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MINERAL DEPOSITS

OF

NEW JERSEY AND EASTERN PENNSYLVANIA

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Guidebook 8: Excursion A–8

MINERAL DEPOSITS
OF
NEW JERSEY AND EASTERN PENNSYLVANIA

Prepared under the direction of
CHARLES P. BERKEY
COLUMBIA UNIVERSITY

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This guidebook contains contributions by the following authors:

Charles P. Berkey, Columbia University.
Paul F. Kerr, Columbia University.
Charles H. Behre, jr., Northwestern University.
Benjamin L. Miller, Lehigh University.
Marius R. Campbell, United States Geological Survey.
George H. Ashley, State geologist of Pennsylvania.
W. L. Cumings, Bethlehem, Pennsylvania.

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MINERAL DEPOSITS OF NEW JERSEY AND EASTERN PENNSYLVANIA

Prepared under the direction of Charles P. Berkey

INTRODUCTION

By Charles P. Berkey

It is the purpose of this excursion to accommodate those members of the Congress arriving in New York who would like an opportunity to see the principal mineral deposits between New York and Washington. The excursion is intended primarily for economic geologists, students of ore deposits, and mineralogists and petrographers interested in the unusual variety of minerals and mineral products of Franklin Furnace and Cornwall. The time is limited to four days, one day being given to each important district in the following order:

Franklin Furnace zinc deposits.
Lehigh Valley slate quarries and cement works.
Lansford anthracite field.
Cornwall iron deposit.

In some respects the mineral products of these fields are unique. The zinc deposit at Franklin Furnace, New Jersey, occurring in the most ancient rocks of the region, exhibits a longer list of minerals than any other in America and raises problems of origin that are still unsettled. It is the most productive single zinc mine in the United States.

The Lehigh Valley is the largest producer of slate and cement in the country, and the conditions represented at the different quarries and the methods used in handling these substances are representative of the best American practice.

One of the anthracite basins will be touched at Lansford, Pennsylvania. Opportunity will be given to see the complicated structural features of a mine where stripping has been practised on a large scale and where the famous Mammoth coal seam is exposed. Opportunity also will be given to observe the methods of underground working.

The iron deposit at Cornwall is an especially fine exhibit of a replacement body of magnetite, clearly associated with igneous intrusion and related activity. The open-pit method of working has exposed the major structure, and virtually the whole range of mineral and rock product can be seen in the open.

Opportunity will be given at all these places to gather samples of typical material.

The journey begins at New York. After crossing the Hudson River the traverse crosses the north end of the State of New Jersey, stopping for most of the day at Franklin, and reaching Easton, Pennsylvania, for the night. From that point the route traverses portions of the Great Valley in the State of Pennsylvania, visiting quarries and plants near Allentown, and reaching Bethlehem at the end of the second day. The next stage crosses the Great Valley and the adjacent Appalachian Mountain folds to Lansford, in the anthracite region, ending the day at Lebanon. The final day is to be spent at the Cornwall iron deposit, and the observational part of the journey ends at Harrisburg. (See pl. 1.)

The characteristics of each of these special districts are discussed separately in the following papers, which have been prepared by different individuals who will take charge of the party in their own fields. In addition to the brief published guide, opportunity will be sought for further explanation and perhaps for evening discussion of special features or problems observed in the field.

ZINC DEPOSITS NEAR FRANKLIN, NEW JERSEY

By Paul F. Kerr

THE ROUTE

The excursion leaves Manhattan Island (see fig. 29) over the Hudson River Bridge. This bridge, joining the Palisades of New Jersey with Washington Heights, New York, was constructed by the Port of New York Authority at a cost of approximately $60,000,000. It is the longest suspension bridge in the world, having a span from support to support of 3,500 feet (1,067 meters). The four main cables are 3 feet (0.9 meter) in diameter, and each cable is made up of 26,474 galvanized steel wires. The zinc used on these cables weighed 1,700,000 pounds (771,000 kilograms) and was produced from ore from the New Jersey Zinc Co.'s Franklin mines.

The west approach to the Hudson River Bridge cuts through the Palisades of New Jersey. The Palisades have been formed by the erosion of an intrusive diabase which penetrated the shale and sandstone layers of the Newark group of New Jersey. From the Palisades westward the route passes across the Hackensack Meadows. Here the soft shales and sandstones of the Newark group (Triassic) have suffered erosion and formed a lowland crossed by sluggish tidal streams. From the Hackensack Meadows westward the route traverses a succession of moderate depressions and elevations. The depressions are due to the erosion of the weaker shale members of the Newark group, and the elevations have been formed by the more or less resistant sandstone members. At Paterson it crosses the First Watchung Mountain, an extrusive sheet of basaltic rock in the Newark group. Many zeolitic minerals have been collected from the trap-rock quarries along the bluff west of Paterson.

The city of Paterson (population in 1930, 138,513) is one of the centers of the silk manufacturing industry in the United States. Several of the silk mills are located along the route.

After passing the First Watchung Mountain, the route continues westward, still crossing the Triassic lowland. The exposures of the Newark sedimentary rocks continue, interspersed with intrusive and extrusive sheets of Watchung basalt, which form the outstanding hills. At Pompton a large fault separates the crystalline rocks of the highlands from the sediments of the Triassic lowland.

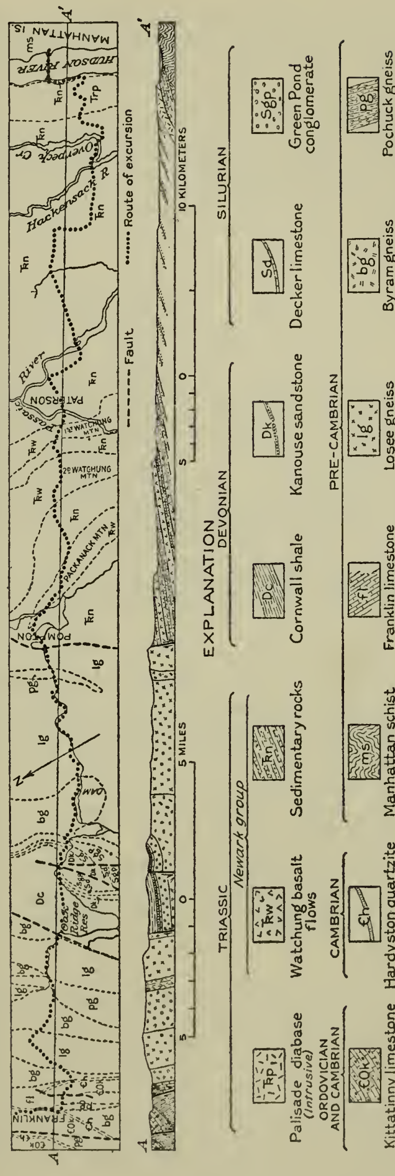

FIGURE 29.—Geologic map and section along route of excursion from New York to Franklin, New Jersey

West of the fault the route passes through a continuous succession of pre-Cambrian gneisses with scattered exposures of Paleozoic strata. The outstanding formations of this region are the Byram gneiss and the Losee gneiss. The most striking of the Paleozoic strata is the Green Pond conglomerate, which forms several escarpments visible from the highway. At a distance of 47 miles (75 kilometers) from the Island of Manhattan the route descends from the Hamburg Mountains of the Highlands into the Wallkill Valley. The town of Franklin and the adjacent zinc mines are located along this valley.

FRANKLIN FURNACE

Franklin Furnace is the old name for the zinc-mining district centered around Mine Hill. In 1913 the borough of Franklin was organized, and the town that forms the center of the zinc-mining activities of the district has since been known as Franklin. The town, which in 1930 had a population of 4,176, is scattered over the low-lying and rolling hills that rise from the floor of the Wallkill Valley. The Mine Hill property of the New Jersey Zinc Co. is within the town, and Sterling Hill, another property owned by the same company, is 3 miles (4.8 kilometers) south, near the village of Ogdensburg. These two properties contain the only deposits of zinc ore known in the district.

HISTORY

The area between the Hudson River and the Delaware River comprised the western portion of a grant by King Charles II of England to his brother, James the Duke of York. The county of Sussex, in New Jersey, in which the town of Franklin is located, was included in this grant.

The date of discovery of the zinc deposits at Mine Hill and Sterling Hill is not known. Iron mining at Franklin, then known as Franklin Furnace, began early in the history of the country and ores from this section were utilized during the Revolution.

Shuster (21)[1] has summarized the history of Franklin as follows:

> The history of events as they relate to the mining industry of the Wallkill Valley may be divided into four periods of time.
>
> The first period, from the early settlement of the country to the end of the eighteenth century, included a term of years in which some attention was given to the exploitation of the zinc veins at Mine Hill and Sterling Hill and the discovery and early development of iron deposits.
>
> The second period extended from 1801 through the first half of the nineteenth century, when the mining, smelting, and forging of the iron became an important industry, not only in this district but in other sections of Sussex County. During this epoch, from 1800 to 1850, the unique ores and minerals of Mine Hill

[1] Numbers in parentheses refer to bibliography, p. 13.

and Sterling Hill were brought to the attention of the mining and scientific world. It was the era of exploration, investigation, and the development of experimental processes for the smelting and utilization of the zinc ore deposits. This work, to a great extent, was due to the personal efforts of Dr. Samuel Fowler and his associates.

The third period, from 1850 to 1897, saw the organization of many corporations, each having various ownerships of various titles. At the end of this period the value of the ores had been fairly well determined and the zinc-mining industry well established. The output of the mines gradually increased to meet the demands of commerce. During this period the legal complications among the conflicting interests of the various mining companies led to a series of lawsuits that intermittently covered a period of 40 years.

The fourth period takes us from 1897 to 1927. Prior to 1897 the operating mines at Sterilng Hill and Mine Hill were owned and operated by four different corporations, each having a subdivision of the ore bodies. In 1897 all interests of Sterling Hill and Mine Hill were united under the name of the New Jersey Zinc Co.

MINING AND MILLING

The mining methods in vogue at Franklin have been described by Haight and Tillson (6). In brief, the ore body is worked by a system of top slicing, the ore being drawn off through haulage levels to one main shaft, the Palmer shaft.

The inclined length of the Palmer shaft is 1,520 feet (463 meters). It is a 4-compartment shaft having an inclination of 47° 30′ with the horizontal.

Electric haulage systems run through the footwall beneath the ore body and parallel with it on the different levels. The broken ore is transferred by small tram cars from the working faces of the mine to the loading chutes. The ore from the chutes is dropped into the haulage cars of the electric trains, which haul it to large bins between the vein and the shaft, below the haulage tracks. Loading pockets supply the ore to 6-ton skips which are operated in the 4-compartment shaft. The mine water is pumped by three electric centrifugal pumps from a pumping station on the 1,050-foot (320-meter) level south of the Palmer shaft.

The ore at Mine Hill is treated in a modern mill. One of the features of the mill is the magnetic method of separation utilized for the concentration of the franklinite ore. Tables and jigs are employed for the treatment of the nonmagnetic minerals. It was in the mill at Franklin that the Wetherill magnetic separator was developed. It is also noteworthy that at one time Thomas A. Edison tried his hand at the treatment of the zinc ores.

The mill at Sterling Hill has a smaller capacity than the mill at Franklin but treats the same kind of ore.

Concentrates from both mills are shipped to the smelting plant of the New Jersey Zinc Co. at Palmerton, Pennsylvania. In addition to numerous zinc products obtained from the ore the manganese and iron that remain are smelted into spiegeleisen.

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A desirable feature of the ore from this district is the almost complete absence of lead.

FORMATIONS

Underlying the Franklin limestone is the Pochuck gneiss (pre-Cambrian). The Pochuck is an injection gneiss, which has had a complicated history. It was probably at one time part of the same sedimentary series to which the Franklin limestone belonged, but has undergone several igneous invasions with a complete change in character.

The Franklin limestone is pre-Cambrian and is considered by some geologists to be equivalent to the Grenville series. It is called the "White limestone" by the miners.

The ore bodies at Sterling Hill and at Mine Hill occur in the Franklin limestone (fig. 30), which rests upon the Pochuck gneiss and is truncated above by an unconformity that separates it from the Hardyston quartzite and Kittatinny limestone. The contact between the Franklin limestone and the underlying Pochuck gneiss at Mine Hill dips steeply to the east, but there is no apparent unconformity. The lines of foliation in the gneiss agree with such meager evidences of stratification as may be observed in the limestone. Also, the inclination of the ore body in the limestone and the inclination of the magnetite layers that underlie the ore are, in general, parallel to the contact.

The Franklin limestone is predominantly a very pure nonmagnesian limestone. In many places, however, it is highly dolomitic. Extensive studies have been made of the magnesian and calcareous character of the Franklin limestone in relation to the ore, without apparently correlating any of the properties of the limestone in so far as dolomite and calcite are concerned with the distribution of the formation. The limestone is satisfactory for cement, and several quarries have been successfully operated.

The Hardyston quartzite is of Cambrian age and ranges in thickness from a few feet to 30 feet (9 meters). It underlies the Kittatinny limestone and rests unconformably upon the Pochuck gneiss and Franklin limestone in the vicinity of the ore body.

The Kittatinny limestone, of Cambrian and Ordovician age, is the "Blue limestone" of the miners. It has a thickness estimated by Kümmel at 2,500 to 3,000 feet (762 to 914 meters). The Kittatinny conforms with the Hardyston quartzite, and the two formations together truncate the ore deposit north of Mine Hill.

RELATIONS OF THE ORE DEPOSITS

The zinc ores occurring in the Franklin limestone are found in a body that imitates in shape a sharply folded sheet. At Franklin the trough of the fold crops out at the Buckwheat pit,

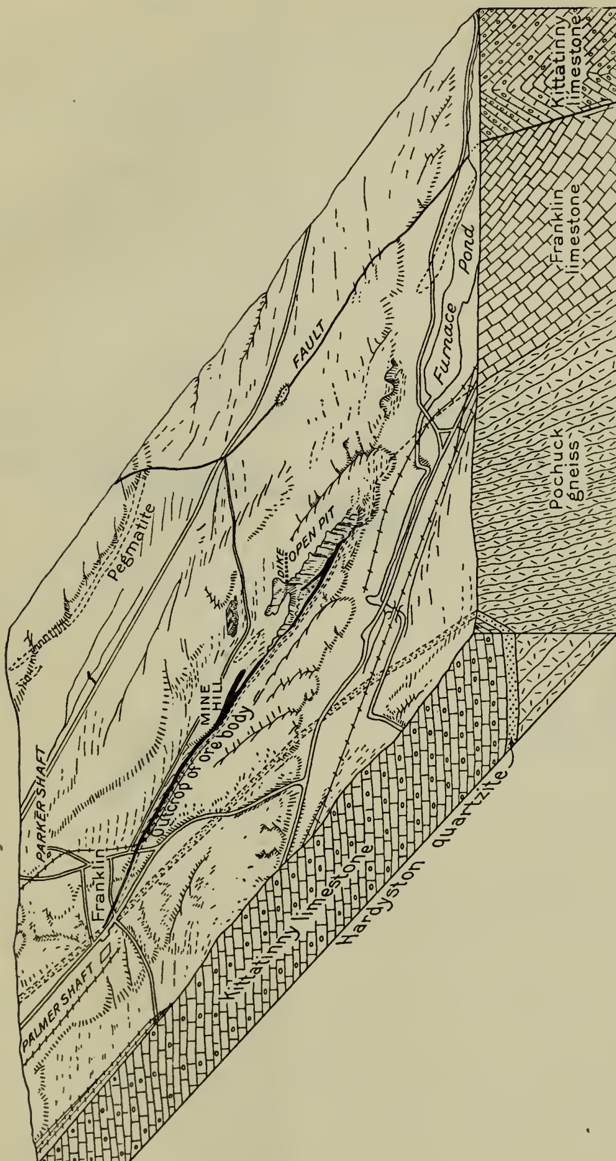


FIGURE 30.—Block diagram illustrating the general relations of the ore deposits at Franklin, the geography of the surface, and the contacts in the vicinity of the ore

the ore body extends thence downward and northward, toward the center of the present underground workings. The east limb of the fold is terminated at an inclined angle beneath the surface. The outcrop of the west limb extends from the open cut to the vicinity of the Palmer shaft, where it goes underground beneath the Hardyston quartzite.

The west side of the ore body is frequently referred to as a vein and in many respects resembles a vein in shape. It inclines toward the east, parallel to the contact between the Franklin limestone and the underlying Pochuck gneiss. Between the ore

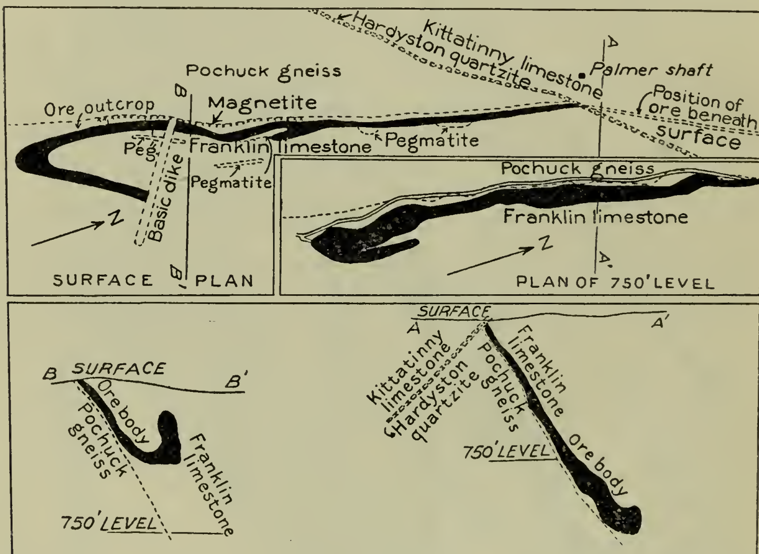


FIGURE 31.—Plans and cross sections of the ore deposit at Franklin. The plan of the surface shows the outline of the ore outcrops in relation to the contact between the gneiss and the Franklin limestone. The plan of the 750-foot level shows the same relation underground. A comparison of the sections indicates the pitch of the deposit

body and the gneiss and in some places in the gneiss itself is a layer of magnetite. Most authors agree that the magnetite was produced at a later period of mineralization than the zinc ore and is not related to the zinc ore body. It has been shown in the mine workings that the magnetite continues beyond the zinc ore body in a straight line and does not correspond to it in curvature. The 750-foot (229-meter) level is representative of the general relations of the ore body. Figure 31 shows a diagram of this level illustrating its relationship to the surface and sections of the ore deposit.

ORIGIN OF THE ORES

A comprehensive study of the origin of the ores involving modern petrographic methods accompanied by field work has been carried on by Ries and Bowen (19). These authors set up the following sequence of events as representing the history of the ore deposits: (1) Metamorphism of the Franklin limestone prior to the deposition of the ore; (2) deposition of the ore minerals, mainly by replacement of the limestone, possibly in some places in cavities; (3) intrusion of the syenite mass in the upper part of the Sterling Hill ore body; (4) folding of the limestone with the ore bodies, resulting in the development of the curious trough-shaped deposits at the two localities; (5) intrusion of the pegmatite at Mine Hill, accompanied or followed by deposition of silicates and some recrystallization of the ore minerals near pegmatite contacts; (6) deposition of later or secondary willemite in possible ore fractures, due either to solution and redeposition of earlier zinc ores, or to introduction of more zinc-bearing solution—the evidence not being as clear as might be wished; (7) fracturing of the ore bodies, accompanied in places by faulting; (8) introduction of sphalerite, pyrite, and chalcopyrite; (9) deposition of carbonates; (10) intrusion of basic dikes of possible Ordovician age; (11) erosion and subsequent slight weathering of the minerals in the ore deposits as shown by the finding of calamine, smithsonite, and azurite.

One of the most recent of the hypotheses that have been advanced to account for the ores as they are now found is that of Palache (16). He considers that metasomatic deposits of the hydrated zinc and iron minerals were formed by replacement of the Franklin limestone, and that simultaneously with the recrystallization of the inclosing limestone as a result of regional metamorphism these bodies were changed to their present mineral composition. The main ores he considers to have been produced by a combination of these two processes. He points out, however, the presence of a number of later and, so far as economic importance is concerned, lesser modifications, which have produced a diverse variety of minerals and numerous interesting mineral relationships. In this group occurred the invasion of pegmatites, resulting in recrystallization of primary minerals near the contacts and forming skarns by the interaction of ores and magmatic materials. Furthermore, pneumatolytic products of the pegmatite magma produced numerous veined minerals throughout the ore body. Later, as the temperature fell, hydrothermal veins of great variety were formed, producing an unusual assortment of minerals.

MINERALS

The region around Franklin constitutes one of the most famous mineral localities in the world. Palache (16) has recently published a list of minerals and a description of their paragenesis. Since Palache's list was published Bauer and Berman (1, 2, 3) have made several additions—beryllium-vesuvianite, barylite, mooreite, fluoborite, loseyite, ferroschallerite, and manganbrucite—and have also shown that clinozoisite should be eliminated from the list of Franklin minerals. The total number of minerals reported is now 143. Palache's list, with clinozoisite omitted, is quoted below.

Paragenetic table of Franklin minerals

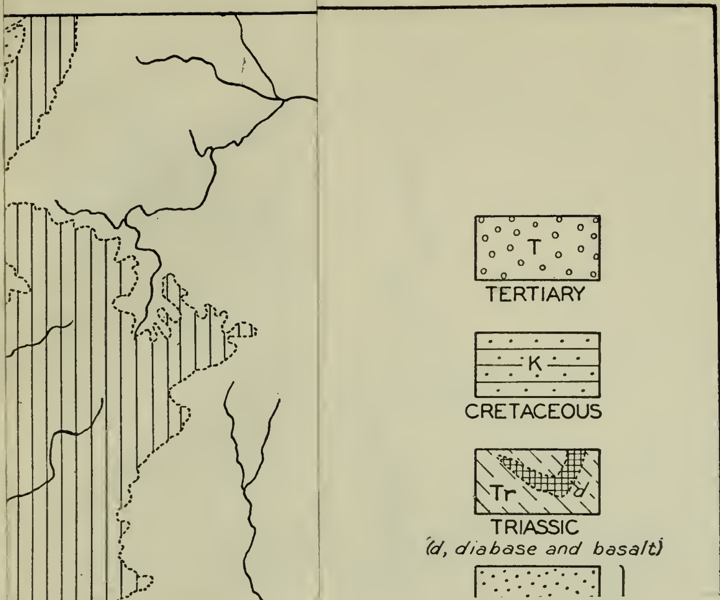
1. Primary ores:
   - Franklinite $(Zn, Fe, Mn)O.(Fe, Mn)_2O_3$.
   - Zincite $(Zn, Mn)O$.
   - Willemite $2ZnO.SiO_2$.
   - Tephroite $2(Mn, Zn, Fe)O.SiO_2$.
2. Pegmatite contact minerals:
   - *Skarn*—
     - Hyalophane $(K_2, Na_2, Ba)O.Al_2O_3.4SiO_2$.
     - Jeffersonite, Schefferite, Zinc-schefferite } $(Ca, Mg)O.(Fe, Mn, Zn)O.2SiO_2$.
     - Fowlerite $(Mn, Fe, Ca, Zn)O.SiO_2$.
     - Bustamite $(Mn, Ca)O.SiO_2$.
     - Manganese hornblende.
     - Manganese garnet.
     - Hardystonite $2CaO.ZnO.2SiO_2$.
     - Tephroite $2(Mn, Zn, Fe)O.SiO_2$.
     - Roepperite $2(Fe, Mn, Zn, Mg)O.SiO_2$.
     - Glaucochroite $MnO.CaO.SiO_2$.
     - Vesuvianite, var. cyprine $3(Al, Fe)_2O_3.6(Ca, Zn, Cu, Mn)O.5SiO_2.2H_2O$.
     - Manganophyllite = Mn-biotite. Var. caswellite, altered Mn-biotite.
     - Gahnite $(Zn, Fe)O.(Al, Fe)_2O_3$.
     - Magnetite $FeO.Fe_2O_3$.
   - *Recrystallization products*—
     - Franklinite $(Zn, Fe, Mn)O.(Fe, Mn)_2O_3$.
     - Zincite $(Zn, Mn)O$.
     - Manganosite MnO.
     - Hematite Fe_2O_3.
     - Willemite $2ZnO.SiO_2$.
     - Tephroite $2(Mn, Zn, Fe)O.SiO_2$.
   - *Pneumatolytic products*—
     - Margarosanite $PbO.2CaO.3SiO_2$.
     - Pectolite $Na_2O.4(Ca, Mn)O.6SiO_2.H_2O$.
     - Willemite $2ZnO.SiO_2$.
     - Nasonite $5PbO.4CaO.PbCl_2.6SiO_2$.
     - Barysilite $3(Pb, Mn)O.2SiO_2$.
     - Glaucochroite $MnO.CaO.SiO_2$.
     - Tephroite $2(Mn, Zn)O.SiO_2$.
     - Larsenite $PbO.ZnO.SiO_2$.
     - Calcium-larsenite $(Pb, Ca)O.ZnO.SiO_2$.
     - Roeblingite $7CaO.2PbO.2SO_3.5SiO_2.5H_2O$.

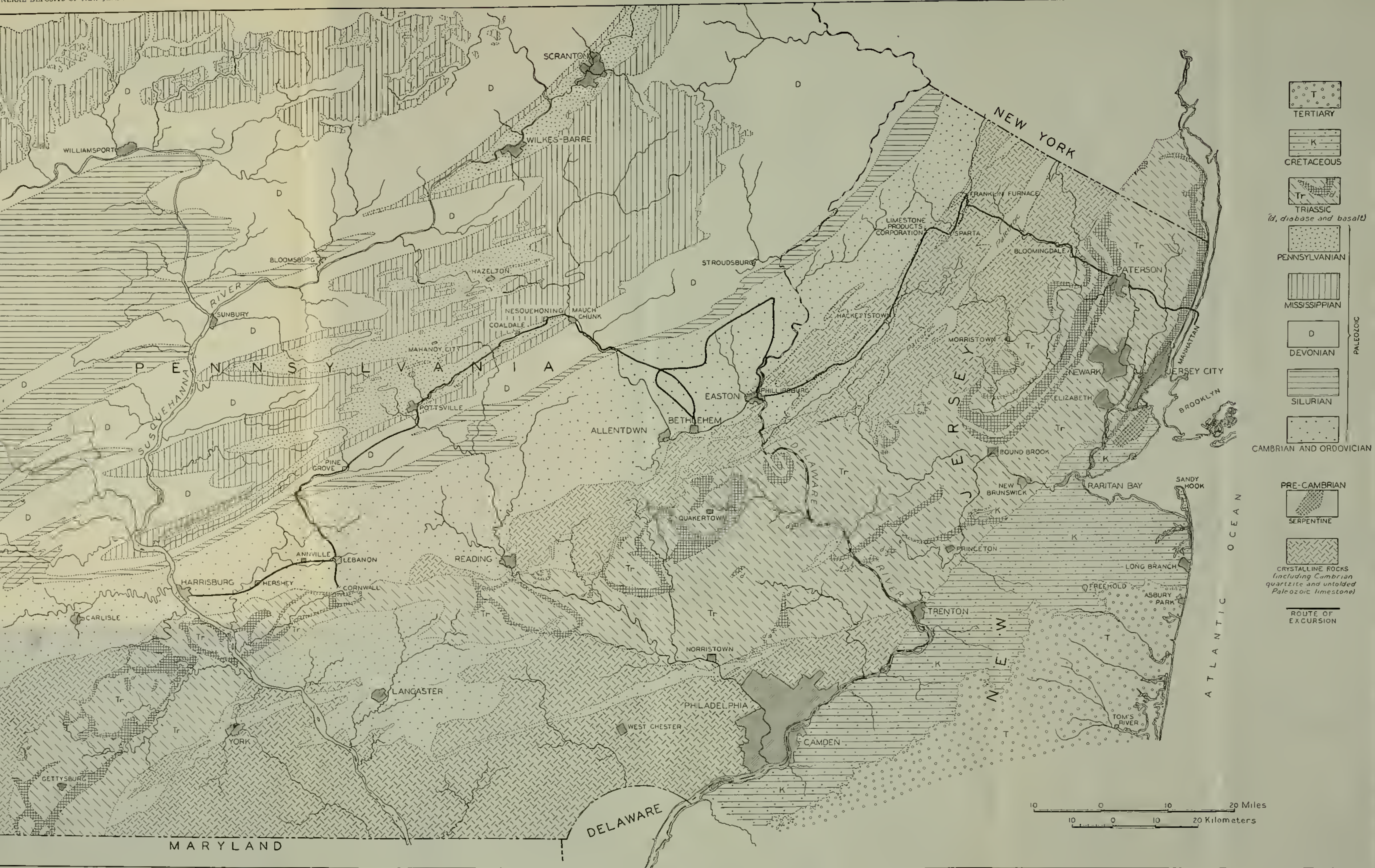
2. Pegmatite contact minerals—Continued.
   Pneumatolytic products—Continued.
   - Hancockite 4(Pb, Ca)O.$4Al_2O_3.6SiO_2.H_2O$.
   - Prehnite $2CaO.Al_2O_3.H_2O.3SiO_2$.
   - Leucophoenicite 7(Mn, Zn, Ca)O.$H_2O.3SiO_2$.
   - Clinohedrite CaO.ZnO.$H_2O.SiO_2$.
   - Hodgkinsonite 3(Zn, Mn)O.$H_2O.SiO_2$.
   - Datolite $2CaO.B_2O_3.H_2O.2SiO_2$.
   - Cahnite $4CaO.B_2O_3.4H_2O.As_2O_5$.
   - Sussexite 2(Mn, Mg, Zn)O.$B_2O_3.H_2O$.
   - Manganese-axinite $2Al_2O_3$.4(Ca, Mn)O.$B_2O_3.H_2O.8SiO_2$.
   - Cuspidine $4CaO.F_2.2SiO_2$.
   - Apatite 8CaO.2(Ca, Mn)F.$3P_2O_5$.
   - Hedyphane 8(Ca, Pb)O.2PbCl.$3As_2O$.
   - Svabite 8CaO.2(Ca, Mn)F.$3As_2O_5$.
   - Franklinite (Zn, Fe, Mn)O.(Fe, Mn)$_2O_3$.
   - Fluorite CaF_2.
   - Barite $BaO.SO_3$.
   - Silver Ag.
   - Copper Cu.
   - Lead Pb.
   - Galena PbS.
   - Chalcocite Cu_2S.
   - Niccolite NiAs.
   - Chloanthite $NiAs_2$.
   - Sphalerite ZnS.
   - Chalcopyrite $CuFeS_2$.
   - Bornite Cu_3FeS_2.
   - Pyrite FeS_2.
   - Löllingite $FeAs_2$.

3. Hydrothermal vein minerals:
   - Albite $Na_2O.Al_2O_3.6SiO_2$.
   - Fowlerite (Mn, Fe, Ca, Zn)O.SiO_2.
   - Actinolite (Mg, Ca, Fe)O.SiO_2.
   - Tremolite (Mg, Ca)O.SiO_2.
   - Crocidolite $Na_2O.2FeO.Fe_2O_3.6SiO_2$.
   - Willemite $2ZnO.SiO_2$.
   - Friedelite $7MnO.MnCl.6SiO_2.4\frac{1}{2}H_2O$.
   - Schallerite $12MnO.9SiO_2.As_2O_5.7H_2O$.
   - Mcgovrenite 21(Mn, Mg, Zn)O.$3SiO_2.\frac{1}{2}As_2O_3.As_2O_5.10H_2O$.
   - Leucophoenicite 7(Mn, Zn, Ca)O.$H_2O.3SiO_2$.
   - Gageite 8(Mn, Zn, Mg)O.$3SiO_2.3H_2O$.
   - Hodgkinsonite 3(Zn, Mn)O.$SiO_2.H_2O$.
   - Ganophyllite $7MnO.Al_2O_3.8SiO_2.6H_2O$.
   - Apophyllite $K_2O.8CaO.16H_2O.16SiO_2$.
   - Thomsonite $Na_2O.Al_2O_3.2SiO_2.2H_2O$.
   - Stilbite (Na_2, Ca)O.$Al_2O_3.6SiO_2.6H_2O$.
   - Epistilbite $CaO.Al_2O_3.6SiO_2.5H_2O$.
   - Heulandite $CaO.Al_2O_3.6SiO_2.5H_2O$.
   - Chlorite $5MgO.Al_2O_3.3SiO_2.4H_2O$.
   - Mn-serpentine 3(Mg, Mn, Zn)O.$2SiO_2.2H_2O$.
   - Bementite $8MnO.7SiO_2.5H_2O$.
   - Talc $3MgO.H_2O.4SiO_2$.
   - Calcite $CaO.CO_2$.
   - Aragonite $CaO.CO_2$.
   - Dolomite (Ca, Mg)O.CO_2.
   - Siderite $FeO.CO_2$.
   - Rhodochrosite $MnO.CO_2$.

3. Hydrothermal vein minerals—Continued.
   - Smithsonite $ZnO.CO_2$.
   - Quartz SiO_2.
   - Zincite ZnO.
   - Hematite Fe_2O_3.
   - Hetaerolite $ZnO.Mn_2O_3$.
   - Goethite $Fe_2O_3.H_2O$.
   - Manganite $Mn_2O_3.H_2O$.
   - Pyrochroite $MnO.H_2O$.
   - Chalcophanite $(Mn, Zn)O.2MnO_2.2H_2O$.
   - Hedyphane $8 (Ca, Pb)O.2PbCl.3As_2O_5$.
   - Arseniosiderite $8CaO.8FeO.6H_2O.3As_2O_5$.
   - Allactite $7MnO.4H_2O.As_2O_5$.
   - Chlorophoenicite $10(Mn, Zn)O.7H_2O.As_2O_5$.
   - Holdenite $8MnO.4ZnO.5H_2O.As_2O_5$.
   - Sussexite $2(Mn, Mg, Zn)O.H_2O.B_2O$.
   - Barite $BaO.SO_3$.
   - Celestite $SrO.SO_3$.
   - Anhydrite $CaO.SO_3$.
   - Galena PbS.
   - Sphalerite ZnS.
   - Greenockite CdS.
   - Pyrite FeS_2.
   - Marcasite FeS_2.
   - Millerite NiS.
   - Tennantite $4Cu_2S.As_2S_3$.
4. Surface oxidation products:
   - Calamine $2ZnO.H_2O.SiO_2$.
   - Neotocite $MnO.SiO_2.nH_2O$.
   - Mn-serpentine $3(Mg, Mn, Zn)O.2SiO_2.2H_2O$.
   - Desaulesite=Ni-genthite $4(Ni, Zn, Fe)O.3SiO_2.6H_2O$.
   - Quartz SiO_2.
   - Cuprite Cu_2O
   - Hematite $Fe_2.O_3$.
   - Hydrohetaerolite $2ZnO.2Mn_2O_3.H_2O$.
   - Limonite $2Fe_2O_3.3H_2O$.
   - Chalcophanite $(Mn, Zn)O.2MnO_2.2H_2O$.
   - Psilomelane Mn-oxide.
   - Cerussite $PbO.CO_2$.
   - Malachite $2CuO.CO_2.H_2O$.
   - Azurite $3CuO.2CO_2.H_2O$.
   - Aurichalcite $5(Zn, Cu)O.2CO_2.3H_2O$.
   - Hydrozincite $3ZnO.CO_2.2H_2O$.
   - Smithsonite $ZnO.CO_2$.
   - Descloizite $4(Pb, Zn)O.H_2O.V_2O_5$.
   - Anglesite $PbO.SO_3$.
   - Gypsum $CaO.SO_3.2H_2O$.

At the picking table in Franklin the visitor has an opportunity to observe the output of the mine as it passes along a central rotating platform before entering the crusher. A number of rare specimens and several new minerals have been found by mineralogists at this point. Here it is that the output of the mine, as it were, passes in review. The common minerals seen on the picking table include willemite, franklinite, zincite, garnet, fowlerite, and calcite.


T
TERTIARY
K
CRETACEOUS
Tr
d
TRIASSIC
(d, diabase and basalt)



GEOLOGIC MAP OF NORTHERN NEW JERSEY AND EASTERN PENNSYLVANIA

A large number of the mineral species found in Franklin fluoresce in ultraviolet light. The New Jersey Zinc Co. has placed an electric arc producing ultraviolet light in a darkened inclosure near the picking table for the convenience of workmen. It is worth while for the visitor to test the specimens picked up from the picking table with this light, as such an examination will often reveal unusual fluorescent minerals that might otherwise be overlooked.

ACKNOWLEDGMENTS

In the preparation of this guidebook great courtesy and consideration has been shown by the officials of the New Jersey Zinc Co., who have also made it possible for the party to visit the mine and mill at Franklin.

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FRANKLIN FURNACE, NEW JERSEY, TO EASTON, PENNSYLVANIA

At the end of the day's visit at Franklin Furnace the excursion will drive to Easton, Pennsylvania, for the night. Both of these places are near the westerly margin of the belt of ancient crystalline rocks forming the highlands of New York and New Jersey. Close at hand on the northwest side of this belt lie the older Paleozoic formations, which, because of their comparative weakness, have been crumbled into complex deformational structure and eroded to form the Great Valley. Here and there patches of these overlying rocks are found infolded and downfaulted within the crystalline belt, and two or three of these blocks are crossed by the highway to Easton.

The trend of the general geologic structure is southwest, virtually parallel with the general course of the traverse. At two or three places the structural relations can be seen. The major areal distribution and structure is indicated on Plate 1.

The party drives south from Franklin to Sparta. From Franklin to Ogdensburg the road passes over Franklin limestone, of pre-Cambrian age. Thence to Sparta the underlying rocks are Cambrian and Ordovician limestones. Turning west at Sparta, the road crosses a ridge of acidic and basic gneisses, and then a stop is made at an extensive quarry of Franklin limestone, which is pulverized for agricultural and other purposes. Unusually coarse crystallization of the limestone is to be noted here, some individual crystals being as much as a few inches in diameter. There are also many silicate and other minerals present in parts of the limestone, but no zinc minerals. This quarry furnishes a better illustration of the Franklin limestone than can be obtained at Franklin.

Leaving the quarry, the route passes in a southwesterly direction to Easton. It traverses Cambrian and Ordovician limestones and Ordovician (Martinsburg) shales. The higher ridges on each side are composed of gneisses.

THE BANGOR-PEN ARGYL SLATE REGION, PENNSYLVANIA[1]

By C. H. Behre, Jr.

ECONOMIC IMPORTANCE

Slate deposits of the United States.—Although slate is known in many parts of the United States and is reported to occur in workable quality and quantity in at least 14 States (35,[2] pl. 1), only six (Maine, Vermont, New York, Pennsylvania, Maryland, and Virginia) have produced roofing slate or slate blocks or slabs in noteworthy amounts in recent years. It is significant that the six States are located where Appalachian orogeny is conspicuous.

The two outstanding regions of slate quarrying are (1) adjacent parts of Vermont and New York east and south of Lake Champlain, which produce chiefly red and green slate, and (2) eastern Pennsylvania (Northampton and Lehigh Counties), which produces blue-gray slate only.

Importance of Pennsylvania production.—Pennsylvania leads all other States in slate production, having yielded between 1913 and 1929 slate to the value of $70,177,163, nearly half the output for the country as a whole. Almost all of the Pennsylvania output has come from the Lehigh-Northampton district, which produces every kind of raw and finished slate material made in the United States, except slate pencils. In recent years it has yielded about 40 per cent of the roofing slate, 90 per cent of the "millstock" (finished slabs for floors, walls, stairs, tubs, table tops, and similar objects), all the blackboards, 19 per cent of the electrical slate, and all school slate produced annually in the United States.

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[1] Published by permission of the State geologist of Pennsylvania.
[2] Numbers in parentheses refer to bibliography, p. 30.

The eastern part of the district, or Bangor-Pen Argyl slate region, is at present more productive than the western part, or Slatington region. It has been described by Dale (35) and recently in greater detail by the writer (31, 33).

LOCATION AND SURFACE FEATURES

The location of the several Pennsylvania slate districts is shown on Figure 4. Of these only the Lehigh-Northampton

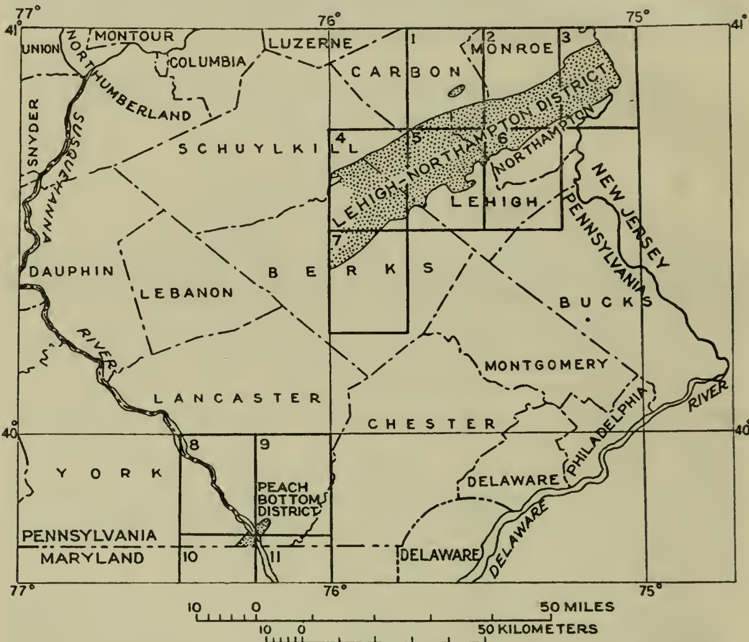

Figure 4.—Outline map of southeastern Pennsylvania, showing slate districts, with counties and quadrangles (indicated by numbers) in which they occur. 1, Mauch Chunk; 2, Wind Gap; 3, Delaware Water Gap; 4, Hamburg; 5, Slatington; 6, Allentown; 7, Reading; 8, McCalls Ferry; 9, Quarryville; 10, Belair; 11, Havre de Grace

district is now active, though there is some quarrying from the southward continuation of the Peach Bottom district in Maryland. The industry in the Lehigh-Northampton district is grouped around three cities—Bangor and Pen Argyl, in the eastern part of the district, and Slatington, in the western part. The rural population is largely of German descent; but in the cities it is partly Welsh, as suggested by the names of many of the towns, and the Welsh language is still spoken in Bangor and Pen Argyl.

The region underlain by the slate averages 750 feet (229 meters) in altitude and 200 feet (61 meters) in relief. It is gently rolling, with many flat-topped divides that suggest ancient peneplanation; the levels thus developed correspond to the Honeybrook and Harrisburg cycles of Bascom (28). To the northwest is a much higher ridge, relatively flat-topped, a remnant of the Kittatinny peneplain. It is crossed by the two prominent water gaps of the Delaware and Lehigh Rivers and by several wind gaps, of which Wind Gap, near Pen Argyl, is the most prominent. The high ridge rises to 1,600 feet (488 meters). It is underlain by resistant Silurian quartzite. In this part of Pennsylvania it is called Blue Mountain. To the southeast is a broad, open valley, the "limestone valley," the altitude of which is some 300 feet (91 meters) lower and to which the slate "terrace" declines by a perceptibly abrupt slope.

A prominent terminal moraine, probably of late Wisconsin age, crosses the Delaware River and extends in a west-northwesterly direction. In general, however, glacial drift is not prominent, and only locally does it form a heavy cover, though many quarries strip about 20 feet (6 meters) of till or outwash before reaching bedrock. The topography dominating the landscape is that of stream erosion. The stream valleys that cross the slate belt have trenched into the surface and form steep-walled gorges differing markedly from the open valleys and meandering brooklets in the limestone valley to the south.

STRATIGRAPHY

General sequence.—The sequence, thickness, and lithology of the formations are shown in the accompanying table.

Geologic formations in eastern Pennsylvania

	Feet	Meters
Silurian:		
Tuscarora—White conglomeratic quartzite.		
Unconformity.		
Ordovician:		
Martinsburg—		
Upper member—Thick beds of light and dark slate, with rare thick interbeds of gray calcareous sandstone	2,600	792
Middle member—Alternating thin beds of gray slate and massive beds of gray calcareous and arkosic sandstone	4,200	1,280
Lower member—Alternating thin beds of gray impure sandstone and gray to black sericitic, siliceous, and carbonaceous slate, with rare thin beds of limestone	5,000	1,524
Jacksonburg—Thin bedded nonmagnesian limestone, locally graphitic	550	168

Unconformity.
Cambrian and Ordovician:
 Older limestones, generally magnesian and more massive than the Jacksonburg limestone; some *Cryptozoon* and some "edgewise" conglomerate.

The shaly and dolomitic limestones that underlie the slate formation are of Cambrian and Lower and Middle Ordovician age. They are described in greater detail in that part of this guidebook which deals with the cement region of Pennsylvania (pp. 30–39). The uppermost of these limestone formations is the Jacksonburg limestone, or "cement rock." This does not everywhere underlie the slate, but where present it grades upward into the slate formation. It is of Black River and lower Trenton age (36). Where the Jacksonburg is absent, other older limestones lie immediately below the Martinsburg, and an unconformity is indicated (40).

The rocks above the slate formation are of lower Silurian age. From the Schuylkill River westward, it is still uncertain just what part of the Silurian is represented, but in the region here described the lowest formation above the slate is a lower Silurian (Medina) (38 [3]) white quartzite and quartzitic conglomerate, the Tuscarora quartzite.

Stratigraphy of the slate formation.—The workable slate occurs wholly in the Martinsburg formation, which in this part of Pennsylvania ranges in age from the Trenton (Middle Ordovician) to the Pulaski and possibly middle Maysville (Upper Ordovician). There are so many structural complications that all estimates of thickness for the beds in this region are uncertain, but the most careful and detailed measurements yet made give an average of about 11,800 feet (3,597 meters). Southward in Maryland and southern Pennsylvania the formation is much thinner.

The Martinsburg formation consists of carbonaceous and carbon-lean sericitic slates, interbeds of calcareous and sericitic sandstone, and rare beds of shaly, siliceous, or pure limestone. This entire series of sediments bears every indication of shallow water, essentially estuarine origin. There are highly carbonaceous layers, linguoid ripple marks, rill marks, numerous minor unconformities, cross-bedding (almost uniformly inclined westward), and tracks and trails of invertebrates. Fossils are rare, partly because of the high degree of metamorphism, but those found include chiefly trilobites, brachiopods, and pelecypods.

The detailed stratigraphy is obscure. Most geologists, including the writer, agree that there are three members, separable on the basis of lithology. It has been suggested, however, that

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[3] Also Ulrich, E. O., oral communication, 1927.

the "uppermost" of the three units recognized is simply the lowest member repeated by folding (39).

The lowest member of the Martinsburg is about 5,000 feet (1,524 meters) thick. It consists of sandstone, sandy slate, and sericitic layers almost wholly free from sand grains. The sericitic rock is worked for slate in a few favorable localities. It consists of varvelike alternations of sericite-rich bands and carbonaceous sericitic bands; both are typically rich in quartz, but the former have relatively larger amounts. Individual bands fluctuate between wide extremes but rarely exceed 6 inches (15 centimeters) in thickness and are typically more closely spaced, averaging about 0.5 inch (1.27 centimeters).

The middle member of the Martinsburg is about 4,200 feet (1,280 meters) thick in the region here described. It thickens westward, however, and grows coarser in the same direction. This member has yielded the only well preserved fossils in the Lehigh-Northampton district and is known to range in age from uppermost Trenton to upper Eden. Although this member includes some gray slaty beds and green and red clay slates which have been quarried and crushed locally for pigments and fillers, it has not yielded commercial quantities of roofing or structural material. The reason for this is that sandstone laminae and massive layers make up most of the formation; some beds are even a fine-grained conglomerate. Being thus more resistant to weathering, this member forms low ridges or hills that stand above the general level of the slate belt.

The upper member of the Martinsburg formation is the chief source of slate in the State. Its thickness is about 2,600 feet (792 meters), but as it has been subjected to erosion in late Ordovician (pre-Tuscarora) time, it varies from place to place. It consists of sericite slate, carbonaceous sericite slate, and sericitic sandstone in alternating beds, all of which in thickness far exceed those of the lower member; thus the sericitic layers range from 1 to 20 feet (0.3 to 6 meters), the sandstone beds reach 15 feet (4.6 meters), and even the carbonaceous layers attain 1 foot (0.3 meter) or more. Generally, thick sandstone layers are succeeded by thick beds of slate. The detailed stratigraphy of parts of this sequence has been carefully worked out. (See p. 26.)

PETROLOGY

The chief minerals of the slate, named in the order of abundance, are sericite, quartz, iron-bearing calcite, chlorite, graphite, pyrite, rutile, biotite, plagioclase, and zircon; the last two are comparatively rare. The quartz is partly in rounded sedimentary grains, partly in irregular masses forming a matrix and manifestly of secondary origin; almost all shows strain shadows and elongation in the direction of the cleavage, the diameter ratios averaging 2:1. The sericite occurs in part in recognizable flakes but mostly forms very thin, hairlike or lathlike masses; generally the basal directions of the flakes are parallel to the cleavage; the lathlike fibrous forms make up masses weaving sinuously in and out among the quartz and chlorite grains. The calcite is highly recrystallized—a part may well be primary, but much of it replaces other minerals, especially the quartz. The calcite

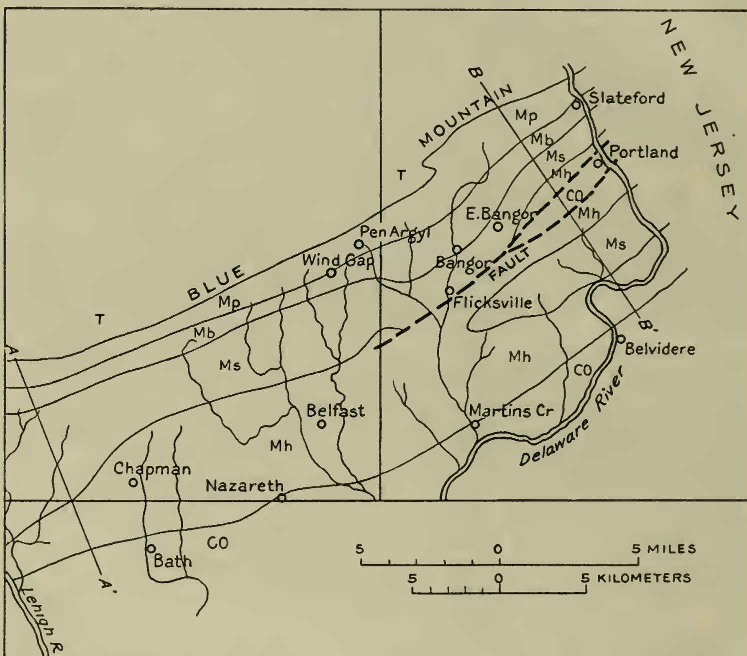
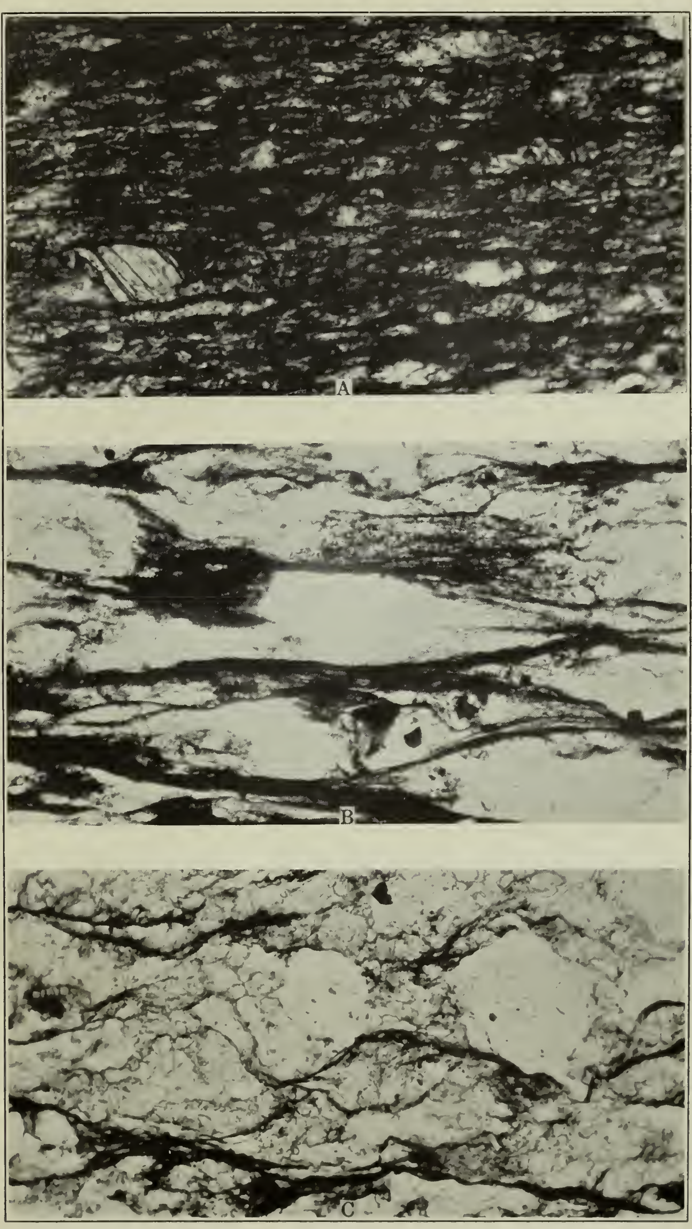


FIGURE 5.—Generalized map showing areal geology of the slate belt in parts of the Allentown, Wind Gap, and Delaware Water Gap quadrangles. For explanation of symbols and sections along lines *A–A′* and *B–B′* see Figure 6.

oxidizes readily, producing a faint rusting. The chlorite forms slender flakes, like the mica. It also occurs in grains, the average dimensions of which are 0.04 by 0.06 millimeters in sections at right angles to the slaty cleavage. Such chlorite individuals have their mineral cleavage inclined at all degrees to the slaty cleavage of the rock; they are probably porphyroblasts. The other minerals do not require special comment. Some idea of the usual texture is gained from Plate 2, *A*.



THIN SECTIONS OF SLATE FROM PEN ARGYL, PENNSYLVANIA

A, Typical "soft" slate. The large lenticular areas crossed by cleavage are chlorite porphyroblasts. *B*, *C*, Coarsely granular slate; *B* cut in plane of grain, *C* at right angles to cleavage and grain. Dark hairlike lines are sericite laths, more regularly arranged in *B*. All enlarged 160 diameters.

A TYPICAL SLATE QUARRY AT PEN ARGYL, PENNSYLVANIA

Courtesy of Bliss Studio, Easton, Pennsylvania.

In detail, the textures in different kinds of slate are characteristic. The usable slate of the lowest member of the Martinsburg, commonly referred to as "hard" slate because of its resistance to abrasion as well as its greater resistance to cleaving, contains slightly more quartz; chemical analysis also shows it to be slightly higher in silica than the "softer" slates of the upper member—60.2 per cent, as against 58.3 per cent in average analyses. In addition to differences in silica (and quartz), the finer grained the slate, as a rule, the more easily it splits and therefore, also, the "softer" it is, in the vernacular of the quarrymen; this statement applies to all varieties examined. Fineness and uniformity of grain are also especially characteristic of "electrical" slate—that best suited for electrical insulation and switchboards; such slate is also low in graphite and pyrite. The dark, carbonaceous beds or "ribbons" are characterized by large amounts of graphite, mineral analyses giving about 3.5 per cent of graphite and chemical analyses about 4 per cent of carbon, as against 2 per cent and less than 1 per cent respectively in the average slate. There are also rare chloritic strata, called "gray beds" by the quarrymen, which are olive gray in color as opposed to the blue gray characteristic of most of the slate; these beds are rich in chlorite and muscovite and lean in graphite and pyrite.

STRUCTURE

General structure.—The areal geology is shown in Figure 5. Broadly considered, the slate beds are part of a large monocline, bearing numerous and complex lesser folds. The strike of this structure is about N. 60° E., and the dip gently northward, so as to carry the Ordovician Martinsburg gradually beneath the Silurian that crops out on Blue Mountain. Southward the same structure continues and brings the pre-Martinsburg Ordovician limestones to the surface. Representative sections are shown in Figure 6.

In the region of Portland, on the Delaware River, there are two major faults bounding an anticline; these features combine to bring the underlying Cambrian and Ordovician limestones to the surface, making possible the development of limestone quarries at Portland. Westward this structure dies out again and the normal large-scale monocline is resumed as far as the Lehigh River. West of the Lehigh the structure once more becomes complex, and several thrust faults are recognized. In that part of the slate belt here described, however, no other large faults are recognizable, though some are known on its southern border, in the underlying limestone.

Details of folding.—Economic problems in the slate district turn more upon details of structure than on the larger features

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described above. Invaluable in this connection is the circumstance, demonstrated again and again, that detailed correlation of beds is possible. The manner of correlation is discussed below, but the method of restoring details of folded structure may be touched upon here. It afforded an answer to several practical problems of great importance, none of them easily solved, in view of the complexity of the structure and the meager outcrops.

It is a common axiom that in regions of heavy recrystallization and cleavage development incidental to folding, the cleavage is in planes roughly parallel to the axial planes of the folds. This fact, amply confirmed by observation, makes possible the follow-

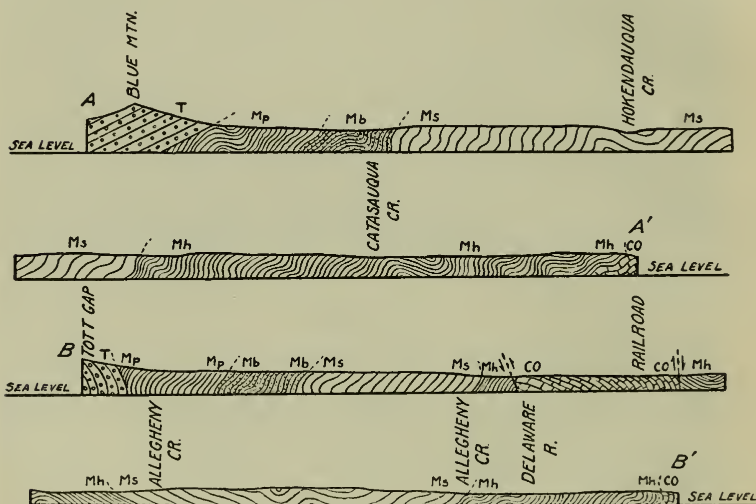

Figure 6.—Structure sections through slate belt along lines *A–A′* and *B–B′* in Figure 5. T, Tuscarora quartzite; Mp, Martinsburg formation, slate beds of Pen Argyl; Mb, Martinsburg, slate beds of Bangor; Ms, Martinsburg, middle member; Mh, Martinsburg, lower member; CO, Cambrian and Ordovician limestones. Scale about 1 : 84,300

ing generalizations. First, where cleavage dip is more gentle than bedding dip, the beds are overturned. (See fig. 7, A.) Second, as the axial planes of the folds in this region were observed to dip southward, almost without exception, steeply dipping beds are inferred to represent the north limbs and gently dipping beds the south limbs of anticlines. (See fig. 7, B.) Third, on a given cleavage plane the angle between cleavage and bedding may be assumed to remain constant and the structure of the beds may be projected downward in accordance with that assumption. (See fig. 7, C.)

With the aid of these principles applied to the smaller outcrops, and with the observations made in railroad and highway cuts and in quarry walls, the general structure of the region may be pictured. There are numerous close folds, with their axial planes tipped northward and striking about N. 60° E. In some places the overturning is so extreme that the structure is essentially recumbent. (See pl. 7, *A*.) Toward the southeast the limbs of the folds are closer together and the folds tighter. The axial planes are flatter toward the east, at Bangor and Pen Argyl, having an average dip of about 15° S., whereas at Slatington, some 20 miles (32 kilometers) southwest along the strike, they dip about 60° S. Compression thus seems to be less both northward and westward along the strike. The maximum thinning of the limbs is on the northwest flanks of the anticlines. As it is the north limb of the anticline that is typically most nearly vertical, it may be that the thinning on this limb is due to the fact that the effective thrust is almost horizontal, or at most nearly at right angles to the vertical position of the beds in this part of the fold.

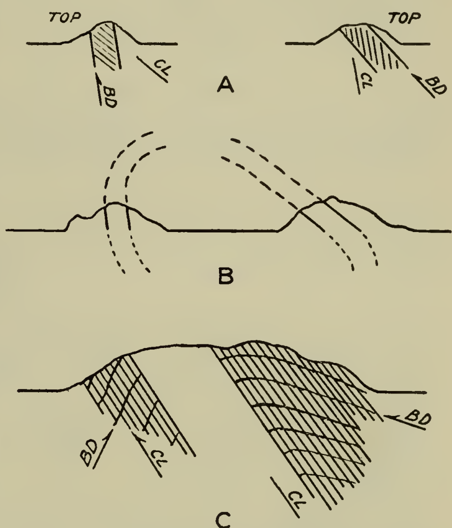

FIGURE 7.—Methods of restoring structure from bedding and cleavage relations. Bd, bedding; Cl, cleavage. Northwest is to the left, southeast to the right of diagrams. A, beds to left overturned, those to right normal. B, beds to left on north limb of anticline, those to right on south limb; dashed lines correct, dotted lines (below surface) incorrect interpretation. C, projection of dip of beds with depth

Details of faulting.—Except for the large faults near the Delaware River, there has been very little faulting, probably because when deformation began the Martinsburg shales were plastic, flowing and recrystallizing upon compression. In places the more brittle calcareous and sandy beds show minute slicing where the adjacent slaty layers merely "flowed" and were folded. (See fig. 8.) A few quarries show small horizontal movements normal to the regional thrust.

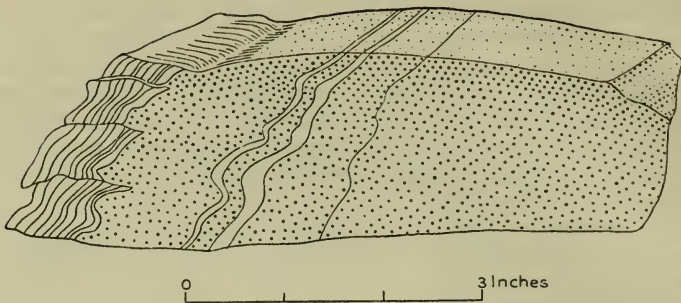

FIGURE 8.—Small-scale faulting in calcareous beds, accompanied by folding in slaty beds. Top of block is cleavage surface. Total length about 15 centimeters

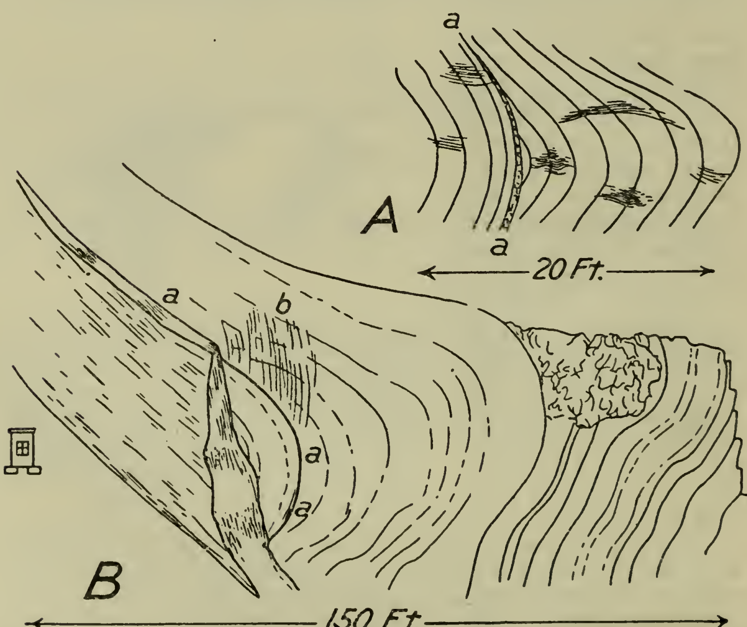

FIGURE 9.—Bedding-slip faults. *A*, Peerless quarry, northeast wall; shows bedding-slip plane (*a–a*), the lower part of which is a quartz-filled crevice. *B*, Albion quarry, Pen Argyl, viewed from southwest wall; shows fault surface (*a–a*) parallel to beds, and vertical joints (*b*)

One type of faulting of particular interest has been called "bedding slip" by the writer (30). This is observed where the folding is very close; the effect is one of shear against the beds on the inner (northwest) sides of synclines, the beds being more closely compressed south of the shear plane. (See fig. 9.) Close jointing spoils the slate on both sides of the fault plane. Five examples of such faulting have been carefully studied. In the two where the fault plane was accessible fault striae indicate that the most recent movement was vertical, possibly a further compression of the "tighter" part of the fold. The mechanics of such deformation are not yet clearly explicable, however.

Other structural details.—Joints are a constant feature, which can be well studied in the accessible quarries, for all of which detailed joint studies have been made. The dominant strike of the joints is northeast, with dips that are nearly vertical.

The outstanding fact of the cleavage features is the constancy in strike. Southwestward in the district the cleavage strikes more easterly, averaging N. 70° E. in the western part (near Slatington) and N. 66° E. in the eastern part (near Pen Argyl and Bangor).

A structural feature not generally recognized in the hand specimen is grain. This shows as indistinct lines on the cleavage surface. When the slate is struck a sharp blow it breaks along these lines, which, though slightly curved and irregular, nevertheless have an average bearing that is constant for the region. Almost all the quarries are laid out with their sides parallel to the grain. Grain direction is also one of greater electric and heat conductivity. Under the microscope it is seen to be produced by the elongation of the mica and chlorite flakes. As a consequence, sections in the plane of the grain have the strands of mica far more uniformly parallel than those cut at right angles to the grain. (See pl. 2, *B*, *C*.) Regionally there are changes in the trend of the grain comparable to those in the cleavage; thus, in the eastern part of the district (Pen Argyl and Bangor) the grain bears N. 40°–45° W., whereas farther west (Slatington) it bears N. 30°–35° W. The grain direction thus has a relatively constant relation to the cleavage direction. Apparently the grain direction represents the maximum elongation incidental to folding.

Age of deformation.—Although it has generally been thought that the folding and schistosity of this part of the Paleozoic section in Pennsylvania represented late "Permo-Carboniferous" (Appalachian) orogeny, it has lately been proved (29, 37, 39) that a post-Ordovician, pre-Silurian unconformity exists in this region. The writer has also shown (30) that pebbles of sericitized slate occur in the overlying Silurian conglomerate and that microscopic evidence suggests two periods of deformation to which the Martinsburg has been subjected, the earlier deformation resulting in sericitization. These data strongly suggest that post-Ordovician, pre-Silurian folding was very intense, at least in this and adjacent parts of the Appalachian region. The fact that the directions of thrust for this and the later (Appalachian) orogeny are similar has been the reason why earlier observers did not recognize two separate orogenic epochs.

ECONOMIC GEOLOGY

The following paragraphs illustrate the bearing of geology upon the specific distribution and economic workability of the slate. A longer discussion has been presented elsewhere (32).

Effect of overburden.—Where glaciation did not strip off the decayed rock, the overburden is highly variable in thickness, and slate that at first glance appears to be sound can not safely be finished and sold. Where glaciation has been effective there is likely to be a cover of loose clay and boulders, which necessitates cribbing the upper walls of the quarry, but the slate at shallow depths below the overburden is firm and usable.

Correlation of beds.—The sequence of dark, carbonaceous beds ("ribbons") and of light blue-gray, carbon-free beds ("clear stock") is moderately constant along the strike and furnishes a basis for correlation. (See fig. 10.) This sequence has now been worked out in terms of feet and inches and has been most useful in interpreting structure, especially in the western part of the district, where, on account of the more nearly vertical fold axes and despite the flatness of the surface, individual beds crop out repeatedly in sections at right angles to the strike. Indeed, certain beds, because of their great thickness, their clear, uniform color, or their excellent cleavage, are desirable and are followed in quarrying or mining, like so many coal or iron ore beds, the adjacent strata being left standing. Knowledge of the detailed sequence has also been most valuable in interpreting diamond-drill cores.

Joints.—It has already been pointed out that joint systems of moderate constancy are recognizable, and further that near bedding slips joints are conspicuous and make for much waste in quarrying. Some quarries, notably near Wind Gap and West Bangor, lie on pitching folds whose axes, contrary to the general rule, are at right angles to the regional folds. Here the joints follow radial patterns, probably because they represent adjustments later than the cleavage development and compensate for movements between the beds. This circumstance of small intersecting angles between joints makes for much waste rock, because triangular slivers of useless slate are produced. It is significant that both of the quarries in which these features are most prominent have been financial failures.

Effect of cleavage dip.—Where the cleavage is flat or nearly flat the slate is much more easily worked than where it dips more steeply. On the flat floors thus developed any type of quarry machinery is easily set up. Where the cleavage dips steeply the difficulties of working the slate are locally even prohibitive.

Effect of bedding dip.—An ideal condition is for the bedding to stand nearly vertical. At Pen Argyl this condition exists,

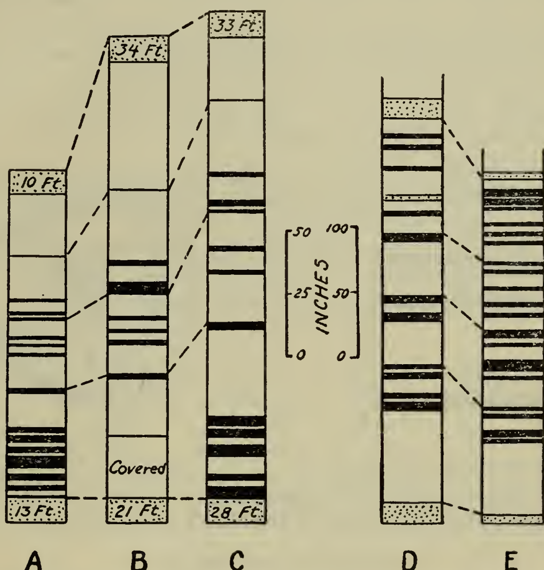

FIGURE 10.—Typical detailed columnar sections in slate belt, drawn to scale, to show correlation. Sandy beds stippled, dark layers in black. Quarries A, B, C near Slatington; D and E near Pen Argyl. Distance from quarry A to quarry C is 3 miles (4.8 kilometers) along strike

and here are developed the deepest quarries in the United States. In one of these, the Parsons quarry, the lowest level was 725 feet (220 meters) below the surface in 1931. By contrast, the quarries at Bangor are in close, recumbent folds; in following a desirable bed down the dip, which is here usually gentle, a large acreage must be stripped, but the depths attained are not as great. At Slatington this difficulty is met in part by mining in galleries or drifts developed on the bed alone.

Mutual relations of pitch and other structures.—For most purposes to which slate is converted—such as panels, stair treads, and roofing slate—rectangular blocks are needed. Hence it is desirable to quarry rectangular blocks, rather than rhombic or triangular blocks, in which the slate occupying the apices of interfacial angles represents waste. As illustrated in Figure 11, ideal conditions are those in which the planes of grain, cleavage, and joints are at right angles to one another. As the "ribbons" are to be avoided in many of the uses to which the slate is put, a further desirable circumstance is that the bedding has a rectangular relation to the other structural features. Hence quarries on the ends of pitching folds are poorly located. If, as in some other slate regions, the rock could be quarried in a mass, without regard to bedding, these considerations would not apply.

Such pitching folds have been disadvantageous in another way, as illustrated in Figure 12; the eastern quarries altogether missed the Klondike bed, which it was hoped to strike at depth.

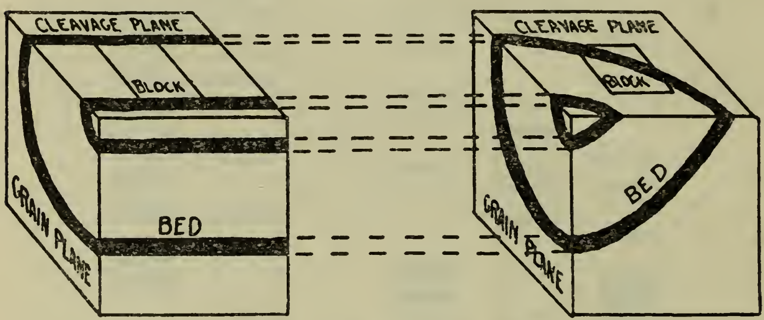

FIGURE 11.—Effect of relations between bedding, cleavage, joints, and grain. Relations are favorable in the figure to the left; unfavorable in that to the right

WORKING METHODS

Slate is quarried much like other rock. Blocks are freed with the aid of channeling machines, with powder, or by drilling a series of holes and breaking out the slate between them. The quarried block is classified according to the intended use. If it is to be made into roofing slate it is sent to the "shanty"; if into millstock, to the mill. A good description of American slate technology has been prepared by Bowles (34).

The outstanding problem is one of reducing waste. It has been said that from 60 to 85 per cent of the slate quarried is not usable.

In the "shanties" (small houses) the slate blocks, which have previously been sawed into smaller sizes, are split to the desired thinness (usually $\frac{3}{16}$ inch, or about 0.48 centimeter). They are then trimmed to the requisite shape by large knives operated with treadles. There are now at Pen Argyl some very modern roofing-slate mills. In these, which are large buildings, the trimming machines are power driven, and waste is carried out on belt conveyors.

In the mill building the slate is sawed into smaller blocks, planed to the desired thickness, cut by saw wheels or carborundum wheels, rubbed smooth by machines using sand or carborundum as abrasives, and finally perhaps even finished and beveled by hand.

Several of the slate companies, working cooperatively with the United States Bureau of Mines, have introduced the "wire

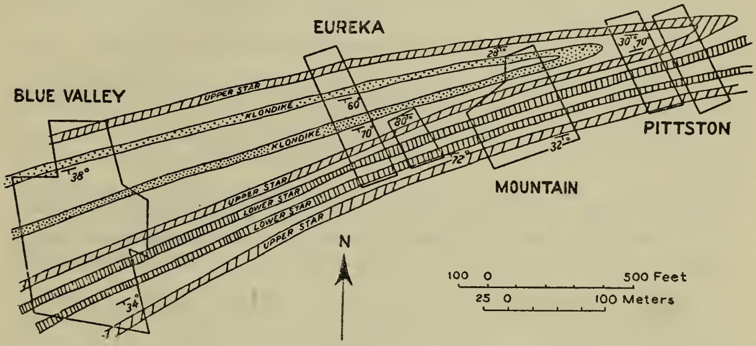

FIGURE 12.—Sketch map of geology and quarries at Eureka, near Slatington, Pennsylvania. Three big beds—the Klondike (above), Upper Star, and Lower Star—appear in a syncline and an anticline, axial planes dipping south. A southwest pitch brings the Klondike bed above the surface in the eastern quarries

saw," a continuous wire, fed with sand and run over the quarry floor or walls to cut the slate in place.

Of recent development also is a form of "marbleized" slate used for paneling. Slabs of millstock are coated with a very resistant enamel which may be made to show a pattern similar to some natural stone.

Slate to be used for electrical insulation is carefully tested for leakage with a milliameter. In this apparatus the terminals are brushlike and are brushed over opposite sides of the slab to be tested.

A view in a typical slate quarry is given in Plate 3.

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THE LEHIGH PORTLAND-CEMENT DISTRICT, PENNSYLVANIA

By Benjamin L. Miller

The Lehigh portland-cement district extends from the Schuylkill River to the Delaware River in Pennsylvania and about 5 miles (8 kilometers) east of the Delaware River in New Jersey, a total distance of somewhat more than 50 miles (80 kilometers). It is embraced within Berks, Lehigh, and Northampton Counties, Pennsylvania, and Warren County, New Jersey. The Pennsylvania portion lies near the northern margin of the limestone belt of the Great Valley or Kittatinny Valley. Reading, Kutztown, Allentown, Bethlehem, Easton, and Phillipsburg are within a few miles of the district and are closely connected with the cement industry, and several smaller towns are practically dependent altogether upon the cement plants in their vicinity. The cement industry of the Lehigh district is one of the foremost mineral industries of Pennsylvania and is surpassed only by those of anthracite, bituminous coal, and iron and steel.

HISTORY

In this country, as well as in Europe, the manufacture of natural hydraulic cement preceded that of portland cement and began in the early part of the last century. The first portland cement used in the United States came from England. During the Civil War (1861–1865) and for a few years afterward it was brought over in continually increasing amounts and rapidly gained favor. Realizing its superior value, David O. Saylor, who was manager and part owner of a natural hydraulic cement plant at Coplay, on the west side of the Lehigh River, began to experiment with the stone from his quarry by burning it harder and making various mixtures of argillaceous limestone and other limestones. He finally obtained results that justified his application for a United States patent for the manufacture of portland cement in 1871. About 1875 he began operating on a commercial scale. Since that time the parent company has continued to produce portland cement, and other plants have been added. Improvements in the quality of the cement have been made from year to year, so that the present product is far superior to that produced by Saylor. Newer and better machinery and larger units have been installed, and the most modern and efficient methods are used.

At present there are in the Pennsylvania portion of the district 19 plants with 25 different mill units, belonging to 13 different companies. There have been three large plants in New Jersey, but in recent years only two have been in operation. The production, which to the end of 1869 was 82,000 barrels (13,985,000 kilograms), has steadily increased until in 1927 the Lehigh district produced approximately 40,000,000 barrels (6,822,000,000 kilograms) or about 23 per cent of the total production of the country. The production has declined considerably during the last few years.

The Lehigh district enjoyed almost a monopoly in the manufacture of portland cement until it was discovered that an equally good product could be made from a variety of materials. Lehigh cement was shipped all over the country, and much of it was exported. No other cement region occupies so favorable a position with reference to accessibility to good cement rock and fuel and proximity to great industrial centers, yet on account of freight charges on a heavy product the market for Lehigh cement has been restricted by the erection of cement plants in other sections of the country. Fortunately, however, the demand for portland cement has kept pace with the growth of cement-manufacturing plants, so that the district continues to prosper regardless of increasing competition.

In this district many improvements have been made since the first successful manufacture of portland cement. For a time the run of quarry rock was used, with the result that some companies owning quarries in which the rock had practically the composition now looked upon as most desirable were able to produce a better product than other companies whose rock was less suitable. Also few companies were able to produce a uniform product, on account of the variation in composition of the rock even in the same quarry. Now, however, the chemist of each company sees that the proper mixtures are used, and the physical tests also serve as a check, so that the old hit-or-miss method has given place to exact scientific processes, and the variations in the product are very slight.

The changes in mechanical processes of manufacture have been equally great, and each year modifications are introduced that tend to increase the output and lower the cost of production. The greatest improvements have been those by which the old upright kilns have given place to the modern rotary kilns, now used throughout the district.

GEOLOGY

FORMATIONS PRESENT

The geology of the Lehigh district is complex and offers many unsolved problems. The formations present in this section of the Great Valley are shown in the following table:

Geologic formations in the Great Valley of Pennsylvania

	Feet	Meters
Silurian:		
Shawangunk formation—Sandstones and conglomerates forming Blue or Kittatinny Mountain and bounding the Great Valley on the north.		
Ordovician:		
Martinsburg formation—Slates, shales, and sandstones constituting the rounded or peneplaned hills immediately north of the cement quarries	5,000	1,524
Jacksonburg formation—Low-magnesium argillaceous limestones used in the manufacture of portland cement	250–600	76–183
Beekmantown formation—Interbedded low and high magnesium limestones	1,000	305
Cambrian:		
Conococheague (Allentown) formation—Dolomitic limestones	1,500	457
Tomstown formation—Dolomitic and shaly limestones	1,000	305
Hardyston formation—Sandstones and quartzites	50–250	15–76
Pre-Cambrian:		
Acidic and basic gneisses constituting the hills bounding the Great Valley on the south.		

In passing through the Great Valley from north to south the traveler passes over the outcropping strata in order of increasing age. This general arrangement is broken in several places by complicated folding and faulting.

Only two of the formations included in the above table, the Beekmantown and Jacksonburg, have furnished material used in the manufacture of portland cement. No stone from the Beekmantown is now being quarried for cement, but in the days of small production, when hand loading was employed in the quarries, some limestone was obtained from this formation. With loading by steam or electric shovel this is no longer feasible, because there is too much interbedded high-magnesium limestone mixed with the limestone suitable for portland cement and separable only by hand picking.

JACKSONBURG FORMATION

Areal distribution.—The Jacksonburg is a discontinuous formation throughout part of the district, owing largely, if not altogether, to structural features. (See pl. 4.) In some isolated areas folding and subsequent erosion and in others faulting and erosion account for the nonappearance of the formation at the surface. There is, however, considerable evidence to support the belief that in certain localities sediments of the type composing the formation were not deposited and that the beds laid down during that interval of time were entirely mud and have been included in the overlying Martinsburg formation. An unconformity between the Beekmantown and Jacksonburg has been determined in New Jersey but has not been observed west of the Delaware River, so that the marked discontinuity in the Pennsylvania portion is not explained by an erosion interval.

Between Leesport, on the Schuylkill River, and Fogelsville there are several areas of Jacksonburg limestone separated by areas where the Martinsburg shales are in direct contact with the underlying Beekmantown limestones. The Allentown Portland Cement Co. has a quarry and plant in one of these isolated areas at Evansville, and the Lehigh Portland Cement Co. has a similar development in a detached area of the Jacksonburg at Fogelsville. A few miles southwest of Egypt the formation appears at the surface, and it continues thence in almost uninterrupted outcrops to the Delaware River, a distance of about 30 miles (48 kilometers). It is within this belt that there has been the greatest development.

The detached area of Jacksonburg in which the three New Jersey cement plants have been operated is southeast of Phillipsburg, about 8 miles (13 kilometers) south of the persistent belt, and seems to owe its position to a sharp synclinal fold by which a portion of the formation was carried down below the present erosion level and hence preserved.

The belt of outcropping Jacksonburg limestone varies greatly in width, owing mainly to structural features but partly to varying thickness. In certain places the strata, although crumpled, have low average angles of dip and consequently wide outcrops; in other places high dips narrow the outcrop. Where the belt crosses the Lehigh River it is more than 2 miles (3.2 kilometers) wide, but in other localities it is scarcely half a mile (0.8 kilometer) wide. The average width of the belt throughout the Lehigh district is about 1 mile (1.6 kilometers).

In most places in the district the northern boundary of the cement rock can be accurately determined by an abrupt change in topography, the line of contact being at the base of the steep slopes that mark the southern margin of the slate belt. This change in slope is due to the relative ease with which the cement rock is removed by weathering, mainly through solution, in comparison with the much less soluble slate.

In several places the southern boundary of the cement rock belt is also marked by a change in slope. The underlying limestone is more soluble than the cement rock and produces a more nearly level topography; hence the change from one belt to the other is marked by a change in slope.

Lithologic characteristics.—The Jacksonburg strata in this district consist of two fairly distinct types of rock—a basal member of crystalline high-grade limestone and an upper member of argillaceous limestone that constitutes most of the formation. In some places the two members are sufficiently distinct to permit separate mapping, but elsewhere they grade into each other, and everywhere a few layers of the basal type are interbedded with the more argillaceous upper member. The basal strata are commonly designated "cement limestone" and the upper strata "cement rock."

The typical "cement limestone" is a light to dark gray coarsely crystalline limestone which, when freshly broken, shows lustrous surfaces of dark calcite. A less common variety is a dark-colored limestone closely resembling in appearance the underlying dolomitic limestones. It is usually massively bedded.

The "cement limestone" grades into the overlying argillaceous limestone or "cement rock" by an intermediate band of interbedded relatively pure limestone and impure argillaceous limestone. For that reason the two kinds of rocks, although lithologically dissimilar, are regarded as constituting a single geologic formation.

At the base the "cement limestone" is in contact with the Beekmantown magnesian limestones. In this region the two formations are approximately conformable, although in many places in New Jersey there is a marked erosional unconformity between them.

The "cement rock" is an argillaceous limestone intermediate both in composition and in stratigraphic position between pure limestone and shale or slate. In color it suggests the overlying Ordovician slates, and in many places it shows marked slaty cleavage. A freshly broken piece is bluish black and shows glistening particles of sericite too fine to be individually distinguishable except as light is reflected by them. The unaltered rock breaks partly along cleavage planes and partly along bedding planes, producing hackly or conchoidal surfaces that are unlike those of either the pure limestones beneath or the slates above. As the rock weathers, however, it separates into small cleavage fragments so similar to those resulting from the decomposition and disintegration of slate that it is difficult to distinguish between a slate soil and a "cement rock" soil. Both are filled with thin rock fragments of a light yellowish-gray color as much as 1 inch (2.5 centimeters) in length.

In almost every quarry the rock shows the effect of great compression by which it has been shattered, permitting water carrying mineral matter in solution to precipitate quartz and calcite in the open fissures and irregular cavities. In some places the vein matter is pure white calcite, in others white granular quartz, but more commonly a mixture of the two. The white veins contrasting with the black rock are very prominent in the working faces of most quarries. The veins are roughly parallel and tend to follow bedding planes, although in many places they break across the beds. Smooth slickensided surfaces coated with a soft black carbonaceous substance resembling graphite are very common on the vein walls.

Small cubes of pyrite are frequently noticed near the veins and occasionally in rock where the vein material is absent. Purple and green fluorite have also been found in a few localities as vein material.

In many quarries it is difficult to determine the bedding planes unless an interbedded stratum of pure limestone can be found. Where such a stratum is absent the quartz and calcite veins, which, in general, are present along the bedding planes, are useful in determining the structure.

Chemical composition.—The chemical composition of the "cement rock" changes from bed to bed or even in the same bed within a single quarry opening. In some quarries the average rock contains almost exactly the right proportion of the various materials required for the best grade of portland cement. In most quarries the rock varies, so that tracks must be run to several parts and the requisite mixture obtained by the proper combination of the various kinds of rock. In some quarries, however, the average rock runs too low in $CaCO_3$ so that it is necessary to add some high-grade limestone. Some of the plants are fortunate enough to have quarries in the underlying "cement limestone," but others must bring limestone from a distance. Much limestone from Annville, Lebanon County, Pennsylvania, is used in the Lehigh district.

A plant whose quarry is near the northern margin of the belt and works the upper beds will need to add high-grade limestone to the "cement rock," and a plant whose quarry is near the southern margin of the belt and works the basal beds may need to add some clay at times.

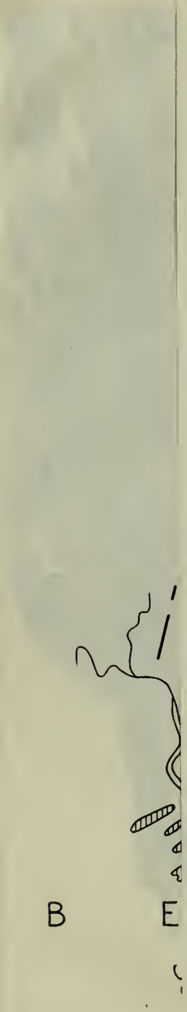
In general the "cement rock" toward the western part of the district runs too low in $CaCO_3$, and the plants located there must buy limestone. The rock in the central and eastern parts of the belt averages almost the desired composition for portland cement but requires at times a small admixture of clay.

The change in composition of the "cement rock" in depth is well shown in the following series of analyses of rock in a 350-foot (107-meter) boring made by the Universal Atlas Cement Co. in its quarry at Northampton. The last 40 feet (12 meters) penetrated was the underlying "cement limestone," and the other high lime analyses are explained by the presence of layers of pure limestone interbedded with the argillaceous limestone ("cement rock").

Average analyses of "cement rock" boring in quarry of Universal Atlas Cement Co., Northampton

Depth (feet)	SiO_2	$Al_2O_3+Fe_2O_3$	$CaCO_3$	$MgCO_3$
0–50	21.72	7.88	63.27	5.33
50–100	21.42	8.26	64.42	4.45
100–150	19.36	7.90	66.80	4.33
150–200	17.22	8.02	67.44	4.95
200–250	16.28	7.00	71.18	4.85
250–300	13.24	7.32	74.78	4.18
300–350	11.08	5.88	78.53	3.58

In addition to the substances given in the above analyses small quantities of TiO_2, FeO, MnO, P_2O_5, SrO, CaS, K_2O, and Na_2O have been found in the "cement rock" of the region. The effect of these constituents in determining the quality of the



MAP SHOW

Pennsylvania:
Ormrod (3
Co., Egyp
Atlas Cem
vania-Dix
Cement C
Portland
Village; 2

MAP SHOWING DISTRIBUTION OF JACKSONBURG FORMATION (SHADED AREAS) AND LOCATION OF PORTLAND-CEMENT PLANTS IN LEHIGH DISTRICT, PENNSYLVANIA

Pennsylvania: 1, Allentown Portland Cement Co., Evansville; 2, Lehigh Portland Cement Co., Fogelsville; 3, Lehigh Portland Cement Co., Ormrod (3 mills); 4, Lehigh Portland Cement Co., West Coplay; 5, Coplay Cement Manufacturing Co., Coplay; 6, Giant Portland Cement Co., Egypt (2 mills); 7, Whitehall Cement Manufacturing Co., Cementon; 8, Lawrence Portland Cement Co., Northampton; 9, Universal-Atlas Cement Co., Northampton (3 mills); 10, Lehigh Portland Cement Co., Bath; 11, Keystone Portland Cement Co., Bath; 12, Pennsylvania-Dixie Cement Corporation, plant 6, Bath; 13, 14, Pennsylvania-Dixie Cement Corporation, plants 4 and 5, Nazareth; 15, Lone Star Cement Co. of Pennsylvania, Nazareth; 16, Nazareth Cement Co., Nazareth; 17, Hercules Cement Corporation, Stockertown; 18, Lehigh Portland Cement Co., Sandt's Eddy; 19, Alpha Portland Cement Co., Martin's Creek. New Jersey: 20, Edison Cement Corporation, New Village; 21, Vulcanite Portland Cement Co., Phillipsburg; 22, Alpha Portland Cement Co., Phillipsburg.

FOLDED BEEKMANTOWN LIMESTONE AT NORTHAMPTON, PENNSYLVANIA

Just south of the cement belt.

cement is problematic. Ullman and Boyer, in a paper in Chemical Engineer, November, 1909, give a series of determinations of TiO_2 in specimens of "cement rock" from this region. They range from 0.14 to 0.24 per cent.

Meade [4] gives the following complete analysis of a sample of "cement rock" that has practically the correct composition for burning:

Analysis of "cement rock" from quarry No. 4 of Penn-Dixie Portland Cement Co.

SiO_2	13.44	K_2O	0.72
TiO_2	.23	P_2O_5	.22
Al_2O_3	4.55	S	.33
Fe_2O_3	.56	C	.75
FeO	.88	CO_2	32.94
MnO	.06	H_2O	1.55
CaO	41.84		
MgO	1.94		100.32
Na_2O	.31		

Paleontology.—The "cement limestone" contains numerous fossil remains, most of which, however, are fragmentary and scarcely determinable. They are seldom apparent except on the weathered surfaces of the rocks. They are of the same kinds as those contained in the limestone layers interbedded with the argillaceous cement rock. Fragments of small crinoid stems are most abundant, but locally bryozoans of several different kinds, chiefly the branching and the headlike colonies, are common. Poorly preserved brachiopods are also found occasionally. At the large quarry of the Universal Atlas Cement Co. and also the quarry near Howertown many crinoid stems, bryozoans, and brachiopods have been found.

The writer has made careful search for fossils in the "cement rock" but has found only one specimen in the typical black argillaceous limestone. This is a fairly well preserved specimen of a graptolite found in the old quarry of the Coplay Cement Manufacturing Co. in Lehigh County. It is probable that the carbonaceous matter that has given the dark color to the rock is due mainly to the remains of graptolites that disintegrated during the metamorphism which the rock has undergone.

Correlation.—The exact correlation of the Jacksonburg formation awaits more careful investigation of the fauna which it contains. It occupies the interval between the Beekmantown and Martinsburg which in other sections is represented by the Black River and Trenton. Whether it will eventually be found to contain forms characteristic of one or more of these or to represent the entire period of time remains to be determined.

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[4] Meade, R. K., Portland cement, 3d, p. 57, 1911.

Thickness.—The crumpled character of the "cement rock," the absence of any beds sufficiently distinct to be recognized in different openings, and the lack of any continuous or approximately continuous section across the belt normal to the strike render the exact determination of the thickness impossible. The local thickening of the beds due to compression also needs to be taken into account in any estimates of thickness.

The Universal Atlas Cement Co. at Northampton proved a thickness of 400 feet (122 meters) without reaching the underlying Beekmantown, and the Nazareth Cement Co. in one part of its property drilled 510 feet (155 meters) before striking the Beekmantown. As the uppermost beds were not present in the Nazareth bore hole the entire thickness of the formation at that point may be as much as 600 feet (183 meters).

Geologic structure.—The massive character of the "cement limestone" beds has prevented them from crumpling, but steeply dipping and overturned folds are present. In the south side of the quarry of the Coplay Cement Manufacturing Co., on the west bank of the Lehigh River, there is a synclinal fold overturned to the north, so that the "cement limestone" both overlies and underlies a mass of "cement rock" with all the beds dipping to the southeast. Elsewhere in the region the "cement limestone" normally dips to the north or northwest at low angles and disappears beneath the "cement rock."

Almost invariably the "cement rock" strata are greatly crumpled and yet have low angles of dip. The normal direction of dip is toward the northwest, beneath the Martinsburg of the slate hills, but in many quarries some beds dip in other directions. When the region was subjected to the great dynamic forces that formed the Appalachian folds, the "cement rock" strata were so weak that they yielded by minor folding and faulting, which locally thickened the different layers but did not produce high angles of dip. In very few places does the "cement rock" dip more than 45°, and usually the dip is much less, whereas in the adjoining limestone belt vertical or even overturned beds are not uncommon. A view of a Beekmantown limestone quarry at Northampton is given in Plate 5 to show the compressive forces that have affected the region. This quarry is just outside the cement belt.

PROCESSES OF MANUFACTURE

The process of portland-cement manufacture has undergone changes since the time of Saylor. Quarries have been deepened until several are now more than 200 feet (61 meters) deep, and one is 385 feet (117 meters) deep. In the quarry process thousands of tons of rock are shot down in large blasts, and the blocks too large to handle are broken by secondary shooting. The stone, loaded by power shovels, is hauled to the mill by locomotives. The coarse crushers are either gyratory or jaw crushers; the finer crushing is done by ball mills, hammer mills, etc. There has been a steadily growing tendency to finer grinding of the raw rock.

In most plants the stone is dried before passing into the fine grinders. In the two newest plants in the district the stone is ground in water to form a slurry, which is stored in upright cement tanks and kept in agitation until fed into the kilns.

All the plants use rotary kilns, which range in length from 60 to 250 feet (18 to 76 meters) and in diameter from 6 to 12 feet (1.8 to 3.6 meters). The first rotary kilns were only 40 feet (12 meters) long; the average now is about 175 feet (53 meters). The fuel used is pulverized bituminous coal.

In some mills the clinker is ground very soon after burning, but a common practice is to store it in great heaps in the open where it may remain several months before being ground. After grinding, the cement is stored in upright "silos."

In the early days most of the cement was shipped in barrels containing 380 pounds (172 kilograms) net, but cloth bags replaced barrels and in turn are now giving place to paper bags. Each bag contains 94 pounds (42.6 kilograms) net. The statistics are still given in terms of barrels, a barrel being considered as four bags, or 376 pounds (171 kilograms). A small amount of cement is being shipped in bulk in specially constructed closed cars. The cement bags are filled by means of a valve bag packer, with which two men in a working day of 10 hours are said to be able to pack 4,000 to 6,000 bags.

The quality of the cement has continually improved. Every stage in the manufacture is now carefully regulated. The laboratories of the organizations control the mix and perform the standard physical tests, and the burning is under the supervision of trained workmen. Within recent years many of the companies have undertaken the manufacture of quickly hardening cements by changing the chemical composition of the mix, generally by increasing the lime content, by finer grinding of the raw product and clinker, and by harder burning or burning twice. Several companies in the Lehigh district are now producing two kinds of portland cement—the ordinary kind, which is still used largely for highways, bridges, and buildings, and the special kind, which hardens quickly. One company makes a high aluminum-cement by using bauxite and also a white cement by using high-grade limestone and white clay.

BETHLEHEM TO NESQUEHONING

Leaving Bethlehem, which is located on Cambrian dolomitic limestones, the route leads northward. Three miles (4.8 kilometers) from the center of the town the road crosses a ridge of pre-Cambrian gneiss which is brought to the surface by a major thrust fault. On the north side of the ridge the Beekmantown limestone, of Ordovician age, appears. At Bath the thin band of Jacksonburg limestone is crossed, and the road ascends the slate hills to the level of the Harrisburg peneplain, which is well preserved in many places. The slate belongs to the Martinsburg formation.

At Lehigh Gap, where the Lehigh River cuts a narrow passage through Blue Mountain, a climb to the tracks of the Lehigh & New England Railroad will disclose an unconformable contact between the Martinsburg shales and the overlying Shawangunk (shon′gum) (Silurian) basal sandstones. Also in the railroad cut slaty cleavage can be observed in some of the fine-grained Martinsburg sandstones.

Just north of Lehigh Gap a hill of red shales of Clinton age presents fine exposures along the highway. Glacial débris and hillside wash conceal all the formations lying between the Clinton and Oriskany. The Helderberg limestones are present and were once quarried a short distance away. The Oriskany sandstone is being quarried and crushed for sand in Stony Ridge.

The Onondaga formation, which is developed in this ridge, contains a bed of fossiliferous blue siderite ore which has long been mined and burned for a metallic paint. It forms a deep-maroon pigment. The ore bed, which averages about 2 feet (0.6 meter) in thickness, is mined through a tunnel. Opposite the extensive reducing plant of the New Jersey Zinc Co. some of the paint ore can be seen at the mouth of the tunnel.

Continuing northward, the road follows the Lehigh River rather closely and passes in turn across the Marcellus, Hamilton, Genesee, Portage, and Chemung shales, the Catskill red sandstones and shales, and the Pocono sandstones. A short distance before reaching Mauch Chunk (mok-chunk′) the red shales of the Mauch Chunk formation are well exposed. Also to be noted are the intrenched meanders of the Lehigh Valley.

At Mauch Chunk the Pottsville conglomerate rests upon the Mauch Chunk shales. At just about the contact, on the road between Mauch Chunk and Nesquehoning, some carnotite has been deposited in the coarse sediments.

THE ANTHRACITE FIELD OF PENNSYLVANIA

By Marius R. Campbell

The anthracite field of Pennsylvania is one of the best-known coal fields of North America. Its area is small, including only about 500 square miles (1,295 square kilometers), but the quality of the coal, the number of beds that can be profitably mined, and its nearness to the large cities of the Atlantic coast have made it of great importance in the past, and it still retains much of its preeminence. Mining on a commercial scale began about 1820 and has been continued, with only short interruptions due to labor troubles, down to the present time.

To the economist and engineer the presence or absence of an adequate supply of coal available for use as fuel is an all-important consideration, but to the geologist the supply of fuel is secondary to the problem of the origin of the deposit which nature has so carefully preserved, and to the reason why in one field or portion of a field anthracite of various kinds may occur, whereas in a near-by field, in rocks of the same geologic age, the fuel may be either low-volatile, medium-volatile, or even high-volatile bituminous coal.

LOCATION AND FAUNAL RELATIONS

The anthracite field of Pennsylvania is far removed from the principal fields of bituminous coal of the Appalachian trough, being about 80 miles (129 kilometers) northeast of the isolated Broadtop field of low-volatile bituminous coal and 75 miles (121 kilometers) east of the very large field of the same kind of coal which lies west of the Allegheny Front and extends longitudinally along it from southern Virginia to the northern part of Pennsylvania. Although the anthracite field is thus now widely separated from the other coal fields of the State, it is geologically so closely related to them, as proved by their fossil floras, that there seems to be little doubt that originally it was merely a prolongation of the bituminous field on the west. Dr. David White, America's best authority on the fossil flora of the Carboniferous period, even goes farther than this and correlates the Buck Mountain coal bed of the anthracite field with the Brookville bed of the bituminous field and the Mammoth bed of the anthracite field with the Upper and Lower Freeport coals of the Pittsburgh district. If some of the principal coal beds of the anthracite field yield the same fossil floras as some of the well-known coal beds of the bituminous fields, it can not well be argued that the difference in the rank of the coal in the two localities is due to differences in the vegetation composing them or to marked differences in the conditions attending the growth or deposition of the vegetal material. On the contrary, the evidence in support of the theory that the increase in rank of the coal from the lowest bituminous to the highest anthracite is the result of regional, progressive metamorphism of the rocks is so complete in this region that the time seems opportune to present it to the visiting geologists, so that they may better appreciate the basis for the American point of view.

STRUCTURE AND METAMORPHISM OF THE APPALACHIAN REGION

The Appalachian region is structurally a unit from the northern boundary of Maine to the central part of Alabama, a distance of approximately 1,500 miles (2,400 kilometers). It is divisible longitudinally into three members—(1) an old land on the southeast side, composed largely of crystalline rocks, the original breadth of which can not be now determined, because much of it is concealed by Tertiary deposits that pass from sight under the Atlantic Ocean; (2) a middle belt of greatly folded and faulted Paleozoic rocks, 40 to 60 miles (64 to 96 kilometers) in width in the south, but narrower and much less regular in the north; and (3) a broad belt of only slightly disturbed Paleozoic rocks, which stretch westward from the crest of the Allegheny Mountains to and a considerable distance beyond the Mississippi Valley. All the coal beds in this general region are of Carboniferous age. Soon after they were deposited the rocks of the region were greatly affected by intense thrusts from the old land on the southeast. In the middle belt this pressure caused the rocks to buckle and form great folds, involving strata having a thickness of thousands of feet. In many places the pressure was so great that the folds broke, resulting in great overthrust faults, whose magnitude is measured in miles rather than feet. This belt of rocks from the center of Alabama to the middle of Pennsylvania is characterized by parallel ridges and valleys formed by the erosion of the softer beds in the folded and overthrust masses.

It is needless to say that the coal suffered more than the inclosing rocks during this period of great pressure produced by periodic thrusts from the southeast, with the result that it lost large percentages of its moisture and volatile matter, and thus was changed to a much higher rank than it had before the pressure was applied. Moreover, the intense thrusts from the southeast were not limited to the belt of folded rocks but were transmitted with gradually lessening power to the relatively undisturbed belt on the northwest. For distances ranging from 25 to 50 miles (40 to 80 kilometers) the pressure was sufficient to produce low folds and to change the coal from high-volatile to medium-volatile rank, but beyond this belt the rocks were only slightly disturbed and the coal gradually declines in rank, as shown by the accompanying table. The proximate analyses given in the table represent samples taken from mines at intervals of about 30 miles (48 kilometers) on an east-west line across the Appalachian trough from Pottsville, in the heart of the high-rank anthracite field, through Pittsburgh and on into Ohio, the last analysis representing a coal near the western border of the trough. The analyses are on the moisture and ash-free basis.

Composition of coals on an east-west line from Pottsville to the western margin of the field in Ohio

Location	Volatile matter	Fixed carbon	Heating value	
			British thermal units	Calories
Pottsville, Pennsylvania	3.3	96.7	15,750	8,195
Shamokin, Pennsylvania	7.5	92.5	15,310	8,505
Lykens, Pennsylvania	10.8	89.2	15,260	8,480
Robertsdale (Broadtop), Pennsylvania	15.2	84.8	15,850	8,805
Johnstown, Pennsylvania	20.0	80.0	15,710	8,530
Ligonier, Pennsylvania	25.0	75.0	15,580	8,655
Blairsville, Pennsylvania	30.0	70.0	15,460	8,590
Connellsville, Pennsylvania	35.5	64.5	15,290	8,495
Greensburg, Pennsylvania	37.4	62.6	15,030	8,355
Pittsburgh, Pennsylvania	39.4	60.6	15,100	8,390
Wheeling, West Virginia	43.3	56.7	15,030	8,350
Ohio, west edge of basin	46.0	54.0	14,670	8,150

LOCAL METAMORPHISM

The general absence of anthracite in the region southwest of Pennsylvania is due largely to the relief of pressure from the thrusts by the formation of folds and overthrust faults. This condition extends into Pennsylvania a few miles northeast of Harrisburg, where, as shown on the geologic map of the State, the folds diminish in magnitude and number until, in the vicinity of Scranton, they practically disappear in the territory northwest of Kittatinny Mountain, the ridge through which the Lehigh River passes a few miles north of Slatington. There is every reason to believe that the thrusts from the southeast were as severe here as they were some distance to the southwest, but the massive sandstones in the Pocono and Pottsville formations in this region formed buttresses against which the thrusts could not prevail, and the localization of the pressure by the buttresses caused the transformation or metamorphism of the coal from bituminous to the highest rank of anthracite. In the same general locality soft shale has been metamorphosed into hard roofing slate.

The Martinsburg shale, of Ordovician age, is a prominent formation throughout Virginia, Pennsylvania, and New Jersey. It underlies Kittatinny Mountain and makes a wide band of upland between that ridge and the low belt of limestones in the vicinity of Easton, Bethlehem, and Allentown. In Virginia and across Pennsylvania, as far as Reading, this formation consists of a soft unmetamorphosed shale, but between Reading and Allentown it suddenly changes to a hard roofing slate of excellent quality. This metamorphosed condition persists northeastward far beyond the confines of either Pennsylvania or New Jersey. As the change of the coal from bituminous to anthracite occurs at practically the same point as the change from shale to hard slate, it seems to be certain that the alteration of both of these substances was due to the same cause, and that cause was the resistance of the sandstone buttresses against which the thrusts exerted their full power.

ANTHRACITE FIELD—MAUCH CHUNK TO LEBANON

By George H. Ashley

The anthracite basins of northeastern Pennsylvania are a group of narrow, highly folded synclinal basins formed at the end of Paleozoic time and affecting a great thickness of Paleozoic sediments which culminated in the "Coal Measures." These basins have been preserved because the depth of folding brought them below the level of subsequent erosional downcutting. They lie east of the main bodies of coal in the Appalachian fields, in which folding was very slight and in which consequently the original coal beds have been changed to the various ranks of bituminous coal only. There are four basins, which have been called the northern, eastern middle, western middle, and southern. The northern and southern basins are long and narrow. There has been some minor folding in the northern basin and much minor folding in the southern basin. The two middle basins are very irregular in shape, owing to the involved minor folding. The four basins have a total area of about 484 square miles (1,253 square kilometers) and are estimated to have contained originally about 20,000,000,000 tons. The amount removed to date is 4,400,000,000 tons, leaving about 16,000,000,000 tons; of which, it is estimated, 9,000,000,000 tons is recoverable. Recent production has

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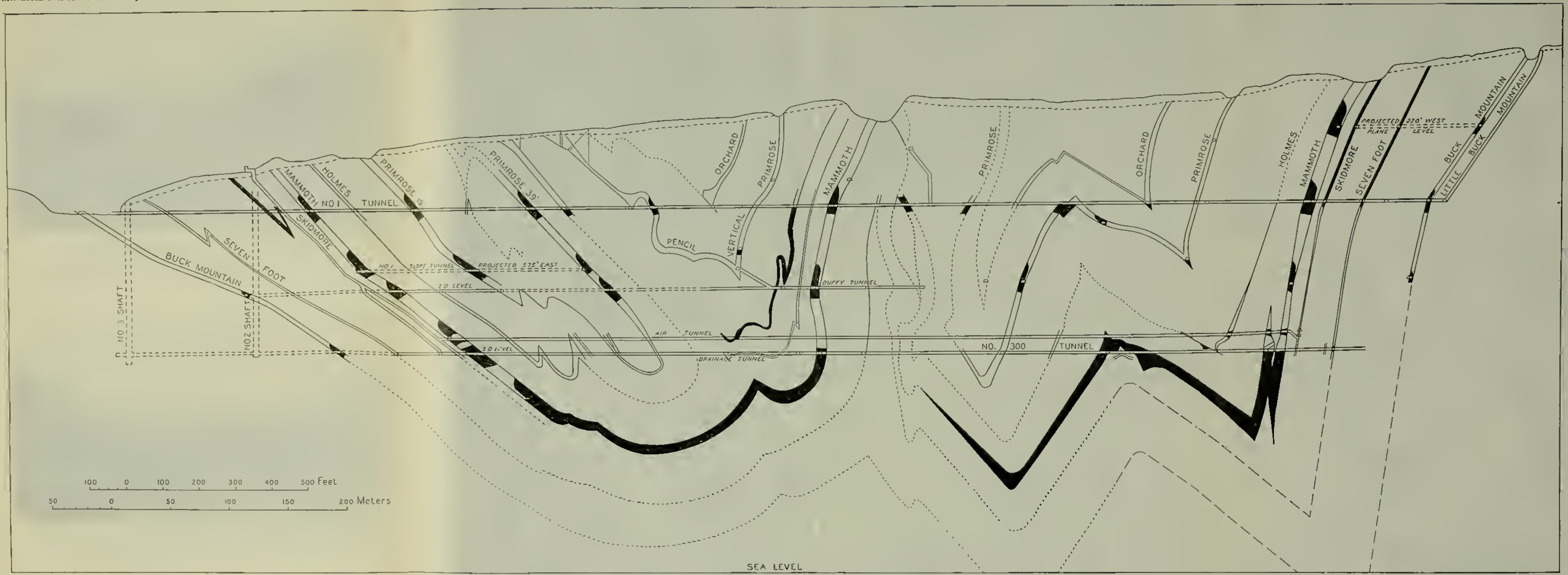


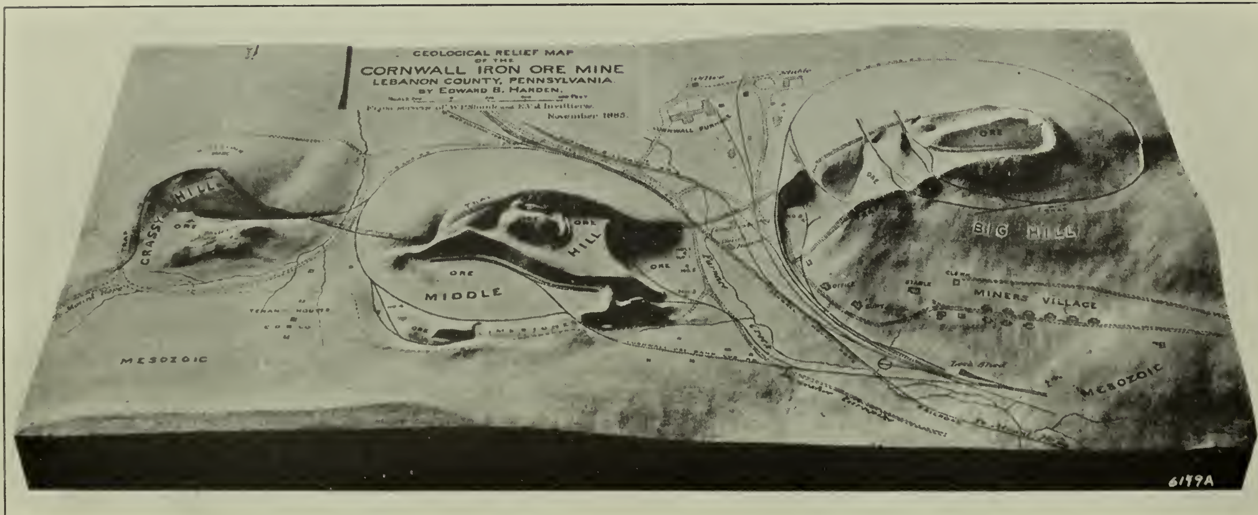
SECTION OF MINE AT NESQUEHONING, PENNSYLVANIA
Following entry 1 and level 301.

A. OLD BANGOR SYNCLINE, BANGOR, PENNSYLVANIA

The axial plane is horizontal. An illusion of unusual tightness of folding is produced because the plane of the quarry wall makes only a small angle with the trough of the fold.

B. ANTHRACITE STRIPPING NEAR NESQUEHONING, PENNSYLVANIA

Showing the closely crumpled floor.



THE CORNWALL MINES AS THEY APPEARED IN 1885

From Pennsylvania Geol. Survey Rept. for 1885, opp. p. 491, 1886.

ranged from 70,000,000 to 99,000,000 tons a year. The present trip traverses about one-half of the southern basin and is intended to show something of the geology of the area, the coal, and the manner of mining, both by stripping and by underground workings.

OUTLINE OF GEOLOGY

In Paleozoic time Pennsylvania was a part of the Appalachian basin of sedimentation, in which the culminating event was the laying down of coal beds over most of the region in middle Carboniferous time. In lower Carboniferous time (Mississippian; Dinantian, or Culm) the Pocono, a massive sandstone 1,100 feet (335 meters) thick, was deposited. This was followed by the Mauch Chunk red shale and sandstone, over 2,000 feet (610 meters) thick. "Coal Measures" time (Pennsylvanian; Stephanian, or Ouralian, and Westphalian, or Muscovian) began with the deposition of a basal member, the Pottsville, 1,300 feet (396 meters) thick, which consists generally of massive ridge-making sandstones. The Pottsville is generally barren of workable coals, with a notable exception at the west end of the southern anthracite basin. Above it is 2,500 feet (760 meters) of "Coal Measures," containing at the base the Buck Mountain bed, averaging 7½ feet (2 meters) thick; the Seven-foot bed, averaging 3 feet (0.9 meter); and the Skidmore, 5½ feet (1.7 meters). About 120 feet (36 meters) above the Buck Mountain is the Mammoth bed, locally in two or three benches, which averages in this field 36 feet (10.8 meters) in thickness but locally reaches 114 feet (34.7 meters) without doubling. Above the Mammoth is 2,000 feet (610 meters) or more of coal and accompanying rocks, including several workable coal beds—the Holmes, Orchard, Diamond, Tracy, etc. The mining to be seen on this trip is on the Mammoth bed.

In late Paleozoic or early Mesozoic time the whole Appalachian basin of sedimentation was narrowed or shortened, as if by pressure from the southeast. The shortening has been estimated to have been as much as 200 miles (322 kilometers). The rocks of southeastern Pennsylvania were crushed into an intricate complex. West or north of Kittatinny Mountain folding predominated. The anthracite basins are the bottoms of certain of these folds that were deep enough to have been below the general level of subsequent peneplanation and thus to have been preserved. The fo'ds, though narrow, are complex, usually containing a number of minor folds within the larger folds. Overturning is fairly common, and some faults are found. The character of the folding is shown in Plate 6.

The coal has been metamorphosed into hard anthracite, though the close folding in the southern basin has resulted in much crushing. The metamorphism of the coal and the accompanying rocks diminishes westward and northward, so that at the west end of the southern anthracite basin the coal is nearly or quite of bituminous rank. A similar westward change is observed in the diminishing westward metamorphism in the slate beds, and in fact in all the rocks of southeastern Pennsylvania.

After the folding of the Paleozoic rocks of Pennsylvania came a succession of uplifts, each followed by a reduction of the area to a peneplain, interrupted probably several times by sinking at the east and sedimentation which covered the peneplain in eastern and possibly in central Pennsylvania. The drainage of the region is believed to have got its original set on the uplift of the last of these blankets of sediments and later to have been adjusted to the underlying structure. The last three uplifts are recorded in the mountain tops (Schooley peneplain, of late Miocene age) and in two lower plains in the shale and limestone levels of Lehigh Valley. The east end of the southern anthracite basin was overrun by one of the older advances of glacial ice, which reached as far as Tamaqua or beyond.

THE TRIP

At Mauch Chunk, where the incised meanders of the pre-Schooley River are well displayed, the river and road cross the east end of the southern anthracite basin just east of a prominent highland made by the resistant Pottsville sandstone. As the road turns wesward up the Nesquehoning Valley it crosses a shoulder cut in the Pottsville conglomerate, which at this point contains a small amount of carnotite. The route then continues up the valley in the Mauch Chunk shales and sandstones on the north side of the basin, dipping sharply southward. At Nesquehoning, a typical mining town, the road turns sharply to the left and climbs the valley of Rhume Run through a gap in the basal Pottsville sandstone, which is well exposed in the gap. Thence it continues down the center of the basin to Pottsville, where it turns south, leaving the basin. The strippings in the coal basin reveal the intense folding to which the coal and adjoining rocks have been subjected. (See pl. 7, *B*.) There are several strippings in this basin having depths as great as 200 feet (61 meters).

At the east end of the southern anthracite basin, which has long been called the Panther Creek Basin, is a simple, fairly symmetrical syncline, which becomes deeper toward the west. Near Mauch Chunk the Pottsville sandstone in the center of the basin rises to form Mount Pisgah, overlooking the town. To the west all of the Pottsville passes below drainage level in the center of the basin, but the formation makes the inclosing ridges where it rises to crop out on each side. As the basin deepens toward the west subordinate buckles or plications divide it into a series of more or less parallel anticlines and synclines. In detail these folds may be rounded, as shown in Plate 7, *B*, or sharp. The coal in areas of sharp folding is commonly much crushed and flaked, or it may be squeezed into a thickness of 100 feet (30 meters) or more. Deepening of the basin is recorded in the altitude of the base of the Mammoth bed, which descends from 1,140 feet (347 meters) above sea level in the eastern part of the basin to 560 feet (171 meters) below sea level at Lansford, where the base of the Pottsville is about 2,000 feet (610 meters) below sea level, or to 970 feet (296 meters) below sea level at Tamaqua. The deepest secondary basin is under Lansford and Panther Creek and is separated on the north by the Shaft anticline from the shallow Greenwood Basin, and on the south by the Coaldale anticline from the Bull Run Basin. South of that is the broad Summit Hill anticline, bringing the Mammoth bed to the surface, with the shallow Summit Hill Basin still south of that. The coal in the Summit Hill Basin caught fire in 1858 and is still burning, notwithstanding the expenditure of millions of dollars and the use of a variety of plans to extinguish it.

The coal in the Panther Creek Basin has a specific gravity of 1.6307, equal to 101.64 pounds to the cubic foot, or 1,976.38 long tons to the acre-foot. An average analysis shows about the following percentages:

Moisture	1.6
Volatile matter	4.0
Fixed carbon	84.0
Sulphur	.5
Ash (5 to 17)	10.0

From Coaldale the route continues through the coal basin to Pottsville, following the valley of Panther Creek to Tamaqua, thence to the head of the Schuylkill River at Tuscarora.

At Pottsville the route turns south without entering the town proper and passes through the Schuylkill River gap of Sharp Mountain. Here the Pottsville sandstone, the Mauch Chunk red shales and sandstones, and the Pocono sandstone show in succession. Beyond Second Mountain, formed by the Pocono sandstone, is a broad valley eroded in the Devonian, bounded on the south by Kittatinny Mountain, formed by the basal Silurian. At Schuylkill Haven the route turns west through this valley, gradually approaching Kittatinny Mountain and passing through the mountain in the gap of Swatara Creek; south of that lies the broad valley in Ordovician shale at the north and

Ordovician and older limestones at the south. Lebanon is in the valley of these limestones. The shale upland of the northern part of the valley is here somewhat below the level of the Allegheny peneplain and the lower valley in the limestone at the level of the Somerville peneplain.

THE CORNWALL IRON MINES, NEAR LEBANON, PENNSYLVANIA

By W. L. Cumings

HISTORY

Iron was first mined at Cornwall in 1740, and mining has been continuous there ever since, so that the Cornwall mine is the oldest continuously operated mine in the United States.

A grant of 5,000 acres (2,023 hectares) was originally purchased from the Province of Pennsylvania and later was assigned to William Allen. At various times between 1734 and 1737 Peter Grubb purchased land from Allen, including the Ore Hills, which later developed into the iron mines. As Cornwall, England, was the ancestral home of Grubb, he gave this name to his new possessions in America. He apparently recognized the iron ore possibilities when the purchases were made and soon after began mining the ore.

After Grubb's death in 1754 the ore property was divided into several tracts under different ownership, resulting in competition and contention, and independent furnaces were built at Lebanon and in the vicinity of Cornwall. In 1864 the Cornwall Ore Banks Co. was formed to consolidate the properties and operate them. In 1916 the Bethlehem Steel Co. acquired a small interest, and subsequently this company got complete ownership.

In recent years the annual production of crude ore has averaged 800,000 tons.

A blast furnace still in existence at Cornwall is believed to be on the site of the original furnace built by Peter Grubb in 1742. The old furnace was of great service to the colonists during the Revolutionary War. The present furnace was built in 1853 and was last operated in 1883, then making cold-blast charcoal iron. It now belongs to the State and is preserved for its historical and metallurgical interest and cared for by the State Historical Commission.

GEOLOGY

The Cornwall deposit is located at the northwest edge of a broad belt of Triassic rocks which extends entirely across the southeastern part of the State. This belt is 5 miles (8 kilometers) wide in the vicinity of the mine but elsewhere it is as wide as 30 miles (48 kilometers). The Triassic rocks consist of conglomerates, sandstones, and shales, generally red or gray. They include some carbonaceous beds that are much darker in color than the prevailing type. Across the whole belt the beds dip uniformly northwest, at angles ranging from 5° to 55° but averaging 30°.

Near Cornwall the usual phase of the Triassic is a reddish quartz conglomerate or sandstone with some garnet, chlorite, and epidote occurring as the result of the diabase intrusion. The diamond drill showed darker phases ranging to shales and slates. An example of this type is seen in the south face of the open pit immediately above the limestone contact. Here the rock is a bluish conglomerate with abundant quartz pebbles. This and similar phases encountered in diamond drilling were examined microscopically, and apatite, andalusite, and tourmaline were noted. Graphite spots were abundant, indicating a notable amount of carbonaceous material. Analysis shows that the Al_2O_3 content is over 25 per cent.

Vugs and cavities lined with quartz and specular hematite are common in the Triassic conglomerate, and the diamond drill showed one phase that contained abundant rounded pebbles of iron ore of very high grade. Possibly these are the result of replacement of limestone pebbles by ore-bearing solutions. Some of them analyzed 60 per cent in Fe, and many were surrounded by garnet reaction rims.

Within the Triassic sediments are large areas of intrusive diabase. Supposedly this exists as vertical dikes and masses, also as sills following the bedding of the Triassic sediments. The largest areas of the diabase are within and along the border of the Triassic area, but narrow dikes extend out from the Triassic area and cut the adjacent rocks.

The Cornwall deposit occurs along the south side of a great dike of diabase cutting Paleozoic limestones. It is just at the northwest border of the Triassic sediments, and the open pit is large enough to show well the relations of the limestone, the diabase, and the Triassic sediments.

The diabase is typical of this class of rocks and consists of feldspar, augite, magnetite, and olivine. As a rule the magnetite is not present in sufficient quantities to cause magnetic attraction. Such quantities occur in places, however, and there is good reason to believe that the diabase in localities some distance from Cornwall contains much more magnetite than immediately at the mine.

The south contact of the diabase dips about 40° S., and the limestone at this contact has been greatly altered. Pure beds were made coarsely crystalline, and impure argillaceous banded limestones, which are characteristic of this Cambrian formation, were largely replaced by magnetite derived from hot solutions that accompanied or closely followed the intrusion of the diabase. These solutions seem to have followed the upper side of the intrusion and were absent from the lower side, where the limestone was altered chiefly by heat and there was almost no mineralization.

One small dike of diabase branching from the main dike cuts the limestone, ore, and Triassic sediments in the open pit. Where it cuts the limestone and hard dense sandstone it is less than 1 foot (0.3 meter) thick, but higher up in the Triassic it encounters softer layers and forms a well-defined but small sill. This probably represents one of the last phases of igneous activity.

The Paleozoic limestone exposed in the pit is the south edge of a belt extending north for several miles. This limestone series is generally dolomitic, but pure calcite stone also occurs and is quarried near Lebanon. At Cornwall the stone is calcitic but is too high in SiO_2 to be of value metallurgically.

Near the top of the limestone series is an impure, highly aluminous bed called the "Mill Hill" slate. This rock is well exposed in a cut near the Cornwall railroad station, also both north and south of the diabase at the new No. 4 mine. This rock is evidently an impure phase of the limestone, high in alumina, which has been baked by the diabase intrusion. Apparently its composition was not changed to any extent, but the effect of the intrusion has been to make it hard and brittle.

Some have assumed the existence of a great fault along the north edge of the Triassic sediments. Such a fault is mentioned in Lesley's description of Cornwall written nearly 50 years ago. The observations of those connected with the mining and exploration developments have led them to doubt the existence of such a fault. Some displacement probably occurred at the time of the diabase intrusion, but it is not believed to have been of great extent.

ORE DEPOSIT

The ore deposit formerly occurred in three hills—Big Hill, Middle Hill, and Grassy Hill. Big Hill lies east of the main highway, and the ore has been entirely mined out. The large deep open pit west of the highway represents the area formerly known as Middle Hill and Grassy Hill. The former relation of these deposits is well shown in the model made in 1885. (See pl. 8.)

The Big Hill deposit was between the main diabase mass and a small tongue lying to the south which projected westward. The deposit deepened to the west as the tongue plunged and disappeared, and the ore in the deep pit lies directly upon diabase which dips about 40° S.

At the west end of the ore body the diabase, as can be seen on the surface and by diamond drilling, turns abruptly to the south and thus limits rather sharply the extension of the ore westward. This southern direction of the diabase contact is a bulge of the diabase mass and not a change in its general direction.

It is apparent that the ore has replaced certain layers in the limestone. This is well shown in the wall of ore forming the old bed of the Cornwall Railroad, which formerly crossed the pit. The south side of the open pit also shows how certain impure limestone layers have been replaced by ore, leaving layers of the purer limestone apparently unaffected. It is probable that the impure phases of the limestone, having abundant bedding planes, offered easier access to the ore-bearing solutions.

As the ore mass pitches to the west it finally becomes too deep to work economically by open pits, and underground mining is also employed. The horizontal width varies greatly—the north side always being in contact with the diabase, but the south contact is always irregular as the ore fingers out in the limestone beds. The deepest point where ore is found at the west end is 50 feet (15 meters) above sea level, or 700 feet (213 meters) below the original surface at that point. The original discovery at the top of Big Hill was about 850 feet (259 meters) above sea level. The deposit can thus be said to have been about 1 mile (1.6 kilometers) long, pitching to the southwest and with horizontal widths from a few feet to as much as 400 feet (122 meters).

A section through the mine on the line of the shaft is shown in Figure 13, A.

About 10 years ago the entire district was surveyed magnetically, with the ordinary dip needle. As a result of this work a new deposit about 1 mile (1.6 kilometers) east of the open pit was discovered by diamond drilling. The ore here does not crop out, as it is entirely covered by Triassic rocks. Exploration has shown conditions similar to those at the old mine, and the structural relations would be similar to those at the old mine. This deposit has been opened by a slope in the diabase footwall and is now ready for production. The ore differs very little in character from that in the old mines to the west.

STRUCTURE

The structure section by Spencer (43)[5] is reproduced in part in Figure 13, B. Nothing has been shown by later mining work to throw any doubt on the correctness of Spencer's idea of structure. He believes that the main diabase area represents the outcrop of

[5] Numbers in parentheses refer to bibliography, p. 54.

a vertical intrusive mass, and that the ore deposit lies on the junction of this mass with a sill which branches from it and follows approximately the bedding of the Triassic beds. This sill supposedly crops out about 2 miles (3.2 kilometers) south of Cornwall.

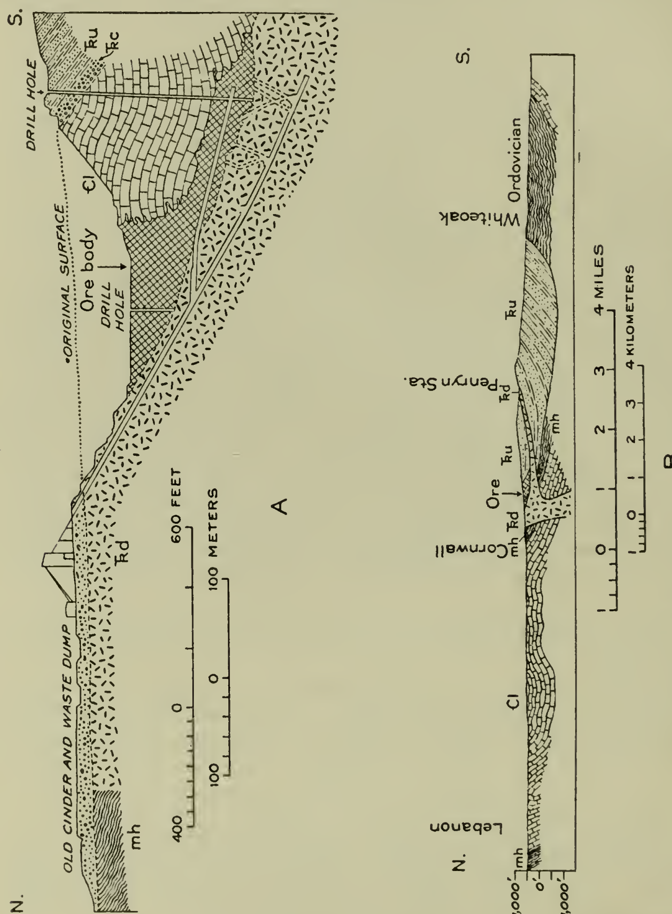


FIGURE 13.—Sections across ore deposit at Cornwall, Pennsylvania. Ꞧc, Triassic conglomerate; Ꞧu, Triassic undifferentiated; Ꞧd, intrusive diabase; Ꞓl, Cambrian limestone; mh, "Mill Hill slate"

ORE GENESIS

It seems certain that Cornwall represents a typical limestone replacement deposit. The replacement of certain impure limestone beds by ore, the gradual fingering out of these ore bodies to the south, and the presence of many contact-metamorphic minerals all point to the diabase as the source of the ore.

MINERALOGY

A detailed account of a careful mineralogic study of the deposit is given by Callahan and Newhouse (41). The ore mass consists of magnetite and some specular hematite, with notable quantities of pyrite and chalcopyrite. The gangue minerals are pyroxene, biotite, actinolite, tremolite, and talc. Abundant garnets, including some of large size and of perfect crystallization, have been found in the limestone at the west end of the open pit.

MINING METHODS

The great bulk of the ore has been won by open-pit methods. Large electric shovels are used for stripping and for mining, and the ore is crushed at Cornwall before being sent to the concentrator at Lebanon. The west end of the ore body, however, is too deep to be mined by open pits, and a slope in the diabase footwall extends to the limits of the deposits in depth.

The new deposit called No. 4, mentioned above, will be mined entirely by underground methods.

ORE ANALYSIS AND CONCENTRATION

The ore as mined runs about as follows:

Fe	42.00	MgO	8.00
P	.016	Al_2O_3	5.00
S	2.00	SiO_2	16.00
CaO	4.00	Cu	.32

This ore is concentrated magnetically at Lebanon, and by flotation a separation of the pyrite and chalcopyrite is also made. The iron concentrates are in the form of fines, generally passing a 10-mesh screen. A typical analysis of these concentrates is given below:

Fe	57.00	MgO	3.50
P	.015	Al_2O_3	2.60
S	1.00	SiO_2	9.00
CaO	2.50	Cu	.18

These concentrates are sintered before being used in the blast furnace. The sintering is done either at Lebanon or Bethlehem. A typical sinter analysis is as follows:

Fe	56.00	MgO	4.00
P	.036	Al_2O_3	2.70
S	.17	SiO_2	10.00
CaO	2.70	Cu	.18

Changes in the treatment process are constantly being tried out, and variations in the compositions given may occur in the future. In mining many beds of unreplaced limestone have to be included with the ore and later removed by magnetic concentration.

BIBLIOGRAPHY, CORNWALL IRON MINES

41. Callahan, W. H., and Newhouse, W. H., A study of the magnetite ore body at Cornwall, Pennsylvania: Econ. Geology, vol. 24, No. 4, pp. 403–411, 1929. A brief but very good description of the mineralogic features of the ore body and the inclosing rocks. The authors agree with Spencer in his conclusion that the ore deposit has been formed by the more or less complete metasomatic replacement of sedimentary rocks "by iron minerals precipitated from heated solutions set into circulation by the invading diabase."

42. Lesley, J. P., and D'Invilliers, E. V., Report on the Cornwall iron ore mines, Lebanon County: Pennsylvania Geol. Survey Ann. Rept. for 1885, pp. 491–565, 1886. A general account of the mines as they existed in 1885. Many details of geologic observations are given, and emphasis is laid on a great fault along the southern edge of the ore body. No conclusion is given as to the origin of the ore, but the inference is that the authors regarded the ore as having been a limonite interstratified with the limestone and changed to a magnetite by the diabase intrusion.

43. Spencer, A. C., Magnetite deposits of the Cornwall type in Pennsylvania: U. S. Geol. Survey Bull. 359, 1908. Contains a description of the Cornwall deposit and all deposits of a similar type known in Pennsylvania except the French Creek mines, in Chester County. Spencer definitely ascribes the origin of the ore and the metamorphism of the limestones and conglomerates to solutions emanating from the diabase.

44. Stose, G. W., U. S. Geol. Survey Geol. Atlas, Fairfield-Gettysburg folio (No. 225), 1929. Contains detailed description of Triassic sedimentation, faulting, and diabase intrusion in adjacent area.

LEBANON TO HARRISBURG

From Lebanon to Hummelstown the road follows the limestone portion of the Kittatinny Valley. Limestone of Stones River (Chazy or Llandeilo?) age is being quarried on both sides of the road. The limestone is used for mixing with the shaly limestones of the Lehigh Valley for cement making and for other purposes. Just beyond Annville the limestone, which is highly calcareous and shows normal bedding structure, crumbles in the hand like so much flour and is being used as mined for agricultural purposes.

At Hershey is an industrial plant manufacturing chocolate, noted throughout the country as a model industrial town with extensive amusement park, golf links, club houses, etc. West of Hummelstown the road climbs over the neck of an almost detached area of Ordovician shale and descends again into a limestone valley, which is followed to Harrisburg. The eastern part of Harrisburg is on a broad river terrace that has been correlated with the time of the Illinoian (Riss) glacial stage. The business part of the city is on another broad terrace correlated with the time of the Wisconsin or Labrador (Würm) ice advances. The river is flowing in a rock-cut channel with here and there deep gravel-filled channels. The reason for its broad, shallow character has not been satisfactorily determined.