MINERAL PAINTS.

INTRODUCTORY NOTE.

During the spring of 1909 field and laboratory studies of two important classes of mineral-paint materials were carried on by the Survey in eastern Pennsylvania under the general direction of Ernest F. Burchard. The work was done by four senior students in mining engineering at Lehigh University and was closely supervised by B. L. Miller, professor of geology at Lehigh. J. C. Stoddard and A. C. Callen studied the ocher deposits between Reading and Allentown, and F. T. Agthe and J. L. Dynan studied the paint-ore deposits near Lehigh Gap. The papers, substantially as published below, were accepted as theses for the degree of engineer of mines at Lehigh University in June, 1909, and an abstract of each was published by the Survey shortly afterward.[a]

[a] Burchard, E. F., Production of mineral paints in 1908: Mineral Resources U. S. for 1908, U. S. Geol. Survey, 1909, pt. 2, pp. 679–687.

OCHER DEPOSITS OF EASTERN PENNSYLVANIA.

By JESSE C. STODDARD and ALFRED C. CALLEN.

ALLENTOWN-READING DISTRICT.

GEOGRAPHY.

The principal ocher belt in Pennsylvania is a comparatively narrow strip extending from Reading to Allentown and approximately following the line of the East Pennsylvania branch of the Philadelphia and Reading Railroad. The district is comprised in the Reading, Slatington, and Allentown quadrangles of the United States Geological Survey and lies in the counties of Berks and Lehigh.

The East Pennsylvania branch furnishes convenient transportation facilities. It passes through the center of the belt and reduces the teaming distance for most of the deposit to less than 1 mile. The roads of the section are very good and the cost of haulage to the shipping point is a small item.

Physiographically, the ocher belt lies at the northern base of the chain of hills designated the Durham and Reading hills in the reports of the Pennsylvania Geological Survey. From the base of these hills the region passes into a low-lying, level limestone valley well drained by numerous streams tributary to Schuylkill and Lehigh rivers.

HISTORY.

Little accurate information is available on the history of the ocher-mining industry, but in general it may be said that the discovery and subsequent working of the deposits were due to the former rather extensive prospects and operations on the local iron ore, which is invariably found above and in intimate association with the ocher. In one of the mines visited the remains of the old drifts and shafts, formerly used in mining iron ore, were encountered, showing the extent to which the iron mining was carried on. The history of each mine will be taken up in the detailed description of the mines.

DEVELOPMENTS.

Owing to the minor importance of the industry and its intermittent operation consequent on the conditions of the market, none of the mines and plants visited have attained any advanced stage of development. On the contrary, the prevalent conditions are primitive, little capital has been invested, and no extensive improvements have been installed. In the spring of 1909 most of the mines were in a dilapidated condition and were either filled with water or squeezed together and caved in as a result of their temporary abandonment for the winter and early spring. For this reason personal examination and study of all the underground workings was impossible and a large amount of the information herein contained was necessarily derived from surface observations and from persons familiar with the mines and the ocher industry.

The mining equipment, including hoisting apparatus, tramming, etc., and the facilities for preparing the ocher for shipment vary little throughout the region. Power is obtained from a small steam plant which operates the mine pumps, hoisting apparatus, washing plant, and grinding machinery in cases where the ocher is given its final treatment at the locality where it is mined. The Cornish pumps, the log washer, and the wheelbarrow are the typical devices employed for pumping, washing the ocher free from the larger particles it contains, and underground tramming.

GEOLOGY.

DISTRIBUTION OF ROCKS.

The rocks of this district, in the order of their formation, are the pre-Cambrian gneiss, the Chickies quartzite (of Cambrian age), and the Shenandoah limestone (of Cambro-Ordovician age).

The gneiss, known locally as the South Mountain gneiss, is highly metamorphosed and has a granitic texture. In a small hand specimen, where the banding is not apparent, it might be mistaken for a granite. It is mainly basic, but in some places it is highly acidic. The acidic phase of the rock weathers easily, decays in place, and forms sand deposits which are worked in many places. The gneiss varies in color from a greenish black to light green. The most common minerals as determined from the hand specimen and under the microscope are quartz, orthoclase, plagioclase, hornblende, biotite, chlorite, and magnetite. The gneiss forms the main mass of the Reading and Durham hills and its width of outcrop varies from 1 to 5 miles.

Above the gneiss and lying unconformably upon it is the Chickies quartzite (formerly called the Potsdam), which varies from a fine to a coarse grained sandstone and in some places, especially near the base, contains layers of quartz pebbles. The grains are rounded and bound together by a siliceous cement. The color of the rock varies from light gray to almost brick-red, the coloring matter, iron oxide, being practically confined entirely to the cementing material. The rock is largely used locally as a building stone. This formation outcrops in a narrow belt, usually less than a mile in width, extending along the base of the hills, and in a few isolated places in the Shenandoah limestone. *Scolithus linearis* is the characteristic fossil of the formation and is found in great abundance in the vicinity of Fleetwood.

Resting conformably upon the Chickies quartzite is the Shenandoah limestone, which is mainly an impure dolomitic limestone characterized by the presence of small lenses of chert near the base. It is oolitic in places and in some localities contains excellent ripple marks. It varies in color from a very dark gray through a bluish gray almost to white. Well-preserved fossils are very rare, *Cryptozoon* being practically the only form found. The limestone forms the floors of the valleys and is very widely distributed throughout the region. It is used as ballast and as road metal and is burned for lime.

ORE DEPOSITS.

The deposits of ocher in the Reading-Allentown district may be called residual, inasmuch as all evidence indicates that they were formed by the oxide of iron left on the decomposition of the Shenandoah limestone.

The only ore minerals present here are the nodules and geodes of limonite. The gangue material is chiefly clay, in which the ocher occurs in irregular masses. The clay is moist and plastic and varies in color from white to brown, some even being reddish and purplish. These clays are the result of the weathering of intercalated hydromica slates, which occur in association with the Cambro-Ordovician limestone and with the Cambrian quartzite. Besides the "ore minerals" there are also present small quantities of turgite, ilmenite, siderite, and pyrite. In the black clay at Breinigsville there is considerable pyrite, and a small spring near the shaft smells strongly of sulphureted hydrogen.

OCHER DEPOSITS.

As ordinarily used the term "ocher" is applied to the earthy and pulverulent forms of the minerals hematite and limonite. It is always rendered more or less impure through the presence of other metallic oxides and of argillaceous or clayey material. Limonite ochers are the only ones referred to in this report. Natural ochers show a variety of colors, which depend on the chemical composition, in general. Hematites give red ochers, and limonites give yellow, buff, or brown. The amount and kind of impurities also influence the color. In brief, the natural color of ocher depends on the degree of hydration and oxidation and the kind and quantity of impurities. As the color of ocher depends mainly on the degree of hydration, a red ocher can be made by calcining common yellow ocher.

The ocher occurs in irregular masses in the clay. At the Keystone Ocher Company's mine at Fleetwood there was evidence of stratification in the clay and ocher. Some of the masses are large and can easily be worked for high-grade ocher, but many of them are simply small pockets, which can be used only for second or third grade on account of the large amount of clay which must be mined with the ocher. Most of this clay is so fine that it can not be separated by washing and settling and so lowers the quality of the finished product. As a rule there is a considerable thickness of clay above the rock. A well boring at Fleetwood gave over 250 feet of clay, below which a bed reported to be unconsolidated gravel was struck, which could not be penetrated by the drill.

From the general evidence it appears that ocher deposits may be derived from any part of the Shenandoah limestone. There is little regularity in the occurrence of the ore, owing to the complexity of the folding of the original rocks. If there were a definite strike and dip to the beds of limestone in large areas, or if there were intercalated shale or sandstone beds, there would probably be a consequent alignment of the deposits due to concentration at these points. But such are not the conditions in this region.

ORIGIN OF THE OCHER.

To explain the origin of the ocher satisfactorily we must first give a reasonable explanation regarding the source of the iron. According to Hopkins,[a] the possible sources of iron in this district are:

1. The Lower Cambrian slate, where it occurs as the sulphide and silicate.
2. The Cambro-Ordovician limestone, where it exists as diffused carbonate, silicate, and sulphide.
3. The overlying Ordovician and Silurian shale and slate, where it occurs as carbonate, sulphide, and hydroxide.

It is a well-known fact that nearly all strata contain some iron, and so it is probable that all the above possible sources have contributed to the iron content of the ore deposits. The amount of iron furnished was not necessarily proportional to the iron content of the strata; the manner of erosion was probably the controlling feature. Sandstones and shales are largely eroded by mechanical means, and so any residual iron material would be washed away as sediment with the

[a] Hopkins, T. C., Bull. Geol. Soc. America, vol. 11, 1900, p. 490.

quartz grains, and not be concentrated. Limestones, on the contrary, are removed mainly by solution, and so the limestones are the most favorable source, as the insoluble content is left behind as a residue. This is the principal reason for believing the Shenandoah limestone to have furnished most of the ore.

Though it is believed by the authors that the limestone was the main source of the iron, yet it must be admitted that there is evidence pointing to the overlying shale and slate as a partial source. These overlying rocks contain iron, and meteoric waters containing organic acids could leach out the iron. The spring at the mine near Breinigsville was evidently seepage from the shale and was impregnated with iron. But, though it be admitted that the shale and slate furnished some of the iron, it it highly improbable that such iron formed any considerable part of the total. As is well known, shales are impervious and would naturally turn the water away from the limestone where the topography permitted. Besides, the greatest number of the deposits are found near the base of the limestone, only the one at Breinigsville being near the shales. And, as was noted before, the erosion of shales is largely mechanical, and their disintegrated material would all be washed away together.

The reasons for believing the Cambro-Ordovician limestone to be the chief source of the iron are the great number and the wide distribution of deposits on the limestone; the manner of erosion of the limestone (by solution); the commingling of the ocher with residual clay and cherty fragments characteristic of these limestones; and the fact that the limestones carry iron—a small percentage, but large enough on concentration to account for the deposits. If the limestone was the original source of the iron the processes by which it was concentrated may have been as follows. The first step is solution. Oxygenated waters acting on pyrite would decompose it, taking the iron into solution as $FeSO_4$. Iron carbonate is soluble in all acidulated waters, and as meteoric waters nearly always carry an acid the solution of the carbonate would be possible. Ferric oxide is quite insoluble as such, but is reducible by organic acids to ferrous oxide, which is easily soluble. In short, meteoric waters reduce, dissolve, and transport the iron. The next step is precipitation, and this is generally caused by oxidation and chemical reaction. The iron may be precipitated as the carbonate, as the hydroxide, or as one of the organic salts, but it is shortly brought to the stable form of the hydroxide.

The precipitation may take place at varying distances from the original source of the iron. It is probable that in the limestone area none of the solutions have been transported very far, because the water would become more and more saturated with lime, and as lime is more soluble than the iron oxide the iron would be precipitated. Deposition has taken place in a number of modes. Much of the iron has formed limonite and has been deposited in caverns, in crevices between loose rock material, in seams in limestone, and at the contact of the limestone with an underlying insoluble layer. Interstratified clay and sand beds aid in concentration by forming alternations of pervious and impervious layers, between which the limonite and ocher may collect from the overlying limestone. The segregating of the oxide may be continued in the residual clays, but less actively than in the orignial beds.

AGE OF THE DEPOSITS.

The age of the original sources of the iron is considered to be Cambrian and Ordovician. However, it is to be emphasized that the deposits themselves are residual deposits, and are *on* and not *in* the rocks of these ages. According to Hopkins, all these deposits have been formed since the uplift of the beds in late Permian or post-Permian time; also the process of formation is going on at present and has been presumably more or less continuous since Carboniferous time.

DETAILED DESCRIPTION OF MINES.

READING PLANT OF THE KEYSTONE OCHER COMPANY.

The Reading plant of the Keystone Ocher Company is situated 1 mile northwest of Reading, Pa., and one-half mile west of the Pennsylvania and the Philadelphia and Reading railroads.

When visited, the plant was not in operation and the underground workings could not be determined.

The equipment consists of a boiler and engine house, a log washer, settling boxes and tanks, a drying shed, and a roasting furnace. The deposit is opened up through four shafts varying in depth from 30 to 65 feet, the ocher being stoped out and hoisted to the surface by a windlass operated by hand. It is then wheeled to the log washer, the larger particles of impurities and foreign matter are separated out, and the fine material is passed into the troughs. Well water is fed to the washer by a perforated pipe running longitudinally along the washer, which is so arranged as to uniformly distribute the flow over the whole length of the log. After the water has been used to float off the ocher it is drained back into the well, which otherwise would be of insufficient capacity to operate the plant.

As the finely divided particles of ocher and foreign material are carried down the troughs, the heavier particles begin to settle out, the current being retarded by baffle boards, behind which the heavier particles collect. Three settling boxes, placed at intervals along the line of troughs, further retard the flow of material and cause more of the foreign particles to settle out, until the final floating is accomplished in the settling troughs. These are board troughs 1 foot square in cross section and 15 feet long, which are so arranged as to almost entirely stop the flow and enable the remaining impurities to settle to the bottom.

The mixture from the troughs is then run into the large settling tanks, 25 by 18 by 3½ feet deep, which are provided with tap holes at different levels, so that the ocher of different degrees of fineness can be drawn out as desired and left to dry until it can be shoveled and put in the drying shed. The shed is 70 feet long and 10 feet wide. There were eight shelves placed 10 inches apart vertically.

The finished material at this plant is of a golden-brown color and is called a sienna. The highest grade runs from 68 to 72 per cent Fe_2O_3. It can be burned on the premises when the demand calls for it, but the greater part of it is put on the market after being ground.

The occurrence of the ocher accords with the general conditions throughout the region, as described elsewhere in this report. It is found in pockets of different size in the clay which immediately overlies the limestone. Limonite nodules are very common.

WADE PROPERTY AT BLANDON.

E. B. Wade's property is one-half mile due south of Blandon and is at present being worked only for clay, which is shipped and refined mostly for use in iron works.

The only evidences of ocher are a few very shallow pits immediately south of the clay pits. Some ocher was formerly extracted from these pits and is said to have been of very high grade, but from all accounts none has been shipped for five years or more, and no considerable quantities were ever shipped. The clay was also formerly refined for certain kinds of paints and is said to have brought $7.50 a ton.

The deposit here lies upon the quartzite, and clays are found from 30 to 50 feet thick overlain by 8 to 10 feet of soil. The clay varies widely in color and texture, the pure-white layers being found on top in moderate quantities. It is said to be useful as an oilcloth base, as a wall-paper base, and for paint. The locality is only in the first stages of development, however, and the extent of its resources, if it has any, is unknown.

FLEETWOOD PLANT OF THE KEYSTONE OCHER COMPANY.

The Fleetwood plant of the Keystone Ocher Company is the only one, besides the adjoining plant of C. K. Williams, which was in active operation when visited. It lies 1¼ miles northeast of Fleetwood, Pa., and three-eighths of a mile from the Philadelphia and Reading Railway. The product of both of the plants is hauled in wagons to the railroad.

The deposit is opened up through two shafts within 60 feet of each other, one being used as a hoisting and pump shaft and the other as an air and timber shaft. The former is 70 feet deep and extends down to the lower level, from which all the ocher is hoisted. The method of carrying on the underground work is to drift along and follow the pockets and stringers of ocher, mining them out in stopes or breasts, and then to drift indefinitely until other deposits are found.

The accompanying plan (fig. 34) shows the approximate layout of the underground workings. The drifts or gangways are 6 to 7 feet high and 5 feet wide, being provided with four-piece round timbering to resist the squeezing action of the clay. Lagging of sawed slabs is laid close on the tops and sides, and the bottom is plank floored for the passage of wheelbarrows. Chutes are provided, as shown (fig. 34), for dumping the ocher from the upper to the lower level, whence it is wheeled to the shaft and hoisted. The stopes are turned off where

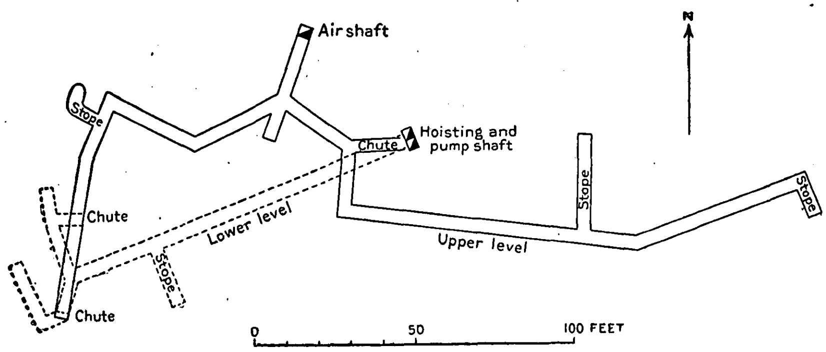

FIGURE 34.—Plan of underground workings of Keystone Ocher Company, Fleetwood, Pa.

pockets are encountered, and if their size demands it they are timbered up with square sets.

The ocher occurs either as small masses in pockets in the clay, or interstratified with the clay, as shown in the accompanying sketches (fig. 35). It is separated by hand from the clay in the mine, and the clay is used to fill up the old workings. The impurities in the ocher are particles of quartzite, cherty limestone, flakes of shaly limestone, and fragments and nodules of limonite. The limonite is picked out on the surface and is saved until a sufficient quantity for shipment has accumulated. No bed rock has been encountered in the mine workings, but a well drilled down the hoisting shaft struck loose bowlders of sandstone at 257 feet, which prevented drilling deeper.

The method of treating the ocher for the market is essentially the same as the methods previously described for the Reading plant, but the equipment is more complete.

The ocher is hoisted from the mine by an engine hoist and then dumped into a log washer, from which it passes to a series of 28 floating troughs. These troughs are 14 to 16 feet long and 13 inches square in cross section. The fine sand is separated out in the first 12 or 13 troughs, and the final separation is accomplished in the smaller set of 15, after which the mixture is run through a long trough to the settling ponds. Here it is left to partly dry as a preliminary to its transfer to the drying sheds.

After it has thoroughly dried in the sheds it is ground in French buhr mills as the final treatment for the market.

The best sienna from this plant brings from $30 to $40 per ton, and the washed ocher brings $15 to $18 per ton.

The land is usually leased for a period of fifteen or twenty years, one year or six months being allowed for exploration before the lease is executed finally. A royalty is paid to the owner either at a nominal rate or according to the amount of ocher taken out at a fixed price per ton.

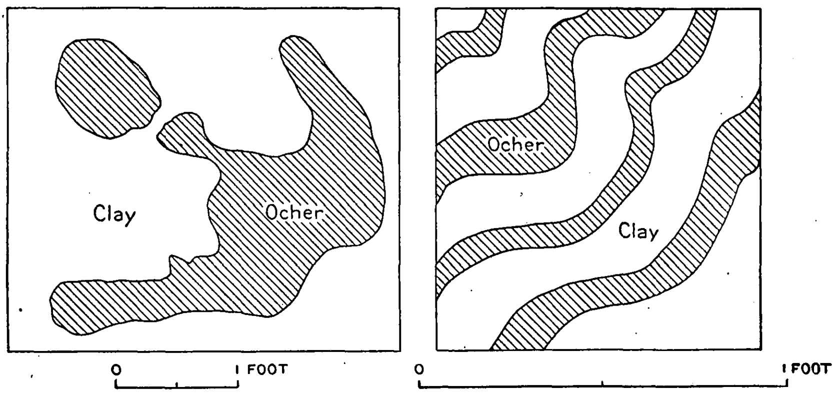

FIGURE 35.—Sections illustrating the stratified and unstratified occurrence of ocher at mine of Keystone Ocher Company, Fleetwood, Pa.

WILLIAMS PLANT AT FLEETWOOD.

The C. K. Williams plant adjoins that of the Keystone Ocher Company just described and differs very little from it.

It has been run for four years under the present management, but for the past twenty-seven years it has been worked intermittently, chiefly for the iron ore, which is found in the upper levels and which is now practically exhausted. Old drifts and shafts show that considerable work was formerly done on the property in working out the limonite deposits.

The present hoisting shaft extends vertically downward 91 feet to the bottom of the lower level and 126 feet to the bottom of the sump, which receives all the mine water and is pumped out at intervals.

Fifty feet from the main hoisting shaft there is an air shaft 46 feet deep, connecting with the upper level of the mine. The underground workings are similar to those of the Keystone Company, but are larger. The two levels are connected by chutes and by an old shaft which has been retimbered and repaired for the passage of the miners.

The washing and drying plant consists of a log washer, 26 floating troughs 16 feet long, four mud dams, and four drying sheds.

The ocher and iron ore occur in pockets, the ore predominating in the upper levels and the ocher in the lower, with clay between. The deposit seems to be in the form of a horseshoe extending along the hill, with its greatest dimension parallel to the hill. The bands of iron ore, clay, and ocher appear to run horizontally. The underlying rock is quartzite, which outcrops along the ridge with a dip of 75° toward the bottom of the hill.

The ocher found at this mine is of three grades, as follows:

1. "Gold dust," called No. 1, the purest variety.
2. "Gravel ocher," which is good ocher but contains particles of limonite that have to be washed out.
3. Clay and ocher, which is the poorest variety and contains pieces of chert up to 2 feet in diameter. The clay is red, yellow, white, and purplish and is of no value.

The time taken to treat the ocher varies, but in general it takes a month to completely fill the mud dams and three weeks more for the material to dry sufficiently to permit being shoveled. When it has dried to the consistency of a stiff mush it is put in the drying sheds, where it has to be left one month more before it is in condition to grind. The material is finished at the company's mills at Easton, Pa.

ERWIN PLANT AT TOPTON.

Henry Erwin & Sons' plant at Topton is one of the larger plants of the district and is worked entirely by open cut. When visited the workings were filled with water, but from an examination of the surrounding country the occurrence appears to be identical with that of the other plants located along the base of the same chain of hills. The ocher is of high grade and is associated with limonite and the other common impurities. It is treated in a log washer and settling and floating devices similar to those at Fleetwood, six mud dams being used to handle the output from the floating troughs. It has been worked intermittently for thirty years, and its output at present goes to the company's plant at Bethlehem, where it receives final treatment.

A smaller plant located near that just described and provided only with facilities for hoisting the ocher was owned by the Atlas Company, but the company has dissolved and the plant has been abandoned. There is one main hoisting shaft and a number of test pits, but no evidences of extensive workings.

LONG PROPERTY AT HANCOCK.

Dr. W. P. Long's property is a quarter of a mile south of Hancock. It shows signs of long abandonment, as no shafts or workings remain open. A considerable quantity of ocher is stocked in piles, and it seems to be of good color and weight. The surrounding ground is honeycombed with test pits, in which water has risen very high. It has been found impossible to construct shafts that will last beyond one working season, as the wet clay breaks the timbering of shafts and gangways, and it was partly because of this trouble that the place was abandoned. The veins on the property dip southeast. They were worked to a depth of about 80 feet below the surface, but at greater depths they were valueless. There are now no remains of hoisting machinery, and washing apparatus was never installed.

PRINCE PLANT AT ALBURTIS.

The Prince Metallic Paint Company has a plant in the town of Alburtis for roasting and grinding the ocher obtained from its mines, which are 1½ miles northwest of the station. The ocher, just as it comes from the mine, is charged into a rotary kiln 30 feet long and 2½ feet in diameter, rotating at a speed of one revolution in 55 seconds. The ocher is charged in at the upper end by shoveling. The kiln is fired at the lower end with soft coal and is blown by a Champion blower No. 4. It is revolved by means of a chain driven by a sprocket in the center of the kiln. After coming from the kiln the ocher is crushed and ground in three buhrstone grinders of Sprout-Waldron make, each machine grinding 18 barrels a day. It is packed into barrels by a device known as a "packer." The packer consists essentially of a platform raised and lowered by a cam, so that the barrel resting on the platform has its contents shaken down most completely.

At the mine from which the mill just described draws its material all the workings had caved in during the winter's idleness, and as they were close to the surface the timbering in the stopes and drifts was exposed to view. The caved-in workings extend over a distance of about a third of a mile. Where visible the ocher lies from 4 to 6 feet below the surface and contains many nodules of limonite and fragments of a thinly bedded sandstone. The overlying soil contains fragments of shale. The timbering is of round 6-inch timbers spaced 5 feet apart, with sawed slabs used as lagging.

The remains of the hoisting machinery were intact and consisted of a two-man windlass arranged for hoisting in balance buckets of 1½ cubic feet capacity.

BEAR PLANT AT BREINIGSVILLE.

The Bear Brothers' workings lie 1½ miles northwest of Breinigsville and include both open-pit and underground workings. When visited the plant was not in operation but showed signs of having been worked within a year, as the equipment was in good repair and a large quantity of ocher was on hand. The plant consisted of a boiler and engine room, with hoisting machinery for hoisting the ocher up the shaft and pulling the loaded cars up an incline from the shaft and pit workings to the log washer. The ocher is treated by the usual floating processes and is dried and ground on the premises. A rotary kiln of antiquated design was used to burn the ocher when the demand called for it. The shaft had two compartments and was provided with a Cornish pump to drain both the open-cut and the underground workings. At the time of visit the water was very high in all the workings and the deposit could not be seen. The deposit occurs near the contact between the Shenandoah limestone and the overlying Ordovician slate, and fragments of slate are common in the excavated material. The water appears very sulphurous, probably owing to pyrite. It is said that stringers of metallic copper have also been found in the material.

DEPOSIT AT CAMELS HUMP.

The deposit at Camels Hump is at present operated by C. K. Williams, of Easton. It is an umber deposit and lies 6 to 10 feet below the surface of the ground where it is worked. From the surface downward the section is as follows:

Section of umber deposit at Camels Hump, Pa.

	Ft.	In.
Dark soil	3	
Reddish-brown material		18
Light-yellow residual material	4–5	
Yellow residual material		3–6
Dark-brown umber (base not exposed)	6	

Fragments of weathered quartzite are abundant in the deposit and it is probably a result of decomposition of the quartzite. The brown color of the umber is due to the presence of manganese. This property was formerly worked by the Erwin Company, but very little material has been taken out. It is worked as an open cut and the umber is loaded directly into wagons. It has to be ground and floated, and when finished it brings from $18 to $20 a ton.

ERWIN PLANT AT BETHLEHEM.

Henry Erwin & Sons have a mill at Bethlehem for the final treatment and packing of the paint ores. It is situated along Monocacy Creek, on the Lehigh and New England Railroad, three-quarters of a mile north of Bethlehem. Here are received paint ores from all parts of the world, which are ground, roasted, and mixed for shipment. The mill draws its principal ocher supply from the firm's mine at Topton, previously described, and manufactures it for use principally as an oilcloth base. Water power is used and the grinding is done in French buhr and emery mills. Most of the umber is obtained from Turkey and Sicily, the sienna from Italy, and the ocher from the United States. The American sienna brings $20 a ton and the imported sells for $100 to $150 a ton.

Much red-oxide paint is also made at this mill from copperas (iron sulphate, $FeSO_4$) and oyster-shell lime. The copperas is obtained from a wire factory in New York. Calcite obtained from Franklin Furnace, N. J., is added to the mixture to dilute its strength. Clinton iron ores are also ground and used as mortar colors.

MOOSEHEAD DISTRICT.

GEOLOGY.

ROCK FORMATIONS.

The rocks in the vicinity of Moosehead belong to the Mississippian series of the Carboniferous system. The extreme eastern part of Luzerne County is composed of the Pocono sandstone, and to the west and south this is overlain by the red Mauch Chunk shale.

The Pocono is composed of gray sandstones with shale and fine siliceous conglomerate and varies in thickness from 800 to 1,300 feet or more. The Mauch Chunk shale consists of reddish, greenish, and yellow shale, with gray and greenish-gray sandstone, in some parts containing quartz and red shale pebbles, and gray conglomerate, some of which also contains red shale pebbles.

At the abandoned Moosehead station on the Lehigh Valley Railroad there is an exposure of 124 feet, as follows:

Section of rocks exposed at Moosehead, Pa.

	Feet.
Conglomerate, gray, siliceous	20
Sandstone, gray	4
Conglomerate, gray	6
Sandstone, gray	3
Conglomerate, gray	3
Sandstone, gray	7
Sandstone, gray, with quartz and red shale pebbles	15
Conglomerate, slate pebbles, large red shale fragments	5
Sandstone, hard, gray	5
Shale, red	28
Shales, yellowish green	10
Ocher, white and yellow	18

The rocks have a low dip (2° to 5°) to the north. The ocher mine is on a low anticline. Considering the structure as exhibited at the ocher mine, at the tunnel of the Central Railroad of New Jersey, and east of the railroad at Wrights Creek, the above-noted series of sandstone and shale beds exists as a flat synclinal to the north of Tunnel Ridge and overlies the southward-dipping Pocono rocks which constitute the south slope of Nescopec Mountain. This series of rocks should hence be placed at the base of the Mauch Chunk, as they are evidently the lowest rocks of that formation.

ORE DEPOSITS.

The ocher deposit at Moosehead is a true bedded deposit. At the mine the bed has a thickness of 15 feet, the ocher being overlain by 12 feet of red shale. The ocher is a soft, crumbling rock, chiefly of a buff-yellow color, with small local bands of a variegated dark color.

The Luzerne Ocher Company owns a tract of about 3,000 acres near Moosehead, and the bed of ocher is practically continuous over this area. As before noted, the ocher bed is on a low, flat anticline and is underlain directly by the Pocono sandstone, which is very hard and compact at this place. Owing to the soft, crumbling nature of the ocher, it is very easily mined and treated. The ocher is really a bed of soft shale containing more than the usual amount of iron oxide. This percentage is low, however, compared to the iron content of a high-grade ocher.

LUZERNE PLANT AT MOOSEHEAD.

The Luzerne Ocher Company's plant, the only one in the district, is 1½ miles from Moosehead, Pa., or 5 miles north of White Haven, Pa. It has been in operation by the same company for twenty-five years. A spur runs from the Lehigh Valley Railroad to the plant. The mining is done entirely by open cut, 12 feet of shale overlying the ocher bed. There is practically no timber on the mountain side, and in winter snow makes mining impossible, so that practically no work is done from December to March.

The mining is done by blasting away the cover and then blocking out the ocher and breaking it up—first with a charge of dynamite to enlarge the drilled holes, and then with a charge of black powder to bring it down. It is then broken into small pieces and trammed to the mill. At the mill it is crushed and ground and finally bolted through silk screens of 156 mesh. There are 12 of these screens, arranged parallel to one another and placed on a slight incline, so as to cause the ground material to pass along. It is fed in at the higher end and the pieces which are too large pass through to the lower end, where they are discharged and reground. The capacity of this set of screens is 20 tons per day. The ocher is light yellow and is used as an oilcloth base.

The quantity of material in this deposit is practically unlimited, as the company owns 3,000 acres of land underlain by it. The total production to December 31, 1908, is reported to have been approximately 50,000 short tons of ocher, and the average retail value of the finished product is about $8 a ton.

ANALYSES.

The following analyses, secured from Henry Erwin & Sons, represent the composition of typical finished ochers. The first three are probably mixtures containing foreign ochers, but the fourth (Topton) is a local product:

Analyses of ochers.

	SiO_2	Fe_2O_3	Al_2O_3	CaO	$CaSO_4$	MgO	MnO	S	P_2O_5	H_2O
Easton ocher	39.70	37.64	13.26			1.37				7.83
"Pure Prince's Brown"	32.8	46.89	10.76	3.00		1.52	1.39	0.5 to 2.0	Tr.	
"Light red oxide"	2.05	37.29			57.65					.10
Topton ocher	55.50	17.49	18.66							[a] 8.35

[a] Combined.

Analyses of ground slate and sienna.

	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	Na_2O	MnO	H_2O
Ground slate [a]	58.84	6.50	19.04	1.60	1.50	2.47	1.75		
Italian sienna	19.23	74.24	1.32	0.48	Tr.			0.50	[b] 4.23

[a] Loss on ignition, 7.24. [b] Combined.

The following analyses for ferric oxide were made in the laboratory of the department of geology at Lehigh University by the writers:

Percentage of ferric oxide (Fe_2O_3) in ochers.

Finished ocher (Bear Bros., Breinigsville, Pa.)	19.50
Finished burnt ocher (Prince Metallic Paint Co., Alburtis, Pa.)	47.32
Finished ocher No. 2 (Henry Erwin & Sons, Topton Pa.)	11.85
Finished ocher No. 4 (Henry Erwin & Sons, Topton, Pa.)	18.42
Finished ocher (Keystone Ocher Co., Fleetwood, Pa.)	27.77
Finished ocher (Luzerne Ocher Mfg. Co., Moosehead, Pa.)	6.26

SUMMARY.

The ocher deposits of eastern Pennsylvania occur in two districts, the Reading-Allentown district and the Moosehead district.

The Reading-Allentown ocher occurs in the Shenandoah limestone, of Cambro-Ordovician age. It is a residual deposit and was formed from the iron in the limestone during its disintegration.

The Moosehead ocher occurs as an original bedded deposit in the Mauch Chunk shale. It is of low quality with respect to its iron content.

Mining is carried on by open cut and also by drifting and stoping. The ocher is washed, dried, and ground.

The ocher market fluctuates greatly, and most of the mines are worked only when there is a demand for the product.

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PAINT-ORE DEPOSITS NEAR LEHIGH GAP, PENNSYLVANIA.

By Fred T. Agthe and John L. Dynan.

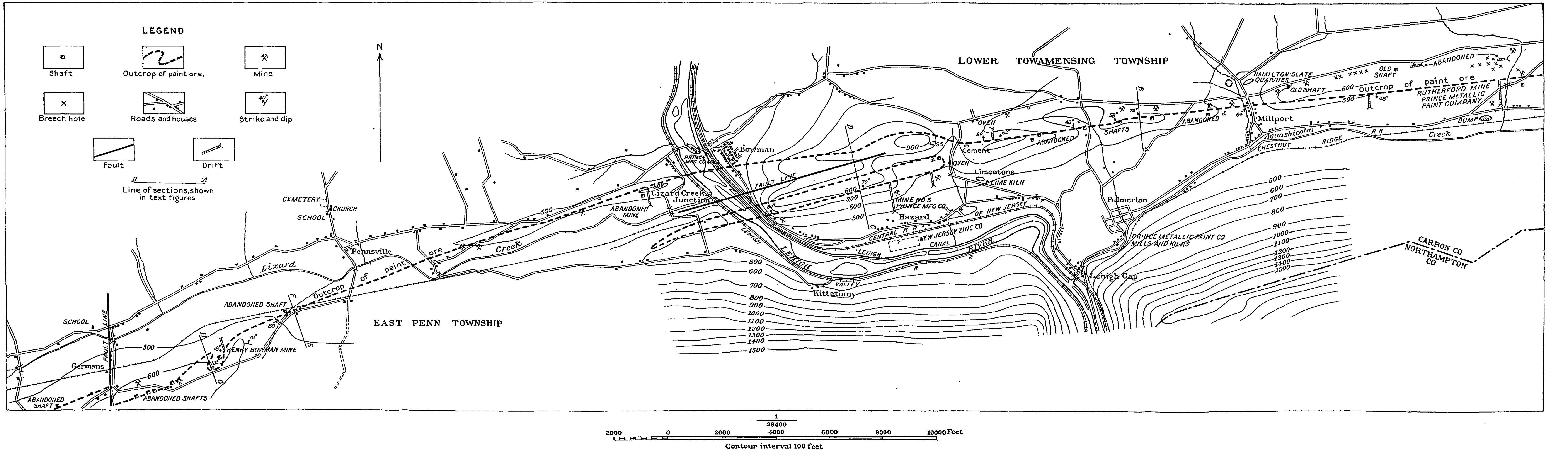
LOCATION.

The paint-ore deposits here considered are situated in the southern part of Carbon County, Pa., 7 miles below Mauch Chunk, and extend in a general east and west direction for about 20 miles. The "paint beds" are of sedimentary origin, Devonian in age, and lie between the Oriskany sandstone and the Marcellus shale. They have been traced west to Germans, 5 miles west of Lehigh River, and east as far as Little Gap. The area in which the deposit lies is a narrow strip, with the stated east and west limits and from one-half mile to 2 miles wide, comprising, in addition to the "paint beds," outcrops of Helderberg limestone, Oriskany sandstone, Marcellus shale, and Hamilton shale.

HISTORY.

It is generally conceded that Mr. Robert Prince and Mr. Rutherford were the first to find the ore and recognize the adaptability of the material for the manufacture of metallic paint. The ore was first found along the outcrop between Bowman and Millport in 1856. These gentlemen independently recognized the quality of the ore as being somewhat different from that of ordinary limestone, and had the material analyzed. Analyses convinced them that the ore was applicable to the manufacture of metallic paints. Both opened deposits. Mr. Prince utilized a mill on Big Creek which he owned to grind the ore and shipped it to Weissport, on Lehigh River, for the market.

Competitors soon appeared in the field, and so great was the desire to find a portion of the bed which could be worked advantageously that the entire outcrop has been prospected from Germans on the west to Little Gap on the east. Indeed, the bed has been traced as far as Schuylkill County along the Lizard Creek valley, though no ore of any value has been removed west of Germans.



MAP SHOWING OUTCROP OF PAINT-ORE BED NEAR LEHIGH GAP, PA.

The two companies now operating are the Prince Metallic Paint Company and the Prince Manufacturing Company. The former company, which developed from the early Rutherford operations, has mines along the ridge east of Lehigh River.

At present the Prince Metallic Paint Company has options on many properties where ore is supposed to exist, and practically all the property along the ore-bed outcrop from Palmerton to Little Gap is controlled by it.

The Prince Manufacturing Company has mills at Bowman, most of the ore being hauled from Hazard, a distance of about 2 miles. This company is the outcome of Robert Prince's discovery and was organized in 1876. The mines of this company are located at Hazard.

Besides these operating companies, the William G. Freman Company, of Mauch Chunk, Pa., has run a drift into the bed along the strike at Little Gap. The tunnel is well timbered and modern in its construction, though little ore has been removed from it. The development of this mine depends upon the availability of the ore, as no expense has been spared to make the operations thorough and modern.

GEOGRAPHY.

This region is part of the Appalachian province and is made up of a series of hills and valleys running east and west. Most prominent of these on the extreme south is Blue Mountain, formed by resistant Silurian and Ordovician formations. This stands as a high, steep, knifelike ridge, 1,100 feet above Lehigh River, which cuts through the ridge at Lehigh Gap.

The Oriskany sandstone forms the most peculiar topographic feature of the region. (See Pl. III.) With only a few interruptions, it stands out as a long continuous ridge. West of the Lehigh this ridge is very narrow and precipitous, at places forming a vertical cliff. In several places it presents the appearance of a huge artificial wall. The slopes are covered with large, detached angular blocks. The dip here is nearly vertical, and immense blocks, their greater dimension parallel to the bedding, stand out on top of the ridge.

The Oriskany ridge is double for a short distance on each side of the Lehigh, owing to a fault that runs along parallel to the strike of the formation and dwindles out gradually in each direction.

East of the Lehigh the ridge is more rounded, except for a short distance from the river eastward a mile beyond Bowman. It loses its double character halfway between Hazard and Lehigh Gap, and from there runs eastward, gradually increasing in width and height as the dip flattens, until at places it rivals Blue Mountain.

Above the Oriskany occur softer rocks, the "paint beds," Marcellus shale, etc. They are marked by a series of gently rolling hills and valleys.

All the formations except the Oriskany weather so readily that outcrops are very hard to find. Moreover, the débris from the Oriskany fills most of the valleys, covering up any outcrops that might occur.

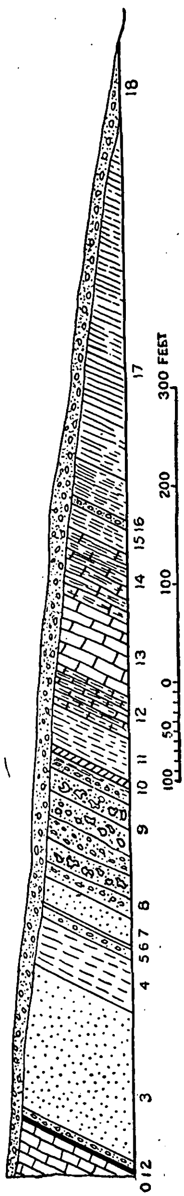


FIGURE 36.—Section through Kline tunnel, Hazard, Pa. 0–2, "Paint beds" (0, cement rock; 1, paint ore; 2, clay); 3, Oriskany sandstone; 4–14, Helderberg limestone (4, shales; 5, yellow clay; 6, hematite; 7, sandstone; 8, clay and flint; 9, arenaceous clay; 10, flint; 11, shale; 12, limy shale; 13, limestone; 14, limy shale); 15, shale; 16, clay; 17, shales; 18, river wash.

GEOLOGY.

GENERAL STATEMENT.

The rocks immediately associated with the paint-ore deposits are sandstone, clay, shale, and limestone, of Devonian age.

These strata outcrop in narrow bands running east and west. At most places the structure is that of a number of monoclinal, conformable sedimentary beds. At the outcrop the beds usually show overturned steep dips to the south. Below the surface there is probably another flexure restoring the normal dip. The country thus consists of the truncated ends of a slightly overturned anticline, which has been entirely eroded south of the present exposures.

The structure is complicated between Bowman and Hazard by the presence of a syncline of Oriskany south of the main outcrop. This is discussed more in detail below.

Large portions of the country are covered with glacial material brought down by the rivers. This shows most prominently on the hillside between Bowman and Hazard, where there are glacial clays and bowlders of material which has evidently been carried from the north.

STRUCTURE.

The structure of this whole region may be explained by a discussion of the Oriskany sandstone, as all the other strata are conformable with it and, owing to its resistant qualities, it is the most prominent. (See figs. 36 to 40.) The Oriskany is also the only bed with good exposures and is quarried in many places for sand. Beginning at the east the main outcrop is a long straight line, broken where the Lehigh cuts through the ridge at Bowman and in places by smaller streams. This continues west of the river as far as the outcrop was followed, with a few irregularities in the vicinity of Germans.

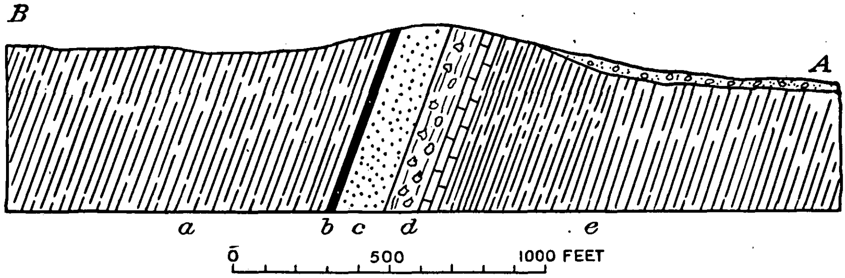


FIGURE 37.—Section along line *A-B*, Plate III. *a*, Marcellus shale; *b*, "paint beds;" *c*, Oriskany sandstone; *d*, Helderberg limestone; *e*, shales.

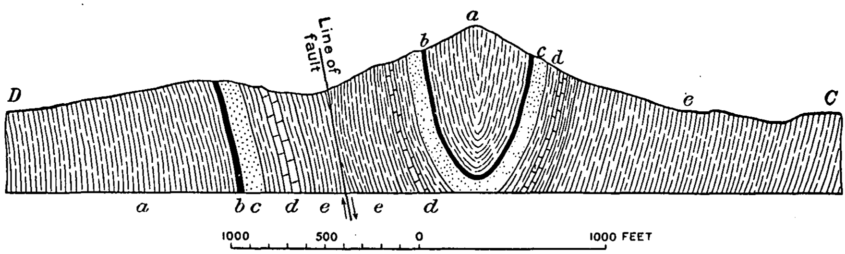


FIGURE 38.—Section along line *C-D*, Plate III. *a*, Marcellus shale; *b*, "paint beds;" *c*, Oriskany sandstone; *d*, Helderberg limestone; *e*, shales. Vertical scale exaggerated.

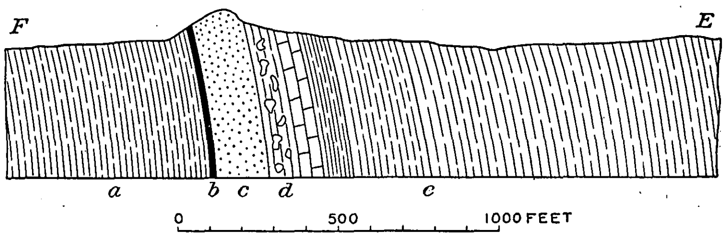


FIGURE 39.—Section along line *E-F*, Plate III. *a*, Marcellus shale; *b*, "paint beds;" *c*, Oriskany sandstone; *d*, Helderberg limestone; *e*, shales.

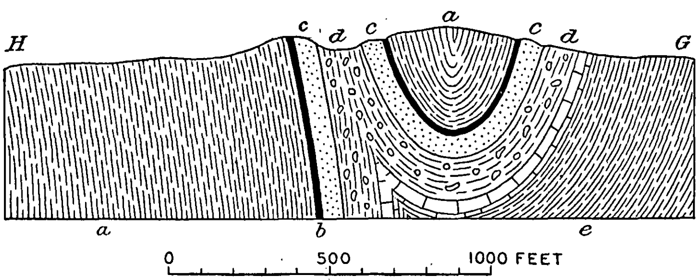


FIGURE 40.—Section along line *G-H*, Plate III. *a*, Marcellus shale; *b*, "paint beds;" *c*, Oriskany sandstone; *d*, Helderberg limestone; *e*, shales.

The dip along this outcrop is in general about 70° S., but at places it is nearly vertical. The dip becomes greater with depth until it is vertical, beyond which point it changes in direction until the strata resume their normal dip to the north. This structure is a large anticline, slightly overturned to the north. North of this large overturn the folding was more gentle, so that the inverted dip probably continues only a short distance beneath the surface. The entire southern part of the anticline has been removed by erosion. Most of the northern arm, also, has been eroded, just enough being left to still show the inverted dip.

In places the anticline has been faulted along its axis, and to this are due the double outcrops which occur around Bowman. The main anticline was not one simple fold but contained a number of minor anticlines and synclines. One of these synclines was formerly south of the locality where Bowman now stands, extending for several miles and gradually flattening out in each direction. A fault running east and west occurred north of this syncline, the downthrow being on the south side. This faulted-down syncline now forms the secondary ridge, or outcrop, of Oriskany, which stands out so prominently. This ridge extends a little east of Hazard and only a short distance west of Lehigh River. Both arms of the syncline dip steeply; the Oriskany has almost, in fact, been folded back on itself. In some places the Hamilton is not found on the top of the hill.

The fault described can not be directly observed from exposures; therefore little is known concerning its nature, dip, and amount of throw.

The other irregularities in the structure are those in the vicinity of Germans. West of this place the outcrop is thrown several hundred feet to the north by a transverse fault. East of the same town there is another irregularity. The outcrop here curves abruptly and retreats to the south, the dip flattening considerably. This produces a small valley, filled by the Hamilton shale. The outcrop turns again eastward for a few hundred feet, and thence makes another sharp double turn northward and then eastward, so that it continues parallel to but a little north of the course beyond the first turn. Toward the east the bed continues nearly in a straight line to the vicinity of the fault mentioned above. It thus appears that at some time after the formation of the main anticline, while the strata were nearly vertical, pressure in an east-west direction caused a folding of the beds at this point, the axes of the folds being vertical. This folding was very close, so that instead of the three ridges of Oriskany which would naturally be expected there is in fact only one. The southernmost outcrop has been worn down, while the other two are folded to form only one ridge. A section through this locality shows the full thickness of the Oriskany three times, two of these thicknesses, where the folding is closest, being directly superimposed.

ROCK FORMATIONS.

HELDERBERG LIMESTONE.

The Helderberg limestone here appears in the form of 150 to 215 feet of beds of clay and flint. The section in the Kline tunnel (mine No. 5) at Hazard is as follows (see fig. 36):

Section in tunnel of mine No. 5, Hazard, Pa.

	Feet.		Feet.
Flint	45	Clay and flint	72
Red clay	1	Fine sandstone	2
Black clay	9	Clay and flint	30
Hematite	1	Sandstone	4
Clay, with chert	3	Flint	20
Sandstone	24		211

The flint beds are regularly stratified. They are of massive structure, with well-developed joints. In color the flint varies from white to black, brown being the most common.

The clay beds consist of a soft and unctuous clay, either red, yellow-white, or blue.

The sandstone beds resemble those of the Oriskany, and vary from coarse to very fine grained. The hematite bed is a low-grade red hematite of no economic importance.

ORISKANY SANDSTONE.

The Oriskany sandstone is about 150 feet thick and consists of a hard sandstone. In composition it is almost a pure quartz sand, running frequently as high as 98 per cent silica. The material varies from very fine grains to coarse pebbles up to a quarter of an inch in diameter. The cement is usually calcareous, and when exposed to the weather dissolves out rather easily. Where this occurs the sandstone crumbles. It is due to this ease of disintegration that the rock is quarried so extensively for sand. The grains are white to yellowish brown in color, and are usually well rounded.

The Oriskany is penetrated by numerous joints, in some places three different systems occurring. There is great difficulty, where the joints appear, in distinguishing them from the bedding planes. The most important system of joints, which extends practically throughout the length of the Oriskany in this region, has a dip of 40° to 50° S. As a result, the south slopes of the Oriskany hills contain many more bowlders than the others, because the large blocks produced by weathering fall to the south.

The Oriskany is at present being worked in a number of places for sand. There are three operating quarries at Fenstermacher's, one opposite Bowman, and numerous smaller ones on the east side of the river. The sandstone after blasting down is easily crushed, and the material is sold for use as molding sand, for concrete, fire brick, etc.

The characteristic fossil of the Oriskany in this region is *Spirifer arenosus*, the specimens of which are large and well preserved.

"PAINT BEDS."

The "paint beds" consist of the following members: Cement rock, 25 feet (variable); paint ore, about 2 feet; and clay, 8 feet—a total of 35 feet. The correlation of these beds with the New York formations has not been satisfactorily determined. The lower 20 feet of the cement bed consists of hard, compact blue rock much resembling the paint ore. It is very fine grained and contains small veins of quartz and calcite. There is no trace of the slaty cleavage so prevalent in the cement rock of the Lehigh district. The upper 5 feet of the cement rock consists of a cherty limestone, the chert occurring as black nodules.

The cement rock was formerly burned for cement in a number of places. It is said to have produced a very good cement, and the material was used in building the locks of the Lehigh Canal, also for several reservoirs in the vicinity.

The paint ore is described in detail below.

The clay beneath the paint varies greatly in its characteristics. It has been provisionally correlated by the New Jersey Geological Survey with the Esopus ("Caudagalli") grit of New York. Fragments have been found showing the typical cockscomb markings, but nowhere in place. This material is a hard white sandy shale. Its color is blue, white, yellow, and red. Its thickness is from 2 to 9 feet.

MARCELLUS SHALE.

The Marcellus consists of slate or shale. It is usually a compact, fine-grained, blue to black shale. The cleavage is very well developed and is in general parallel to the bedding but is not so everywhere. Locally the shale has been greatly crushed and contorted, so as to result at many places in the formation of a series of grooves parallel to the cleavage. This produces a very striking resemblance to petrified wood. The Marcellus weathers easily, breaking up into small pieces and losing its dark color. Hence there are few good outcrops and it is difficult to obtain specimens except from the underground workings. The thickness of the formation is about 800 feet.

The Marcellus was formerly quarried in a few places for roofing slate. These operations have been abandoned, with few exceptions, owing to the greater strength and other advantages of the Martinsburg shale ("Hudson River slates") to the south. There is one large quarry still working at Millport, Pa.

ORE DEPOSITS.

DESCRIPTION.

The paint ore in this vicinity consists principally of carbonate of iron. This material is found in the beds between the Marcellus shale above and the Oriskany sandstone beneath. The ore bed varies in thickness, in some places being 1½ to 2 feet thick and in others pinching out to but a few inches.

No outcrops were observed anywhere along the entire portion of the bed traversed. Even though the bed is approximately vertical in many places, the débris from the Oriskany, which projects prominently above the other formations, has entirely covered the outcrop. The presence of test pits and air shafts and the outcrop of the Oriskany mark the general position of the bed.

There is no sharp line between the ore and the Marcellus shale above. Descending waters have carried the mineral materials into the lower clay, so that the overlying cement rock is usually low in mineral value and shows up poorly after burning. The miners distinguish the iron-bearing strata chiefly by the specific gravity of the material. The lithologic characteristics of the paint ore and cement rock are very similar. They both resemble a compact limestone, rather dark blue and crystalline. Upon close examination, however, the rather compact structure of the paint ore and the presence of pyrites in most places are noticeable; also the fact that the ore is not so crystalline as the cement rock.

The ore throughout resembles a blue limestone, and were it not for the high specific gravity the casual observer would not suspect the presence of any mineral of value. It is dark blue and is usually associated with pyrites. The ore mined from the first tunnel, known as the Kline tunnel (mine No. 5) is pyritic, but farther east the ore has not this pyritic character and also bears fewer fossils. In the extreme east of the region traversed the ore is pyritic in places, as, for instance, the ore in the mine east of Millport; but in the vicinity of Little Gap the ore is not pyritic. In the mine east of Millport, however, the drift was run in too high, so that the paint bed has not been much exposed by the workings. As very little ore has been removed up to the present time, its exact characteristics are somewhat doubtful. It is safe to assume, however, that the ore closely resembles that taken from the Rutherford tunnel, located west of this mine, near Millport, Pa.

The ore bed is a compact mass, is almost entirely mineralized, and contains few waste materials. For this reason the only separation that is necessary is the hand sorting, which is carried on in the mine. Successful mining of the ore requires only that care be exercised in stoping. The clay below is easily removed, being soft and unctuous. The cement rock above is rather more difficult to separate, but with some experience the miners become very adept in judging the ore. The ore is so easily separated underground that the ore pile is nearly all pure paint rock. This rock is generally placed under sheds, so that the weather will not affect it. It is common to see lying around shafts, drifts, etc., fragments of this ore which are reddish in color throughout, having been oxidized to the ferric state since the ore was mined. This is called "sun-burned ore."

THEORIES OF ORIGIN.

The presence of carbonate of iron, associated as it is with rather compact cement rock above and a clay beneath, has given rise to several theories as to the origin of the ore.

One theory suggests that the "paint beds" were deposited and concentrated in a swampy region during Devonian time. From a careful study of the beds in proximity to the ore it has been observed that they seem to be richest where the underlying Oriskany sandstone contains very little iron. The Oriskany is now extensively worked at these places for white sand. This theory suggests that the Oriskany was deposited under peculiar climatic conditions. The climate was probably very dry, and for this reason little iron was leached out of the various formations and deposited in the sea while the Oriskany sandstone was being deposited. Later there was a long interval during which the climate changed and became rather moist, so that the iron was leached from the exposed formations and deposited in the swamp. It is rather difficult to explain, however, the origin of a band of hematite iron ore found beneath the clay bottom of the paint bed. It is plausible, however, to assume that this bed, being composed of oxidized material, was first deposited during the change from a dry to a moist climate.

The last period of deposition and concentration was marked by the formation of iron carbonates. The overlying Marcellus shale is rather carbonaceous, especially the lower measures. This carbonaceous deposition is exemplified in the region to the east, where the Marcellus shale has been worked for "coal," as at Kimbletown, about 11 miles east of Lehigh Gap. The abundance of carbon in the Marcellus would seem to have some connection with the iron carbonates of the "paint beds." It may be safe to assume that the necessary carbon for the ferrous iron carbonate was obtained from these measures, reducing the iron from the ferric to the ferrous state and forming a carbonate iron ore. The pyrites found disseminated throughout the "paint beds" have been formed also by the reducing action of the carbon, probably changing the iron from a sulphate to a sulphide.

Another theory which may be advanced is that of metasomatic replacement of the cement rock by iron. The descending waters bearing iron in solution may have replaced the cement rock, molecule for molecule. The one objection to this theory is that the iron in the paint ore is in a ferrous condition, and that as descending waters usually contain oxygen the iron would presumably be in a ferric state. The iron, however, might have been reduced by the carbon leached from the overlying formations at some period after its precipitation.

It has been found that the ore changes to limonite near the surface, owing to oxidation, also that the ore grows leaner as the distance below the water level is increased. Such conditions as these support the theory that the ore deposit is due to descending waters. No extensive observations have been made at great depths below the ground-water level. It has been found where a few test pits have been sunk from the drifts that the ore grows leaner with depth and presents a rather shaly appearance. However, too few observations have been made for this condition to be stated as absolutely prevailing, for some of the miners in the vicinity maintain that the ore is concentrated in the lower workings and that ore will be found of a much better grade when it becomes necessary to work the lower levels.

Eastward from Little Gap the Oriskany becomes very thick and forms a well-rounded mountain closely resembling the Blue Ridge and almost as high. It has been found by the operations carried on in the vicinity that the ore is entirely a low-grade hematite. Though a tunnel has been driven through the base of the mountain, no carbonate ore was found. Just why the ore is of different character in this locality is a matter for conjecture, but the change may have been caused by the oxygen-bearing percolating waters.

ANALYSES.

Partial analyses of the ore are as follows:

Average partial analysis of crude paint ore of Lehigh Gap district.[a]

Metallic iron	33
Metallic manganese	.01
Silica	25
Carbon dioxide	25

[a] Averaged from analyses in report of Second Pennsylvania Geol. Survey, 1886; also analyses furnished by Prince Metallic Paint Co., Allentown, Pa.

The specific gravity of the paint ore varies from about 3.2 to nearly 4.0. It contains, in addition to the substances stated above, small amounts of lime, magnesia, sulphur, and phosphorus.

MINING.

PRESENT EXTENT OF WORK.

The paint ore has been very extensively worked in the past along the entire length of outcrop described above. Most of the old workings have been abandoned, and there are at present no working mines west of Lehigh River. Within a mile of Germans are five old shaft mines and two that were worked through tunnels. There are also a number of abandoned mines east of the river.

The mines now working are the two tunnels and the shaft of the Prince Manufacturing Company at Hazard and the tunnel and shaft of the Prince Metallic Paint Company east of Millport.

METHODS.

The deposits are worked through both tunnels and shafts. Tunnels are used wherever practicable. In most places the Oriskany sandstone, next to which the ore occurs, stands out as a prominent hill, and the favorite method of working the bed has been to drive a tunnel from the hillside through the Oriskany, striking the ore at a depth of 50 to 150 feet below the top of the hill. This gives the tunnel a length of 500 to 1,500 feet. In many places, particularly in the older workings, it appears that a great part of this length could be more economically carried on as an open cut, as the overburden is locally but a few feet thick.

The Kline tunnel of the Prince Manufacturing Company at Hazard may be taken as a typical example of the tunnels of this region. This tunnel starts in the river wash, which here covers the side of the hill, and extends 1,400 feet in a north-south direction to the ore bed. From the end of the tunnel drifts are driven along the strike of the bed, which is east and west, and the ore is stoped out by the overhead method, with filling. Where the tunnel goes through a great thickness of soft shale and clay, close timbering and lagging is necessary. The tunnel is 6 feet high and about as wide. The sets consist of two posts and a cap of 8-inch timber and are placed 3 to 6 feet apart. They are lagged with rough poles 15 feet long. The track has a gage of 2½ feet. No timbering is necessary in passing through the Helderberg limestone or the Oriskany sandstone.

The mines east of Millport probably show to best advantage the mining methods in use, and a detailed description of one of these mines follows.

The ore bed here outcrops well back in the Oriskany hill and dips steeply from 60° to 70° due north. It has been worked for 2,000 feet along the strike, and a timbered air hole marks the present western limit of the workings. One thousand feet east of this the bed was first encountered by a tunnel driven from the hillside 999 feet due north. Six hundred feet east of the point where the tunnel strikes the bed is the bottom of the shaft, and from this point the workings continue 400 feet farther east. This tunnel is similar to the one described above. A shaft was put down in the hanging wall and struck the bed at a depth of 159 feet, the same level as that at which the tunnel enters it. The shaft is 5 feet square and is timbered with 6-inch cribbing, on the inside of which are nailed 1-inch boards forming a complete lining.

The drifts along the strike are 7 feet high, 5½ feet wide at the bottom and 5 feet at the top. They are driven along the ore, which is here 2 feet thick, and are timbered their entire length. Only one post is used in the sets, as the cement-rock hanging wall is sufficiently firm to permit supporting one end of the cap in a hitch cut in it. Nine-inch timber is used. The sets are placed 3 feet apart and are closely lagged.

A pillar is left to protect the shaft, and beyond this the stoping commences. The drift is driven 30 to 40 feet at a time, after which a section of this length is stoped up to the surface, or to the overburden of earth and clay. Overhead stoping with filling is the method used. The stope is kept inclined in advancing, so that the top corner farthest from the shaft is kept about 20 feet ahead of the face of the drift. The ore can thus be rolled down from the working face to the drift. Six-inch props are placed at intervals to support the roof while the ore is being removed. The stopes are 4 to 6 feet wide, 2 feet being ore and the rest clay and cement rock. The ore is carefully sorted out and rolled down. The clay and cement rock are used as filling. At intervals air holes are driven from the top of the stopes to the surface. The air is then carried from them to the working places by a small monkey gangway, which runs along the top of the worked-out and filled-in stopes. This also is timbered and lagged. As the workings advance, new air holes are driven and the old ones are abandoned.

The ore is blasted down with dynamite, the holes being drilled by hand. After being sorted and rolled down to the drift it is loaded into boxes holding about half a ton. These are mounted on trucks and trammed to the shaft. The boxes have rings at the corners, and four chains suspended from the hoisting rope are hooked in these rings. The hoisting is done by a horse hoist. The ore, after hoisting, is stored in sheds ready for the mill.

This mine is rather wet, but the natural drainage through the tunnel disposes of all the water. At present one shift of four men is engaged in stoping and the output is 10 tons a day.

OUTLOOK FOR THE INDUSTRY.

The mining problems so far have been very simple, because only slight depths have been attained, and natural drainage is in most places relied on to drain the workings. None of the mines has as yet opened a second level, because of the great horizontal extent of the ore. At the mine just described there is enough ore on the one level within the property lines to maintain the present output for over twenty-five years. It appears probable, however, that with the growing demand for metallic paints increased production will necessitate the opening of lower levels. The future of the region hence depends largely on the depth of the ore body, and practically nothing is known of this. The idea that the ore is due to deposition by descending waters does not argue well for its continuance with depth, but nothing can be definitely stated from our present knowledge. The deepest workings are in an old mine at Millport, where ore is reported to have been found at 200 feet.

The general conditions are very favorable to cheap mining. Shipping facilities are good, as the Central Railroad of New Jersey runs through Hazard and the Chestnut Ridge Railroad through Millport. The Lehigh Valley Railroad also furnishes ample means of shipment to the east and west. There are no expenses for fuel or mechanical power, and labor is extremely cheap.

PREPARATION OF PAINT.

METHOD OF TREATMENT.

The treatment of the ore, as carried on in this region, consists of calcining and grinding it to a fine powder, in which state it is sold to be mixed with oil.

The ore is carted from the mines to the mills, where it is dumped into bins. It is then broken up with sledges to about 6-inch pieces, when it is ready for calcination. This was formerly carried on in stone kilns, but these are giving way to more modern steel-jacketed shaft kilns. The kilns are generally situated at the foot of a hill, the ore bins being higher up, so the ore may be trammed over a trestle to the charging door at the top of the kiln.

Certain typical kilns are of brick construction, with sheet-steel sheathing 25 feet high and 10 feet in diameter. There are two fireplaces, one on each side, making the width of the kiln at the bottom 18 feet. Cordwood is used as fuel, and the average temperature attained is 500° F. The run lasts twenty-four hours, and every twelve hours 10 tons of calcined ore is withdrawn through the door at the bottom, a corresponding amount of raw ore being charged at the top.

The calcined material is very compact and of a dark reddish-brown color. It has the same composition as the finished product, the rest of the process consisting simply of grinding. The loss during calcination is about 20 to 25 per cent.

Two such kilns are in operation at Lehigh Gap. The product is trammed to the mill, 100 feet distant, and ground to buckwheat size by a gyratory crusher in the cellar. A conveyor then carries it to bins at the top, and thence it is fed automatically to the fine grinding apparatus on the first floor. This consists of three 36-inch horizontal buhr mills and three vertical mills. Their product is shipped in barrels containing 300 pounds.

Power for this mill is furnished by a 75-horsepower water turbine.

COMPOSITION AND PROPERTIES.

The ground paint ready for market has the following composition, according to the analyses of the Prince Metallic Paint Company:

Composition of ground paint from Lehigh district.

Fe_2O_3	41 –47	MnO	0.35–1.8
SiO_2	32 –37	P_2O_5	.14– .17
Al_2O_3	9 –11	S	.5 –1
CaO	.1–3	CO_2	1.5 –2.5
MgO	1.7– 3.5	H_2O	.6 – .9

The particular advantage of this paint is its great durability. Other advantages are that it requires no dryer and that it is free from grit.

The manufacturers, in their directions for using the paint, recommend mixing 7 pounds of paint with 1 gallon of boiled linseed oil. This is sufficient for one coat over an area of 500 square feet. Another important point claimed for it is that there is no trouble from the paint settling. The completeness of the grinding reduces the paint to an impalpable powder, which does not easily settle or harden.

USES IN THE ARTS.

The paint from this region is recommended by the manufacturer for both wood and steel, for use under the most severe conditions of exposure, as railroad cars, exposed structural steel work, etc.

There is more of this paint used for freight cars than for any other purposes. Other uses are for structural steel, filling in oilcloth and linoleum, tanks, ships, and in tin roofing.

The paint brings a price from $12 to $14 a ton.

PRODUCTION AND STATISTICS.

The entire production of the whole region to date is in the neighborhood of 100,000 tons. Of this amount 25,000 tons has come from the mines now operating at Millport. Approximately an equal amount has been mined from the present workings at Hazard, and the remainder was from mines now abandoned.

There is still available, above ground-water level, about 200,000 tons of ore, or enough to last for twenty-five years longer at the present rate of production. This estimate was made on the assumptions that the ore averages 1½ feet in thickness and that there is 65 feet above ground-water level.

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