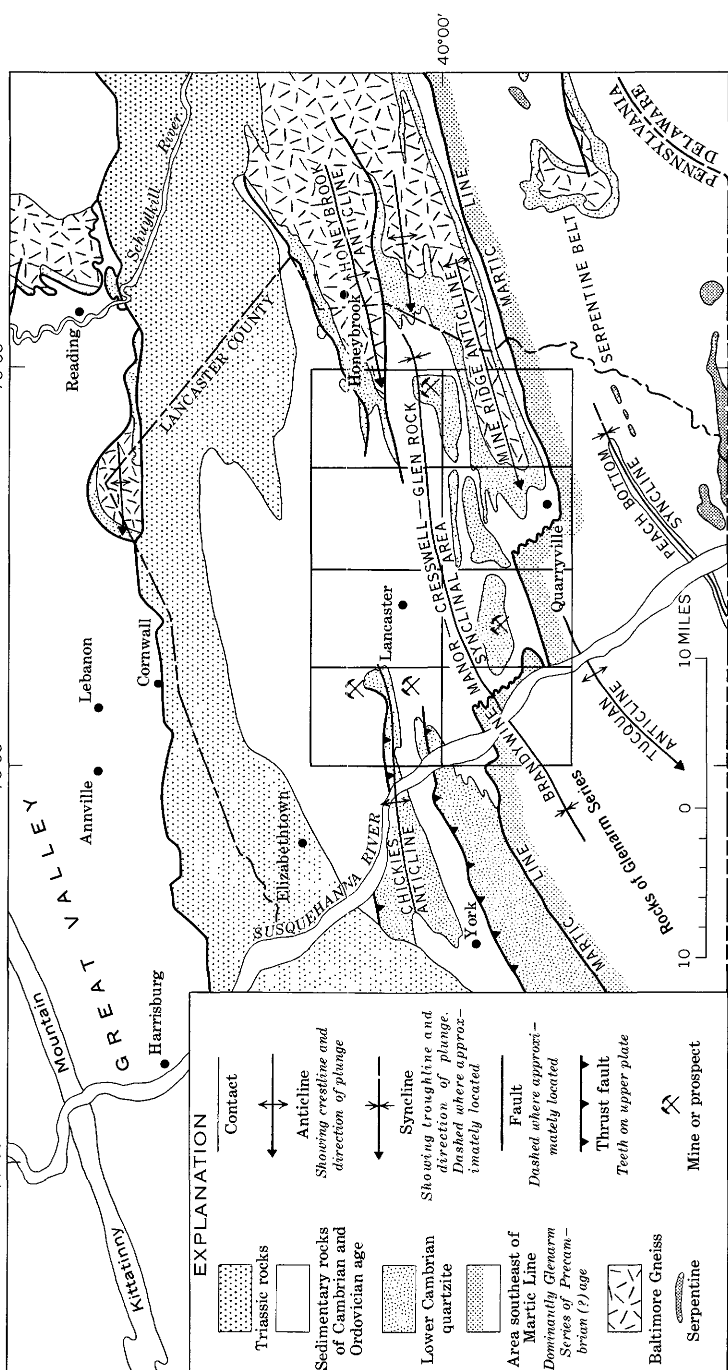


**FIGURE 2.**—Generalized geologic map of Lancaster County and adjacent areas in Pennsylvania. Modified from Stose and Stose (1944). See figure 1 for names of quadrangles and mine areas.

The rocks underlying the southern part of the county (fig. 2) are dominantly schists, phyllites, and quartzites of the Precambrian(?) Glenarm Series (Knopf and Jonas, 1929a). The central part consists of lower Paleozoic clastic and carbonate rocks. These rocks have undergone multiple deformations which locally have brought older rocks to the surface. The northern part is underlain by gently dipping block-faulted Triassic continental red beds which are injected by diabasic sheets.

### BALTIMORE GNEISS

The Baltimore Gneiss, in the interior of the Mine Ridge anticline, is Precambrian in age and unconformably underlies the Lower Cambrian Hellam Conglomerate Member of the Chickies Formation. Knopf and Jonas (1929b) considered the Baltimore Gneiss a metasedimentary rock. The upper layers are composed of biotite-albite schist; this schist is underlain by biotitic, quartzose, and graphitic gneiss and is interlayered with biotitic hornblende schist and amphibolite. All parts of the gneiss have been injected lit-par-lit by light-colored granitic rocks.

### WISSAHICKON FORMATION

The Wissahickon Formation has recently been redefined by Southwick and Fisher (1967, p. 10–13):

> The Wissahickon Formation is redefined to include all rocks called Wissahickon Formation by Knopf and Jonas (1929a; 1929b) as well as rocks formerly termed Peters Creek Formation (Knopf and Jonas, 1929a), Sykesville Formation, and Laurel Formation (Hopson, 1964). It is subdivided into five mappable lithofacies which are (1) lower pelitic schist, chiefly a garnet-biotite-muscovite schist, derived from nonsandy argillaceous rocks; (2) boulder gneiss, derived from coarse-grained, chaotic submarine slump deposits and associated metagraywackes; (3) metaconglomerate, derived from gravels and coarse sandstones; (4) metagraywacke, derived chiefly from flyschlike, rhythmically interbedded graywacke and shale; and (5) upper pelitic schist, derived from argillaceous and silty rocks. Reduction of the Peters Creek, Sykesville, and Laurel Formations to lithofacies of the Wissahickon is necessary in order to retain the name Wissahickon Formation for the whole schist-metagraywacke complex of the Glenarm Series, a usage which is desirable in light of both previous usage and geologic relations. Reduction of these units also serves to emphasize their local character and to deemphasize their use in regional correlation.

Although correlation of the Wissahickon Formation in Pennsylvania with the same formation in Maryland has not yet been made, the lithofacies approach seems a more valid one than previous definitions. The age of the Wissahickon is Precambrian(?).

### CHICKIES QUARTZITE

The Chickies Quartzite is the basal Paleozoic formation in the area. It contains the Hellam Conglomerate Member at its base, which overlies the Baltimore Gneiss in outcrops on Mine Ridge. In York County the Hellam overlies Catoctin-type volcanic rocks and is a very thick and coarse unit that is composed principally of quartz pebbles and boulders. The Hellam thins eastward into an arkosic facies (Thomas Lane, unpub. data, 1968). Overlying the Hellam Conglomerate Member is thick white vitreous quartzite of the Chickies Quartzite, which in turn is overlain by sericitic quartzite interbedded with quartz-mica schist and quartz schist (Knopf and Jonas, 1929b).

### ANTIETAM SCHIST

The Antietam Schist crops out near each of the old mines and prospects. Cloos and Hietanen (1941, p. 11) did not distinguish between Antietam and Harpers Formations. Their petrographic description follows:

The Antietam schist is a light-gray to bluish mica schist with abundant biotite, muscovite, quartz, and albite. It varies between a fine-grained quartz mica schist and a coarse-grained albite-chlorite schist. Toward the top the Antietam schist becomes increasingly calcareous and grades into the overlying Vintage Dolomite. Thin, light-gray to yellowish dolomite beds appear, and bedding becomes more distinct. The zone of gradation is roughly 10 feet thick and can be studied in the Safe Harbor quarry where the whole sequence from the lower Antietam into the Conestoga limestone is excellently exposed.

The thickness of the formation cannot be determined because the base is nowhere exposed, and bedding can rarely be observed.

The quartz-mica schist is relatively resistant to erosion and forms prominent ridges. They may be many miles long and very straight like the one from the Susquehanna River to Refton. Where the schist forms large open folds, as at Conestoga, the ridges bend in crescent-like fashion.

Exposures of the schist series are abundant in many road cuts, gullies, and river banks. Larger exposures are in the Safe Harbor quarry, three-quarters of a mile east of Burnt Mills, where bedding and a large overturned fold can be seen, at Pequea Valley, in the Pequea Creek gorge, southeast of Conestoga, and many other localities.

### CAMBRIAN CARBONATE ROCKS

Most of Lancaster Valley is underlain by carbonate rocks of Cambrian age. The rock descriptions in table 1 are taken from Meisler and Becher (1968, p. G3). Units of particular importance because they are host rocks for mineral deposits in the study areas are the Vintage Dolomite at Gap, Pequea, and Manor Hills, and the Ledger Dolomite at Bamford.

### CONESTOGA LIMESTONE

The Conestoga Limestone, of Early Ordovician age, consists of varied lithologic units that overlie formations from Vintage Dolomite to the Conococheague Group. A basal black carbonaceous phyllite unit is present only overlying Vintage Dolomite (D. H.

TABLE 1.—*Generalized section of the carbonate rocks of Cambrian age in the Lancaster quadrangle*

[From Meisler and Becher, (1968, p. G3)]

| System | Formation | | Thickness (feet) | Character |
|---|---|---|---|---|
| Cambrian | Conococheague Group | Richland Formation | 0–500 ± | Limestone and dolomite, interbedded, gray; beds of fine conglomerate and calcarenite, rare cryptozoon. |
| | | Millbach Formation | 1,200–2,000 | Limestone, white to pinkish-gray and gray; scattered beds and laminae of gray dolomite. |
| | | Snitz Creek Formation | 300–400 | Dolomite, gray, argillaceous, silty, sandy. |
| | | Buffalo Springs Formation | 1,500–3,800 | Limestone and dolomite, interbedded, white to pinkish-gray and gray. Dolomite is commonly argillaceous, silty, sandy; scattered sandstone beds, cross laminae, ripple marks, rare cryptozoon. |
| | Zooks Corner Formation | | 1,600 ± | Dolomite, gray, commonly silty and sandy; little gray limestone, cross laminae, ripple marks. |
| | Ledger Dolomite | | 1,000 ± | Dolomite, light gray, mostly coarsely crystalline, sparkling, partly mottled. |
| | Kinzers Formation | | 300–600 | Shale, gray, rusty weathering; white to gray limestone commonly containing reticulated argillaceous and silty laminae; some dark-gray earthy dolomite. |
| | Vintage Dolomite | | 350–550 | Dolomite, gray, very finely to coarsely crystalline; locally contains interbedded limestone. |

Lehman and S. N. Thompson, unpub. data, 1968), although carbonaceous matter is found locally in units higher in the stratigraphic succession. An extensive conglomerate unit occurs at or near the base of the Conestoga Limestone. It is apparently an intraformational limestone conglomerate containing fragments as much as 8 feet in diameter. The most common occurring unit is a platy blue-gray medium-grained limestone containing local black phyllite interbeds which range from ½ to 2 inches in thickness.

Lehman and Thompson (unpub. data, 1968) described a unit of the formation: "The Schistose limestone is a medium-dark-gray, often pyritic, fine-grained, thinly laminated limestone interlaminated with phyllite. Weathering along the phyllitic laminae generally produces a somewhat punky surface. It commonly appears as a ridge former." They also described a banded limestone as "medium- to coarse-grained white crystalline marble and dark-gray limestone or phyllite in 2–3-mm-thick alternating even bands. The unit is 25 feet thick." Another unit that they mention is a coarsely crystalline, white to light-gray, thin-bedded to massive marble, which has a reddish tinge at places. It is generally less than 5 feet thick and appears as a marker unit near the base of the Conestoga in much of the Leola quadrangle. Still another unit is an arenaceous calcarenite that is typically a ridge-forming lithologic unit. This unit is near the base of the Conestoga Limestone. It is light to medium gray, specked with as much as 25 percent medium-sized quartz grains which weather out, and contains about 10 percent organic material. Higher in the section, it contains even more quartz, oolitic pellets, and probably dark algal organic nets.

The upper members of the Conococheague Group are missing in this section (pl. 1), and the Stonehenge Formation of the Beekmantown Group, the next formation to the north, contains shaly laminae and fossiliferous calcarenite beds (Meisler and Becher, 1968).

### SOILS

Lancaster County is underlain by a residual regolith in which the soil profiles vary in maturity. According to R. S. Kier (unpub. data, 1965), the red soils of the Lancaster area were formed during a previous warmer climate. He noted that under present cool climatic conditions the upper horizons of the red soils in the area are being podsolized and transformed in color from red to brown. Carey (1959), in his soil survey of Lancaster County, listed the soils in the Bamford area as belonging dominantly to the Duffield-Hagerstown association of residual soils which formed over Paleozoic sedimentary rocks. Detailed subdivisions of soils in the soil survey bear little or no relationship to the underlying rock type or to geochemical concentrations.

## STRUCTURE

The Lancaster Valley is underlain by Cambrian and Ordovician sedimentary rocks that have been folded into recumbent and open folds which have brought up basement rocks along anticlinal axes (fig. 2). The Precambrian(?) schist belt with serpentine intrusions lies just south of the folded sedimentary rocks. Further to the south are areas of granitization and (or) intrusion; extensive mantled gneiss domes in the Baltimore area show the effect of flowage.

### FOLDS

The major folds from north to south (fig. 2) are the Chickies anticline and the Honeybrook anticline, the Brandywine Manor–Cresswell–Glen Rock syncline, Mine Ridge anticline and its extension, the Tucquan anticline, and Peach Bottom syncline.

Chickies Ridge (fig. 2), underlain by Chickies Quartzite, is a complex anticlinal structure (Wise, 1965) that is asymmetric with northward overturn of axial planes. Minor folds plunge both east and west.

The Honeybrook anticline exposes Precambrian granitic and gabbroic gneisses flanked by Chickies and younger formations.

Lower Cambrian clastic and carbonate rocks occupy the Brandywine Manor–Cresswell–Glen Rock syncline. South of Lancaster these rocks form recumbent folds with horizontal axial planes which have been subsequently arched by later folding. Along the Tucquan anticline a similar kind of folding has been imposed on facies of the Wissahickon Formation.

Mine Ridge anticline is a second generation upwarp involving basement rocks that arched Chickies Quartzite and underlying Precambrian Baltimore Gneiss. The flanks dip steeply on either side of the uplift but become more gentle north and south.

Peach Bottom syncline is tightly folded and the slate within it shows divergent directions of cleavage.

#### FAULTS

The principal faults in the area are (1) the controversial Martic Line (fig. 2), (2) the overthrust south of York, (3) the east part of the overthrust, north of Chickies Ridge, and (4) imbricate thrusting in a thrust belt, north of the Tucquan and Mine Ridge anticlines, and a number of high-angle faults.

The eastern part of the overthrust that forms the north edge of Chickies Ridge thrusts Chickies Quartzite over the Buffalo Springs Formation of the Upper Cambrian Conococheaque Group (Meisler and Becher, 1968). Dips in both it and Chickies Quartzite are 20°–30° S. on either side of the thrust. There were apparently two stages of faulting. In the flowage stage, nappe formation and break thrusting took place along the overturned limb; in the later stage, vertical uplift established the trend of the ridge at N. 85° E. and created late normal faults that can be seen on the cliff of Chickies Rock along Susquehanna River. The Bamford zinc mine is near the east end of this thrust sheet.

According to Wise and Kauffman (Field Conference of Pennsylvania Geologists, 1960) there are five major inverted repetitions of imbricately thrusted sequences of the Antietam, Vintage, and Conestoga Formations in the region north of the Mine Ridge-Tucquan anticline. This thrust interpretation depends on defining the black basal phyllite of the Conestoga Limestone and the light-gray mottled finely crystalline dolomite of the Vintage Dolomite as two distinct rock types, each indicative of and restricted to its own formation. There is increasing evidence that the duplication of stratigraphy at the Pequea silver mine may be due to interfingering of shallow and deeper sea facies of carbonate-bank

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sedimentation instead of overthrusting (D. H. Lehman and S. N. Thompson, unpub. data, 1968).

The high-angle faults, like those at Chickies Rock, are presumably second-generation faults associated with vertical uplifts locally involving basement rocks. Some of these high-angle faults and other structural features are discussed in more detail later in the report in sections on mineral deposits.

# GEOCHEMICAL INVESTIGATIONS

## OBJECTIVES OF STUDY

The principal objective of this study was to determine whether anomalous geochemical distribution patterns might be identified from soil, stream sediment, and rock samples. Physical and chemical characteristics of anomalous patterns that were identified in the vicinity of mines and prospects were studied in detail to determine whether they indicate larger potential exploration targets than do surface geological features. Patterns obtained in areas of little or no outcrop were studied for information on underlying geologic structures as well as for use as prospecting guides to potential exploration targets. The principal indicator elements sought were zinc, lead, and copper. Because of the ever-increasing industrial demand for silver, close attention was given to the potential for silver ores at the Pequea silver mine and to other localities where silver might be associated with zinc, lead, and copper.

## SAMPLING METHODS

Sampling consisted dominantly of soil samples. Rock and stream-sediment samples also were collected, but because concentrations of metals in these were erratic, compared with the concentrations found in soil samples, their number was limited to less than one-tenth of the total. Water samples were not taken, because most spring and stream waters become contaminated by flowing through farmland out of overflow ponds through iron pipe and by coming into contact with galvanized iron culverts, fences, and discarded farm equipment.

Soil samples were collected by hand from holes dug 3–9 inches deep, and from auger holes 6 inches to 3 feet deep. Enough soil was collected to fill a 3- by 5-inch envelope. Most of the samples were collected at the contact of the $A_2$ and B soil zones. Samples also were taken of $A_1$, B, and C zones and from deeper sites in roadcuts, railroad cuts, and stream-cut banks and at excavations for new buildings.

The pattern of soil sampling varied with the area being investigated. In the Bamford area, soil samples were collected on a generalized 500-foot grid, although efforts were made to take samples from ridges or hilltops, from valley bottoms, and at stratigraphic contacts or along faults, because these features had to be considered in evaluating the resulting geochemical distribution patterns. At the Pequea silver mine, most samples were collected as close as possible to anticlinal axes or to contacts of the Conestoga Limestone and the Vintage Dolomite (Cloos and Hietanen, 1941). Only spot reconnaissance samples were taken at other localities in the study area.

## ANALYSIS OF SAMPLES

In total, 2,132 samples were analyzed, most of them by the semiquantitative spectrographic method. More than 900 samples were analyzed by atomic-absorption spectrophotometry, a method that provides more precise analyses than does semiquantitative spectrographic analysis. About 120 samples were analyzed by wet-chemical tests, in which the sample was fused with potassium bisulfate, leached with dilute hydrochloric acid in a hot-water bath, and suitable aliquots were then tested with dithizone in carbon tetrachloride (Ward and others, 1963). A few of these samples were checked by atomic spectrophotometry, after 10 grams of the sample was leached with aqua regia.

## GEOCHEMISTRY OF ZINC, LEAD, AND COPPER

Geochemical exploration is a proven technique for identifying anomalous concentrations of metals in residual soils (Hawkes and Webb, 1962). Data obtained from analyses of samples containing the indicator elements zinc, lead, and copper also provide information on possibly associated precious metals. How these indicator elements occur and react in the ground is critical in evaluating their use in geochemical prospecting.

### ZINC

The occurrence of zinc in soils has received much attention in the past (Hibbard, 1940; Jones and others, 1936; Goldschmidt, 1954; Rankama and Sahama, 1950). White (1957) found a definite and direct relationship between zinc and iron in some composite Tennessee soils. The amount of zinc in limonite was greater than the amount in surrounding soils, and the size fraction of a soil having the highest zinc content also had the highest iron content. About half the total zinc in soils was tied to hydrous iron oxides in either absorption compounds or solid solution. An average of 35 percent zinc was held in the lattice structure or replaced aluminum in clay. Base-exchangeable zinc averaged 2.6 percent. In summary, 60–90 percent of zinc in the soils was accounted for in iron oxides, in the clay lattice, and by base exchange. The balance could be found in organic matter or in resistant minerals such as ilmenite, magnetite, or zircon.

During weathering, divalent zinc is quite mobile and tends to be concentrated in the oxidized zone. The zinc ion is soluble as a sulfate or a chloride and may be transported towards the surface by ground water (Rankama and Sahama, 1950). According to Goldschmidt (1954, p. 712) zinc may undergo enrichment in the zone of weathering where it is redeposited as a sulfide, oxide, carbonate, or silicate. The process may lead to complete extraction of zinc from the upper parts of zinc sulfide ore bodies. The enrichment process has worked to quite an extent in the oxidized zone of the Bamford area.

Hibbard (1940) showed that zinc is concentrated in vegetation. Its influence is evident near the Bamford mine, where Cannon (1947) observed that plant species present were mainly ones that are tolerant of zinc. She also observed that along the west side of the woods at the mine site there was a large patch of stunted soybeans only 3–4 inches high. She inferred that the soil the stunted soybeans were growing in was contaminated by zinc that had been introduced during the operation of the old furnace.

### LEAD

Lead combines with sulfur to form most commonly the sulfide and the sulfosalt. Lead minerals in the oxidation zone of lead deposits include carbonates, sulfates, chromates, phosphates, and vanadates. Goldschmidt (1954, p. 402) noted that probably lead in soils is bound by ion exchange to hydromicas and montmorillonite. Lead may also be held in the lattice of clay minerals. Cerussite is the only oxidation compound of lead found at Bamford and Pequea.

The lead sulfide, galena, is a common host for many rare elements, but silver is apparently the only precious metal to be found in galena at Bamford and at the Pequea silver mine. Galena from the Bamford zinc mine contained 4.4 ounces of silver per ton, and two specimens from the Pequea silver mine analyzed 167 ounces and 600 ounces of silver per ton.

### COPPER

Copper compounds are very soluble, and the probability of finding them in high concentrations in residual soil is low. On the other hand, the organic content of black shales in euxinic environments may show enrichment of copper and other elements (Mason, 1966). The shale in the Kinzers Formation probably developed in a reducing environment. It is dominantly a gray, locally black fissile brown-weathering rock that has a range in copper content from 10 to 1,000 ppm. About half the samples of shale from the Kinzers Formation contain anomalous copper. The highest copper content of rocks or soils that were sampled was associated with Triassic diabase, and the lowest with rocks of the Upper Cambrian Conococheague Group.

The only copper minerals reported from the Bamford area are primary tetrahedrite-tennantite(?) and secondary aurichalcite; copper minerals reported from Pequea are chalcopyrite, aurichalcite(?), and vauquelinite(?). Some copper could also be tied up in the small amount of pyrite present, but it was not observed in polished section.

## MINERAL DEPOSITS

### BAMFORD ZINC MINE

The Bamford zinc mine is in East Hempfield township, Lancaster County, 1½ miles southeast of Landisville and about 5 miles northwest of Lancaster (pl. 1 and fig. 2), in the Columbia East 7½-minute quadrangle at 40° 05′ N., 76° 23′ W. The mine is in a wooded grove in gently rolling, mostly cultivated terrain on the farm of J. Irvin Denlinger and is accessible by the Yellow Goose Road (fig. 3). The area is drained by Swarr Run, which flows eastward into Little Conestoga Creek. The water table stands at about 10–18 feet (varying with the season and with dry and wet years) below ground level in the immediate vicinity of the mine.

Land values are increasing because of the general growth of this suburban area and because of industrial development. Development of potential mineral deposits in the region, therefore, will have to compete with other uses of the land.

#### HISTORY AND PRODUCTION

The history of the Bamford zinc mine has been fairly well documented by Frazer (1880), Landis (1904), Miller (1924), Mosier (1948), and Cannon (1947). In 1845, Samuel Pickel, a fence maker, was digging post holes for a fence on the farm of Henry H. Shenk when his shovel turned up some lead ore (Landis, 1904). The ore taken to Dr. Fahnestock, a Lancaster chemist, for analyses, showed zinc, lead, and traces of silver. The Lancaster Mining Co. was "granted perpetual mining privileges" (Book F,

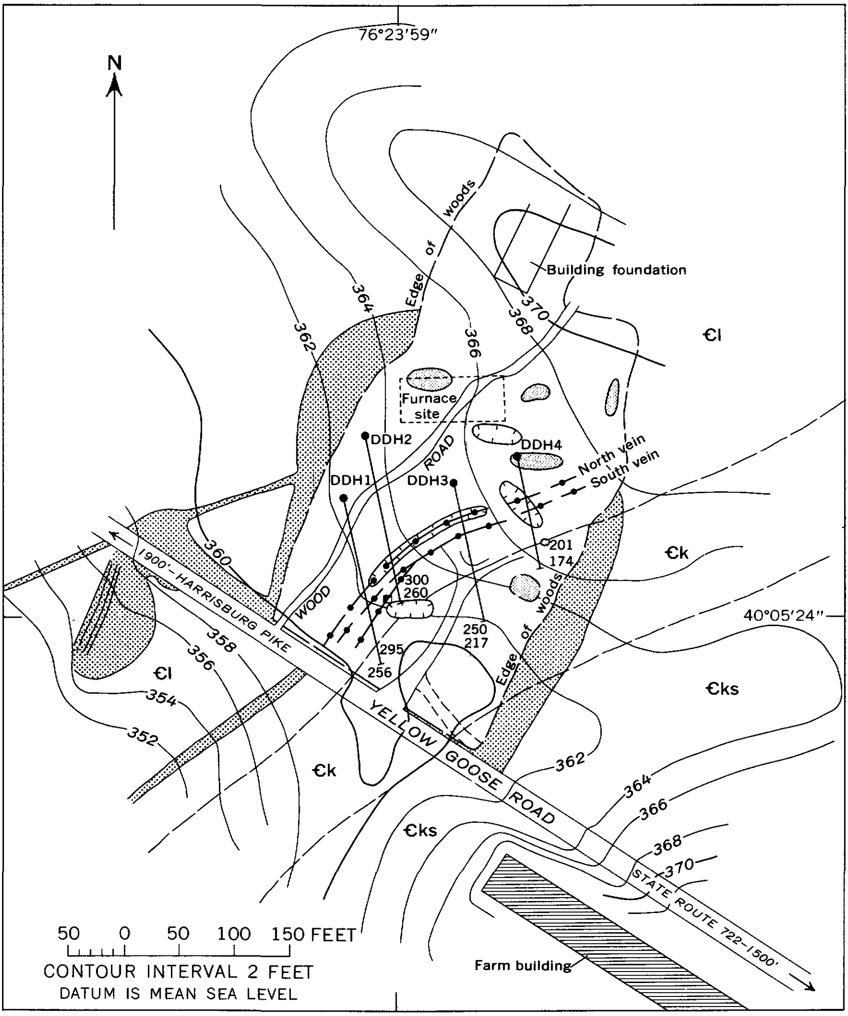



FIGURE 3.—Bamford zinc mine. Base and geology mapped by Jacob Freedman, 1967.

p. 499, Lancaster Recorder's Office) on 105½ acres for the sale price of $25,000 on December 13, 1847. The sale of stock realized $30,675, and buildings were constructed for the production of zinc oxide for paints. The capacity of the 10 furnaces in the plant was 1 ton of zinc oxide per day. The only production figure available from these operations is $1,989.53, which was realized from the sale of zinc oxide (Miller, 1924, p. 49). The firm failed, closed its plant, and the buildings were torn down. However, sporadic minor production continued until 1872.

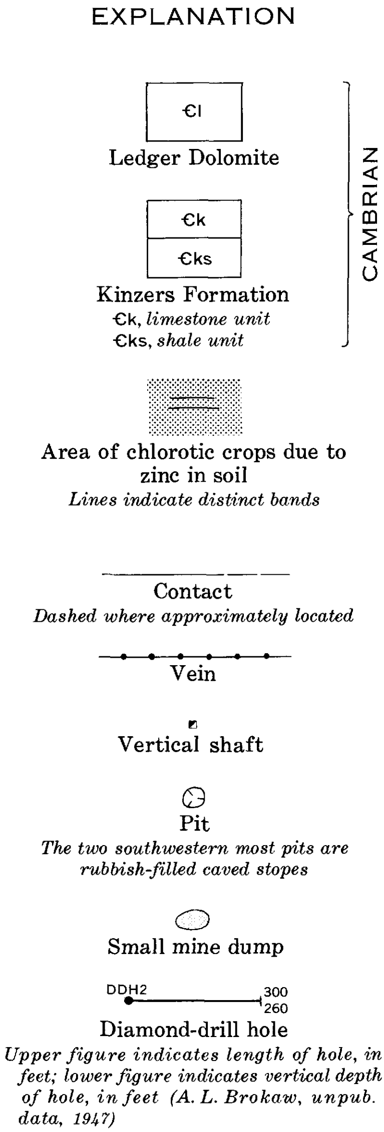



FIGURE 3.—Continued

In 1872, Captain Tamlin, a traveling mining expert, arranged for Charles Bamford, a wealthy English pork packer, to buy the mine and to purchase machinery from Wales. Bamford paid $100,000 for the mine and spent another $100,000 in development. Without investigating the quantity or quality of the ore, complete works for the production of metallic zinc were installed. By 1874, the realization that the grade of mined material was only about 12 percent zinc led to the installation of a Hartz system for mechanical concentration of ore. At first the zinc produced from the mine was hauled to the railroad station at Landisville, but later a siding was laid from the Pennsylvania Railroad main line directly to the smelter. The cost of producing a pound of zinc in 1877 was $0.05; the sale price ranged from $0.07 to $0.11 (Frazer, 1880).

Reports of the productive capacity of the Bamford zinc mine show disparate figures. Spilsbury (Frazer, 1880, p. 203) presented figures from company records that showed a slight profit with a daily production from 40 tons of ore or 10,800 pounds of spelter. However, Frazer (1880, p. 198) noted that general average daily yield of spelter was about 1,500 pounds (810.85 kilograms). Production of spelter was apparently not maintained continuously at that level, however, for Siebenthal (1919), from information supplied by Spilsbury, reported only 357 tons of spelter from 1873 to 1876, a continuously productive period.

Mosier (1948) estimated that about 25,000 tons of ore and waste rock have been removed from the mine since its discovery. Using figures given by Spilsbury (Frazer, 1880, p. 201) on the dimensions of the mined-out parts of the veins and assuming an average specific gravity of 3.0 for dolomite and ore, calculations indicate about 67,000 short tons of ore and waste. Using Spilsbury's estimate of 12 percent average zinc and Mosier's estimate of ore, about 3,000 tons of zinc may be calculated to have been contained in the mined ore. The difference between 357 tons of produced spelter and a minimum of 3,000 tons of calculated zinc content of mined ore is difficult to resolve. On the one hand, there very likely was a poor recovery of zinc in concentrating and smelting. On the other hand, the grade of ore may not have been maintained at the level reported by Spilsbury.

Frazer (1880) reported the average content of 14 analyses of smelted zinc ore from Bamford mine to be

| | *Percent* |
|---|---|
| Zinc | 99.687 |
| Cadmium | .034 |
| Lead | .262 |
| Copper | Trace |
| Iron | .017 |
| Total | 100.000 |

In April 1883, the Lehigh Zinc and Iron Co. of Bethlehem, Pa., leased the mines for a 10-year period. The owners were granted a royalty of $1.00 per ton of ore mined and $1.50 per ton for treating ore from elsewhere. Under the management of a Captain P. O. Dwyer, they operated the plant only till October 1883. Too little ore and difficulties working the machinery which had lain idle since 1877 forced them to close down. There is no record of any production during the interval from 1883 to 1904. About 1904, Logenbach and Morton, zinc smelters of Canton, Ohio, secured mining leases for several months, but there is no information of any production.

## GEOLOGY

The Bamford area is underlain by folded and faulted Cambrian and Ordovician clastic and carbonate rocks (pl. 1). A high hill in the south-central part of the area shown in plate 1 is formed by locally undifferentiated Chickies, Harpers, and Antietam Formations in the core of the eastward-plunging Chickies anticline. Overlying the clastic rocks conformably to the east and north are the Vintage Dolomite, shale and limestone of the Kinzers Formation, and Ledger Formation. Zooks Corner, Buffalo Springs, and Snitz Creek Formations are to the north, thrust over the Ordovician Stonehenge Formation of the Beekmantown Group.

Details of the geology are dependent on information from the literature and from the few natural and manmade exposures in the vicinity of the Bamford zinc mine. Shale of the Kinzers Formation crops out back of a machine shop belonging to the Denlinger farm on the north side of Yellow Goose Road; Ledger Dolomite crops out in the shaft of the mine, in a trench north of the shaft at the edge of the first pit in the road into the woods north of the Yellow Goose Road (fig. 3), on the flood plain near Swarr Run, and in the foundations of the new Getz Brothers, Inc., garage.

### Structure

The structure in the Bamford area is dominated by the Chickies anticline and by the thrust plate underlying the area (pl. 1). An eastward-plunging part of the Chickies anticline (shown in the south-central part of pl. 1), underlain by locally undifferentiated Chickies, Harpers, and Antietam Formations, is the core around which younger formations wrap. The Bamford area is on the north flank of this plunging anticline.

*Folds.*—The Chickies anticline plunges east beneath the area to the east of that shown in plate 1. Subsidiary folds on the flanks of the anticline range in wavelength from about 1,000 feet to a few feet.

One subsidiary fold in shale and limestone of the Kinzers Formation one-half mile south of Landisville is an anticline that plunges eastward toward Bamford. East of Bamford are two elongated areas of Kinzers Formation that are apparently doubly plunging. South of Florys Mill, Kinzers shale and limestone and Ledger Dolomite are repeatedly interlayered as though cross-folded along a northeasterly axis athwart the dominant east-west structural trend of the area.

When the Getz Brothers trucking firm excavated for a garage north of Yellow Goose Road and west of Swarr Run, they exposed a small anticline, asymmetric to the north and plunging 50° E. In the same area, alternations of the gray crystalline and the mottled blue dolomite in the Ledger Dolomite could be caused by primary deposition or by tight folds with wavelengths of 25–50 feet.

An aerial photograph of the area shows vague arcuate patterns of light and dark gray in plowed fields. These and the distinct arcuate pattern of the geochemical anomalies (pl. 2 and fig. 7) suggest the typical patterns of plunging folds.

*Faults.*—The major fault in the Bamford area is the thrust fault shown in part in plate 1. Most of the stratigraphic sequence shown on the map is apparently thrust northwestward over Cambrian Ledger, Zooks Corner, and Buffalo Springs Formations in the southwestern part of the mapped area and over the Ordovician Stonehenge Formation in the northern part of the mapped area. The thickness of the formations from the Chickies Quartzite to the Ledger Dolomite (Jonas and Stose, 1930) amounts to about 2,700 feet, and this might be the maximum stratigraphic throw of the thrust fault.

The next most important fault forms a possible horst trending northeast from Landisville. This fault is postulated to have brought Vintage and Kinzers rocks in contact with the Zooks Corner Formation. If the Ledger Dolomite is 1,000 feet thick here as indicated elsewhere (Jonas and Stose, 1930) in the Lancaster quadrangle, its thickness is the approximate stratigraphic throw of the horst.

In the southern part of the area shown in plate 1, an east-west vertical fault separates Kinzers Formation from the upthrown Vintage Dolomite on the south. In the western part of the mapped area, two northwest-trending faults bring up Vintage and Kinzers rocks against Zooks Corner Formation in a horst. A possible extension of the south boundary of the Landisville horst might intersect the more easterly of the two northwest-trending faults.

On the east side of the mapped area, an east-west vertical fault intersects a northwest-trending vertical fault. The east-west fault brings up Vintage Dolomite and Kinzers Formation against Ledger Dolomite to the south. The northwest-trending fault has Ledger Dolomite faulted against itself in the south, but brings up Kinzers Formation and Ledger Dolomite against Zooks Corner Formation on the north.

The thrust fault was probably formed early during tectonic transport of the region from southeast to northwest. The high-angle faults were probably formed later, partly because of release of compressional stresses.

## ORE BODY

In his Report of Progress, 1877, Frazer (1880, p. 198) quoted E. G. Spilsbury, superintendent, who described the Bamford zinc mine as

> Two parallel bed-veins in the lower Silurian Limestones, near their line of contact with the shales of the same epoch * * *.

Jonas and Stose (1930) identified the rock formations involved as the Ledger Dolomite overlying the Kinzers Formation and underlying the Elbrook Limestone. Spilsbury continued (Frazer, 1880, p. 199)

> The roofs or hanging walls are, in each case, well defined and regular, although the Limestone of the hanging wall has a decidedly brecciated appearance, is partially decomposed, of a whitish gray color and highly siliceous. It is full of seams and cavities, some of the latter attaining the dimensions of small caves, being from 15 to 20 feet long and equally broad, with a height of from 4 to 6 feet. All these seams and openings are completely filled in with a dark red sandy loam, * * *. In none of the cavities examined in this mine have I ever found a trace of mineral.
>
> This broken and dislocated appearance of the upper Limestone bed is not only apparent on the surface, but extends down at least so far as the bottom of the pump shaft, which is 110 feet.
>
> The footwall, although having a generally regular dip, conformable to the hanging wall, is not so uniformly smooth, but has the appearance of a series of layers, between which the ore bearing limestone of the vein has been intercalated, sometimes to a depth of eight to ten feet.

The Bamford zinc mine operators apparently sank three shafts on the "veins," which were traced on the property for half a mile. The first shaft, No. 1, was sunk on the north vein, which, according to Frazer, was opened to a length of more than 300 feet and worked out to a depth of 50 feet. The "vein" had an average width of 12 feet. It was reportedly cut and explored on the 75-foot level.

The second shaft, No. 2, was reported by Frazer (1880, p. 201) to be on a vein 50 feet south of the north vein. Frazer described the south vein as the most regular and profitable and said that it was worked out to the 75-foot level for a length of 400 feet. The width throughout this distance ranged from 14 to 18 feet. Some parts of the vein were rich, but the average grade of ore never exceeded 12 percent zinc, and no ore was ever pure enough to treat without concentration except the surface deposits of calamine. The richest ore was found within 75 feet of the surface. At the 110-foot level, the vein was well defined, but there was little or no ore in the exposed vein, and the little ore seen was in stringers, not disseminated as it was nearer the surface. All that can be seen of the workings on the south vein is the vertical shaft shown in figure 3. Frazer (1880) mentions a third opening, a shaft sunk in the outcrop of the south vein northeast of the Nos. 1 and 2 shafts, from which much calamine (perhaps 50 or 60 tons) was mined.

From published information, it is apparent that the ore was not mined out along its reported length of one-half mile but that work was halted because the ore ran out at depth on the two known veins. As seen in figure 3, the north band of ore trends southwestward into a zone where farm crops are chlorotic. The south band of ore trends into a less distinct chlorotic area, indicating that mineralized rock possibly continues in that direction.

To check possible extensions of the ore at depth, the U.S. Bureau of Mines (Mosier, 1948) put down four diamond-drill holes in 1947; they were inclined at angles of 60° and their bearings were approximately perpendicular to the strike of the veins. These holes ranged from 174 to 260 feet in depth (fig. 3) and all presumably extended to or beyond the projected continuation of the veins. No zinc mineralization was found in the drill cores (A. L. Brokaw, written commun., 1947), which are stored at the Bureau of Mines core library at Minneapolis, Minn.

The reasons for the ore petering out at 50 and 75 feet respectively in the north and south veins are problematical. From the descriptions of the ore bodies and the ore specimens, it is apparent that the ore is in brecciated beds of dolomite filled with sphalerite. Thus, one possible reason is that the dolomite was not brecciated below the levels mentioned and hence provided no openings for mineral filling. Another possible explanation might be that the brecciation and ore filling is discontinuous and may recur below the zone reached by mine development and drilling.

Another explanation, based on Spilsbury's (Frazer, 1880, p.

201) early statement that the ore is definitely bedded and his later statement that the vein continued downward with little or no ore, is that mining may have followed the uniformly dipping brecciated hanging wall down along a fault instead of the ore-filled brecciated bed in the fault block. Spilsbury's reference to the thickness of ore-bearing limestone also raises questions about the geologic relationships. His sketch (Frazer, 1880, p. 199) shows interlocking rectangular wedges of "ore body" and footwall "dark blue limestone" that could be interpreted as either infolding of the two or imbricated normal faulting of the footwall into the ore body. Specimens of solution breccia filled with sphalerite have been sheared, and stringers of sphalerite have been dragged into the shear zone. This feature indicates postore faulting.

The questions still unanswered are: Do the beds continue downward at an angle of 72° N., well below mined and drilled levels, or are the beds folded? And what effect does the major thrust fault have on the ore body and its extension? Further drill data may answer these questions. One area that needs further investigation is the sole of the fault. If much brecciation developed along it, spaces could have opened up for mineralization.

### Mineralogy

Gordon (1922) listed the following minerals reported from Bamford: galena, sphalerite, tetrahedrite(?), tennantite, calamine, dolomite, smithsonite, cerussite, aurichalcite, and hydrozincite. Spilsbury (Frazer, 1880) noted specular hematite(?) (possibly ilmenite) in calcite druses in the dark-blue to black limestone footwall. Neither mineral was listed by Gordon (1922) or Beck (1952), nor were they observed by the writer. Gordon and Beck did not list pyrite which I observed in thin and polished sections, nor limonite that was associated with the dry bone smithsonite. Beck (1952, p. 2) stated that the tetrahedrite reported by Eyerman (1911, p. 22) had never been confirmed and that the masses of tennantite in limestone were distinguished by qualitative analysis only. Neither mineral was observed in the present study either in hand specimen, polished section, or thin section.

The minerals listed above may be separated into the primary ore minerals sphalerite, galena, and tennantite or tetrahedrite(?), and the secondary ore minerals of the oxidized zone that were formed principally above the water table. Of the primary minerals, sphalerite is the most abundant. It occurs as open-space fillings in breccia and as scattered blebs in highly fractured and healed white to dirty-gray dolomite of the Ledger Dolomite (fig.

4). Locally dark-blue limestone of the Kinzers Formation is altered to white and light-gray limestone with scattered grains (2–5 mm in diameter) of smithsonite and hydrozincite (fig. 5). Two varieties of sphalerite were observed: an early dark-brown to black variety and the later pale-golden-yellow transparent to translucent variety which makes up most of the sphalerite content. In polished sections, open-space filling is dominant but replacement of dolomite with sphalerite is indicated by irregular contacts. The average of 14 analyses of the sphalerite (Frazer, 1880) is as follows:

| | *Percent* |
|---|---|
| Zinc | 65.8 |
| Sulfur | 32.28 |
| Iron | .81 |
| Lead | .34 |
| Cadmium | .07 |

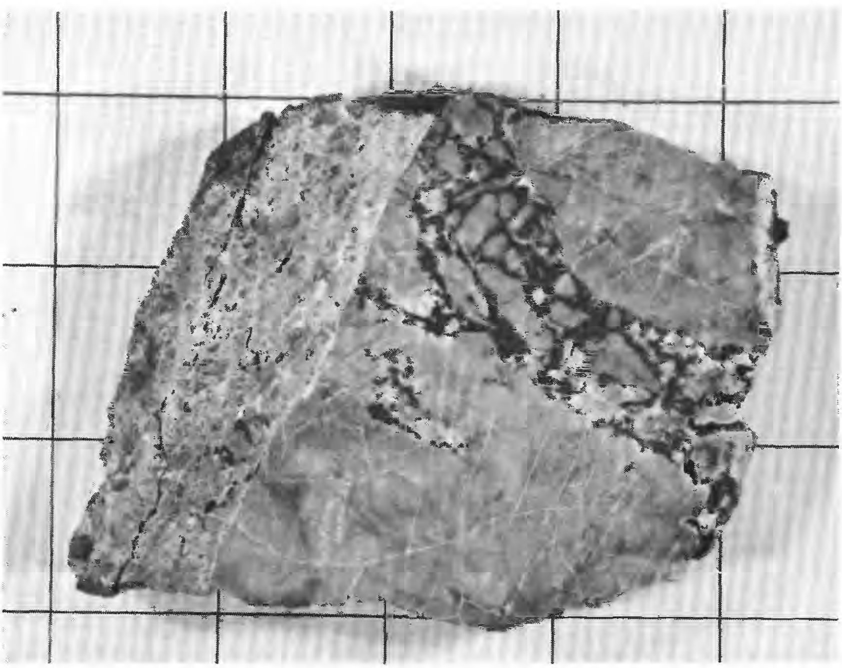
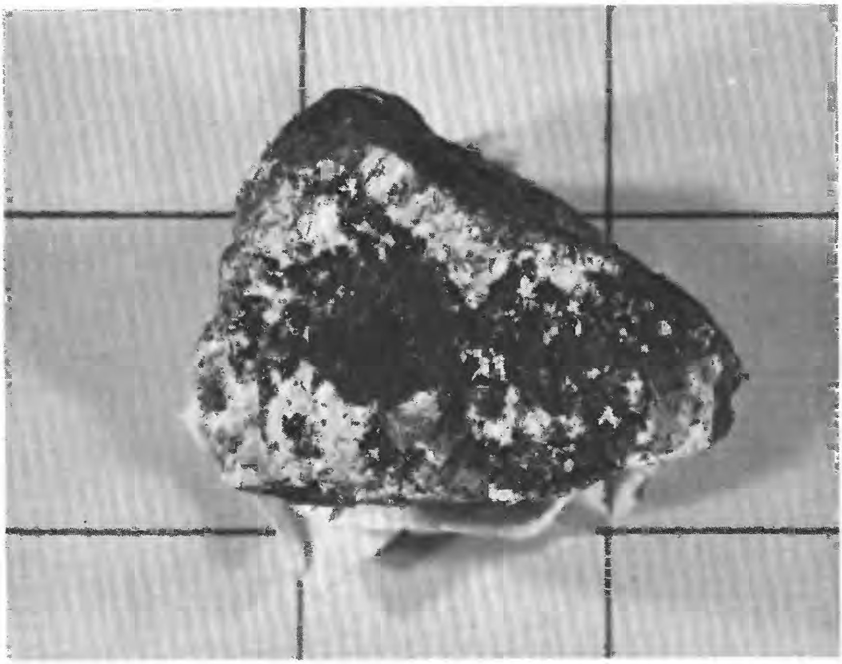
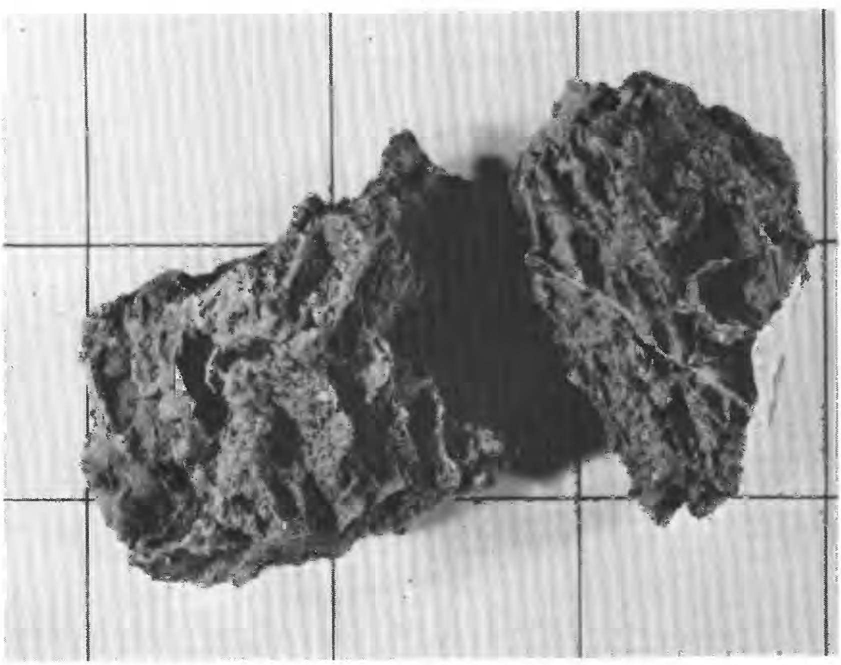


FIGURE 4.—Sphalerite-filled solution breccia vein in dolomite of Ledger Dolomite from the Bamford zinc mine. Grid is 1 inch square.

FIGURE 5.—Sphalerite (*A*) and smithsonite (*B*) from Bamford zinc mine. In *A* the dark-gray cores of limestone from the Kinzers Formation contain scattered grains of black sphalerite; the white areas are hydrozincite and smithsonite. Grid is 1 inch square.



*A*



*B*

The ore specimen shown in figure 4 was brecciated in two stages: a coarse breccia (5.0–60.0 mm) formed first that appears similar to solution breccias in dolomite from Kentucky and Tennessee and that has the interstices filled with sphalerite; this breccia in turn was crushed in a shear zone and picked up traces of crushed sphalerite.

The Ledger Dolomite appears to have been brecciated and healed repeatedly. In some specimens, sphalerite is associated with dirty-gray dolomite healed with white dolomite; in others, thin veins of sphalerite cut across gray and white dolomite. The dolomite probably formed from primary limestones; shrinkage during the dolomitization process may have aided in the formation of the solution breccias.

In the present study, galena was rarely observed in hand specimens. In thin and polished sections it is seen as small grains or veinlets. According to Frazer (1880, p. 200) it is "chiefly found in bunches, or little strings, running along on or near the hanging wall, whilst the Blende thoroughly impregnates the whole of the vein matter in greater or less proportions."

The term "calamine" has been used for minerals other than calamine. Gordon (1922) and Beck (1952) apparently refer to hemimorphite when they use the term. As used by Frazer and Spilsbury (Frazer, 1880), I suspect that calamine refers to brown skeletal dry bone smithsonite. Beck (1952, p. 7) also may have referred to smithsonite in describing massive, concretionary grayish-white to brown calamine. Calamine, formed by the oxidation of sphalerite, was the ore mineral removed from open pits at shallow depths and was the only ore that did not require mechanical concentration. Specimens of the brown skeletal variety of smithsonite (fig. 5) can still be collected from the mine dumps and in nearby fields as float.

No cerussite was observed during this study, but Gordon (1922) and Beck (1952) noted that Genth (1875, p. 163) reported minute crystals of cerussite on galena at "Bamfordville."

Aurichalcite is referred to by all three sources mentioned above as acicular crystals and fine pale-bluish-green scales or incrustations upon dolomite or smithsonite. Gerald Lintner and Richard Haefner, members of the Pennsylvania Mineralogical Society, have collected acicular aurichalcite from Bamford.

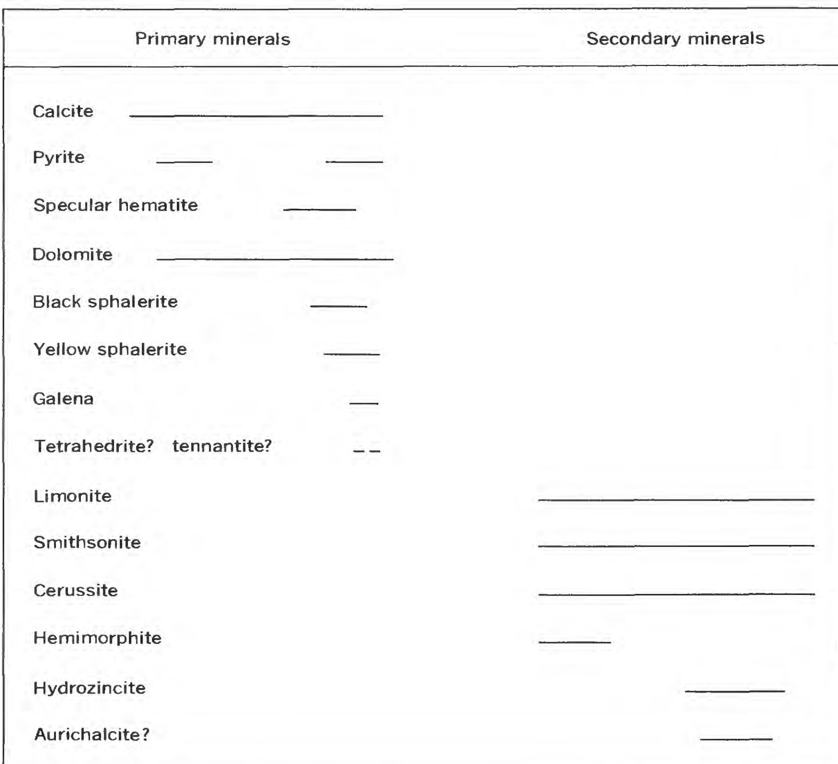
Hydrozincite occurs as white encrustations on smithsonite (Beck, 1952). In this study, hydrozincite was observed in a piece of float encrusting dark-blue limestone that contained scattered sphalerite.

Silver was produced from ore of the Bamford zinc mine. The content ranged from "a couple of dollars" to $2,000 per ton of ore minerals, based on the 1877 price of silver (Frazer, 1880, p. 200). The average value of silver per ton of ore minerals was estimated by Spilsbury to be about $22. The silver may be present in the galena, the tetrahedrite, or the sphalerite. A crushed and separated sample of sphalerite analyzed by the U.S. Geological Survey contained 420 ppm (parts per million) silver, which is equivalent to 12.264 ounces of silver per ton of sphalerite. An X-ray diffraction study of this sample and another sample of sphalerite indicated neither galena nor tetrahedrite, but indicated argentite in the sphalerite. A hand specimen of galena analyzed 150 ppm of silver equivalent to 4.4 ounces of silver per ton of galena.

The order in which the minerals formed in the Bamford zinc mine is shown in table 2.

The order of emplacement of minerals at the Bamford locality is as follows: Ledger dolomite was deposited as primary limestone

TABLE 2.—*Paragenesis at the Bamford zinc mine*



which became dolomitized after compaction. Shrinkage and subsequent folding brecciated the brittle dolomite. Heated waters either brought in from below, or leached from surrounding rock, zinc-rich solutions from which were precipitated sphalerite, galena, and tennantite or tetrahedrite in open space. Edges of dolomite breccia fragments were partly replaced by sphalerite. Later movements sheared sphalerite near contacts. This ended the primary stage. The secondary stage consisted primarily of oxidation of sphalerite to a brown, limonitic skeletal variety of smithsonite. Galena altered to cerussite, tennantite-tetrahedrite to aurichalcite, and hydrozincite crusts formed on smithsonite and limestone containing scattered sphalerite. Late joints opened and were filled by ground waters with calcite and quartz.

### GEOCHEMICAL EXPLORATION

In the Bamford area, 969 samples of soil, rock, and stream sediment (more than 90 percent were soil samples) were collected and analyzed for zinc and lead; 435 of these were analyzed for copper. A few samples were tested by semiquantitative analysis for about 30 elements. Analyses for zinc, lead, and copper content showed a range of from <5 to 30,000 ppm zinc, <5 to 1,000 ppm lead, and <5 to 1,000 ppm copper. Median values of the samples were 100 ppm zinc, 25 ppm lead, and 15 ppm copper. Histograms were prepared from these data. The various data sets used in preparing the histograms are presented in table 3.

TABLE 3.—*Frequencies and data sets of analyses of samples from the Bamford area*

| Class interval (ppm) | Frequency (number of samples) | Cumulative frequency | |
|---|---|---|---|
| | | Number of samples | Percentage of samples |
| **Zinc** | | | |
| Less than 50 | 142 | 142 | 14.6 |
| 50–100 | 286 | 428 | 44.2 |
| 100–300 | 379 | 807 | 83.8 |
| 300–500 | 92 | 899 | 92.8 |
| More than 500 | 70 | 969 | 100.0 |
| **Lead** | | | |
| Less than 25 | 474 | 474 | 48.9 |
| 25–50 | 310 | 784 | 80.9 |
| 50–100 | 141 | 925 | 95.5 |
| 100–150 | 27 | 952 | 98.2 |
| More than 150 | 17 | 969 | 100.0 |
| **Copper** | | | |
| Less than 25 | 322 | 322 | 74.0 |
| 25–50 | 84 | 406 | 93.3 |
| 50–100 | 21 | 427 | 98.2 |
| More than 100 | 8 | 435 | 100.0 |

Hawkes and Webb (1962, p. 31) suggested that only the uppermost 2.5 percent of samples analyzed be considered anomalous. Hawkes and Lakin (1949) indicated that a soil residuum containing 500 ppm zinc was an indication of mineralization. G. E. McKelvey (unpub. data, 1966) chose a 150 ppm zinc threshold because he found a natural break at that value in the limited number (150) of samples he had collected. The writer adopted thresholds of 300 ppm zinc, 100 ppm lead, and 50 ppm copper as being high enough above the background to indicate anomalous values.

The zinc and lead content of different soil horizons in the Bamford area was checked by collecting samples from different depths within the same hole (table 4). No uniformity of increase or decrease in metal content was found at depth. Some values were unchanged, some increased, and some decreased with depth. The highest zinc and lead values were taken from the A and B soil horizons.

TABLE 4.—*Zinc and lead content of samples taken at different depths in the same hole, Bamford area*

[Grouped according to hole]

| Sample | Depth of sample | Zn (ppm) | Pb (ppm) |
|---|---|---|---|
| 546 | 3–12 in | 200 | 20 |
| 547 | 12–18 in | 70 | 20 |
| 548 | 18–30 in | 70 | 20 |
| 549 | 30–36 in | 200 | 20 |
| 608 | 6–12 in | 500 | 20 |
| 609 | 12–18 in | 150 | 70 |
| 501 | 6 in | 700 | 30 |
| 502 | Top of B horizon | 700 | 20 |
| 503 | 2 ft in B horizon | 1,000 | 30 |
| 506 | Surface | 500 | 20 |
| 504 | Boundary of A and B horizons. | 300 | 15 |
| 505 | 2-ft interval at boundary of B and C horizons. | 300 | 15 |
| 508 | Surface | 700 | 30 |
| 507 | 1-ft interval at boundary of B and C horizons. | 500 | 20 |
| 519 | 1-ft interval at clay-sand boundary. | 700 | 30 |
| 520 | 12–16 in. interval at clay-sand boundary. | 700 | 30 |
| 528 | 2–6 in. (A horizon) | 500 | 30 |
| 529 | 9–15 in. (B horizon) | 500 | 20 |
| 530 | 1–9 in. (A horizon) | 1,500 | 50 |
| 531 | 9–15 in. (B horizon) | 700 | 20 |

*A*

*B*

FIGURE 6.—Stunted corn in anomalous zinc areas near Bamford zinc mine. *A*, Stunted and normal corn west of wooded area and north of Yellow Goose Road. View looking north. *B*, Stunted and normal corn north of Yellow Goose Road. View looking S. 45° W.

*A*

*B*

FIGURE 7.—Stunted crops in anomalous zinc areas near Bamford zinc mine. *A*, Band of stunted rye in field south of Yellow Goose Road. View looking S. 45° W. *B*, Light areas in the center of the photograph are stunted vegetation. View looking west along Yellow Goose Road.

Stunted and chlorotic vegetation was observed in some areas where the soil contained anomalous values of zinc (figs. 6, 7). Some of these areas are more or less at the same sites noted by Cannon (1947), and their vegetation support her observations. The stunted vegetation seems to have resulted from toxicity because of excess zinc.

Plate 2 shows a striking pattern of zinc anomalies in the Bamford area. The general trend of the principal anomalous zone is east, parallel to the trend of underlying host rocks. The geochemical map for lead and copper shows less parallelism (pl. 2). More difficult to explain are the arcuate patterns shown by zinc anomalies east of the Bamford zinc mine. If these patterns are conformable to underlying host rocks, they suggest a series of plunging folds. Unfortunately, the absence of outcrops in the area makes it impossible to prove this thesis. The presence of major and minor folds nearby, however, make a southeastward-plunging folded pattern seem most likely. If this interpretation is correct, the anomalous pattern shown by values of more than 500 ppm zinc outline a plunging anticline with synclines northeast and southwest of it. At the mine site, the straight alinement of the anomalous zinc pattern is indicative of that found over vein deposits; however, the linearity parallels the strike of the country rock at this vicinity. Moreover, previous descriptions of Bamford veins suggest that they parallel the strike of enclosing rocks; this parallelism suggests that they are bedded deposits rather than veins. Certainly the arcuate patterns east of the mine suggest bedded ore rather than a vein deposit. Moreover, the size and strength of the anomalous area is indicative of a potential zinc deposit, the value of which may be determined only by subsurface exploration.

## POSSIBLE CAUSES OF ANOMALIES

The principal cause of zinc, lead, and copper anomalies in the Bamford area unquestionably is the metal content in underlying rocks. Nevertheless, other possible causes must be considered.

The mine area is immediately suspect of dumped ore or gangue, smelter fumes, and fly ash. There are dumps in the wooded area, and there may have been dumps in the now cultivated areas. The arcuate and linear patterns (fig. 3) may represent train or wagon roads between mine, concentrator, smelter, and stockpiles. If fumes and fly ash were responsible, one would expect the anomalous areas to extend downwind southeast of the furnace. This is not the case.

It has already been indicated that farm crops are chlorotic and stunted by the toxicity caused by excess zinc in the soil. The accumulation of zinc and lesser amounts of lead and copper in soils could have resulted from the very considerable annual contribution of metals concentrated and left behind by the decaying vegetation. The high content of zinc negates this suggestion. The annual contribution could account, however, for some unusually high values found in the A soil horizon. Boyle and Dass (1967) concluded that the marked concentration of metals in the A horizon is obviously biochemical.

As most of the samples in this study were taken from cultivated fields, the possibility of contamination from fertilizers and soil conditioners spread by farmers must be considered. The amount of most fertilizers needed to increase the metallic content of a soil one order of magnitude would be in the order of tons of fertilizer per acre (Lakin, H. W., oral commun.); this is much more than is used. Furthermore, because fertilizer is spread uniformly over large areas, it would not produce concentrations of metal; instead, it would simply raise the background metal content.

Biased sampling also could lead to high values, but most samples were collected away from the immediate vicinity of the mine, which undoubtedly was contaminated.

Accidental salting by shot from bird and small-game hunting also could contaminate the soil. Large quantities of shot have been contributed to the soil since hunting began in this popular bird and small-game area. The samples were screened, however, before they were analyzed and any shot was removed, although possibly small amounts of lead could have been left in the sample material.

The possibilities that ore or metals could have been distributed by streams from a source other than the mine should be considered. The Bamford zinc mine is about 1,000 feet east and 400 feet north of the present location of Swarr Run. In the past, Swarr Run may have had its course much closer to if not directly over the mine. Much of the anomalous area, however, is upstream from the mine and is parallel to the stream. Anomalous content from any earlier drainage would have been eroded by the present drainage.

## OTHER ZINC PROSPECTS IN THE BAMFORD VICINITY

The old Herr prospect is about 1½ miles east of the Bamford zinc mine (pl. 1, loc. 2). Frazer (1880, p. 56) noted that at that locality calamine and zinc blende, intimately mixed with limestone, were exposed in a Penn Central Railroad cut. He noted further that the railroad company mined about 40 tons of ore here and that a Mr. Herr took out about an equal amount.

Two other prospects are reported near East Petersburg, Pa., by Frazer (1880, p. 201). One of these was an excavation made on the side of the Petersburg Township road (pl. 1, loc. 4), just beyond the Penn Central Railroad. The Petersburg Township road referred to is apparently State Route 722, and the deposit would be about one-fourth mile southwest of East Petersburg. The second deposit is about 1½ miles northeast of the first one and southeast of Mechanicsville; here a deposit of calamine was found in building the Lancaster Branch of the Reading and Columbia Railroad (pl. 1, loc. 5). Actual tonnage excavated at this locality was apparently a few tens of tons of oxidized zinc ore.

Oxidized ore also is believed to have been taken from open pits east of State Route 722 and north of U.S. Route 230, but no indications of this activity were found in 1966.

A quarry (pl. 1, loc. 6) in intensely fractured Ledger Dolomite is east of a farmhouse and of a tributary to Little Conestoga Creek about 2,000 feet north of Florys Mill. This area is reputed to have been a zinc prospect. The area was sampled, but no evidence of mineralization was observed, although one sample contained 140 ppm lead.

## PEQUEA SILVER MINE

Pequea silver mine is 1.7 miles east of the road junction at Conestoga, Conestoga Township, Lancaster County, at lat 39° 56′ 48″ N., long 76° 18′ 53″ W. (pl. 3). It was on the farm of Aaron R. Groff, north of Silver Mine Road and about 2,000 feet north of the junction of Silver Mine Run and Pequea Creek.

Principal mine workings consist of a quarry and two adits, one about 300 feet long and the other about 100 feet long (pl. 4). Both adits were accessible in 1966, although the mine had long been idle. A shaft or caved area is over the longer adit; another shaft was dug on the crest of the hill west of the mine area at the present site of a pylon for a powerline. A third shaft is reported on a bluff on the north bank of Pequea Creek (Foose, 1947), and a fourth shaft (waterfilled in 1966) plus a few small pits are west of the south end of the steel bridge over Pequea Creek on Route 324, about 3,000 feet S. 40° E. of the main mine area. There are numerous open pits west of Silver Mine Run. Galena occurs in a quartz vein at Burnt Mills about 700 feet northeast of the Pequea Creek bridge, on the hill east of the sharp bend in the road north of Burnt Mills, and in a pit west of the bridge over Pequea Creek.

### HISTORY AND PRODUCTION

The Journal of Silver and Lead Mining Operations of Mining

Magazine (1853) contains an article, "Silver Mines in Pequea Valley, Penn.," which describes the mine workings. The article notes that the mines were worked up to the time of the Revolutionary War and that the area was the site of extensive former mining operations.

Price (1947) noted that there is no accurate information about the history of the mines between the periods of early activity and the Civil War, when, according to Eckman (1927), the mine was worked by a Captain Joseph Buzzo, who is believed to have gotten a considerable amount of silver from it.

The Lancaster Lead Co. acquired the mine, and a company prospectus that is dated 1863, a copy of which is in the Fackenthal Library of Franklin and Marshall College, Lancaster, describes plans and operations at the mine. There are no records of production between 1863 and 1874, at which time the mine was owned by Harvey Filley, a silversmith of Philadelphia (Eckman, 1927). Eckman describes work done at the mine in 1874–75, when a shaft was sunk that went in to old mine workings. Price (1947) could find no record of mining between 1875 and about 1900, although residents of the area informed him that the mines were worked sporadically for several years by the Emily Brothers at about the latter date. He noted that the last attempt to work the mine was about 1930, when a Mr. Dixon of Lancaster planned to mine ore and country rock, the latter to be crushed and sold as fertilizer. Burned lime was produced from an old lime kiln on the property.

Records of production are scanty. There are no production records of the colonial activity. The Mining Magazine (1853) mentions 2 tons of ore and additional gossan at the mine. The Lancaster Lead Co. prospectus claimed production of 100 pounds of galena per day over a possible 6-month period in 1863. A minimum estimate of this production would be about 10 tons of galena. Estimations based on accessible mine openings and on other underground workings indicate that 3,500–5,000 tons of rock may have been mined. At least an equivalent amount has been quarried at the surface, most likely for lime production. At any rate the total production must have been small.

### GEOLOGY

The Vintage Dolomite is the host rock for the Pequea deposit (pl. 3, 4). In the vicinity of the mine, the Vintage is a massive mottled light-gray to blue-gray finely crystalline rock. It is overlain by the Conestoga Limestone, which is characterized by its basal black carbonaceous and calcareous phyllite, and it is overlain locally by a coarse conglomerate or breccia containing limestone blocks about as large as 1 foot in diameter and (or) white marble containing numerous phyllitic layers. The Antietam Schist forms a ridge a few hundred yards north of the mine.

The deposit is in the "thrust belt" beneath the third of Cloos and Hietanen's (1941) five imbricate thrust sheets which are shown in plate 3. The interpretation of thrust faulting, however, according to Wise (in Field Conference of Pennsylvania Geologists, 1960), depends on the black basal phyllite of the Conestoga Limestone and the light-gray, mottled, finely crystalline dolomite of the Vintage Dolomite being two distinctive rock types, each indicative of a formation. That the black phyllite is restricted to the Ordovician Conestoga Limestone is becoming less certain. Similar rocks have been observed interbedded in the Vintage Dolomite at the Bellemont quarry in Paradise. Rogers (1968) questioned the Ordovician age of the black phyllite and its restriction to the base of the Conestoga Limestone. He suggested that the sedimentary deposition along the eastern edge of the North American Continent during Cambrian and Early Ordovician time was similar to that of the Great Bahama banks. Deposition of clastic sediments balanced subsidence of the sea floor much of the time. Where subsidence outstripped deposition, deeper water euxinic environments developed in which black muds with sulphur became pyritic black shales. These shales would be interfingered with, instead of unconformable over, all the formations from the Antietam Schist to Ledger Dolomite, according to Rodgers' persuasive theory. Rodgers' interpretation would offset some of the strongest evidence for imbricate thrusting in the "thrust belt."

Whether the result of thrusting or cyclical sedimentation, there is a duplication of the sequence black phyllite over Vintage Dolomite at the Pequea silver mine. This duplication is seen in the quarry east of Silver Mine Run and is shown in plate 4 and figure 8.

Vintage Dolomite and black phyllite in the mine area are complexly folded. Bedding and the first cleavage strike generally northeast with moderate to gentle dips. The attitude of this cleavage is parallel to the recumbent fold axial planes (Freedman and others, 1964).

## ORE BODY

Argentiferous galena is the primary mineral at the Pequea deposit. The galena occurs as scattered grains, cubic crystals, and lenses one-quarter of an inch to a few inches thick and a few inches long in quartz veins. The silver content of the galena has been confirmed by various analyses. Genth (1875) determined

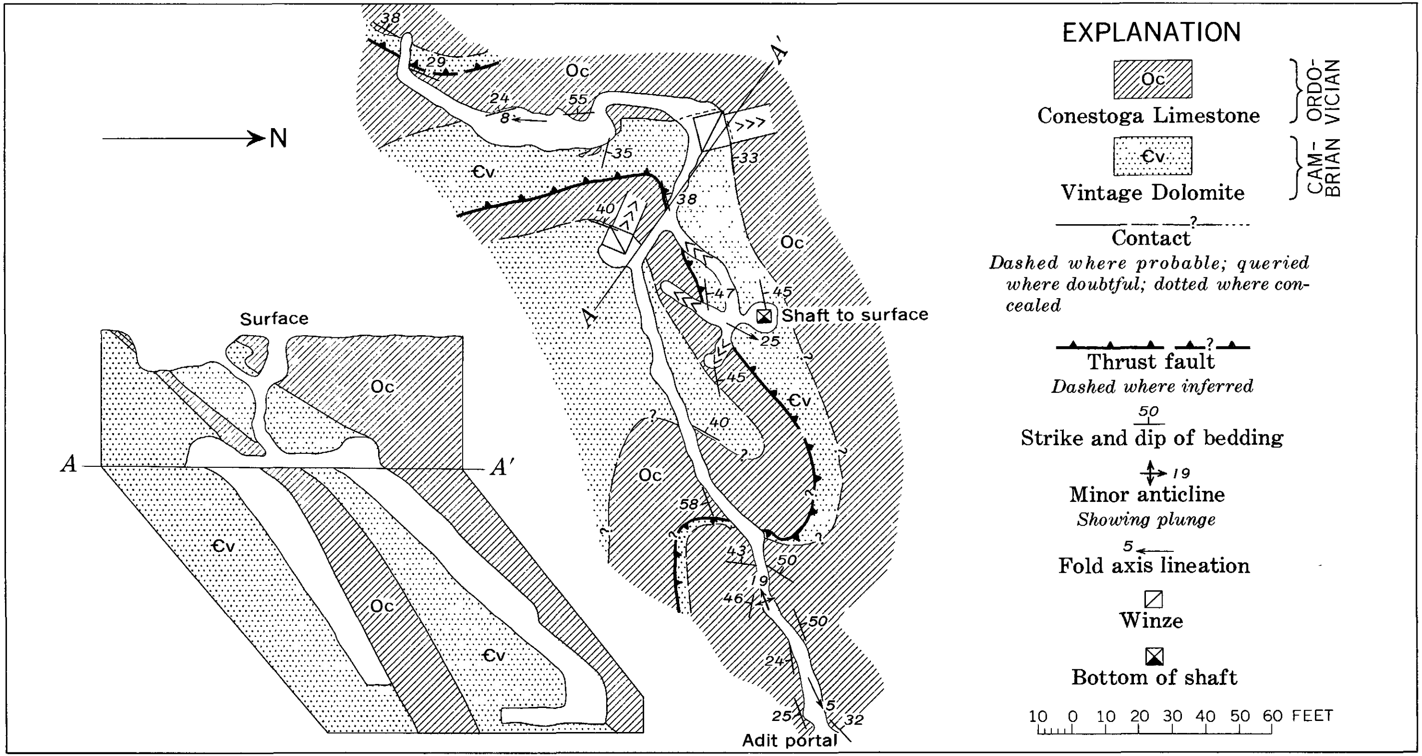



FIGURE 8.—Pequea silver mine. Map and section modified from Wise and Kauffman (in Field Conference of Pennsylvania Geologists, 1960).

250–300 ounces of silver per ton of galena, and Beck (1952) quoted Torrey as finding $179\frac{1}{5}$ ounces per ton of galena. Two specimens of galena analyzed by the U.S. Geological Survey contained 168 and 600 ounces, respectively, of silver per ton of galena.

In addition to galena, Gordon (1922) listed quartz, rutile, and adularia as primary minerals. Pyrite was present both in the black carbonaceous phyllite and in scattered crystals in quartz. Secondary minerals included calcite, siderite, cerussite, calamine, anglesite, vauquelinite, wulfenite, and chloritoid. Foose (1947) observed chalcopyrite in the center of masses of galena, and Beck (1952) reported aurichalcite. Brown and Ehrenfeld (1913) listed sphalerite and wulfenite. The writer found muscovite in a pegmatite along with quartz and feldspar, microscopic crystals and crusts of cerussite on galena, and minute radiating needlelike crystals of vauquelinite in quartz.

The galena is mostly found associated with quartz. Quartz veins range from tiny veinlets to masses 6 feet thick. The quartz occurs almost entirely in the Vintage Dolomite near and along the contacts with the overlying black carbonaceous phyllite. Quartz is at a maximum near fold crests and in the thrust–repeated sheet (?) of Vintage Dolomite. According to Wise (in Field Conference of Pennsylvania Geologists, 1960, p. 56):

> The control of the ore is largely the result of yield differences between the Conestoga black phyllites, which flowed without separation, and the more brittle Vintage dolomite, in which open joints were created to produce ready access for the quartz-bearing solutions. In effect, a permeability trap was created in the fold by differences in yield characteristic. The close association of the quartz with the fold structure and joints implies quartz injection during or possibly after the folding period.

Quartz veins associated with successive fold systems (Freedman and others, 1964) imply either successive injections or almost continuous injection. Foose (1947) observed that galena occurs only near the footwalls of the larger quartz veins. Specimens indicate that galena lenses extend from the quartz veins into joints and bedding planes in the dolomite and that the quartz is veined by the galena.

The origin of the galena-bearing solutions may have been deep seated, associated with the faulting in the area, or the galena may have been leached from the surrounding rocks by lateral secretion. The latter source is suggested by research on metals concentrated by humate, wherein natural and chemically extracted humate (water-soluble organic material from northwest Florida) can sorb 1–17 percent dry weight of Co, Cu, Fe, Pb, Mn, Mo, Ni, Ag, V, and Zn. The mechanism is unknown, but may account for the enrichment of metals in ancient carbonaceous sedimentary rocks during exposure to metal-bearing natural waters (Swanson and others, 1966). Analyses of black phyllite from near the Pequea mine show very few parts per million of Cu, Pb, and Zn, but a number of soils that developed over the black phyllite are anomalous for lead, zinc, and even copper. Because the nearest igneous rock, the Triassic diabase dike at Safe Harbor, is 2½ miles away, an igneous source is questionable.

The order of emplacement of minerals at the deposit is as follows. The dolomite was covered by the black carbonaceous mud which was metamorphosed to a pyritic phyllite during folding. Quartz filled joints and bedding planes as they opened during and after folding. Pegmatite composed of quartz, muscovite, and feldspar, was injected, and after solidification, was fractured and then injected by chalcopyrite, galena, and minor sphalerite. This ended the primary stage. The secondary stage consisted of a shallow zone of oxidation in which the galena was altered to cerussite, anglesite, and vauquelinite; the sphalerite(?) to calamine; and the chalcopyrite to aurichalcite. Calcite was dissolved from the carbonates in the walls and reprecipitated in veins and vugs probably throughout the history of the area.

## GEOCHEMICAL EXPLORATION IN "THRUST BELT" AREA

In total, 984 soil, rock, quartz, and stream-sediment samples were collected in the "thrust belt" area. Most of these were soil samples. Values in lead ranged from 5 to 1,700 ppm, although the the median was 30 ppm. Values in zinc ranged from 3 to 860 ppm; the median value was 100 ppm. Copper values ranged from 2 to 186 ppm, and the median value was 25 ppm. Histograms were prepared from these data, and those for zinc and lead are shown in plate 3. The various data sets used in preparing the histograms are presented in table 5.

From study of the histograms, thresholds of 100 ppm zinc and 50 ppm lead have been determined and used to analyze sample data from the "thrust belt" area.

Although in the Bamford area the anomalous values have an arcuate pattern, the distribution of anomalous values in the "thrust belt" area does not make a very distinctive pattern. The "thrust belt" area is characterized by a high lead background with isolated spots of higher anomalous values. Some areas in the "thrust belt" are characterized by vague curves suggestive of plunging folds, but most anomalies are simply isolated values. The largest anomaly is at the Pequea silver mine. Plate 3 shows two conspicuous anomalies for lead. One area is about 1 mile west

TABLE 5.—*Frequencies and data sets of analyses of samples from the thrust belt area*

| Class interval (ppm) | Frequency (number of samples) | Cumulative frequency | |
|---|---|---|---|
| | | Number of samples | Percentage of samples |
| | **Zinc** | | |
| Less than 50 | 533 | 533 | 54.2 |
| 50–100 | 322 | 855 | 86.9 |
| 100–200 | 86 | 941 | 95.6 |
| 200–500 | 35 | 976 | 99.2 |
| More than 500 | 8 | 984 | 100.0 |
| | **Lead** | | |
| Less than 50 | 838 | 838 | 85.2 |
| 50–100 | 71 | 909 | 92.4 |
| 100–200 | 43 | 952 | 96.7 |
| 200–500 | 25 | 977 | 99.3 |
| 500–1,000 | 6 | 983 | 99.9 |
| More than 1,000 | 1 | 984 | 100.0 |
| | **Copper** | | |
| Less than 25 | 273 | 273 | 88.9 |
| 25–50 | 29 | 302 | 9.4 |
| 50–100 | 3 | 305 | 1.0 |
| 100–200 | 2 | 307 | 0.7 |

of Baumgartner along Route 324, and the other extends from Burnt Mills westward for about 1 mile.

Table 6 gives the location and geology of anomalous lead areas shown in plate 3 and the location of anomalous samples and values in nearby quadrangles.

Zinc apparently is not an abundant element in the "thrust belt" area. It has lower median and threshold values there than does

TABLE 6.—*Location, geology, number of samples, and values in lead (ppm) of anomalous samples in the thrust belt area*

| Location and geology | Number of anomalous samples | Anomalous values |
|---|---|---|
| **Safe Harbor 7½-minute quadrangle** | | |
| East edge of quadrangle. In black phyllite of Conestoga Limestone, along the axis of a west-plunging anticline. | 2 | 290 |
| **Conestoga 7½-minute quadrangle (pl. 3)** | | |
| Stone Hill area—west-central part of map. Antietam Schist thrust over Conestoga Limestone. | 3 | 1,700<br>213<br>81 |
| North part of sheet. Pegmatite at contact of Antietam thrust over Conestoga Limestone. | 1 | 1,010 |
| Hill southwest of Silver Mine Road and Goode Road. Westward-plunging anticlines in Vintage Dolomite. | 2 | 1,160<br>91 |

TABLE 6.—*Location, geology, number of samples, and values in lead (ppm) of anomalous samples in the thrust belt area*—Continued

| Location and geology | Number of anomalous samples | Anomalous values |
|---|---|---|
| **Conestoga 7½-minute quadrangle (pl. 3)—Continued** | | |
| Hill west of Pequea silver mine. Black phyllite-Vintage and Vintage-Antietam contacts. | 5 | 436<br>230<br>197<br>120<br>120 |
| Pequea silver mine. Folds in black phyllite-Vintage contacts. | 6 | 350<br>310<br>270<br>160<br>140 |
| New roadcut on Silver Mine Road west of Route 324. Crossfaulted thrust sheet in Vintage Dolomite and black phyllite. | 7 | 678<br>467<br>300<br>232<br>185<br>173<br>96 |
| Burnt Mills on Route 324. Anticline in Vintage Dolomite with crossing quartz veins containing galena, | 3 | 420<br>320<br>190 |
| Farm pond north of Penn Grant Road. Numerous large boulders of limonitic quartz in Conestoga Limestone. | 1 | 810 |
| Junction of three roads—Lat 39° 56′ long 76° 20′. Synclinal axis in Antietam Schist. | 1 | 760 |
| Martic Forge. Black carbonaceous phyllite near contact with Antietam Schist. | 1 | 510 |
| Junction of Baumgartner Road and Route 324. In a synclinal axis of Vintage Dolomite and the edge of a thrust sheet of Antietam Schist over Conestoga Limestone. | 10 | 460<br>420<br>200<br>190<br>170<br>120<br>120<br>120<br>89<br>88 |
| Sharp bend in Route 324 north of Good's Run. In a synclinal axis in Conestoga Limestone. | 2 | 98<br>83 |
| Route 324, south of meander in Pequea Creek. Northeast-plunging nose of an anticline in Antietam and Vintage Formations. | 1 | 240 |
| **Quarryville 7½-minute quadrangle** | | |
| Road northwest of Lime Valley (northwest corner of the quadrangle). The west-plunging nose of an anticlinal thrust sheet in Antietam and Vintage Formations. | 2 | 570<br>82 |

TABLE 6.—*Location, geology, number of samples, and values in lead (ppm) of anomalous samples in the thrust belt area*—Continued

| Location and geology | Number of anomalous samples | Anomalous values |
|---|---|---|
| **Quarryville 7½-minute quadrangle—Continued** | | |
| North of Strasburg and west of North Star School. Cross-fault offsetting anticlinal thrust sheet in Antietam and Vintage Formations. | 2 | 150<br>110 |
| **Gap 7½-minute quadrangle** | | |
| Southwest of Bellemont (near northwest corner of quadrangle). In a synclinal axis, Conestoga Limestone. | 1 | 110 |
| North of Wolf Rock Hill (near northwest corner of quadrangle). Quartzite of Antietam Schist. | 1 | 190 |

zinc in the Bamford area. Although a threshold of 100 ppm zinc was determined for the area, only those areas of 200 or more ppm zinc are considered anomalous. (See pl. 3.)

There are six isolated areas containing 50 or more ppm copper in the general vicinity of the Pequea mine. The values in these areas reach a maximum of 186 ppm copper.

Although chalcopyrite (Foose, 1947), aurichalcite, and vauquelinite (Gordon, 1922) are reported from the Pequea area, these occur in small quantities. The geochemical evidence supports the observation that the "thrust belt" is low in copper content.

## INTERPRETATION OF THE DATA

The geologic and geochemical data leave a number of unanswered questions about the "thrust belt" area as a potential source of ore deposits. The mineralization seems to have been controlled by the contact of the brittle-yielding Vintage Dolomite with the plastically flowing carbonaceous phyllite of the Conestoga Limestone. Some of the primary mineralization was formed during or shortly after the major folding if association with fold axes may be so construed. Some of the mineralization is associated with presumably later cleavages. Previous writers have attempted to tie the mineralization to injections of upper Triassic diabase dikes similar to those associated with the Cornwall, Pa., magnetite mine. Whether mineralization took place at one time or was spread over geologic time is not established.

Four facets that tend to make the "thrust belt" area interesting from an economic point of view are (1) the high content of silver, (2) the possibility of more ore below the shallow workings, (3) the geochemically anomalous areas, and (4) the numerous widely spread mineral occurrences.

## GAP PROSPECT AREA

The Gap prospect is 1 mile N. 10° E. of the junction of U.S. Route 30 and State Route 41, near Gap (pl. 5). A small, abandoned quarry in Vintage Dolomite is about 100 feet west of an unnamed stream flowing north to Pequea Creek. W. B. Satterthwaite and R. E. Wright (unpub. data, 1958) noted the presence of sulfides there.

### GEOLOGY

The rock is a white, finely crystalline dolomite, interlayered with numerous, very thin phyllitic layers composed of muscovite, biotite, and locally chlorite. It weathers to a distinctive light or dark ivory hue. The minerals observed are sphalerite, galena, chalcopyrite, and pyrite; they occur as scattered euhedral to subhedral grains as much as 0.1–0.2 mm in diameter and in veinlets as much as 5 mm thick along the phyllitic cleavage planes. In both thin and polished sections, crystals can be seen to have grown across the sheared, oriented micaceous minerals. These growths imply that the metallic minerals were emplaced after the deformation that formed the cleavage. The occurrence of sulfide minerals along cleavage planes also was noted by John Garihan and A. W. Snoke (unpub. data, 1967).

### GEOCHEMICAL EXPLORATION

The Gap prospect area was investigated geochemically by G. E. McKelvey (unpub. data, 1966). Most of the interpretation of anomalous areas for zinc shown in plate 5 is from his paper.

The analyzed values for zinc range from 42 to 4,230 ppm. The threshold for zinc was placed at 150 ppm by McKelvey. Of the 150 samples, 28, or 18.7 percent, are anomalous. The average of all the samples is 180 ppm zinc. Of all below the threshold, the average is 85 ppm; of all 28 anomalous values, the average is 590 ppm.

Although the background and threshold for zinc are not as high in the Gap prospect area as in the Bamford area, the Gap prospect area is definitely anomalous enough in zinc to indicate extensive mineralization beyond that observable at the surface.

The analyzed values for copper range from 11 to 115 ppm. Fourteen samples, or 9.2 percent of the 150 samples, are anomalous. The average of all the analyses is 28 ppm copper. Samples containing quantities below the threshold average 24 ppm copper; those samples containing quantities above the threshold average 74 ppm copper.

Several sample sites shown in plate 5 are anomalous for copper. The samples, which have a copper content above the threshold of 45 ppm copper, were distributed over an area 9,500 feet long. Of all the Lancaster County areas tested, the Gap area has the highest background in copper.

There is a 65 percent overlap of the anomalous areas for zinc and copper. The anomalies and the mineralization occur primarily in two lithologic units—a white, finely crystalline Vintage Dolomite with phyllitic shear planes and a schistose quartzite called Kinzers Formation by W. B. Satterthwaite and R. E. Wright (unpub. data, 1958), Antietam Formation by Jonas and Stose (1926) and Knopf and Jonas (1929), and Vintage Formation by Steven Curran and John Gucwa (unpub. data, 1967).

## GRUBB LAKE–MUD LAKE AREA

The Grubb Lake–Mud Lake area of Lancaster Valley is about 3 miles northeast of Columbia. Limonite deposits in this vicinity have been mined sporadically for more than 50 years. Throughout the history of the area, the deposits have attracted the attention of geologists, who have advanced different opinions regarding their origin.

H. D. Rogers (1858, p. 182) visited the mines and reported on them in the First Survey of Pennsylvania. He described the geologic structure of the valley as apparently synclinal, with gentle dips and central parts nearly flat. He stated that the ore lay in the lowest layers of the "Primal" newer slates; that the ore was very widespread (one property alone covered 11 acres); and that the ore was in rocks that had been dug through to the underlying "Primal White Sandstone" in several places. Persifor Frazer (1880) noted that the horizon of limonitic ores is in hydromicaceous schists that separate quartzite from limestone.

Jonas and Stose (1930, p. 89) described the iron ore as occurring chiefly along the contact of the ferruginous Antietam Schist and the overlying Vintage Dolomite and along faults in the Lower Cambrian arenaceous rocks, the Vintage Dolomite, and younger limestone. They reasoned that the brown ores were precipitated from circulating underground waters that contained iron in solution and that found passage along contacts of limestone and other rocks or along fault planes. They considered that the ores associated with the Vintage-Antietam contact had probably been derived from iron originally deposited in the rocks in the form of carbonate or some other readily soluble mineral.

Later, geologists considered the importance of permeability in the precipitation of these ores (R. M. Foose, oral commun.). The relatively soluble carbonates provided the iron that precipitated in the pore spaces in the top of the sandstone of the Antietam Schist, making it a barrier to percolation. Continued precipitation formed limonite deposits as much as 100 feet thick.

In contrast to earlier observations and interpretations, Meisler and Becher (1966) believed that in the Grubb Lake–Mud Lake vicinity, a klippe of Antietam Schist rests on Ledger Dolomite. If this is so, the thrust fault may have provided a focal area for localization of mineral deposition, and if so, the limonite may be a gossan.

Allen V. Heyl (oral commun.) also questioned whether some of the limonite deposits were not actually gossans over sulfide deposits. He called attention to fairly high percentages of zinc in some of the limonite deposits and noted that early reports commented on iron-furnace smelting being blocked by condensation of zinc on the walls of the furnace flues. Rogers (1858), in his study of the area, observed octahedral crystals of magnetite in limonite; their presence would imply that the limonite had been formed by hydration of a magnetite body.

Soil samples were taken in the Grubb Lake–Mud Lake area to determine whether limonite deposits were gossans or secondary deposits of brown iron ores deposited by ground water. Thresholds of 150 ppm zinc and of 50 ppm lead were used to evaluate soil samples. Three red clay soil samples from Grubb Lake and three from Mud Lake were anomalous for zinc. At Grubb Lake, the samples analyzed 260, 310, and 370 ppm zinc, whereas at Mud Lake, they analyzed 170, 260, and 630 ppm zinc. In the Mud Lake area, two samples were anomalous for lead. One sample near Grubb Lake contained 50 ppm lead, and one east of Grubb Lake contained 54 ppm lead.

Although the sample data are insufficient to determine positively whether the limonite ore was formed by downward percolating waters or whether it represents gossan over sulfide ore bodies, the high zinc values certainly suggest that zinc minerals occur at the source of the iron.

## OTHER AREAS

Brief reconnaissance sampling was undertaken in the New Holland quadrangle, about 1–3 miles north of the Gap prospect, approximately at lat 40° 03′ N., long 76° 03′ W., to check for possible extensions of the mineralization found in the Gap area. Twenty-seven samples were collected and analyzed for lead and zinc. If 50 ppm lead is accepted as the threshold, four samples were anomalous for lead. One of the four samples contained 150 ppm lead. Only one sample contained more than 150 ppm zinc. Although there are a few anomalously high values, too few samples were taken to develop a distribution pattern of lead and zinc or to find any extension of mineralization from the Gap area.

Samples also were collected from the Binkley and Ober limestone quarry, a quarry north of Florys Mill, and from a hill near the junction of the Harrisburg Pike and Rohrerstown Road—all in the northern half of the Lancaster 7½-minute quadrangle. Values in the 42 samples collected ranged from 24 to 140 ppm lead and from 10 to 790 ppm zinc. Of the 11 samples taken in the Upper Cambrian Conococheague Group rocks at the Binkley and Ober quarry, three contained more than 50 ppm lead, and only three contained less than 45 ppm lead. One sample from the quarry contained 170 ppm zinc. A sample of Ledger Dolomite from the quarry north of Florys Mill analyzed 140 ppm lead, and another sample analyzed 170 ppm zinc. Samples from the shale of the Cambrian Kinzers Formation at the hill near the junction of the Harrisburg Pike and Rohrerstown Road included one that analyzed 100 ppm lead and another that analyzed 180 ppm zinc.

## SUMMARY

Geologic and geochemical findings indicate that ore mineralization in most of the Lancaster Valley is stratigraphically controlled. In the Bamford vicinity, the arcuately curved anomalous areas suggest plunging folds. The ore is in the Ledger Dolomite, although some is along the Ledger-Kinzers contact. Some anomalous zones in the Bamford area may overlie oxidized deposits close to the surface. Past references to discoveries and open pits in this type of ore and the wide scatter of anomalies indicate that oxidized ore may be widespread. That these oxidized deposits may be underlain by primary sphalerite and galena is indicated by observations at the Bamford zinc mine.

In the Pequea area, scattered anomalous zones may be localized along the axial parts of folds, whereas in the Gap area, anomalous elliptical patterns may be tied to the white finely crystalline dolomite of the Vintage Dolomite.

The Bamford area is dominantly characterized by sphalerite with minor galena; the Gap area, by chalcopyrite, sphalerite, and galena; the Pequea area, by galena with very minor sphalerite and chalcopyrite. In the Manor Hills area, sphalerite is also apparently the dominant mineral. Geochemical prospecting for silver can be most successful in the Lancaster Valley by analyzing for the indicator elements zinc and lead, although in future geochemical studies of the area it is suggested that samples also be analyzed for copper. Each new area should be checked for all three elements to insure the best possibilities of outlining anomalous areas.

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