Issued March 20, 1912.

U. S. DEPARTMENT OF AGRICULTURE,

BUREAU OF SOILS—BULLETIN No. 81.

MILTON WHITNEY, Chief.

A REPORT ON THE NATURAL PHOSPHATES OF TENNESSEE, KENTUCKY, AND ARKANSAS.

BY

WILLIAM H. WAGGAMAN,
Scientist in Chemical and Physical Investigations.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1912.

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Soils,
Washington, D. C., October 30, 1911.

Sir: I have the honor to transmit herewith the manuscript of a report covering the phosphate-rock industry of Tennessee, Kentucky, and Arkansas, and to recommend that it be published as Bulletin No. 81 of this bureau. The report forms one of a proposed series of bulletins embodying the results of researches now being conducted by the bureau on the phosphates of lime. These substances form the basis of fertilizer manufacture the world over, and are of the utmost importance in the intensive handling of the soil.

Respectfully,

Milton Whitney,
Chief of Bureau.

Hon. James Wilson.
Secretary of Agriculture.

CONTENTS.

ILLUSTRATIONS.

PLATES.

FIGURES.

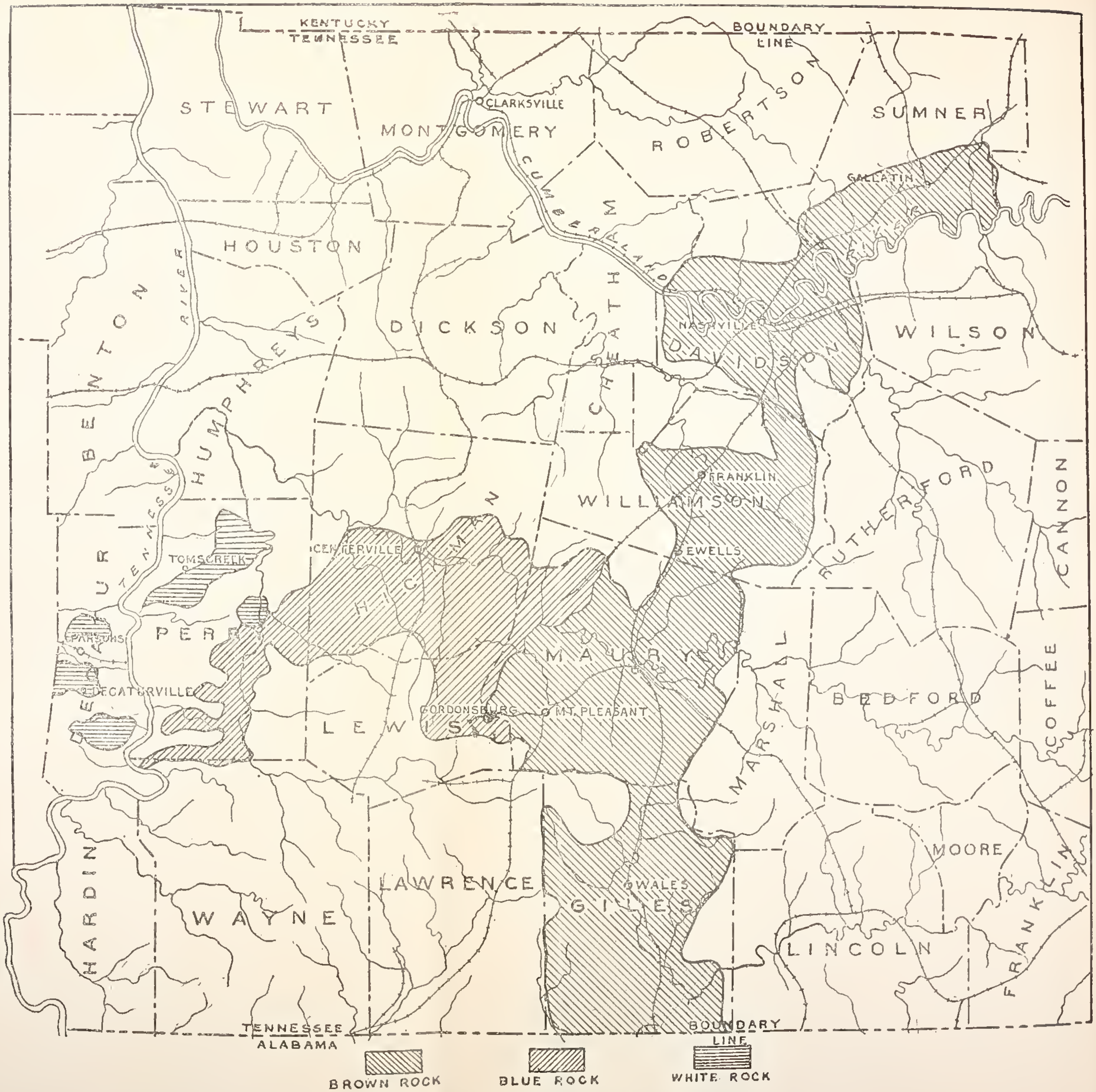

FIG. 1.—Approximate distribution of the Tennessee phosphates.

16315°—12. (To face page 5.)


FRANKLIN
COFFEE
CANNON

A REPORT ON THE NATURAL PHOSPHATES OF TENNESSEE, KENTUCKY, AND ARKANSAS.

NATURAL PHOSPHATES OF TENNESSEE.

INTRODUCTION.

The phosphate deposits of Tennessee rank next in importance to those of Florida. Much work has been done in these fields and valuable geological and chemical reports have been published.

It is the purpose of this report to describe conditions in these fields, to outline the modern methods of mining and handling the rock, and to show what disposal is being made of the finished product and waste material or by-products of the industry.

The conditions in the Tennessee fields have changed considerably within the last few years, mining methods have improved, deposits of lower grade rock are being exploited, and many of the old mines and dumps are being reworked.

GEOGRAPHY AND TOPOGRAPHY.

Tennessee is well situated for the distribution of fertilizer material to the Southern and Middle Western States. Its phosphate deposits occur in what is known as the Central Basin of Tennessee (elevation, 600 feet) and in the valleys of the western part of the Highland Rim (elevation 1,000 feet) surrounding this basin. (See fig. 1.)

The Central Basin extends across the State from north to south, lying between the Cumberland Plateau on the east and the Tennessee River on the west. It covers an area of approximately 7,000 square miles of gently undulating country. The phosphate deposits have been developed only in the western part of this area, workable beds lying in parts of Sumner, Davidson, Williamson, Lewis, Maury, Hickman, and Giles Counties.

The main streams in the phosphate regions are the Cumberland, Duck, and Tennessee Rivers, but there are numerous creeks and tributaries of the Duck River that are of great importance in the development of the deposits, as sources of water supply for mining and handling the rock.

Both the Cumberland and Tennessee Rivers have been utilized for transporting phosphate rock, but mining in the vicinity of these streams has practically ceased and no recent shipments have been made. Considerable material will probably be shipped down the

Tennessee River in the near future, following the development of the white phosphate deposits of Perry and Decatur Counties.

Most of the mines are reached by the Louisville & Nashville, the Nashville, Chattanooga & St. Louis, and the Middle Tennessee Railroad.

GENERAL GEOLOGY.

All the exposed strata of these regions are of sedimentary origin. The phosphate occurs in rocks of Ordovician and Devonian age. Table I, compiled from the report of Hayes and Ulrich[1] on the Columbia quadrangle, which covers parts of Williamson, Hickman, Lewis, and Maury Counties, gives the stratigraphic position of the various phosphate beds and their relation to the overlying, surrounding, and underlying formations.

TABLE I.—*Geologic formations in the Columbia quadrangle, Tennessee.*

Age.	Formation.	Description.
Carboniferous	St. Louis limestone	Gray and blue cherty limestone.
	Tullahoma formation[1]	Very cherty shale.
Devonian	Chattanooga shale	Carbonaceous black shale. (Phosphate horizon.)
Silurian	Clifton limestone	Even-bedded, compact, gray or blue limestone.
	Fernvale formation	Soft green or brown shale with bands of crystalline limestone.
	Leipers formation	Knotty, earthy limestone and interbedded shale. (Phosphate.)
	Catheys formation	Knotty, earthy limestone and shale with bands of blue limestone. (Phosphate.)
Ordovician	Bigby limestone	Granular, crystalline, laminated phosphatic limestone. (Phosphate.)
	Hermitage formation	Shale with siliceous limestone below and phosphate limestone above. (Phosphate.)
	Carters limestone	Massive, compact, white or blue cherty limestone.
	Lebanon limestone	Thin-bedded, compact bluish limestone.

[1] Since the publication of the Columbia folio this formation has been correlated with the Fort Payne chert, the older name, and "Tullahoma" has been abandoned by the U. S. Geological Survey.

Table I shows four formations in the Ordovician rocks which contain phosphate beds. It must be understood, however, that these formations are not always in normal succession, some of them being absent in certain areas, nor are the beds always highly phosphatic. Local conditions during their deposition and subsequent changes have caused wide divergence in composition.

CLASSES OF PHOSPHATE.

There are three economically important classes of phosphate rock in Tennessee, namely, the brown phosphate, or Ordovician rock, which is divided by Hayes and Ulrich into several groups; the blue, or Devonian phosphate, of which there are several classes, and the white rock deposited from solution in caverns. The nodular and conglomerate phosphates, though widely distributed, are not found in sufficient quantities to be profitably mined by themselves. Each of the three classes mentioned will be treated separately.

[1] Columbia Folio, No. 95, U. S. Geological Survey, 1903.

Brown-Rock Phosphate.

LOCATION OF DEPOSITS.

Workable deposits of brown-rock phosphate are found scattered over a very wide area, as many different beds occur in the several formations of Ordovician age. The most important are those in Sumner, Davidson, Williamson, Hickman, Maury, Lewis, and Giles Counties. Most of the mines are reached by the Louisville & Nashville and the Nashville, Chattanooga & St. Louis Railroads, but several of the deposits being worked in Hickman and Davidson Counties are several miles from the railroads. The brown-rock deposits west of Nashville, in Davidson County, and those of Sumner County, in the vicinity of Gallatin, have easy access to the Cumberland River.

GEOLOGICAL OCCURRENCE AND ORIGIN.

All of the Tennessee brown-rock phosphate occurs in rocks of Ordovician age. There are numerous phosphatic horizons in this series, some of which frequently occur so close together that they can be mined as a single bed. Taken in order of their stratigraphic succession, the phosphate bearing rocks are given in Table II.

Table II.—*Geologic formations in west-central Tennessee, which carry brown-rock phosphate.*

Age.	Formation.	County where found.
Ordovician	Leipers formation	Lewis, Hickman, Sumner.
	Catheys formation	Maury, Hickman (unimportant).
	Bigby limestone	Maury, Giles.
	Hermitage formation	Maury, Williamson, Davidson.

The deposits of brown phosphate are generally conceded to be formed by the leaching of phosphatic limestones by carbonated waters. The solution and removal of carbonate of lime has been attended by a diminution in thickness and consequent settling of the phosphatic strata. Some secondary deposition has also taken place in the pores and interstices of the leached mother rock.

The phosphate beds occur in two distinct forms, known as collar and blanket deposits. The first occurs where the horizontal phosphatic limestone stratum outcrops on the slope of a steep hill. The stratum passes through the hill but has been leached only at the outcrop, the overburden of younger rocks protecting the main part of the bed from the action of percolating waters. This class of deposit has proved very deceptive to the miner, who, finding the outcrop a very high grade phosphate rock, has tunneled into the hill to discover that the stratum passes rapidly to a phosphatic limestone.

The blanket deposits, on the other hand, sometimes cover wide areas. They usually lie near the surface of gently undulating hills where the underdrainage is favorable to their formation. Almost ideal conditions existed in the Mount Pleasant regions for the production of such deposits.

In this section the highly phosphatic Bigby limestone lies very near the surface and is underlain by an easily soluble fine-grained limestone through which the percolating water readily drained. The leaching began where the surface water gained access to the beds along the joint planes, but gradually worked through the entire mass, carrying away the carbonate of lime in solution and leaving the less soluble phosphate of lime.

The blanket deposits are always more or less wavy in their character, owing to the irregularity of the leaching. Large columns, bowlders, and cones of unaltered phosphatic limestone occur throughout these deposits. In Plate I, figures 1 and 2, are shown strata and bowlders of phosphatic limestone, with the leached brown phosphate occurring both above and below them.

There is also a secondary tufaceous brown phosphate which occurs in the Hermitage formation, but it occurs in very small quantities, is essentially a pocket formation, and is of no great economic importance.

According to Hayes and Ulrich,[1] the limestone from which the brown phosphate is derived was probably deposited in a sea so shallow that the bottom was affected by wave action and currents. These authors consider the deposits to be largely of organic origin and to consist of the remains of phosphatic and carbonaceous shellfish. The carbonate of lime was partly replaced by the phosphate, forming beds of more or less phosphatic limestone, which upon being elevated above the surface were further enriched as outlined above. Brown [2] and Ruhm [3] agree with Hayes and Ulrich in their theories as to the origin of the Ordovician phosphate.

PHYSICAL PROPERTIES.

The Ordovician phosphate varies considerably according to location. The beds derived from the different formations have definite characteristics which aid the geologist and mining engineer in identifying the horizon. The rock varies in color from a light gray to a deep chocolate brown and in texture from a porous rock, disintegrating into phosphatic sand, to a hard, close-grained rock very resistant to weathering. As a whole the rock is brown or gray and occurs in plates of varying thickness. The beds range in thickness from a few inches to 20 or 30 feet, with an average of 6 to 8 feet. The mean specific gravity of the Tennessee brown rock is about 2.8. The yield of phosphate per foot per acre is from 600 to 1,000 tons.

[1] Columbia Folio No. 95, U. S. Geological Survey, 1903.
[2] Engineering Association of the South. Trans., 15, 93–94 (1903–4).
[3] Engineering and Mining Jour., 83, 522 (1907).

In Table III are given the results of analyses of different types of brown-rock phosphate, the samples being taken in several localities:

TABLE III.—*Analyses of samples of Ordovician brown-rock phosphate from Tennessee.*

No.	Location.	Thickness of bed.	Geologic formation.	P_2O_5.	$Ca_3(PO_4)_2$.
		Feet.		*Per cent.*	*Per cent.*
3 and 5	Mount Pleasant, Maury County	3	Bigby	34.50	75.42
46	Near Nashville, Davidson County	4	Hermitage	34.32	75.02
70	Centerville, Hickman County	3	Leipers	35.79	78.21
76	Near Centerville, Hickman County	40	......do	35.01	76.33
39	Near Gallatin, Sumner County	6	......do	23.62	51.62
40	Wales Station, Giles County	8	Bigby (disintegrated)	31.11	67.98

METHODS OF MINING.

Only within the last few years have modern mining methods been employed in the Tennessee phosphate fields. For years the richest deposits of brown rock in the Mount Pleasant regions were worked by hand, and only when these deposits were considered to be nearly exhausted did the operators seem to realize the crudity, wastefulness, and inefficiency of the methods they were using. Even now a few small firms and farmers are employing the pioneer method of shaking out all rock not held by the tines of a potato fork and drying the larger pieces in the sun or on ricks of wood.

The larger operators have adopted much more thorough and economical methods of working the deposits. The overburden is first removed by steam shovels or scrapers, and the phosphate rock, together with its matrix, dug out with picks and forks, loaded into tramcars, and hauled to the washer, where it is put through a cleansing process described below. In the vicinity of Centerville they have installed the hydraulic system of mining which has been used so successfully in the Florida land pebble regions. By employing a screen to prevent large pieces of rock from entering the centrifugal pump this method is expected to prove very satisfactory. The Tennessee phosphate regions have distinct advantages over those of Florida for hydraulic mining, as the Tennessee product occurs in the hills, where the overburden can be disposed of by gravity. The rock itself does not have to be pumped to a great height, as is the case in many of the Florida mines, where the pits are so far below the level of the washer plant. Plate II, figure 1, shows the method of mining brown-rock phosphate.

The modern Tennessee washing plants differ considerably in some features, but the general scheme of separating the phosphate from its impurities is the same with all of them. The phosphate rock, together with the matrix in which it is frequently embedded, is brought from the mines in tramcars, hauled to the top of the washer, and dumped into a hopper. Streams of water are played upon the mass, washing the material down to a crusher, which breaks up the larger lumps of rock. From this point it either goes through a log washer similar to that employed in the Florida phosphate fields,[1] or is conveyed over a series of screens by a kind of chain scraper.

The material passing through these screens then goes to the revolving rinser, where it is thoroughly sprayed. The portion passing through the half-inch perforations of the rinser falls into a hopper, is taken up by pumps, and passed through a series of settling tanks, being finally discharged into the draining bins. After the water has partly drained off the washed product is drawn out and sent to the driers. Plate II, figure 2, shows one of the most modern types of phosphate washers.

Where the log washer is employed, the backwash, together with the overflow from the settling tanks, is led through troughs fitted with riffles to catch the finely divided phosphate. The clay and other impurities held in suspension with very finely divided phosphate is finally discharged into waste ponds. This method of washing has proved so efficient that many of the old deposits are being reworked and a very high grade product obtained.

In Table IV a comparison is made of the coarser rock which was saved by the old mining methods and the fine material formerly thrown out, but which modern washer plants have now made it profitable to mine.

TABLE IV.—*Analyses of coarse and fine, washed, Tennessee brown phosphate.*

Location.	Coarse fragments.		Rock fragments, less than one-half inch diameter.	
	P_2O_5	$Ca_3(PO_4)_2$	P_2O_5	$Ca_3(PO_4)_2$
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Charleston, S. C., Mining & Manufacturing Co., Mount Pleasant, Tenn	33.50	73.23	34.32	75.01
Volunteer State Co., Centerville, Tenn	35.01	76.33	33.23	72.64
Mount Pleasant, Tenn., International Agricultural Corporation plant	36.91	80.65	35.72	78.05

The old kiln method of drying phosphate on ricks of wood is still employed to some extent in the brown-rock region, but is used only for the larger plates or fragments of rock. A few small operators still dry their rock in the sun, but the output of material dried in this way is very small.

Most of the rock is dried in rotary cylinders, which are so largely employed in the pebble regions of Florida.[2] Some of the miners prefer to feed their phosphate rock into the hottest end of the drier—that is, the end in which the flames and gases of combustion enter—while others introduce the phosphate into the cooler end of the

[1] Waggaman, Bul. No. 76, Bureau of Soils, U. S. Dept. Agr., 1910.

[2] Waggaman, Bul. No. 76, Bureau of Soils, U. S. Dept. Agr.; Menninger, C. G., Eng. News, **60**, 1908.

cylinder and allow it to work toward the hotter end. The latter method seems on the whole more efficient and economical, since the partly dried rock does not come in contact with atmosphere highly charged with moisture, and there is also probably less danger of loss of finely divided rock through the stack. Kentucky coal is used as fuel.

COST OF PRODUCTION.

The cost of preparing brown-rock phosphate for the market has increased considerably in recent years. When the rock was first mined no plant was required to treat the phosphate, hand labor was employed, and a few rough sheds were erected in which to store or dry the material. At that time thousands of tons were mined at a cost not exceeding 75 cents per ton.

With the increased cost of labor and fuel and the expense of erecting washing and drying plants, the cost of production has advanced greatly. In the Mount Pleasant district, where the old deposits are being reworked, and in Giles County, where the phosphate is in a disintegrated condition, much waste material has to be handled to obtain a high-grade product. It is also necessary to remove a much heavier overburden than formerly to reach the phosphate deposits. Many of the operators find it profitable to remove 4 feet of overburden for every foot of underlying phosphate. The average cost of taking off this overburden is 15 cents per cubic yard, though it is claimed that where hydraulic methods are employed it can be removed at a much lower figure.

On account of these numerous factors the average cost of producing high-grade rock for the fertilizer trade is not far from $2.50 per ton.

MARKETING.

The current freight rates from the principal mining districts in the brown-rock regions to the manufacturing cities and markets are given in Table V.

TABLE V.—*Freight rates on phosphate rock (lump rock) per long ton.*

Location of deposit.	Destination.	Rate per ton.
Mount Pleasant, Columbia, and vicinity; Wales and vicinity, Franklin, to	Cincinnati, Ohio	$2.50
	Cleveland, Ohio	3.80
	Columbus, Ohio	3.40
	Louisville, Ky	2.25
	Indianapolis, Ind	3.10
	Atlanta, Ga	2.45
	Montgomery, Ala	1.75
	Savannah, Ga	3.75
Gallatin and vicinity to	Cincinnati, Ohio	2.25
	Cleveland, Ohio	3.55
	Columbus, Ohio	3.15
	Louisville, Ky	2.00
	Indianapolis, Ind	2.85
Centerville and vicinity to	Cincinnati, Ohio	2.50
	Nashville, Tenn	[1]1.75

Ton of 2,000 pounds.

Most of the brown-rock phosphate mined in Tennessee is disposed of in this country, though a considerable quantity of the highest grade—rock containing from 78 to 80 per cent $Ca_3(PO_4)_2$—is shipped abroad.

The fertilizer trade (manufacturers of acid phosphate) demands a rock containing not less than 72 per cent bone phosphate of lime ($Ca_3(PO_4)_2$) and not more than 5 per cent iron and alumina. This produces an acid phosphate containing 16 per cent available phosphoric acid.

Within the last few years the sales of ground-rock phosphate for direct application to the field have grown considerably. Excellent results have been reported from its use at the Ohio and Illinois experiment stations and from individual farmers. Several companies are handling this product exclusively. The rock is ground to varying degrees of fineness. One company has two grades; No. 1 is ground so that 90 per cent will pass a 60-mesh sieve and No. 2 ground so that 95 per cent will pass a screen containing 100 meshes to the inch. The ground rock is sold on a guaranty of 60 to 65 per cent bone phosphate of lime ($Ca_3(PO_4)_2$) and shipped chiefly to States in the Middle West.

In Sumner and Hickman Counties new phosphate fertilizers are being prepared. The processes are patented and the manufacturers claim that they obtain a product containing fully as much phosphoric acid as superphosphate, without the objectionable feature of free acid. Under these new processes rather low grade rock can be used.

WASTE MATERIAL.

Within the last few years the main sources of waste in the brown-rock phosphate fields have been largely eliminated. When phosphate was first mined in the Mount Pleasant district probably half of the rock was thrown away. Much of this will never be recovered, as it has become mixed with foreign matter and covered by overburden too heavy to make reworking commercially practicable. A large proportion of the Mount Pleasant deposits, however, are now being worked over. Modern washer plants save upward of 75 per cent of the phosphatic material, recovering much of the finely divided or disintegrated rock. The operators state they can hold and cleanse material fine enough to pass a 60-mesh sieve.

Considerable finely divided phosphate is discharged into the waste ponds. Samples of material taken where the wash water enters these ponds are found to be quite rich in phosphoric acid, but the quality of the deposited residue falls off as the middle and far end of the pond is reached, since the heavier particles, which are mainly phosphate rock, have settled out. Part of these waste ponds can and doubtless will be worked over to advantage.

In putting the rock through the mechanical dryer considerable phosphate dust is carried up the flue and out of the stack by the powerful draft. Many of the stacks are now provided with hoods and baffles to catch these "floats." Weather conditions affect the amount of material thus carried up the flues, but, roughly figured, about 2 tons of "floats" are saved by these hoods for every 100 tons of rock charged to the dryers.

The limestone "horses," or unleached phosphatic limestones, occurring in most of the brown-rock phosphate beds frequently contain a high percentage of phosphoric acid. No attempt has been made as yet to utilize these bowlders, although they would be valuable when ground, as they contain a considerable quantity of lime phosphate mixed with lime carbonate. Under the present method of mining the phosphate is dug from around these bowlders and the pits are then either abandoned or filled in with overburden from adjoining deposits. These bowlders could be removed, broken up, and crushed at small cost, and would prove of considerable value as fertilizer material.

Another method of utilizing these phosphatic limestones would be to burn them in a kiln, afterwards slaking them with steam or hot water. There is frequently sufficient carbonate of lime present to make this a practical means of disintegrating the rock.

In Table VI the phosphate content of a number of samples of phosphatic limestone before and after burning are given. These samples were first dried for several hours at 100° C. and then analyzed. They were then heated to the highest temperature obtainable with a blast lamp until they ceased to lose in weight, and again analyzed.

TABLE VI.—*Analyses of phosphatic limestone, underlying phosphate beds, and bowlders before and after burning.*

No.	Location.	Content of P_2O_5.	
		Before burning.	After burning.
		Per cent.	*Per cent.*
2	Mount Pleasant, Tenn., underlying limestone	16.05	21.15
4	.....do	9.48	11.12
6	.....do	19.43	21.42
8	.....do	18.30	23.86
11 W	Near Mount Pleasant, Maury County	12.53	21.15
47	6 miles west of Nashville, Davidson County	22.97	27.05
65	2 miles north of Centerville, Hickman County	14.69	19.75
75	.....do	16.32	17.72

In Table VII there are given the results of some experiments carried on in cooperation with L. R. Coates, of Baltimore, Md., the object of which was to test the slaking properties of phosphatic limestones after heating to various temperatures.

The samples grouped opposite A were burned at the temperatures indicated in column 2 and sent to the laboratories of this bureau. Here they were then slaked and sifted, and the percentages of the several sized particles determined. Each was then analyzed for phosphoric acid.

The samples under B were all burned and analyzed in the physical laboratory of the H. S. Spackman Engineering Co., Philadelphia, Pa. It is understood they were ground before being burned. This fact no doubt accounts for the small percentage of nodules in the samples.

TABLE VII.—*Mechanical and chemical analyses of phosphatic limestone after burning and slaking.*

1	2	3	4	5						6
Sample No.	Temperature.	Time of heating.	Loss on heating (percent).	Percentage of separates after heating and their phosphoric acid content.						$CaCO_3$ in nodules (per cent).
				Nodules.	P_2O_5.	0.1–0.25 mm.	P_2O_5.	0.1 mm.	P_2O_5.	
A	*C°*									
Check for 1 and 2.	....	Not heated..	....	100	22.80	....	......	....	......	....
1..........	800–812	7 hours......	15.30	55+	27.24	26+	27.96	18+	24.00	7.45
2..........	909–914	......do	15.50	38+	29.04	28+	28.44	33+	24.28	5.65
Check for 3.	....	Not heated..	....	100	24.56	....	......	....	......	....
3..........	700–705	7 hours......	8.40	78+	25.88	13+	29.72	9+	26.24	26.86
B										
Check for 4, 5, 6, and 7.	....	Not heated..	....	......	24.56	....	......	....	......	....
4..........	700	15 minutes..	18.15	4+	18.00	36+	27.16	58+	24.68	....
5..........	800	......do	18.23	1+	26.96	28+	29.16	69+	24.28	....
6..........	900	......do	18.90	6+	25.20	41+	26.44	52+	22.08	....
7..........	1,000	......do	18.95	3+	26.76	43+	28.60	53+	22.16	....

In every instance (except two, where the temperature was only 700° C.) the percentage of phosphoric acid is lower in the finest of the three grades of separates. This is to be expected from the character of the rock, since the free lime in slaking readily disintegrates. The figures in Table V, *A*, seem to indicate that slaking takes place much better when the phosphatic limestone has been heated to 900° C. or higher.

Another source of waste is at the picking belt, where the clay balls, flint, and limestone are picked out by hand and thrown away. Unfortunately a poor class of labor is usually employed for this purpose, and much good phosphate is lost in the operation.

In Table VIII are given the analyses of the various samples of phosphatic material, much of which is wasted in preparing the rock for the market.

TABLE VIII.—*Analyses of material lost in the pioneer methods of mining brown-rock phosphate.*

No.	Location.	Description.	SiO_2.	Fe_2O_3-Al_2O_3.	P_2O_5.	$Ca_3(PO_4)_2$.
			Per ct.	*Per ct.*	*Per ct.*	*Per ct.*
12	Arrow mine, Charleston, S. C., Mining and Manufacturing Co., near Mount Pleasant, Tenn.	Material discharged into waste pond; sample taken close to mouth of trough.[1]	5.77	4.19	34.32	75.01
22	Property of International Agricultural Corporation at Mount Pleasant, Tenn.	Phosphate, sand, and mud discharged into waste pond.	....	....	27.32	59.70
20	Property of Charleston, S. C., Mining and Manufacturing Co., near Mount Pleasant, Tenn.	Phosphate, sand, and mud, formerly thrown away, now being worked over.	16.65	6.48	28.22	61.66
16	Arrow plant of Charleston, S. C., Mining and Manufacturing Co., near Mount Pleasant, Tenn.	Material thrown from picking board—clay balls containing limestone, flint, and phosphate.	35.40	6.17	22.49	49.14
21	Blue Grass plant of International Agricultural Corporation, Mount Pleasant, Tenn.	Sample of floats saved by placing hood over stack—phosphate dust containing carbon.	....	....	30.51	66.67

[1] This material will no doubt be worked over and much of the phosphate recovered.

PRESENT CONDITION OF THE INDUSTRY.

There are fully 30 companies which own brown-rock phosphate property in Tennessee, but during the early part of 1911 only 15 of these were actually engaged in mining operations. The combined capacity of the 15 operating plants was about 900,000 tons per annum, but few were running full time and many only intermittently.

Brown-rock mining is being carried on at or near Mount Pleasant, Columbia, and Southport, in Maury County; near Gallatin, in Sumner County; at Wales Station, in Giles County; near Centerville, in Hickman County, and near Ewells Station, Williamson County.

After several years of depression the brown-rock phosphate industry during 1910 showed considerable activity, resulting in a substantial gain over 1909 in the material marketed. The control of the fields, however, is passing rapidly into the hands of the large fertilizer corporations. These companies have installed modern washer plants and are working deposits which the small operator was unable to handle with limited capital. Mining operations, however, have not resumed their former activity. This is due both to the increased cost of labor and the greater expense of handling the remaining deposits of phosphate. The enormous development in the last few years of the Florida pebble phosphate is also accountable for the falling off in the production of Tennessee rock.

The average price of brown-rock phosphate (72 per cent) f. o. b. mines is about $3.75 per ton. Apparently the price of this material has reached its level, and wide variations from the price given are not to be anticipated, barring some unusual and unexpected development in the industrial or labor worlds.

Table IX is a summary taken from the report of F. B. Van Horn [1] and shows the production of Tennessee phosphate during the last six years.

TABLE IX.—*Production of phosphate rock of the several classes in Tennessee from 1905 to 1910, inclusive.*

[Long tons.]

Year.	Brown rock.	Blue rock.	White rock.	Year.	Brown rock.	Blue rock.	White rock.
1905	438,139	44,031	689	1908	374,114	79,717	1,600
1906	510,705	35,669	1,303	1909	266,298	66,705	....
1907	594,594	38,993	5,025	1910	329,382	68,806	....

FUTURE OF THE INDUSTRY.

A few years ago the life of the Mount Pleasant phosphate fields was considered limited to six or seven years at most. With the advent of new machinery and modern mining methods many deposits which were regarded as exhausted promise to yield as much high-grade rock as has been removed in past years. Many of the rich deposits are still practically untouched, and it is safe to assume that the brown-rock fields will continue to produce a large tonnage for many years.

BLUE-ROCK PHOSPHATE.

LOCATION OF DEPOSITS.

The important deposits of blue-rock, or Devonian, phosphate in Tennessee lie along Leatherwood Creek, in the western part of Maury County, south and east of Centerville, on both sides of Swan Creek, in Hickman County, and in the eastern part of Lewis County.

The mines are reached by the Louisville & Nashville, Nashville, Chattanooga & St. Louis, and Middle Tennessee Railroads. The rock is usually dried and then shipped to various points in the South and Middle West. The Duck River is the only navigable stream convenient to the blue-rock fields. Practically no phosphate has been shipped on this river in recent years.

GEOLOGICAL OCCURRENCE.

The blue-rock phosphate belongs to the Devonian period and occurs in the geologic formation known as the Chattanooga shale. The beds vary in thickness up to 4 feet and differ widely in their content of phosphoric acid in different locations.

The phosphate stratum is usually overlain by a massive blue-black shale or slate, 3 feet or more in thickness, containing at its base phosphatic nodules, and is underlain normally by Silurian limestone.

[1] Production of Phosphate in 1910, Mineral Resources, U. S. Geological Survey.

FIG. 1.—STRATUM OF PHOSPHATIC LIMESTONE OCCURRING IN PHOSPHATE BEDS.

FIG. 2.—BROWN-ROCK MINING, SHOWING BOWLDERS OF PHOSPHATIC LIMESTONE.

FIG. 1.—BROWN-ROCK MINING, CENTERVILLE, HICKMAN COUNTY, TENN.

FIG. 2.—ONE OF THE MOST MODERN TYPES OF PHOSPHATE PLANTS, MOUNT PLEASANT, TENN.

Frequently an unconformity exists which brings the Devonian phosphate directly over the brown Ordovician rock. Under these conditions mining should be carried on very profitably.

The analyses of some typical sections of phosphate from areas where such conditions occur are given in Table X.

TABLE X.—*Analyses and descriptions of phosphate beds from localities where the blue rock directly overlies the brown phosphate of the Leipers formation.*

No.	Location.	Thickness of strata.	Description.	Analysis.	
				P_2O_5.	$Ca_3(PO_4)_2$.
		Ft. in.		*Per cent.*	*Per cent.*
68	Blue Buck mines, 6 miles southeast of Centerville, Tenn.	0 9	Coarse, hard blue rock	24.80	54.20
69	.....do	9	Fine-grained, hard blue rock	27.91	60.99
70	.....do	2 6	Brown phosphate (Leipers formation).	35.79	78.21
60	Corn Belt Phosphate Co., 8 miles east of Centerville.	1 3	Coarse, oolitic gray rock	25.25	55.18
61	.....do	8	Close-grained, hard blue rock	32.95	72.01
66	.....do	1 6	Brown disintegrated phosphate (Leipers formation).	32.40	70.82
71	Meridian Fertilizer Factory, 2 miles south of Centerville	1 8	Coarse oolitic blue rock (sampled in tunnel).	26.44	57.79
72	.....do	1 2	Fine-grained, hard blue rock (in tunnel).	36.66	80.11
(1)	.....do	....	Brown phosphate (Leipers formation).	....	....

[1] No sample collected.

According to Hayes and Ulrich [1] the blue-rock phosphate was laid down under conditions somewhat similar to those under which the Ordovician phosphate was deposited, except that the shellfish and organisms from which the deposits are in part derived were more highly phosphatic than those existing in Ordovician times, and consequently the deposits required no subsequent leaching to make them of economic value. Another important factor in the formation of the richer deposits of blue phosphate, according to these authorities, is the highly phosphatic Leipers limestone, which in places directly underlies the Devonian phosphate, and which through leaching and subsequent disintegration has given the blue rock much of its substance.

The beds of the highest-grade phosphate, therefore, are of both primary and secondary origin, consisting of the rolled and leached fragments of Ordovician limestone and the phosphatic remains of Devonian life.

PHYSICAL PROPERTIES.

The physical properties of blue-rock phosphate differ according to the conditions of its deposition. The unweathered rock varies in color from a blue black to light gray, depending on its content of organic matter, and in texture from a hard, close-grained, massive

[1] Loc. cit.

calcareous rock to coarsely oolitic, loosely cemented material, very readily broken up. In general the phosphate-bearing formation may be described as a bluish-gray rock, composed of flattened ovules and the waterworn casts of phosphatic shells. In the fresh state the rock is very hard and difficult to grind. It weathers upon exposure into a rusty-yellow material. The average specific gravity of the rock is about 2.87. This means that a stratum 1 foot thick will run about 3,200 tons per acre.

The blue rock, as a rule, has a lower content of phosphoric acid than the brown, but this objection is largely offset by the fact that it contains less iron and alumina than the brown rock.

In Table XI the analyses of several types of blue-rock phosphate are given, with their more prominent physical characteristics.

TABLE XI.—*Analyses of different types of Tennessee blue-rock phosphate from various localities.*

No.	Location.	Description.	Analysis.	
			P_2O_5	$Ca_3(PO_4)_2$
			Per cent.	*Per cent.*
49	Leatherwood Creek, Maury County	Hard blue rock, partly weathered to rusty brown.	31.39	68.58
54	Blue Buck mines, 6 miles southeast of Centerville.	Hard, close-grained blue rock	32.21	70.39
56	.....do	Hard, close-grained blue rock (high grade).	36.79	80.41
58	.....do	Coarse, gray oolitic rock, yet not as hard as No. 58.	31.66	69.19
59	.....do	Kidney phosphate, occurring in slate above blue-rock phosphate.	33.86	73.99
60	Corn Belt Phosphate Co., 8 miles east of Centerville.	Coarse, oolitic gray rock, overlying blue rock.	25.25	55.18
61	.....do	Hard blue rock, underlying No. 60	32.95	72.01
71	Meridian Fertilizer Factory, 2 miles south of Centerville.	Coarse, oolitic blue rock (unweathered)	26.44	57.79
73	.....do	Coarse, oolitic blue rock (weathered), overlying high-grade blue rock.	28.82	62.98
72	.....do	Fine-grained, hard blue rock (sampled in tunnel).	36.66	80.11
74	.....do	Fine-grained, hard blue rock (sampled outside tunnel).	35.75	78.12
123	Mayfield mine, Gordonsburg, Lewis County.	Kidney phosphate, embedded in slate roof.	27.58	60.27
124	do	Fine-grained, hard blue rock (high grade).	36.20	79.11

METHODS OF MINING.

The blue-rock phosphate is mined by first stripping around the face of the hill, then drifting in on the stratum as the overburden becomes too heavy to remove. The blue shale or slate directly overlying the phosphate forms, as a rule, an excellent roof, requiring no great amount of timbering for its support. Owing to its hardness, the rock is loosened by blasting and then broken up with picks. Compressed-air drills are now largely used in mining. The material is loaded into tramcars and wheeled or drawn by mules to the drying and crushing plant, where it is prepared for shipment. No washing is necessary for the bedded blue-rock phosphate. In Plate IV, figure 1, is shown the method of mining blue-rock phosphate.

The rock is dried both in kilns and in mechanical dryers, such as described under brown-rock phosphate. As it comes from the mines the rock contains a rather low percentage of moisture, and some of the miners deem it unnecessary to dry it at all. Since it contains both carbonate of lime and organic matter, the burning or drying process serves to increase the percentage of phosphoric acid in the finished product.

COST OF PRODUCTION.

In comparing the cost of mining blue-rock phosphate with that of brown there are a number of factors to be considered. Tunneling is more expensive than mining by open cut, except where the overburden is very heavy or composed of a hard rock like that usually overlying the Devonian phosphate.

The blue rock must be blasted or drilled out, whereas the brown-rock phosphate can be removed with pick and shovel. The blue rock does not have to be washed and contains but little moisture, while much of the brown rock (as mined to-day) must be put through an elaborate cleansing process, during which considerable foreign material is handled for each ton of phosphate produced. In addition, a large quantity of fuel must be consumed to remove the water. Formerly the cost of mining blue rock was greater than that of mining brown, but the expense at present is nearly the same, approximately $2.50 per ton.

One point in favor of blue-rock mining is that work can go on in the tunnels during wet weather, while the brown-rock mines are forced to suspend work.

DISPOSAL OF PRODUCT.

Although some specimens of blue-rock phosphate will run as high as 78 to 80 per cent of bone phosphate of lime, which is the grade demanded for export, the average grade of the rock is not usually more than 70 to 72 per cent. Most of the blue-rock phosphate mined in Tennessee is consumed in this county in the manufacture of acid phosphate.

FREIGHT RATES.

Since much of the blue rock is found in the same localities as the brown, the freight rates given on page 11 also apply to this product.

EXTENT OF OPERATIONS.

Extensive development work in the blue-rock region has been done along Swan Creek and its tributaries in Hickman County, along Leatherwood Creek in Maury County, and at Gordonsburg in Lewis

County, but only at the latter place is much mining going on at present.

According to Van Horn,[1] the total quantity of blue-rock phosphate produced from 1905 to 1910 is 333,921 tons.[2] The annual output is given in Table IX.

PRESENT CONDITION OF THE INDUSTRY.

Five companies are mining blue-rock phosphate at the present time, but only one of these has a large annual output. The production of this class of phosphate is falling off considerably. This is due to a number of causes: First, many of the deposits are of an uncertain character. Sometimes the phosphate stratum thins out to almost nothing when followed into the hills, while in other localities the beds may grow thicker but become so poor in phosphoric acid that the rock is of no commercial value. Second, the enormous development of the Florida pebble phosphate fields during the last few years has caused a decline through competition. Third, new methods of handling the disintegrated brown-rock phosphate, formerly considered waste, have caused a revival in these fields at the expense of the blue-rock industry.

FUTURE OPERATIONS.

With the exception of the high-grade blue-rock deposits and those beds which rest directly on the brown rock, so that both can be worked together, the blue phosphate will probably not be extensively mined for a number of years. The operators have so often been deceived in what promised to be extensive high-grade, blue-rock deposits, but which subsequently "pinched out," that they prefer to await better prices before undertaking to mine strata of uncertain composition. Should the price of phosphate advance, it will doubtless cause renewed activity in these fields.

White-Rock Phosphate.

LOCATION OF DEPOSITS.

The white phosphate rock of Tennessee so far exploited occurs in Perry and Decatur Counties.

In the former county[3] the mines are located at Toms Creek, from 5 to 6 miles east of the Tennessee River. In Decatur County[4] the phosphate has been developed along the tributaries of Beech River, between Parsons and Decaturville. The mines are from 6 to 8 miles west of the Tennessee River and from 3 to 4 miles from the Nashville,

[1] Production of Phosphate Rock in 1910. Mineral Resources, U. S. Geological Survey.
[2] This includes a small tonnage from Arkansas.
[3] Hayes, Ann. Report, U. S. Geological Survey, Part III, 1899-1910.
[4] B. Eckel, Bul. 213, U. S. Geological Survey, 418-419 (1903).

Chattanooga & St. Louis Railroad at Parsons, Tenn. There is a good wagon road between Parsons and Decaturville.

Although the deposits of white phosphate occur mostly in pockets and can not be expected to have any great lateral extent, some of more or less importance have been reported at several widely separated localities in Perry and Decatur Counties.

GEOLOGICAL OCCURRENCE AND ORIGIN.

The white phosphates are all of secondary origin, and belong to a much more recent geologic period than the Silurian and Devonian rocks with which they are associated. Hayes[1] divides them into three classes, namely, the stony, breccia, and lamellar phosphate. The first two classes, though widely disseminated, are in quantities too small and too thoroughly mixed with chert and foreign matter to be profitably mined. Fortunately, the lamellar phosphate is not only the richest, but the most plentiful of the three varieties. It is seldom found as an outcrop, but is encountered as the beds are followed into the hills. According to Hayes, it was deposited from solution in caverns in the upper Silurian limestone, the character of the rock indicating that the deposition frequently took place under hydrostatic pressure. As the limestones above these caverns were gradually dissolved by percolating and running water, the overlying strata settled down on the phosphate beds, causing a breaking up of the phosphate layers and more or less mixing with the chert fragments and residual clays from the overlying formations.

The phosphate is usually overlain by 3 to 8 feet of blue or yellow clay carrying phosphate fragments, which in turn is overlain by several feet of red and yellow clay containing limestone bowlders and fragments of chert.

PHYSICAL PROPERTIES.

Much of the white phosphate of Tennessee resembles the hard-rock phosphate of Florida. The breccia variety consists of chert fragments embedded in a matrix of high-grade phosphate, while the stony phosphate consists of siliceous skeletons formerly filled with carbonate of lime, but now containing phosphate. Both of these grades, unless they are separated from the associated chert, are too low in phosphoric acid to be of much importance.

The lamellar variety is very high grade material. It occurs in plates of various thicknesses, which are frequently cemented together, forming large bowlders weighing many tons. These plates vary from white or cream colored to pink and deep red. Some of the layers are rather porous, but the rock as a whole is close grained, very hard, and frequently coated with a thin, lustrous layer of precipitated phos-

[1] Mineral Resources, Part 4, 623–630, 1894–95; Ann. Report U. S. Geological Survey, 1899–1900, Part III, 484–485. Ann. Report U. S. Geological Survey, 1895–96, Part II, 236–250.

phate. Picked samples of the lamellar phosphate will run as high as 85 to 90 per cent bone phosphate of lime, and there is little difficulty in obtaining rock in carload lots which will grade from 72 to 78 per cent.

A number of different types of white phosphate were collected when the author visited these fields early in 1911, but unfortunately through some mistake the various types were mixed and analyzed as one sample. Some of the samples contained large quantities of chert, so that the analysis of the whole, though given below (No. 82) is of little value. Some other phosphate analyses of the Tennessee white rock from Perry and Decatur Counties are given which show that much of this material is of excellent quality and well suited for the manufacture of superphosphate.

METHODS OF MINING.

The Tennessee white phosphate has been mined by both open cut and by tunneling. The former method has been employed wherever the character and depth of overburden permit, but the overload is frequently so heavy as to render its removal impracticable, and under such circumstances tunneling is resorted to. Owing to the loose character of the overlying clay, extensive timbering is required in the tunnels and much of the white phosphate embedded in the clay above can not be economically recovered.

As the phosphate is extremely hard and often occurs in very large bowlders, it is usually loosened by blasting, broken up with picks, and then loaded into tramcars and sent to the plant to be crushed into pieces of uniform size.

The objectionable features of tunnel mining and hardness of the rock are largely offset by the fact that it is unnecessary either to wash or dry the white phosphate to obtain a product grading from 72 to 75 per cent of bone phosphate of lime. The results of analyses are given in Table XII.

TABLE XII.—*Analyses of samples of Tennessee white-rock phosphate.*

No.	Location.	Description.	Analyst.	Analysis.			
				SiO_2.	Fe_2O_3 Al_2O_3.	P_2O_5.	$Ca_3(PO_4)_2$.
				Per ct.	*Per ct.*	*Per ct.*	*Per ct.*
82	Toms Creek, Perry County.	Phosphate and chert	C. C. Stark			26.77	58.49
85	....do	Phosphate from storage bins.	....do	6.55	2.71	32.76	71.60
86	Beech River Phosphate Co., Decatur County.	High-grade lamellar phosphate.	....do	7.56	3.48	34.49	75.36
87	Bowlder washed out of limestone cavern on Beech River, Decatur County.	Cherty white phosphate.	....do	47.09	3.90	18.61	40.66
	Perry County	Picked sample	L. P. Brown		1.38	37.89	82.74
	....do	Sample of shipment	....do		2.57	35.32	77.14
	Decatur County	Average of three small shipments.	....do		2.90	33.88	73.89

COST OF PRODUCTION.

On account of the uncertain character of these deposits and the varying factors influencing the class of mining employed, it is difficult to estimate the average cost of preparing the white phosphate for market. Moreover, no mining has been done in these fields for several years, during which time both labor conditions and mining methods have changed.

Brown [1] states that the average cost of production should be slightly below that of Florida hard-rock phosphate. Considering the various factors enumerated above, it is probable that the cost of preparing the white rock for the market is somewhat higher than that of the Tennessee blue rock.

WASTE MATERIAL.

The clay associated with and directly overlying the lamellar phosphate frequently contains many small fragments of high-grade rock. In the tunnel method of mining this phosphate is lost. Even when mining with open cut much of this phosphatic material is wasted, since the plants are not equipped for separating the good rock from the clay matrix.

The breccia and stony varieties of white phosphate have not heretofore been considered worth mining. Their low content of phosphoric acid is mainly due to the large quantity of silica or chert with which they are associated.

Hayes [2] suggests that the breccia variety might be utilized by crushing, and subsequently screening out the chert. It is possible that the stony variety could be handled in the same way. Another method of raising the grade of these two classes of white phosphate would be to grind the rock and then put it through a washing process similar to that employed in the brown-rock fields. It is very doubtful, however, if these varieties exist in sufficient quantities at any one place to justify the installation of expensive machinery.

EXTENT OF OPERATIONS.

Mining operations have been carried on in but two localities in the white-rock fields, namely, at the junction of Welsdorf Branch with Toms Creek, Perry County, about 5 miles east of the Tennessee River, and on Beech River, between Parsons and Decaturville, Decatur County, 6 to 8 miles west of the Tennessee River. The plants at these two places have not been operated for several years and will need considerable repairing before work can be renewed.

The total quantity of white phosphate marketed, according to Van Horn,[3] is about 8,600 tons. The annual output from 1905 to 1909 is given in Table IX.

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[1] Engineering Association of the South, Transactions, 15, 123 (1904).

[2] Mineral Resources, 4, Part IV, 625–626 (1894–95).

[3] Production of Phosphate Rock in 1909. Mineral Resources, U. S. Geological Survey.

PRESENT CONDITION OF THE INDUSTRY.

No work has been done in the white-rock fields since 1909. The uncertain character of the deposits, the expense of mining, and the inaccessibility of many of the deposits has discouraged both prospecting and development work. When the author visited these regions early in 1911 plans were under way to renew mining operations. The property of the Perry Phosphate Co. has been taken over by a new concern, a right of way has been secured to the Tennessee River, and several acres along the river front leased with a view to shipping the rock down this stream to Paducah, Ky.

Some New York capitalists are prospecting the property of the Beech River Phosphate Co. in Decatur County, and, if indications are favorable, expect to mine the phosphate on the west side of the Tennessee River.

FUTURE OPERATIONS.

Thorough prospecting is necessary to determine the value and extent of the white-rock phosphate deposits. Although several areas known to contain good rock are practically untouched, a systematic prospect of these will prove quite expensive. It is doubtful if the development of this class of rock will advance very rapidly as long as large, accessible, and more uniform beds of high-grade brown-rock and blue-rock phosphate remain available.

NATURAL PHOSPHATES OF KENTUCKY.

DESCRIPTION OF DEPOSITS.

Within the last few years considerable interest has been manifested in the phosphate deposits of Kentucky, but conflicting rumors concerning the value of these fields have confused the prospective investor and discouraged mining development. Mention was first made of the phosphatic nature of certain strata in Kentucky by Robert Peter[1] in 1877. This author described a thin layer of highly phosphatic limestone occurring in the "Lower Silurian" (Ordovician) near Lexington. These layers were regarded as of too irregular distribution among the poorer limestones to be of any great commercial value.

LOCATION OF DEPOSITS.

No importance was attached to these fields until the summer of 1905, when a negro formerly employed in the phosphate mines of Mount Pleasant, Tenn., discovered a deposit of similar nature while digging post holes on the farm of H. L. Martin, near Midway, Ky. He showed the material to Mr. Martin and Mr. A. W. Davis, both of whom were familiar with the Tennessee phosphate, and who recognized the value of the discovery. Since that time prospecting has

[1] Kentucky Geological Survey; chemical analysis A, 1877.

been carried on intermittently at various points in Fayette, Woodford, Scott, and Jessamine counties, but no satisfactory and unbiased report on these deposits has as yet been published.

Unfortunately, many of the prospect pits have been filled in and the natural exposures are few, although plans are under way for starting development work.

The phosphate area so far examined lies in Woodford, Fayette, Scott, and Jessamine counties, but the most thoroughly prospected properties lie in Woodford County, in the vicinity of the little town of Midway. Here a number of pits and prospect holes have been dug and deposits of considerable value discovered. The phosphate area is certainly of wider extent than is generally believed (fig. 2), and though the material obtained from some localities does not appear to be of much economic importance, more thorough examination will no doubt lead to the discovery of other valuable deposits.

In Table XIII are given the analyses of samples of Kentucky phosphate from various localities. It must be understood that these samples are selected and do not in any case represent the average of that locality.

Table XIII.—*Samples of high-grade Kentucky phosphate from various localities.*

No.	Location.	Description.	Analysis.	
			P_2O_5.	$Ca_3(PO_4)_2$.
			Per cent.	*Per cent.*
110	Farm of M. D. Steel, 2½ miles south of Midway, Ky.	Hard, brown plates	34.02	74.35
112	Cogar farm, ½ mile south of Midway, Ky.	Thin, soft plates	33.75	73.74
115	Slack's farm, 3 miles northwest of Midway, Ky.	Hard, brown, heavy plates	37.10	81.08
118	Outside State University grounds, Lexington, Ky.	Thin, brown, brittle plates	26.13	57.10
125	Smith's farm, 2½ miles east of Georgetown, Ky.	Brown, medium hardness	27.14	59.43
128	Cut 6 miles south of Lexington, Jessamine County, Ky.	Thin, brown plates	34.10	74.52

GEOLOGICAL OCCURRENCE.

The Kentucky phosphate region forms part of the great Cincinnati anticline extending from Nashville, Tenn., in a northeasterly direction through Lexington, Ky., almost to Cincinnati. South of this city it divides into two broad domes, one culminating near Nashville and the other in Jessamine County, Ky. This latter is known as the Jessamine Dome.

Erosion has destroyed much of the domelike structure of this last section, and in cutting through the younger formations has caused numerous exposures of the underlying strata.

All the exposed rocks of these regions are of sedimentary origin. The arching of the strata probably took place very gradually and

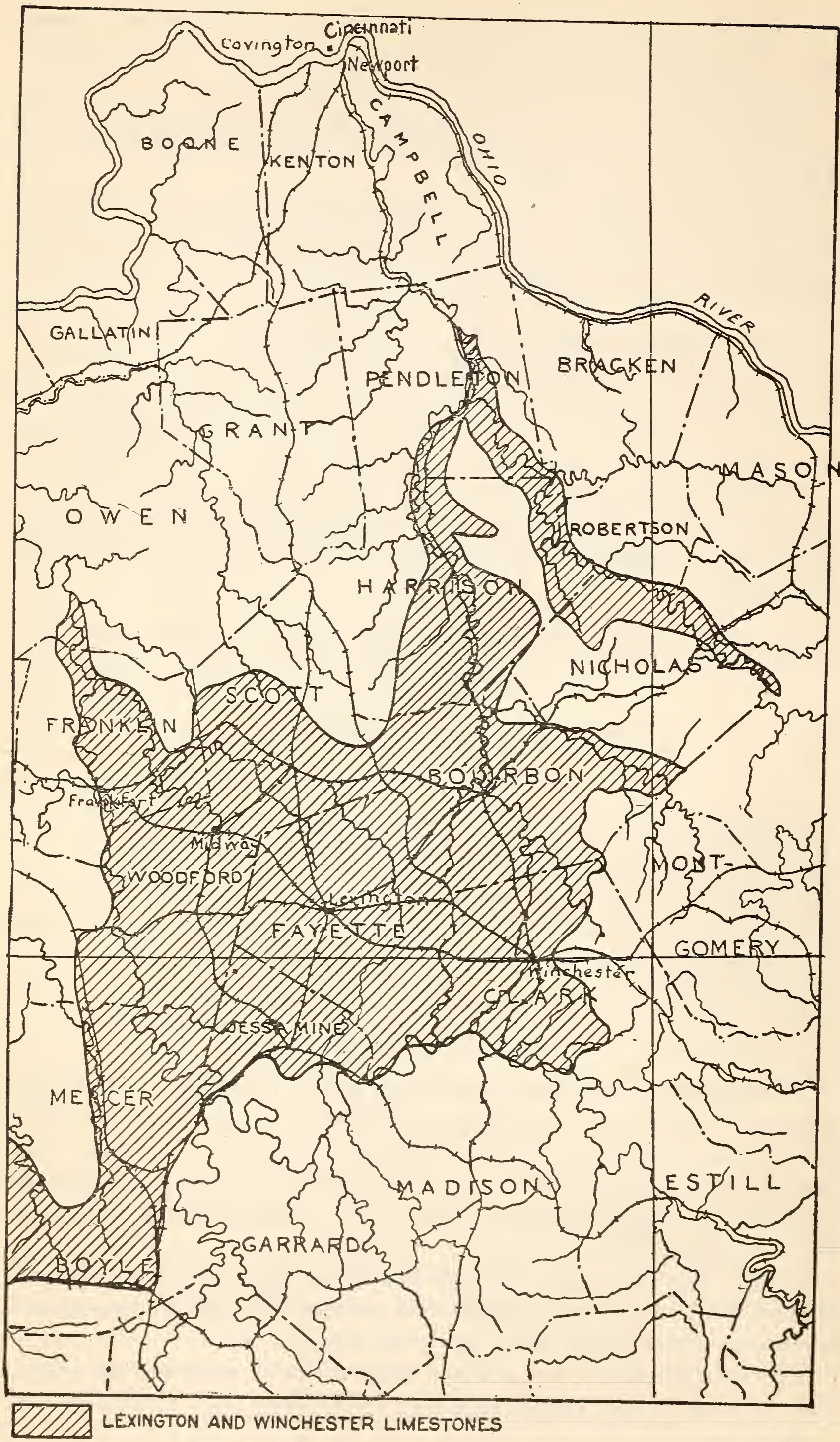

FIG. 2.—Map of the bluegrass region of Kentucky, showing distribution of the Lexington and Winchester limestones, between which phosphate occurs.

has altered the horizontal position of the rocks but little. The beds rarely dip more than a few feet to the mile.

The phosphate occurs in the Ordovician ("Lower Silurian") system, at the top of the geologic formation known as the Lexington limestone.

Table XIV, taken from the report of Matson[1] on the "Water Resources of the Bluegrass Region, Kentucky," shows the overlying and underlying formations which are more or less related to the phosphate beds.

TABLE XIV.—*Section showing phosphatic and related formations.*

System.	Formation.	Description.	Thickness.
			Feet.
Silurian and lower part of Devonian.	Panola	Blue shales and yellow limestone	60
Ordovician	Richmond	Heavy bedded, arenaceous limestone	60
		Blue limestone and shales	125
		Interbedded blue limestone and shales	80
	Maysville	Interbedded blue limestone and shales, thin and nodular; shales predominate.	230
	Eden shale	Shaly sandstones in southern part of region; blue shales in northern part.	200+
	Winchester limestone	Blue and gray limestone, with some blue shales	60
	Lexington limestone	Gray crystalline limestone, cherty (Flanagan chert member).	75
		[Phosphate Horizon.]	
		Argillaceous limestone and shale and bedded blue limestone.	194
		Heavy, bedded, coarse-grained crystalline, cherty limestone, usually gray.	30
	Highbridge limestone	Dense fine-grained gray limestone	90
		Dense fine-grained dove-colored or gray limestone.	20-60
		Dense, fine-grained, dark, heavy bedded limestone.	285
		Limestone known only from well records	100+
	St. Peters sandstone	Siliceous limestone	

The phosphate rock occurs in thin plates embedded in a matrix of clay, siliceous material, and disintegrated phosphate, the whole having a thickness varying from a few inches to 10 or 12 feet. In some of the deposits considerable chert occurs, which may render the mining and grading of the phosphate somewhat difficult.

PHYSICAL PROPERTIES.

The phosphate rock itself varies somewhat in its physical properties. In color it ranges from a light gray to a rich chocolate brown and in texture from a compact, close-grained plate rock to porous cellular fragments and disintegrated phosphate.

Most of the rock is in thin, close-grained plates, brownish gray in color and fairly hard. The average apparent specific gravity is about 3.

Samples of the various types were analyzed, and the results of these analyses are given in Table XV, where the composition is compared with the predominant physical properties.

[1] Water Supply Paper, No. 233, United States Geological Survey. 1909.

TABLE XV.—*Composition of the different varieties of Kentucky phosphate.*

No.	Location.	Description.	SiO_2	$Fe_2O_3Al_2O_3$	P_2O_5	$Ca_3(PO_4)_2$
			Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
200 K	Near Midway, Ky.	Light yellow, brown, soft....	24.29	17.18	21.34	46.71
201 K	.....do.............	Brown, chocolate, close grained, thin bedded.	2.63	2.75	35.71	78.17
202 K	.....do.............	Brown, chocolate, porous, hard.	4.88	3.67	34.00	74.43

METHODS OF MINING.

Owing to the presence of so much finely divided foreign material in the phosphate deposits, it will be necessary to wash the phosphate rock before it can be used for the manufacture of acid phosphate. Plants for washing out the foreign material and at the same time saving the finely divided phosphate rock have proved very successful in the Tennessee phosphate fields. The method of separation is based on the difference between the specific gravities of the phosphate and the siliceous and clay matrix.

Where water is available both the overburden and phosphate might be successfully handled by the hydraulic method of mining. Since the deposits occur on the hills, the waste material could be disposed of by gravity. These methods entail considerable initial outlay, a fact that will probably militate against the small operator, as from an economic standpoint it is advisable that plants should be erected that will reduce the element of waste to a minimum.

In Table XVI the phosphate content of samples of the Kentucky phosphate before and after washing are given. The washing process, however, was not very thorough, as will be seen from the analysis.

TABLE XVI.—*Analysis of samples of Kentucky phosphate before and after washing.*

Sample number.	Location.	Depth.	Amount recovered after washing.	Analyses.					
				Before washing.			After washing.		
				SiO_2	Al_2O_3 Fe_2O_3	P_2O_5	SiO_2	Al_2O_3 Fe_2O_3	P_2O_5
		Ft. in.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
99–109	Shallow pit, filled, farm of M. D. Steel, 2½ miles from Midway, Ky...........	2	80.00	....	....	31.74	....	....	33.57
100–101	.....do...............	2 4	69.60	....	....	23.90	9.48	5.46	31.05
108–107	Deep pit on farm of M. D. Steel.........	3½	77.80	....	....	25.45	11.27	6.28	29.42
106–105	.....do...............	3 6	73.80	....	....	22.82	17.05	7.89	26.89
104–103–102	.....do...............	6 10½	76.00	....	....	22.85	11.96	7.55	29.23
[1] 113–114	Farm of J. Slack, 2 miles northwest of Midway, Ky.......	....	66.70	....	....	19.83	....	....	26.16
126–127	From cut 6 miles south of Lexington, in Jessamine County, Ky........	8 3	36.36	....	....	23.70	16.01	12.34	29.29

[1] Contained considerable chert.

MARKETING.

As a distributing point for the Middle West, Kentucky is much better situated than Tennessee. During the year 1910 the sales of ground rock phosphate in those regions greatly increased, and though the average mine run of the Kentucky phosphate is probably not as high as that from the Tennessee brown-rock area, the difference in freight rates will compensate in many instances for the difference in the grade of the product.

Table XVII gives the freight rates from Midway, Ky., to towns in the middle West as compared with those from the phosphate regions of Tennessee.

TABLE XVII.—*Freight rates from mines in Kentucky and Tennessee to important near-by markets.*

Destination.	Location of mines.	Freight rates.
Cincinnati, Ohio	Midway, Ky	$1.57
	Mount Pleasant, Tenn Wales Station, Tenn Nashville, Tenn	2.50
Louisville, Ky	Midway, Ky	1.57
	Mount Pleasant, Tenn Wales Station, Tenn Nashville, Tenn	2.00
Cleveland, Ohio	Midway, Ky	3.72
	Mount Pleasant, Tenn Wales Station, Tenn Nashville, Tenn	3.80

PRESENT CONDITION OF THE INDUSTRY.

Up to the spring of 1911 work on the Kentucky phosphate area had been confined to prospecting. A small plant is now in course of construction which will start operations this year, and will probably accelerate greatly the development of the area.

The owners of phosphate lands are holding their property at high figures. This is partly due to the fact that shortly after the rock was discovered large sums were paid for options on several farms in the vicinity of Midway. These options were renewed upon payment of other large sums, but were finally allowed to lapse, owing to lack of capital to develop the properties. The farmers therefore have a somewhat exaggerated idea of the value of their farms.

Recently there were 2,400 acres under option or leased by companies and individuals interested in the phosphate industry. The land under lease is to be mined on the royalty basis, 25 cents to 50 cents being paid on every ton of rock produced, with a guaranty of a certain tonnage each year.

OUTLOOK.

It is only a question of time before the Kentucky phosphate fields will be developed. The value of the deposits has not as yet been sufficiently well established to encourage the outlay of much capital, but the erection of the plant cited above will draw attention to this area, and it seems probable that its favorable location and the character of the output will put mining operations in the area on a sound footing.

NATURAL PHOSPHATES OF ARKANSAS.

GENERAL DESCRIPTION OF DEPOSITS.

The phosphate deposits of Arkansas are not generally regarded as of great economic importance. Compared with the product of the Tennessee and Florida fields the rock is rather low grade. The deposits are well situated to supply the growing demand for fertilizers west of the Mississippi River, and, though much of the material is too low in phosphoric acid and too high in iron to make it desirable for the manufacture of superphosphate, the increasing consumption of ground rock phosphate for agricultural purposes will no doubt hasten further development in these fields.

The phosphate rock was not recognized as such until 1895, and it was not until 1896 that Branner [1] published a report on these deposits. In 1902 Branner and Newson [2] made a fuller geological report on these fields, embodying a large amount of analytical data and including a discussion of the transportation facilities and market for the product.

Purdue[3] published a short paper on the Arkansas phosphates in 1902, shortly after the plant of the Arkansas Fertilizer Co. was burned, but since that time, so far as can be learned, no publication of any note has been issued.

LOCATION OF DEPOSITS.

The portion of the phosphate fields now being worked lies in the northwestern part of Independence County, along Lafferty Creek, north and east of the White River. The deposits, however, extend over a considerable area in north-central Arkansas (fig. 3), and the phosphate horizon has been recognized in Stone, Izard, Searcy, Marion, Baxter, and Newton Counties.

Mention has also been made of the occurrence of phosphate nodules in Clark County at a different geological horizon, but the pebbles have never been found in sufficient quantities to prove of economic interest.

Some of the samples from other sources have analyzed very much higher than those from the deposits along Lafferty Creek, but transportation facilities are poor or, upon further investigation, the material has been found to be limited in quantity. This is the objection to the deposits found in Hickory Valley, where samples have been collected which ran over 73 per cent of $Ca_3(PO_4)_2$.

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[1] Amer. Inst. Min. Eng., 26, 1896.

[2] Bul. No. 74, Ark. Agr. Expt. Sta., 1902.

[3] Bul. 315, U. S. Geological Survey, 463–473 (1907).

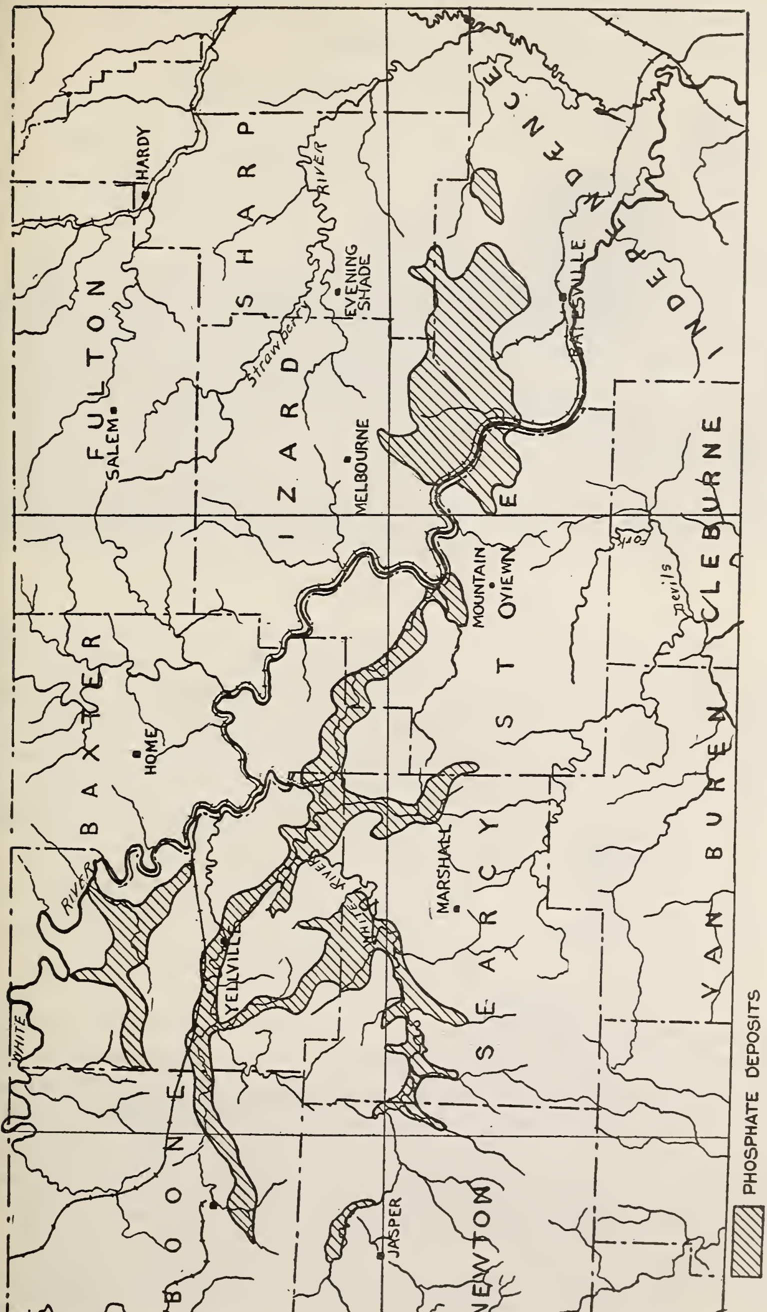

FIG. 3.—Map of northern Arkansas, showing location of reported phosphate deposits.

The analyses given in Table XVIII, taken from the report of Branner and Newson,[1] give some idea of the character and richness of the phosphate rock from other localities.

TABLE XVIII.—*Analyses of Arkansas phosphates.*

Location.	Thickness and character of beds.	Analysis.	
		$Ca_3(PO_4)_2$.	$Fe_2O_3Al_2O_3$.
		Per cent.	*Per cent.*
Milligan place, 12 miles northeast of Batesville (T. 14 N., R. 5 W., sec. 6).	5 feet	47.19	
Do	Washed pebbles	73.76	3.82
Do	Not determined	57.03	5.89
Do	do	64.17	3.08
Do	Bowlders	67.79	8.01
Do	Fragments	73.20	5.19
Do	Not determined	62.03	2.97
Meeker place, ½ mile west of Cushman (T. 14 N., R. 7 W., sec. 8).	2 feet 6 inches	49.38	8.82
Meeker place, ½ mile west of Cushman (T. 14 N., R. 8 W., sec. 12).	2 feet	58.31	5.85
Meeker place, ½ mile west of Cushman (T. 14 N., R. 8 W., sec. 14).	1 foot 6 inches	68.72	8.31
Tate's field (T. 14 N., R. 8 W., sec. 4)	1 foot	66.39	4.13
Keeling's place (T. 16 N., R. 16 W., sec. 18)	4 feet (reported)	76.62	7.21
Monkey Run, near St. Joe, Searcy County	Nodules (black)	69.31	8.10
Do	Nodules (brown)	56.58	9.01

GEOLOGICAL OCCURRENCE.

The exposed rocks in Northern Arkansas are all of sedimentary origin, the strata lying almost horizontally. The commercially important deposits of phosphate were formerly considered of Devonian age,[2] but more recent investigations have shown that they are older, but that they are not younger than the Silurian period.[3] The Cason shale, in which they occur, is of Ordovician age. The following summary, taken from the report of Purdue, shows a general section, with the formations more or less related to the phosphate beds:

Carboniferous	Boone chert, including St. Joe marble.
Devonian	Chattanooga shale and Sylamore sandstone.
Silurian	St. Clair limestone.
Ordovician	Cason shale (phosphate horizon). Polk Bayou limestone. Izard limestone.

As will be seen from inspection of the above table, the phosphate occurs between two limestone formations, both of which are characteristic and hence form excellent guides to the phosphate horizon. The overlying or St. Clair limestone in the vicinity of the developed phosphate deposits varies from 6 to 10 feet in thickness. It is a medium-grained, crystalline limestone, pinkish white in color, containing characteristic fossils, which stand out prominently on weathered surfaces.

The Polk Bayou limestone, the underlying formation, varies considerably in thickness, ranging from 75 to 130 feet. It occurs in

[1] Bul. No. 74, Ark. Agr. Expt. Sta., 1902.

[2] Branner, Amer. Inst. of Min. Eng., 26, 1896; Branner and Newson, Bul. 74, Ark. Agr. Expt. Sta., 1903,

[3] Purdue, Bul. 315, U. S. Geological Survey, 463–473 (1907).

FIG. 1.—BROWN-ROCK PHOSPHATE PLANT, SHOWING WASTE POND IN FOREGROUND.

FIG. 2.—BROWN-ROCK PHOSPHATE PLANT, SHOWING HOOD OVER STACK AND SETTLING TANKS FOR FINELY DIVIDED PHOSPHATE.

BLUE ROCK MINE, TWO AND ONE-HALF MILES SOUTHEAST OF CENTERVILLE, HICKMAN COUNTY, TENN.

massive beds and varies in color from light gray to chocolate brown. Its texture is very coarse, the rock being made up of fossil fragments cemented together with crystals of calcite. This limestone rests directly upon the Izard limestone, which consists of a very close-grained limestone, almost fine enough to be used as lithographing stones. In some localities the Izard attains a considerable thickness.

The rocks of the phosphate horizon vary considerably in character, but there are always bands of shale occurring among the phosphate strata. Manganese ore is also closely associated with the phosphate in many places, much of the rock being stained by this substance. The finding of manganese ore has often led to the location of the phosphate.

Branner [1] states that the Arkansas phosphate is derived from the droppings and remains of fish and other marine agencies laid down gradually in deep water. Clark [2] is of the opinion that these deposits were formed in a similar manner to those of Tennessee, i. e., laid down in a shallow sea as phosphatic limestones and subsequently enriched by mechanical and chemical processes. Purdue [3] concludes, from the conglomerate character of the rock, that the deposition of the phosphate beds took place in shallow water, having closely followed the shore line as it advanced inland. The presence of large quantities of organic fragments indicate, in the opinion of this authority, that the deposits are the result of wave action.

Taking into consideration the close-grained character of the phosphate rock, it is unlikely that there has been any enrichment brought about by the leaching out of carbonate of lime subsequent to the final deposition of the phosphate strata.

The following sections (Table XIX), sampled at two different localities, show the nature and phosphoric-acid content of the various phosphate strata:

Table XIX.—*Analysis and description of phosphate strata from different localities.*

Sample No.	Location.	Thickness of strata.	Description.	Analyses.	
				P_2O_5.	$Ca_3(PO_4)_2$.
		Feet.		*Per cent.*	*Per cent.*
	"Phosphate," 12 miles northwest of Batesville.	2.5	Ferruginous limestone (roof)	Trace.	Trace.
93	.....do	.5	Green shale (weathered powder)	5.82	12.72
89	.....do	4.0	Hard, gray, nodular	28.85	63.05
91	.....do	2.0	Hard, gray, less nodular	14.16	30.94
97	1¾ miles north of Phosphate.	1.5	Ferruginous phosphate	19.60	42.94
	.....do	.5	Thin-bedded shale (not sampled)	....	....
96	.....do	3.0	Hard, gray oolitic phosphate	22 96	50.18
95	.....do	1.0	Hard, gray oolitic phosphate, low grade.	10.01	21.87
98		Undetermined	Ferruginous shale	7.53	16.45

[1] Amer. Inst. Min. Eng., 26, 1896.

[2] Data of Geochemistry.

[3] Bul. 310, U. S. Geological Survey, 471-472 (1907).

PHYSICAL PROPERTIES.

The phosphate in the developed area occurs in two strata, one directly overlying the other. The first or upper layer is from 3½ to 6 feet in thickness and consists of a hard, massive rock made up of rounded fragments of organic débris closely cemented together. Its specific gravity is about 3. It varies in color from light gray to brownish-black, the color depending largely on the content of iron and manganese. This is the bed considered worth mining.

Directly under this bed lies another stratum of phosphate rock from 2 to 4 feet in thickness and closely resembling that just described. It is, however, less oolitic and contains appreciably less phosphoric acid. This stratum is discarded in mining.

Table XX gives the analyses of typical samples of Arkansas phosphate, together with the more prominent physical characteristics of the rock.

TABLE XX.—*Analysis of typical samples of Arkansas phosphate.*

No.	Location.	Thickness.	Description.	Analyses.		
				SiO_2.	Fe_2O_3-Al_2O_5	P_2O_5.
		Feet.		*Per cent.*	*Per cent.*	*Per cent.*
96	1½ miles north of Phosphate..	3	Hard, gray oolitic...........	39.94	7.00	22.96
95	.....do......................	1	Hard, brownish black, low grade.	58.25	2.43	10.01
92	"Phosphate." Arkansas Fertilizer Co., east side of creek.	6	Hard, grayish brown, oolitic high grade.	24.31	9.33	24.80
91	"Phosphate." West side of creek, Arkansas Fertilizer Co.	2	Hard, gray, low grade.......	24.94	7.43	14.16

METHODS OF MINING.

The Arkansas phosphate is mined in the same way as the blue-rock phosphate of Tennessee, by first stripping around the face of the hill till the overburden becomes too heavy to be profitably removed. Drifts are then run into the hillside and the rock blasted out. From the tunnel mouth it is loaded for shipment or piled upon ricks of wood and burned, the latter process being favored at the mines, as fuel is abundant and burning reduces freight charges by expelling most of the moisture from the rock.

It is claimed by the fertilizer manufacturer that burning the rock also facilitates crushing, since the ovules, which are usually the richest part of the phosphate rock, are rendered brittle and can be more finely ground for the subsequent acid treatment.

COST OF MINING.

The actual cost of mining varies considerably, depending on the accessibility and character of the deposit which is being worked. On the property of the Arkansas Fertilizer Co. most of the phosphate occurs some distance above the level of Lafferty Creek, but dips below this stream as one follows the stratum south. The extraction of material in the latter case will no doubt prove quite expensive.

Owing to the resistance of phosphate to weathering influences, the rock frequently forms a kind of bench around the hills, the overburden being largely removed by erosion for some distance back from the phosphate outcrop. Mining under these conditions can be carried on for some time by simply scraping off the light overburden or detritus and blasting or cutting out the rock thus exposed. This class of mining should be carried on at a cost not exceeding 75 cents per ton.

As the overburden gets heavier it becomes necessary to run drifts into the hillside and mine the material very much like a seam of coal. This latter method is more expensive than the open-cut systems, since much waste material has to be hauled out of the tunnels and considerable timber used in supporting the roof. As the tunneling proceeds farther into the hills less timbering is usually required, as the St. Clair limestone and unweathered slate overlying the phosphate form a fairly substantial roof. The average cost per ton is rather hard to strike, but, all things considered, it is probably less than $2.25.

MARKETING.

All the material mined on Lafferty Creek is at present shipped to Little Rock, Ark., and either made into acid phosphate or sold directly to farmers as ground rock phosphate. The acid phosphate contains about 14 per cent of phosphoric acid.

The freight rate on phosphate rock from Batesville to Little Rock, Ark., is $1 per ton.

OPERATING CONDITIONS.

The phosphate stratum directly underlying the main bed is either left untouched or taken out and discarded in mining operations. It varies from 1 to 4 feet in thickness and contains an average of 30 to 40 per cent of tricalcium phosphate, $Ca_3(PO_4)_2$. At present it would not be practicable to ship this material, since the freight rate is too high and the material of too low grade for the direct manufacture of acid phosphate.

Ground rock phosphate has not been used to any extent west of the Mississippi River, the present demand being for 62 per cent rock. This lower-grade phosphate would prove of value when ground, but the application would have to be heavy, and unless the market was within easy reach of the mines it would not be possible to dispose of the material at a profit. If the present tunnels are not allowed to collapse it will be possible to return and mine the low-grade rock when the market and improved methods of handling it shall make it profitable.

Only one company has mined Arkansas phosphate to any extent. In sec. 14, T. 14, R. 8 W, 12 miles northwest of Batesville, near the junction of East and West Lafferty Creeks, the phosphate has been opened up by 9 tunnels run into the hill on the west side of the creek. Numerous rooms branch out from these main tunnels, and fully 50,000 tons of rock have been taken out. The stratum of high-grade phosphate here has an average thickness of 3½ to 4 feet.

As the phosphate is traced southward on the west side of the creek the beds dip rather sharply, and when the mines were visited in May, 1911, a shaft was being sunk below the level of the creek in order to locate the deposit.

On the east side of the creek the beds are nearly horizontal and considerably thicker, a 6-foot stratum being in evidence for one-half mile along the hillside. An analysis of an average sample of this stratum is given in Table XX.

OUTLOOK.

There is every probability that the mining operations in the Arkansas phosphate fields will be extended. A fertilizer company of Little Rock, Ark., is preparing to enlarge an already extensive plant and is contemplating the erection of a sulphuric-acid factory. A number of other companies and individuals have large interests in these fields, and although some of them were bought primarily to develop the manganese deposits, they will no doubt handle the phosphate rock as the demand for this material increases. The fact that manganese and phosphate are so closely associated in these regions is sufficient guaranty that the deposits will be extensively worked at some future date.

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