

STATE OF ARKANSAS

Arkansas Resources And Development Commission

Wayne C. Fletcher, Executive Director

DIVISION OF GEOLOGY

Harold B. Foxhall, Director

BULLETIN 15

HICKORY VALLEY PHOSPHATE DEPOSIT
IN INDEPENDENCE COUNTY, ARKANSAS

with

Especial Reference to
Economic Possibilities of
North Arkansas Phosphate Region

By

Clayton J. Wells

including
Preliminary Geologic Map of Central Part of
Batesville Manganese District, Arkansas
prepared by the United States Geological Survey, 1949

Little Rock, Arkansas

1949

STATE OF ARKANSAS

Sid McMath, Governor

Arkansas Resources And Development Commission

Wayne C. Fletcher, Executive Director

COMMISSIONERS

Marion L. Crist, Chairman	Little Rock
L. R. Branting	Bauxite
Frank Dyke	Fort Smith
W. S. Fox	Pine Bluff
Clarence F. Byrns	Fort Smith
A. Carlson	Truman
W. T. Murphy, Jr.	Texarkana
Peter F. Watzek	Crossett
R. C. Bryan	Osceola
George Peck	Hope
Robert L. Burton, Sr.	Benton
LeRoy Carter	Leachville
Dr. T. W. Hardison	Morrilton
K. A. Engel	Little Rock
Henry Koen	Harrison

DIVISION OF GEOLOGY

Harold B. Foxhall, Director

HICKORY VALLEY PHOSPHATE DEPOSIT IN INDEPENDENCE COUNTY, ARKANSAS

Clayton J. Wells

ABSTRACT

The occurrence of phosphate rock in Independence, Stone, Izard and Searcy Counties in north-central Arkansas has been known since 1895, but there has been no commercial production of phosphate since 1912. The beds of phosphate rock vary considerably in thickness and extent and lie entirely within the relatively flat-lying Cason shale formation of Ordovician age. There are several localities known in Independence County where these phosphate beds aggregate more than 3 feet in thickness and have an average grade of 40 percent B. P. L. (bone phosphate of lime) or greater. In 1947 one of these occurrences near Hickory Valley, Independence County, Arkansas, was explored by test pitting and churn drilling. A small deposit containing an estimated 160,000 long tons of phosphate rock with an average B. P. L. content of 40.97 percent was outlined. The average thickness of the phosphate rock in the deposit was 16 feet with an overburden of residual clay and chert averaging 12 feet in thickness. The phosphate rock in the deposit is a soft, earthy, light brown rock consisting mainly of collophanite and quartz with small amounts of carbonate and clay minerals and limonite. Beneficiation tests were made on a bulk sample from the deposit by metallurgists of the Tennessee Valley Authority. These tests indicated that moderate improvement in the grade of the rock can be effected by washing, and that by a combination of washing, grinding and flotation, approximately 70 percent of the phosphate in the rock can be recovered in a concentrate containing 69.9 percent B. P. L. The phosphate rock from this deposit is not high-grade enough to meet present specifications (68-76% B.P.L.) for rock used in the manufacture of superphosphate. However, it may have economic possibilities as finely-ground natural rock phosphate fertilizer in certain long range soil improvement programs. With the availability of cheap electric power from the several proposed White River hydro-electric development projects, a plant for the processing of this phosphate rock into elemental phosphorus will undoubtedly receive serious consideration.

INTRODUCTION

Purpose and Scope of the Project

The Clark and Cowden Drilling Company of Dallas, Texas, through their geologist, Mr. Paul Teas of Dallas, and Mr. E. J. Risley, Trust Officer of the Commercial National Bank, Little Rock, became interested in the north Arkansas phosphate deposits in the summer of 1947. The Hickory Valley deposit was selected for exploration and drilling during the fall of 1947 in hopes of developing sufficient high-grade phosphate tonnage for a commercial operation. The State Division of Geology took advantage of this drilling project and made a detailed geological study of this particular deposit in order to evaluate to some extent the possibilities of the north Arkansas phosphate district as a whole.

Realizing that the Arkansas phosphate rock was lower in average grade than the present commercial rock, (68-76% B.P.L.), the Division submitted a bulk sample of rock from the Hickory Valley deposit to the laboratories of the Tennessee Valley Authority where extensive beneficiation tests were made on the rock.

Location, Extent and Accessibility of the Area

Phosphate-bearing rocks are known to occur in Independence, Stone, Izard, and Searcy Counties in north central Arkansas.

The Hickory Valley phosphate deposit is located in the N $\frac{1}{2}$ of the NW $\frac{1}{4}$ of sec. 6, T. 14N, R. 5W, approximately twelve miles northeast of Batesville in the extreme northern part of Independence County. The paved state highway No. 11, which runs north and south, intersects the gravel Cushman road at Hickory Valley, a distance of one-half mile from the deposit. From Hickory Valley Highway No. 11 leads south six miles into Pfeiffer, and the Cushman road leads west 12.3 miles into Cushman. Both Pfeiffer and

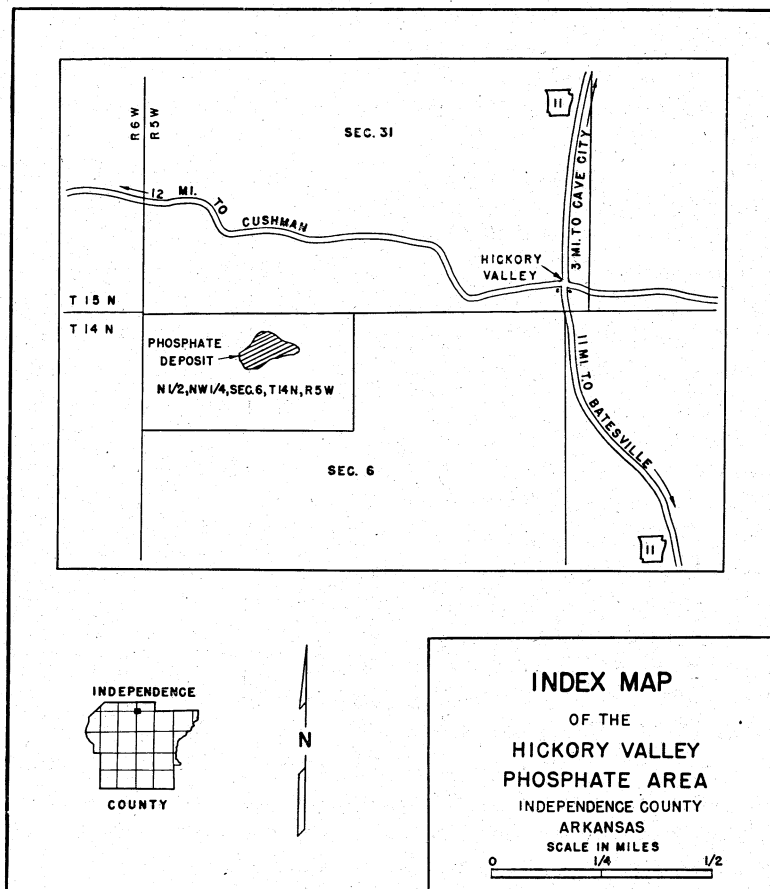


Fig. 1

Cushman are stations on branch lines of the Missouri Pacific railroad.

History and Previous Investigations

The identification of the phosphate rock in the Cason shale formation was made in 1895 by Dr. John C. Branner, former State Geologist of Arkansas. Shortly thereafter, Dr. Branner began a study of the entire north-central Arkansas phosphate region and published a joint report¹ with Dr. J. F. Newsom in 1902 in which he described the character and

¹ Branner, J. C. and Newsom, J. F., The phosphate rocks of Arkansas: Ark. Agric. Exp. Sta., Bull. No. 74, 1902.

distribution of the phosphate rock in the district. Many phosphate localities were described in detail, including geologic sections and chemical analyses of samples. The Hickory Valley deposit was described in the Branner-Newson report as the Milligan tract. In 1902 the Arkansas Phosphate Company began the mining of phosphate rock from deposits situated on Lafferty Creek near the junction of East and West Lafferty Creek four miles southwest of Cushman in Independence County. Superphosphate fertilizer was manufactured by this company in a small plant on Lafferty Creek until the plant burned in 1904 and mining operations were suspended. A new fertilizer plant was then built in North Little Rock in 1906 and the company name was changed to the Arkansas Fertilizer Company. Phosphate mining was resumed in the Lafferty Creek area in 1906 and the rock was shipped to the North Little Rock plant until 1912 when mining was finally abandoned because of the availability of the higher grade Tennessee rock. The total production of phosphate rock from north Arkansas, all of which was mined in the Lafferty Creek area, is estimated at 31,742 tons. In 1906, A. H. Purdue² described the geology of these developed phosphate deposits on Lafferty Creek. Hugh D. Miser³ made a survey of the manganese deposits in the Batesville district in 1918, and although the report emphasizes manganese, it also describes the stratigraphy and structure of the district and contains a good geologic map of the area.

Methods of Investigation

A base map of the Hickory Valley phosphate area was prepared by enlarging a section of the U. S. Geological Survey Cave City topographic quadrangle map to a scale of 1 inch=100 feet. Drill holes and other features were mapped with Brunton compass and tape. (See Plate I) The drill holes were spaced from 100 to 300 feet apart and locations of the holes were based on the accessibility and the topo-

² Purdue, A. H., Developed phosphate deposits of northern Arkansas: U. S. Geol. Surv. Bull. 315, pp. 463-473, 1907.

³ Miser, H. D., Deposits of manganese ore in the Batesville District, Arkansas: U. S. Geol. Surv. Bull. 734, 1922.

graphy of the area, and the few exposures of the phosphate rock.

A truck-mounted Star churn drill with a four-inch bit was used to explore the deposit. A total of 17 holes were drilled varying in depth from 18 to 70 feet. All holes that encountered phosphate rock were drilled through the phosphate into the underlying Fernvale limestone. Some of the drill holes that did not disclose phosphate rock were drilled into the Fernvale limestone formation, thereby establishing the absence of the phosphate horizon at those locations. The barren drill holes south of the deposit, however, were abandoned in the excessive overburden of the Boone chert formation and its debris, leaving the underlying phosphate horizon untested. Casing was set into the top of the phosphate bed only in drill holes 15 to 17 inclusive. It is quite likely, therefore, that there was some contamination of the samples from the chert in the overburden in drill holes 1 through 14, even though these samples were washed free of clay before being analyzed. The full depth of all drill holes was logged and samples were collected at two-foot intervals in the phosphate rock beds. The washed samples were analyzed in the Division of Geology laboratory by Troy W. Carney, Chief Chemist.

After the drilling was completed, a test pit was sunk to a depth of 27 feet at the site of drill hole 11. A bulk sample of the phosphate rock from this pit was later sent to the Chemical Engineering Division of the Tennessee Valley Authority at Wilson Dam, Alabama, for beneficiation tests.

REGIONAL GEOLOGY

General Geology

All of the rocks of the Batesville region are sedimentary in origin. They consist of sandstones, shales, limestones, and chert beds ranging from Ordovician to Mississippian in age. The formations outcropping at the Hickory Valley deposit include the Plattin limestone, the Kimmswick limestone, the Fernvale limestone and the Cason shale, all of Ordovician age. The Boone chert (Mississippian) caps most of the hills in the region. A recent preliminary geologic map of the central part of the Batesville manganese

district, Arkansas, published by the U. S. Geological Survey, 1949, has been included in this report to show the distribution of these formations in the region. (See envelope in back).

The region is rough but the relief is not great. Many narrow valleys trench all parts of the surface, so that the interstream areas are mainly hills and ridges. The few level tracts and more gentle slopes are mantled with residual soil or with wash from higher ground. Rock outcrops are abundant in the more rugged areas of the district but are rather scattered in the gentle slopes of the Hickory Valley area.

Structure

The structure of the area has been excellently summarized by Mr. Hugh D. Miser in U. S. Geological Survey Bulletin 921-A, "Manganese Carbonate in the Batesville District, Arkansas." The paragraph below is from page 12 of this publication.

The rocks of the Batesville district have undergone little deformation. They have been warped slightly by minor folds and have been broken by a few normal faults. Thus they lie in a horizontal or nearly horizontal position. The folds consists of small irregular domes or anticlines and irregular basins or synclines. The folding and faulting in this district affected all the beds, including those of Mississippian age, and therefore took place either late in the Mississippian epoch or at a later time. Not only was the faulting probably contemporaneous with the folding but both were probably contemporaneous with like movements that took place near the end of the Carboniferous period in other parts of the Ozark region. There is, however, some evidence of slight folding at different times, the earliest being at the end of the Ordovician period.

Stratigraphy

The **Plattin** limestone (Ordovician) is the surface rock over a large part of the Batesville district and is exposed in the relatively flat areas west and north of the Hickory Valley deposit. The formation is composed of an even-bedded, grayish-blue compact limestone which breaks with a conchoidal fracture. In some places it contains abundant

calcite veinlets but fossils are uncommon. Many areas where the Plattin limestone is exposed have an exceedingly rugged surface due to the abundance of ledges and loose boulders of this rock. The formation is overlain in most of the phosphate area by the Kimmswick limestone.

The **Kimmswick** limestone (Ordovician) is exposed in very narrow belts on the hill slopes in much of the Batesville area. Outcrops of the Kimmswick limestone formation are common on the north slope of the hill below the Hickory Valley phosphate deposit. The formation is mainly an even-bedded, massive, light gray, medium to coarse-grained limestone with a characteristic surgary texture. The exposed surfaces of the Kimmswick limestone are usually rough and knobby and in many places are covered with moss growth and lichen. The formation is overlain by the Fernvale limestone.

The **Fernvale** limestone (Ordovician) is the surface rock on the hill slopes in much of the Batesville area. At Hickory Valley the Fernvale limestone is largely concealed by its own residual clays, and clays and chert fragments derived from younger rocks. The limestone served as a guide in the drilling, however, since it immediately underlies the Cason shale formation which is the phosphate horizon. The formation is composed principally of coarsely crystalline, massive, pinkish gray, cross-bedded limestone. Where the Fernvale limestone is overlain by the Cason shale or younger formations its upper surface is slightly irregular containing in places channels and fissures a few feet deep. Where the formation is overlain by residual clays and other surficial materials, however, the surface of the unweathered limestone is very irregular, containing debris-filled underground hollows and channels 50 or more feet deep that have been formed by solution.

The **Cason** shale (Ordovician) is of particular importance because it is the horizon at which all the phosphate deposits of the north Arkansas district occur. Outcrops of this formation are scattered over a wide east-west belt reaching from the Ball mine, two miles east of Hickory Valley in Independence County, westward to the town of Jasper in Newton County. The formation is absent in many

places throughout this belt and is exposed chiefly in Stone, Independence and Izard Counties. Good outcrops of the formation are not common and are limited to the steeper slopes and ridges of the region. However, since many of the manganese deposits of the Batesville district occur in this formation, numerous manganese mines and prospects have exposed the formation and manganese float ore marks the position of the formation at many places.

The thickness of the formation is variable, the recorded maximum being 20 feet. The formation usually consists of shale, and small amounts of sandstone, argillaceous limestone, phosphate rock and manganese and iron minerals. The shale is greenish-gray, platy and calcareous and in most of its exposures has weathered to a yellow, red or brown color. There is much variation at different localities in both the quantity and character of the several constituents of the formation. At the Hickory Valley deposit, for example, the Cason shale formation consists almost entirely of phosphate rock. Purdue⁴ described the Cason shale section at the abandoned phosphate mine on the west side of Lafferty Creek in Section 15, T. 14N, R. 8W, Independence County, as follows:

Section Containing Phosphate Beds

Formation	Thickness in Feet
St. Clair limestone	
Cason shale:	
Brown to black shale	2.0
Low-grade mangiferous iron ore	1.3
Green to dark clay shale	1.2
Light gray conglomeratic phosphate rock (high grade)	4.5-6.0
Mangiferous iron ore	0.2
Dark greenish compact phosphate rock (low grade)	4.0
Fernvale limestone	

Miser's description⁵ of the section at the Club House mine, half a mile north of Cushman, Independence County is another example of the many variations in lithology in the Cason shale formation:

⁴ Purdue, A. H., op. cit., pp. 469-470.

⁵ Miser, H. D., op. cit., p. 214

Section at the Club House Mine

Formation	Thickness in Feet
Boone chert:	
Massive, thin-bedded hard gray chert	50.0
Cason shale:	
Sandy platy shale and platy sandstone	2.5
Shaly sandstone, largely replaced by porous red and brown iron oxides and manganese oxide	2.0
Fernvale limestone:	
Pinkish-gray, granular, crossbedded limestone	95.0
.	

The phosphate beds are restricted to the Cason shale formation. The outcrop of this formation is several hundred miles in length, but the significant deposits of phosphate rock are local developments of comparatively limited extent within the formation.

The Cason shale formation is overlain disconformably in some places in north Arkansas by the St. Clair limestone formation of Silurian age, but generally all the Silurian and Devonian rocks are missing and the Boone chert formation (Mississippian) rests unconformably on the Cason shale.

The **St. Clair** limestone (Silurian) is exposed in several small areas in the Batesville district but is absent at the Hickory Valley deposit. The formation is mainly a pinkish-gray coarse-grained limestone but at a few places its upper part is bluish gray and fine-grained.

The **Boone** chert (Mississippian) is the surface rock over a larger area of the Batesville district than any other formation. Owing to its wide distribution, this rock and the debris derived from it are found at most localities. At Hickory Valley the phosphate deposit itself is overlain by Boone chert debris and the drilling indicated that the unweathered chert and limestone of the formation overlie the Cason shale formation (phosphate horizon) south of the deposit. The formation consists predominantly of chert but it also contains much limestone and a minor amount of sandstone and shale. The relative proportions of chert and limestone vary both vertically and horizontally, but the chert is the principal rock in the upper and lower parts of the formation while most of the limestone that is free from chert is found near the middle of the formation. The Moore-

field shale (Mississippian) overlies the Boone formation several miles to the south of the phosphate region.

DESCRIPTION OF THE HICKORY VALLEY DEPOSIT

Character of the Phosphate Rock

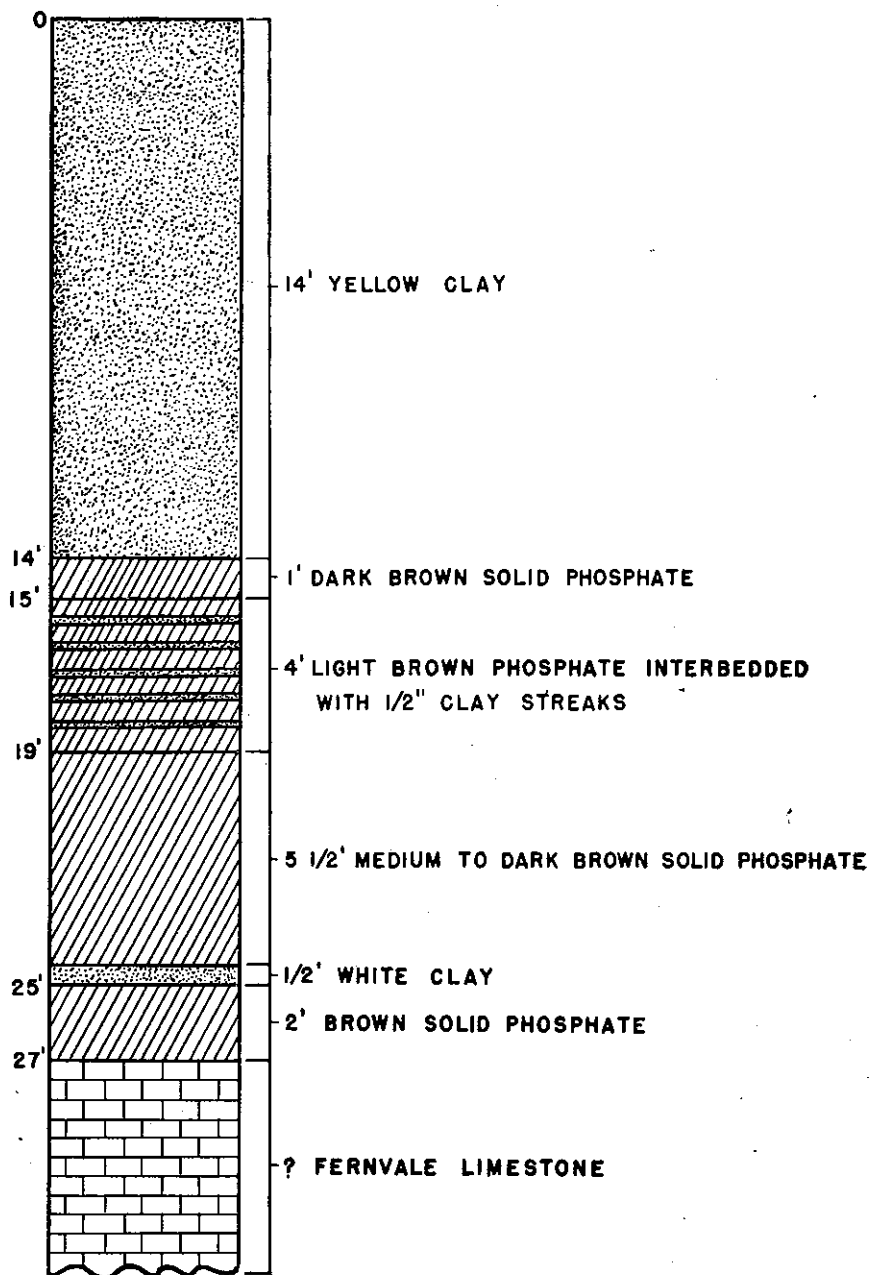
The phosphate rock in the Hickory Valley deposit varies somewhat in its appearance. Branner⁶ described a fairly complete section of the phosphate beds which were at that time exposed in the cave at the northwest boundary of the deposit. His description included nine separate beds with an aggregate thickness of 18.3 feet as follows:

- Bed No. 1, Five feet of brown, pebbly phosphate rock, with some chert fragments.
- Bed No. 2, Two feet of cherty fragments with some phosphate pebbles.
- Bed No. 3, Eighteen inches of rich pebbly phosphate rock, brown in color, bleaching gray.
- Bed No. 4, Marble, twenty inches.
- Bed No. 5, Thirty-three inches of pebbly phosphate rock, with some chert mixed in.
- Bed No. 6, Ten inches of cherty material.
- Bed No. 7, Twenty-two inches of phosphate conglomerate with a slight mixture of chert.
- Bed No. 8, Fifteen inches of cherty material.
- Bed No. 9, Eighteen inches of apparently rich phosphate conglomerate, exposed in the bottom of the pit.

The phosphate rock section in the recent test pit differed somewhat from that exposed in the cave. The test pit disclosed an aggregate thickness of 13 feet of phosphate rock in which the conglomeratic rock and some chert layers were present but there were also some beds of hard compact brown phosphate rock and a few layers of laminated, brown to gray phosphatic shale. The nodular or conglomeratic characteristic of one or more of the phosphate beds is common throughout the north Arkansas district and such beds are generally higher in grade than the other beds present. Another type of phosphate bed commonly found in the north Arkansas district but not present in the Hickory Valley deposit is a more or less sandy bed that varies considerably in phosphate content but at most localities is relatively low grade.

⁶ Branner, J. C., and Newsom, J. F., op. cit., p. 69.

**COLUMNAR SECTION OF PROSPECT SHAFT
SUNK ON SITE OF DRILL HOLE #11**



The Minerals Unit of the Chemical Engineering Division of the Tennessee Valley Authority made the following petrographic study in conjunction with the experiments with the Hickory Valley phosphate rocks in order to determine the feasibility of future beneficiation:

A petrographic study was made of thin sections from several lumps typical of the matrix. This study revealed the materials to be a siliceous, partially oolitic limestone which has been altered by replacement silica cementing the phosphorite oolites and containing quartz, collophanite, and an iron-bearing phosphate as disseminated inclusions. The marked continuity of the silica structure on a microscopic scale was evidenced by the fact that acid-leaching of lumps of the crushed material to remove phosphate and iron had little effect upon the size or shape of the particles. The skeletal material consisted of fine grains of quartz imbedded in and cemented together by amorphous replacement silica, with the latter being the major phase. The presence of carbonate was evidenced by effervescence during solution with acid, and residual nodules of fine-grained dolomite limestone largely altered to collophanite were observed.

The drill hole samples were analyzed by Troy W. Carney, Division of Geology chemist. The results of the analytical work showed that there is some variation in the grade of the phosphate rock and that the average grade of the entire deposit computed from the individual drill-hole samples is 40.97 percent B. P. L. ($P_2O_5=18.8$ percent) An analysis of samples from an average drill hole indicated that the phosphate rock has an Fe_2O_3 content of 6.56 percent and an Al_2O_3 content of 2.96 percent. The logs of the individual drill holes including the chemical analyses of samples are tabulated below.

Drill Hole No. 1 200' South from old main trench (Uncased Hole)

Depth	Lab. Number	Type Sample	Field Description	B. P. L.	
				P_2O_5	$Ca_3(PO_4)_2$
0-8	.....	.....	Soil and chert overburden	Not analyzed	
8-10	1a	Washed in field	Br. phosphate & chert	4.1	9.0
10-12	1b	Washed in field	Br. pebbly phosphate	9.8	21.7
12-14	1c	Washed in field	Br. pebbly phosphate	6.7	14.6
14-16	1d	Washed in field	Br. pebbly phosphate	10.5	23.0
16-18	1e	Sludge	Br. pebbly phosphate	15.8	34.6
18-20	1f	Sludge	Br. pebbly phosphate	15.2	33.2
20-22	1g	Sludge	Br. pebbly phosphate	13.1	28.7
22-24	1h	Washed in field	Black Phosphate shale	18.1	39.6
24-26	1i	Washed in field	Black Phosphate lime	22.6	49.4

Drill Hole No. 2 200' N 65° W from Hole No. 1 (Uncased Hole)

Depth	Lab. Number	Type Sample	Field Description	P ₂ O ₅	B. P. L. Ca ₃ (PO ₄) ₂
0-4½	.....	.....	Soil & chert boulders	Not analyzed	
4½-8½	.....	.....	Gray plastic sticky clay	Not analyzed	
8½-11	2a	Washed	8½-10½ gy. clay; 10½-11 phosphate	10.9	23.9
11-13½	2b	Washed	Dk. br. & blk pebbly phosphate	17.8	38.8
13½-15½	2c	Washed	Dk. br. & blk pebbly phosphate	15.6	34.0
15½-17	2d	Washed	Dk. br. & blk pebbly phosphate	17.4	37.9
17-19	2e	Washed	Phosphate-blk. chert hd. lms. layer 17½-18	14.4	31.5
19-21½	2f	Washed	Blk. phosphate & blue gy. lms.	10.9	23.9
21½-23½	2g	Washed	Gy. chert-some blk. phosphate	10.8	23.6
23½-24½	2h	Washed	Chert & phosphate	16.1	35.1
24½-27½	.....	.....	Hd. limestone (Fernvale)	Not analyzed	

Drill Hole No. 3 200' S 55° W from Hole No. 2 (Uncased Hole)

Depth	Lab. Number	Type Sample	Field Description	P ₂ O ₅	B. P. L. Ca ₃ (PO ₄) ₂
0-8	.....	.....	Soil & gray sticky clay	Not analyzed	
8-10	3a	Washed	Black chert & phosphate	20.2	44.2
10-12	3b	Washed	Phosphate	20.92	45.8
12-14	3c	Sludge	Phosphate—sludge as rec'd	6.8	14.9
12-14	3d	Washed	Phosphate—washed in lab	18.1	39.6
14-16	3e	Sludge	Phosphate	12.0	26.1
16-18	3f	Washed	Phosphate 16-17½ Hd. lms. 17½-18 (Fernvale)	13.2	29.0

Drill Hole No. 4 200' S 5° E from Hole No. 3 (Uncased Hole)

Depth	Lab. Number	Type Sample	Field Description	P ₂ O ₅	B. P. L. Ca ₃ (PO ₄) ₂
0-20	.....	.....	Blue clay & chert	Not analyzed	
20-26	.....	.....	Yellow clay	Not analyzed	
26-28	4f	Washed	Yellow clay-phosphate	11.7	25.6
28-31	4a	Washed	Chert phosphate	12.9	28.1
31-33	4b	Washed	Brown phosphate	18.5	40.5
33-35	4c	Washed	Brown phosphate	20.9	45.8
35-38	4d	Washed	Brown phosphate	21.9	47.8
38-40	.....	.....	Hard gray limestone	Not analyzed	

Drill Hole No. 5 200' S 5° E from Hole No. 2 (Uncased Hole)

Depth	Lab. Number	Type Sample	Field Description	P ₂ O ₅	B. P. L. Ca ₃ (PO ₄) ₂
0-11	.....	.....	Yellow clay and chert	Not analyzed	
11-13	Sample missing		Clay chert & phosphate	(?) Sample missing	
13-15	5a	Washed	Phosphate	1.0	2.2
15-17	5b	Washed	Phosphate	0.9	2.0
17-19	5c	Washed	Phosphate	4.8	1.7
19-21	5d	Washed	Phosphate	0.9	2.0
21-23	5e	Washed	Phosphate	0.9	2.0
23-25	5f	Washed	Phosphate	0.9	2.0
25-28	.....	Washed	Chert & yellow clay	Not analyzed	

Hole No. 6 150' S 31° W from Hole No. 7

Depth	Field Description
0-26	Chert fragments and clay
26-29	Chert fragments and clay
25-31	Chert fragments and clay
31-34	Chert fragments
34-37	Chert fragments
37-40	Chert fragments
40-43	Chert fragments
43-46	Chert fragments
46-49	Chert fragments
49-52	Chert fragments
52-55	Chert fragments
56-60	Chert solid, hard (Boone
60-70	Chert solid, hard (chert)

} Not Analyzed

Hole No. 7 200' S 65° E from Hole No. 5

Depth	Field Description
0-5	Brown chert clay
5-10	Brown chert clay
10-15	Brown chert clay
15-20	Brown chert clay
20-25	Brown chert clay
25-30	Brown chert clay
30-35	Brown chert clay
35-39	Brown chert clay
39-41	Limestone (Fernvale ?) (limestone)

} Not Analyzed

Hole No. 8 200' S 60° E from Hole No. 7

Depth	Field Description
0-3	Yellow clay
3-6	Yellow clay and yellow chert fragments
6-9	Yellow chert fragments
9-12	White chert solid
12-15	White chert solid
15-18	White chert solid
18-21	White chert solid
21-24	White chert solid
24-27	White chert solid
27-30	White chert solid
30-33	White chert solid
33-36	White chert solid
36-39	White chert solid
39-40.5	White chert

} (Boone chert) Not analyzed

Drill Hole No. 9 427' N 38° E from Hole No 8 (Uncased hole)

Depth	Lab.		Field Description	B. P. L.	
	Number	Type Sample		P ₂ O ₅	Ca ₃ (PO ₄) ₂
0-3	.....	.....	Loose Cher* & yellow clay	Not analyzed	
3-6	.....	.....	Loose Chert & yellow clay	Not analyzed	
6-8	9a	Washed	Brown phosphate (?)	0.9	2.0
8-10	9b	Washed	Brown phosphate (?)	Trace	Trace
10-12	9c	Washed	Brown chert	None	None
12-14	.....	.....	Chert loose	Not analyzed	
14-16	.....	.....	Chert loose	Not analyzed	
16-18	.....	.....	Chert	Not analyzed	
18-21	.....	.....	Brownish yellow clay	Not analyzed	
21-24	.....	.....	Brownish yellow clay	Not analyzed	
24-55	.....	.....	Brown clay	Not analyzed	

Drill Hole No. 10 296' N 35° E from Hole No. 9

Depth	Field Description	
0-5	Yellow clay	
5-10	Chert & clay (loose)	
10-12	Chert & clay	
12-15	Brown chert	
15-18	Brown chert	
18-21	Chert to lime	(Boone chert?)
	T. D.	

} Not Analyzed

Drill Hole No. 11 300' N 6° E from Hole No. 8 (Uncased hole)

Depth	Lab.		Field Description	B. P. L.	
	Number	Type Sample		P ₂ O ₅	Ca ₃ (PO ₄) ₂
0-6	.....	.....	Brown clay	Not analyzed	
6-9	.....	.....	Loose chert and lime	Not analyzed	
9-12	.....	.....	Yellow clay	Not analyzed	
12-15	11a	Washed	Brown phosphate	16.3	35.7
15-18	11b	Washed	Brown phosphate	14.3	31.2
18-21	11c	Washed	Brown phosphate	21.1	46.1
21-24	11d	Washed	Brown phosphate	32.5	71.2
24-26½	11e	Washed	Brown phosphate	26.1	57.1
26½-28	11f	Washed	Phosphate & lime	31.1	68.1
28-30	11g	Washed	Phosphate & lime	28.8	63.0
30-31	11h	Washed	Phosphate & lime	22.5	49.2
31-32½	.....	.....	Grey limestone	Not analyzed	

Drill Hole No. 12 226' S 6° W from Hole No. 9

Depth	Field Description	
0-5	Clay and chert	
5-10	Chert solid	
10-15	Chert solid	} (Boone chert)
15-20	Chert solid	
20-23	Lime T. D.	

} Not analyzed

Drill Hole No. 13

120° S 45° W from Hole No. 3

Depth	Field Description	
0-3	Light yellow clay	} Not Analyzed
3-6	Light yellow clay	
6-10	Light yellow clay	
10-13	Light yellow clay	
13-16	Light yellow clay	
16-18	Light yellow clay	
18-20	Limestone (Fernvale)	

Drill Hole No. 14

230° S 4° W from Hole No. 4

Depth	Field Description	
0-5	Chert fragments and clay	} Not Analyzed
5-10	Chert fragments and clay	
10-15	Yellow clay	
15-20	Yellow clay	
20-25	Yellow clay	
25-30	Yellow clay	
30-35	Yellow clay	
35-37	Yellow clay	
37-40	Limestone (Boone or Fernvale)	

Drill Hole No. 15

100° S 62° E from Hole No. 2

(Cased hole)

Depth	Lab. Number	Type Sample	Field Description	B. P. L.	
				P ₂ O ₅	Ca ₃ (PO ₄) ₂
0-15	....	Washed	Chert	Not analyzed	
15-17	15a	Washed	Phosphate and chert	22.7	49.6
17-35	15b	Washed	Phosphate, brown to black	15.3	33.4
35-45	15c	Washed	Phosphate & lime	19.4	42.4
45-47	....	Washed	Limestone (Fernvale)	Not analyzed	

Drill Hole No. 16

118° S 72° E from Hole No. 1

(Cased Hole)

Depth	Lab. Number	Type Sample	Field Description	B. P. L.	
				P ₂ O ₅	Ca ₃ (PO ₄) ₂
0-15			Chert and clay	Not analyzed	
15-20			Brown clay	Not analyzed	
20-22	16a	Washed	Phosphate and chert	9.9	21.5
22-37	16b	Washed	Phosphate	23.4	51.2
37-39	16c	Washed	Phosphate and lime	23.6	51.5
39-43	....		Limestone (Fernvale)	Not analyzed	

Drill Hole No. 17

183° N 6° E from Hole No. 1

(Cased hole)

Depth	Lab. Number	Type Sample	Field Description	B. P. L.	
				P ₂ O ₅	Ca ₃ (PO ₄) ₂
0-3			Clay chert	Not analyzed	
3-5	17a	Washed	Phosphate and chert	13.1	28.7
5-10	17b	Washed	Phosphate	21.7	47.4
10-13	17c	Washed	Phosphate and lime	21.7	47.4
13-16			Limestone (Fernvale)	Not analyzed	

Extent of the Deposit

The limits of the Hickory Valley phosphate deposit are shown on Plate I. The lateral extent of the deposit is shown by the outer or zero isopach line on the surface map, and the cross-sections indicate the thickness of the deposit. The isopach lines which connect points of equal thickness of phosphate rock were drawn at intervals of 10 feet with reference to both the drill hole data and the few exposures of the phosphate horizon. The deposit covers an irregular area of approximately 4.86 acres, and varies considerably in thickness with an average drill-hole thickness of 16 feet. Using a figure of 150 pounds per cubic foot for the phosphate rock in place, it was estimated that the Hickory Valley deposit contains approximately 160,000 long tons of 40.97 per cent B. P. L. phosphate rock.

Except for a few exposures of the phosphate rock in a cave and in trenches along the north boundary, the deposit is masked by an overburden of clay and chert. The overburden averages 12 feet in thickness and increases rapidly in thickness up the slope of the hill to the south of the deposit. The phosphate rock was deposited on the eroded surface of the Fernvale limestone formation and the uneven base of the deposit is a reflection of the irregularities of this erosion surface. The north and west boundaries and possibly the east boundary of the deposit as shown on Plate I probably represent the limits of the phosphate rock in those directions since weathering and erosion have probably removed the phosphate horizon. It seems likely, however, that the deposit might be extended southward by additional deeper drilling, since the southernmost drill holes (Nos. 6, 7, 8, and 12) probably were bottomed in the Boone chert formation which immediately overlies the Cason shale formation (phosphate horizon).

REPORT ON BENEFICIATION OF ARKANSAS PHOSPHATE MATRIX

Tennessee Valley Authority
Division of Chemical Engineering
Wilson Dam, Alabama

A 100 pound sample* of phosphate matrix from Arkansas was studied to determine its amenability to beneficiation.

Physically, the sample consisted of a mixture of fairly dense hard lumps, weathered friable lumps and finely divided earthy solids. The distribution of solids with respect to particle size was determined by tumbling a 50 per cent suspension of matrix in water in a jar mill for 1 hour followed by wet-screening. The size distribution is shown in Table I.

TABLE I

Size Distribution of Solids in Arkansas Phosphate Matrix

Size Fraction	Wt. %	Cumulative Wt. %
+ 0.5"	16.6	16.6
— 0.5" + 4 mesh	20.6	37.2
— 4 + 8	10.3	47.5
— 8 + 14	7.2	54.7
— 14 + 28	6.0	60.7
— 28 + 48	4.0	64.7
— 48 + 100	3.9	68.6
— 100 + 200	2.1	70.7
— 200	29.3	100

The amenability of the matrix to beneficiation by washing was determined in a small-scale test. To obtain a fairly small portion that was representative of the whole matrix, the entire sample was thoroughly mixed and quartered. One quarter was stage crushed to pass 4-mesh, and a 300-gram portion separated by riffing. This sample was mixed with water containing sodium hydroxide and agitated at 800 rpm for 10 minutes. This treatment simulates the

* (Composite sample obtained from test pit at Drill Hole 11, Hickory Valley Deposit.)

mechanical action to which the material is subjected in the washing operation and serves to break down and disperse the softer solids. After agitation the suspension was wet-screened and the size fractions were analyzed. The chemical composition of the size fractions is shown in Table II.

TABLE II

Chemical Composition of Size Fractions of Arkansas Matrix

Size Fraction	P ₂ O ₅	Acid	F	CaO	Al ₂ O ₃	Fe ₂ O ₃	Ignition
	%	Insol. %	%	%	%	%	loss. %
— 4 + 6 mesh	25.4	21.7	2.86	35.6	1.6	8.0	2.4
— 6 + 8	25.0	22.2	2.76	35.0	2.3	8.0	3.3
— 8 + 10	25.7	21.1	2.76	35.8	2.4	7.5	2.4
— 10 + 20	25.1	21.5	2.74	35.4	2.0	8.0	3.0
— 20 + 35	21.5	27.6	2.54	30.4	3.5	9.3	3.5
— 35 + 100	25.8	20.1	2.74	36.4	1.5	7.8	3.5
— 100 + 325	26.6	18.0	2.84	37.6	1.9	7.5	3.2
— 325 + 10	5.7	72.1	0.58	8.4	2.6	5.8	3.8
— 10	7.0	55.7	0.56	10.0	7.0	10.3	5.8

The composition of the size fractions down to 325-mesh is remarkably uniform. Silica is the major gangue constituent, and the iron content is high. Clay is a minor component of the plus 10-micron material, as indicated by the low alumina content. The presence of large amounts of carbonates is precluded by the small ignition loss which includes organic matter. The ratio of flourine to P₂O₅ is approximately the same as that for Tennessee and Florida phosphate.

The weight distribution of solids with respect to particle size is shown in Table III. There, also, is summarized the cumulative recovery of both solids and P₂O₅ with respect to decreasing particle size, and the cumulative grade of the size fractions.

TABLE III
Distribution of P₂O₅ with Respect to Particle
Size of Arkansas Matrix

Size Fraction	Solids		P ₂ O ₅			
	Wt. Pct.	Cumulative Wt. Pct.	Analysis Percent	Cumulative Anal. Pct.	Percent of Total	Cum. Pct. of Total
— 4 + 6 mesh	9.8	9.8	25.4	25.4	12.9	12.9
— 6 + 8 mesh	9.6	19.4	25.0	25.2	12.4	25.3
— 8 + 10 mesh	10.5	29.9	25.7	25.4	13.9	39.2
— 10 + 20 mesh	14.2	44.1	25.1	25.3	18.4	57.6
— 20 + 35 mesh	11.6	55.7	21.5	24.5	12.9	70.5
— 35 + 100 mesh	10.1	65.8	25.8	24.7	13.4	83.9
— 100 + 325 mesh	4.9	70.7	26.6	24.8	6.7	90.6
— 325 m.+ 10 microns	14.6	85.3	5.7	21.5	4.3	94.9
— 10 microns	14.7	100.0	7.0	19.4	5.3	100.2

The results shown in Table III indicate that significant improvement in grade can be effected by washing the matrix. Ninety-one per cent of the P₂O₅ in the matrix can be recovered in a plus 325-mesh washed concentrate. The improvement in grade from 19.4 to 24.8 per cent P₂O₅ represents an enrichment ratio of 1.28.

A comparison of the cumulative weight percent solids in Table III with that in Table I reveals that crushing effected little change in the percentage of minus 100-mesh solids. Therefore, the conclusions drawn from Table III should be equally valid for the uncrushed matrix.

.

The intimate intergrowth of silica and phosphate observed microscopically indicated that rather fine grinding would be a prerequisite to further beneficiation. Therefore, a 2-kilogram sample of matrix was crushed to pass 4-mesh, and washed by tumbling in a ball mill and screening on a 325-mesh screen. The undersize was reserved as washer tailing. The oversize was ground wet in a ball mill to pass 80-mesh to liberate the minerals, scoured by agitation at high pulp density to clean the surface of the grains, and deslimed at 20-microns. The minus 20-micron material was reserved as scoured slime. The minus 80-mesh plus 20-micron sand was subjected to fractional flotation. The sand was mixed with water to yield to pulp containing

30 per cent solids, and NaOH was added to pH 9. An increment of collector was added and, after conditioning, a flotation concentrate was taken off. This operation was repeated until no further material would float. The collector employed for flotation was a mixture of two parts of kerosene and one part of Neo-Fat No. 9, a vegetable oil distillate produced by Armour and Company and containing approximately 50 per cent saponifiable matter. The results of the flotation test are shown in Table IV.

TABLE IV

Results of Fractional Flotation of Arkansas Phosphate

Fraction	Neo-Fat No. 9, lb. per ton of feed	Solids, pct. of flotation feed	Composition, pct.		
			P ₂ O ₅	Fe ₂ O ₃	Acid Insol.
Conc. 1	0.2	20	35.4	2.6	3.7
Conc. 2	0.2	33	33.3	4.3	6.6
Conc. 3	0.2	19	30.8	6.8	10.3
Conc. 4	0.2	10	25.8	10.8	18.2
Conc. 5	0.2	2	12.6	16.0	44.8
Tailing	—	16	2.2	9.9	78.4
Scoured Slime	—	—	21.2	8.9	27.7

The cumulative recovery and grade of the important constituents from both the flotation and washing operations are summarized in Table V.

TABLE V

Cumulative Recovery and Grade of Products from Washing and Flotation of Arkansas Phosphate Matrix

Fraction	Cumulative Recovery of Total in Matrix, Pct.				Cumulative Grade, Pct.		
	Solids	P ₂ O ₅	Fe ₂ O ₃	Acid Insol.	P ₂ O ₅	Fe ₂ O ₃	Acid Insol.
Flot. Conc. 1	11.0	18.3	4.0	1.3	35.4	2.6	3.7
Flot. Conc. 2	29.4	47.0	14.9	5.2	34.1	3.7	5.5
Flot. Conc. 3	39.9	62.2	24.6	8.6	33.2	4.5	6.8
Flot. Conc. 4	45.3	68.7	32.7	11.8	32.4	5.2	8.1
Flot. Conc. 5	46.6	69.5	35.6	13.6	31.8	5.5	9.1
Scoured Slime	70.8	93.6	68.5	35.1	28.2	7.0	15.5
Flot. Trailing	79.4	94.5	79.0	56.7	25.4	7.2	22.4
Washer Tailing	100	100	100	100	21.3	7.3	31.2

The data in Table V show that approximately 70 per cent of the phosphate in the matrix can be recovered in a concentrate containing 32 per cent P_2O_5 by a combination of washing, grinding and flotation. If the slime produced by grinding and scouring the washed concentrate be recovered and combined with the flotation concentrate, the recovery of phosphate is increased to 93 percent with a decrease in grade to 28 percent P_2O_5 .

The conditions of the tests reported in Tables IV and V were not necessarily the optimum. In practice, flotation concentrates number 4 and 5 would be recycled to the grinding and scouring circuit with a resulting improvement in grade. The scoured slime which contains one-quarter of the total P_2O_5 is low grade and would be difficult of beneficiation. Its production probably could be minimized by more careful grinding in closed circuit with the flotation operation to remove the phosphate as soon as liberated.

In summation, silica is the principal gangue constituent of the matrix. Moderate beneficiation can be effected by washing the ore, and greater improvement is possible by means of flotation. Grinding is required, however, and the ore is friable and tends to slime formation.

E. H. Brown, Division of Chemical Engineering.
J. E. Davenport, Division of Chemical Engineering.
May 17, 1948.

OTHER SIGNIFICANT PHOSPHATE ROCK DEPOSITS IN THE NORTH ARKANSAS DISTRICT

All the constituent parts of the Cason shale formation are more or less phosphatic in composition, but there are only a few localities known where the phosphate layers have a combined thickness greater than three feet and are sufficiently high in phosphorus content (40 to 60 percent B.P.L.) to be of potential economic interest. Since the Cason shale formation is poorly exposed throughout the north Arkansas phosphate district, it is possible that exploration will disclose additional deposits in the area.

One of the known deposits occurs in the north side of Pine Hollow in the SW $\frac{1}{4}$ NE $\frac{1}{4}$ of sec. 14, T. 14N, R. 8W, about 4 miles west of Cushman, Independence County, Ar-

kansas. This deposit yielded the first phosphate rock mined commercially in Arkansas. The rock was first mined by stripping and later by underground methods when the overburden became excessive. A bed varying from 2 to 4 feet in thickness and averaging 60 to 65 percent B.P.L. is exposed in the mine workings. It is impossible to estimate the tonnage remaining in this deposit because of the caving in the workings and the lack of surface exposures.

Another deposit of comparatively high-grade phosphate rock is located in the SE $\frac{1}{4}$ NW $\frac{1}{4}$ of sec. 15, T. 14N, R. 8W. on the west side of the hill that lies between Lafferty Creek and the White River, 1 $\frac{1}{4}$ miles due west of the Pine Hollow deposit. This deposit was also mined during the early phosphate operations in the district and is the one described in detail by Purdue ⁷. The deposit was worked for a distance of about 1,000 feet along its outcrop by both underground and surface mining methods. Two beds of phosphate rock are exposed at the deposit, an upper high-grade bed with a coarse texture and gray color, and a lower, more compact, darker bed with a greenish cast. Only the upper bed was mined. It varied from 31 to 63 inches in thickness and from 45 to 56 percent in B.P.L. content. As in the case of the Pine Hollow deposit, the lack of exposure does not permit an estimate of the phosphate rock reserves of this deposit.

Another significant deposit of phosphate rock known in the district is located in the SW $\frac{1}{4}$ NW $\frac{1}{4}$ of sec. 8, T. 14N, R. 7 W, on the north bank of Blowing Cave Creek 1 mile west of Cushman. Dr. J. C. Branner ⁸ described three phosphate beds exposed in a test pit at this locality. These beds had an aggregate thickness of 53 inches and an average B.P.L. content of 44 percent. Branner estimated that the deposit would average 4 feet in thickness and contain about 464,000 tons of phosphate rock, most of which would have to be mined by underground mining methods.

⁷ Purdue, A. H., op. cit.

⁸ Branner, J. C., and Newsom, J. F., op. cit., p. 80.

USES AND ECONOMIC POSSIBILITIES OF ARKANSAS PHOSPHATE ROCK

According to statistics⁹ published by the U. S. Bureau of Mines 59 percent of the phosphate rock produced in the United States in 1947 was used in the manufacture of superphosphates. Briefly, the manufacturing process consists of treating the ground rock with sulfuric acid and converting the relatively insoluble calcium phosphate into phosphorus salts that are soluble in water and thus readily available to the plant. At the present time there are two companies in Arkansas manufacturing superphosphate mainly from Florida phosphate rock that averages between 72 and 75 percent in B.P.L. content and less than 3 percent alumina and iron oxide content.

In the consideration of the grade of the north Arkansas phosphate rock, it was pointed out that the known significant deposits did not contain phosphate rock beds that would average higher than 60 percent in B.P.L. content. Thus, it is apparent that the grade of the raw phosphate rock from the north Arkansas deposits is too low to be acceptable for the manufacture of superphosphate. However, the beneficiation tests on the sample from the Hickory Valley deposit by the T.V.A. did show that 70 percent of the phosphate content of the raw rock could be recovered in a concentrate containing 70 percent B.P.L. and 5.5 percent iron oxide, by a combination of grinding, washing, and flotation. Since this concentrate approaches the present market specifications, perhaps additional investigations would result in an ore dressing procedure that would yield a marketable concentrate from the Arkansas rock.

The manufacture of phosphorus chemicals, ferrophosphorus and elemental phosphorus consumed 13 percent¹⁰ of the total phosphate rock produced in the United States in 1947. The plants which produce these chemicals are located in or near the phosphate areas of Florida, Tennessee, and a few western states, consequently, Arkansas phosphate

⁹ U. S. Bureau of Mines, Minerals Yearbook, p. 980, 1947.

¹⁰ U. S. Bureau of Mines, op. cit., p. 980.

rock could not compete with the local supplies of phosphate rock available.

The nation's largest producer of elemental phosphorus is the Monsanto Chemical Company's plant at Monsanto, Tennessee. The electric furnace production of phosphorus pioneered by T.V.A. is one of the latest developments in the Tennessee phosphate industry. A lower grade phosphate rock than is used in the manufacture of superphosphate can be used in this process. According to Smith and Whitlach¹¹ as low as 50 percent B.P.L. phosphate rock can be used in the furnace charge. The mined phosphate rock is first sintered, then mixed with coke and fed into furnaces heated electrically by means of carbon electrodes. Electric current obtained from the nearby transmission lines of the Tennessee Valley Authority is delivered to the furnace at 44,000 volts. The coke reduces the phosphate rock liberating the phosphorus. The silica, alumina, and the lime present in the rock form a slag and the iron present combines with phosphorus to form ferrophosphorus which is cast into pigs and sold to the steel industry. The ferrophosphorus and the slag in a molten condition are tapped intermittently from the base of the furnace. The phosphorus passes up through the furnace charge, is piped from the furnace and condenses to a liquid which is collected under water in sumps. The elemental phosphorus is converted to phosphoric acid of high purity which may be used to produce phosphate of sodium, calcium, ammonium and other salts.

The north Arkansas phosphate district will, in the near future, be a favorable locality for an electrothermal processing plant similar to the Monsanto operation. The White River basin development program of the U. S. Army Corps of Engineers includes eleven dams; three of these have been approved for flood control and power: three have been approved for flood control and are under consideration for power and five are under consideration for flood control and power. Some of these will be located near the phosphate area, and it is estimated that the electric power from these installations will be available in 1955.

¹¹ Smith, R. W., and Whitlach, G. I., The phosphate resources of Tennessee; Tennessee Division of Geology Bull. 48, pp. 127-128, 1940.

Although the grade of the Hickory Valley phosphate rock was only 40.97 percent B.P.L., the beneficiation tests indicated that crushing and washing would raise the grade to 50 percent B. P. L., and it is possible that similar processing of phosphate rock from other deposits in the district would produce a grade suitable for the electric furnace process.

The use of finely-ground phosphate rock as a fertilizer is becoming increasingly important in the United States. In 1947, nine percent ¹² (764,000 long tons) of the total domestic production of phosphate rock was used in this manner. The specifications for raw ground phosphate rock show some variation in those states receiving assistance under the Agricultural Conservation Program (See Table VIII), but most of this fertilizer now being marketed has a grade of 30 percent P_2O_5 (65% B.P.L.) or higher and is ground so that most of it passes a 200 mesh screen. This finely-ground rock does not contain any so-called "soluble phosphate" that is readily available to the soil, but if this fertilizer is mixed with the soil, ground waters and organic acids slowly would change the relatively insoluble phosphorus compounds in the fertilizer to soluble phosphates. Through this process it is estimated that over a period of about five years approximately 25 percent of the insoluble phosphates are made available for plant use. The comparatively availability in the soil of the phosphorus in the raw ground phosphate rock and in superphosphate has been investigated by many state and federal agricultural agencies. Since the issues involved are not geological, it was considered advisable to include extracts from pertinent bulletins of several of these state agencies and from articles and letters of individuals familiar with this problem.

In Arkansas, the Agricultural Experiment Station of the University of Arkansas College of Agriculture has conducted experiments in which the effectiveness of finely-ground phosphate was compared to that of other fertilizers in the growth of several different crops. A series of such

¹² U. S. Bureau of Mines, op. cit., p. 980.

studies¹³ based on a four-year crop rotation of corn, oats, wheat, and red clover were conducted at the Main Experiment Station during the period 1920 to 1932. According to Dr. R. P. Bartholomew,¹⁴ Associate Director of the College of Agriculture, experiments (Table VI) with raw rock phosphate have also been conducted by the Department of Agronomy at the Livestock and Forestry Experiment Station of the University of Arkansas. The results obtained from plots of sudan grass and soybean hay are as follows:

Table VI. Results of Experiments with Phosphates at the Livestock and Forestry Experiment Station, Batesville, Arkansas.

Source of phosphorus*	Yield per acre of Sudan grass					Average for years grown
	1938	1939	1940	1941	1942	
	Pounds	Pounds	Pounds	Pounds	Pounds	Pounds
None**	440	370	840	1,070	1,850	914
None	1,058	1,000	1,130	2,310	2,860	1,672
Superphosphate 20%	1,870	3,330	5,367	5,950	5,500	4,403
Rock phosphate	----	1,240	2,000	3,900	4,330	2,867 ¹
Concentrated superphosphate	1,380	2,460	3,655	5,030	4,380	3,381
Calcined phosphate	1,340	2,640	3,055	5,750	4,580	3,473
Fused rock phosphate	1,360	2,750	3,330	6,050	4,950	3,788
Calcium metaphosphate	1,320	3,270	3,470	5,480	4,590	3,626
Potassium calcium metaphosphate	----	----	3,660	5,300	4,890	4,616 ²
Potassium metaphosphate	----	----	2,980	5,320	3,980	4,093 ²

*All but the unfertilized plots received an application at the rate of 100 pounds per acre each of ammonium sulphate, nitrate of soda, and muriate of potash. Phosphorus was applied from the different sources in an amount equivalent to 300 pounds per acre of 20 per cent superphosphate.

**No fertilizer.

¹ Compare with average check of 1,825.

² Compare with average check of 2,100.

¹³ Nelson, Martin, Soil fertility studies; University of Arkansas, Agricultural Experiment Station, Bull. 290, 1933.

¹⁴ Bartholomew, R. P., Personal communication, June 3, 1948.

Yield per acre of Soybean hay.

Source of phosphorus*	1938	1939	1940	1941	1942	Average for years grown
	Pounds	Pounds	Pounds	Pounds	Pounds	Pounds
None**	320	420	1,210	1,370	950	862
None	590	1,034	1,890	3,170	2,000	1,737
Concentrated superphosphate	500	1,440	3,390	3,400	2,910	2,308
Superphosphate 20%	780	1,650	3,920	3,250	2,840	2,488
Rock phosphate	----	1,210	3,350	3,560	3,110	2,808*
Calcined phosphate	600	1,750	3,460	3,370	3,520	2,540
Fused rock phosphate	670	1,540	4,110	2,570	3,240	2, 26
Calcium metaphosphate	710 [†]	1,720	3,770	3,650	3,150	2,600
Potassium calcium metaphosphate	----	----	3,710	2,880	2,890	3,160 [†]
Potassium metaphosphate	----	----	3,720	3,290	3,350	3,453 [†]

*All but the unfertilized plots received an application at the rate of 100 pounds per acre each of ammonium sulphate, nitrate of soda, and muriate of potash. Phosphorus was applied from the different sources in an amount equivalent to 300 pounds per acre of 20 per cent superphosphate.

**No fertilizer.

[†] Compare with average check of 2,100.

[‡] Compare with average check of 2,353.

Dr. Bartholomew,¹⁵ commenting on these experiments, said:

The results at the Livestock and Forestry Experiment Station confirm previous experiments conducted here and those conducted in other stations. They show for non-leguminous crops such as sudan grass, corn, cotton, etc., that rock phosphate is not as satisfactory a fertilizer as the more available forms. They also show that where the rock phosphate is used as a source of phosphorus for legumes that it produces about the same results as more available phosphates. On the basis of similar information, the general program of fertilization through the United States has promoted the use of rock phosphate where it was going to be used in a livestock system of farming. The legumes are fed the livestock and the manure put back on the soil. Under such a system where rock phosphate has been used, the results have been very satisfactory. However, in most cases where the practical application is made to farming systems, the rate of application with P_2O_5 is considerably more than would be applied from superphosphate. We have recom-

¹⁵ Bartholomew, R. P., Personal communication, June 3, 1948.

mended that where similar practices are to be followed in Arkansas that rock phosphate would be a good source of material for increasing crop production.

Investigations¹⁶ carried out by the Oklahoma Experiment Station showed that yields of sweet clover resulting from the application of finely-ground phosphate rock compared favorably with those resulting from application of superphosphate. The results of one of these studies are in Table VII.

Table VII. The Effect of Method of Application of Different Commercial Fertilizers, Limestones, and Farm Manure on the Growth of Biennial White Sweet Clover on Series 1700, N. W. Perkins Farm. Crop planted in 1913 and harvested in 1932.

No.	Treatment	Rate of Application in pounds per Acre	Average Yield of Sweet Clover in Pounds per Acre
1	None	---	1080
2	Basic Slag	200	1050
3	Basic Slag	400	1375
4	Rock phosphate	200	1760
5	Rock phosphate	400	2120
6	Superphosphate†	200	1650
7	Superphosphate†	400	1470
8	None	---	870
9	Superphosphate 45% P ₂ O ₅	89	1430
10	Limestone	400	1236
11	Limestone	400	
	Rock Phosphate	200	1750
12	Limestone	600	
	Superphosphate	200	1560
13	Limestone	600	
	Superphosphate	200	1310

† 20% P₂O₅ except as indicated

¹⁶ Harper, H. J., Soil fertility and sweet clover production in Oklahoma; Okla. A. and M. College Experiment Station Bulletin No. 206, 1932.

14	None	---	1010
15	Limestone*	4000	1310
16	Limestone*	4000	
	Rock Phosphate*	400	1480
17	Limestone*	4000	
	Rock Phosphate	400	1960
	Manure*	12000	
18	Rock Phosphate*	400	1460
19	Rock Phosphate*	400	
	Manure*	12000	1830
20	None	---	990
21	Manure*	12000	1620
22	Limestone*	4000	
	Manure*	12000	1585
23	4-12-4	200	1073
24	4-12-4	400	1207
25	Limestone	400	
	4-12-4	200	1510
26	None		943
27	12-24-12	167	1250
28	Limestone	400	
	12-24-12	167	1670

* Broadcast and disked into the soil

Finely-ground phosphate rock fertilizer is the chief source of phosphorus in Illinois. The conditions under which this fertilizer has been profitably applied to the soil are outlined in the following extract from an article by F. C. Bauer¹⁷ of the University of Illinois:

In some sections, finely ground rock phosphate carrying 30 to 34 per cent P_2O_5 is an efficient source of phosphorus. The phosphorus in this carrier is not water-soluble (capable of dissolving in water) but it becomes usable to crop plants by means of changes within the soil and the use of crops in

¹⁷ Bauer, F. C., When your land needs phosphorus; Successful Farming, October, 1945.

the rotation that possess high feeding capacities for it. Because of the difference in chemical behavior and price, rock phosphate should be used somewhat differently than super-phosphate. It is usually applied at intervals of ten or more years at rates of 1,000 pounds or more an acre. Applied in this manner and in connection with cropping systems built around the regular use of legumes, rock phosphate has proven to be an effective source of phosphorus for the crops in rotation, and will fit well into a long-time, soil improvement program.

Mr. John Adler of the Missouri State Production and Marketing Division in the following letter dated July 8, 1948 to the Division of Geology describes the use of finely-ground phosphate rock in Missouri.

The application of raw rock phosphate is an approved practice under the Agricultural Conservation Program for our state. A compilation of data reveals that in 1946 Missouri farmers participating in the program applied 2,352 tons of such material and that 3,610 tons were used in 1947. This includes only that tonnage for which Government assistance was given under the program.

In addition to the above we have information which shows 3,971 tons of raw rock phosphate were distributed in Missouri by fertilizer manufacturers and dealers in 1946. For 1947 the total tonnage reported by dealers and manufacturers was 11,841.

Either of the above comparisons shows the use of rock phosphate is definitely on the increase for this state. While its use is not nearly as extensive in Missouri as in some other states, it is being used more and more and information available to this office indicates a much greater tonnage will be used in 1948 than in the past. Such material is being given considerable recognition where a long time rotation of grasses and legumes is contemplated. For these reasons, it appears the use of rock phosphate will increase many times in the next few years.

Specifications in our programs require a minimum of 30% P_2O_5 in the rock phosphate if assistance is to be given. To our knowledge practically all the material used in Missouri is well above such minimum. The best information we have available indicates the material coming into Missouri ranges from 31% to 35% P_2O_5 depending on the source of the material.

In many states the value of finely-ground phosphate rock as a fertilizer has been recognized to the extent that

the use of this fertilizer in conservation practices is being subsidized by the respective Production and Marketing Divisions of the U. S. Department of Agriculture in those states. Table VIII lists the states receiving this assistance in 1948.

Table VIII. The Amount of Assistance per Cwt. for Rock Phosphate, and Specifications for Each State Receiving Assistance under Agricultural Conservation Program for 1948.

State	For material containing a total of:	Assistance Per. Cwt.
Florida	28% or more P_2O_5 and ground so 50% will pass through a 200-mesh sieve (wet screening method)	20c
Illinois	30% or more P_2O_5	30c
	From 25% to 30% P_2O_5 (Moisture free bs.)	20c
	From 18% to 25% P_2O_5 (Moisture free bs.)	10c
Indiana	30% or more P_2O_5	25c
Iowa	30% or more P_2O_5	30c
Kansas	28% or more P_2O_5 and ground so 80% will pass through a 200-mesh sieve	40c
Kentucky	28% or more P_2O_5	45c
Louisiana	28% or more P_2O_5 and ground so 85% will pass through a 200-mesh sieve (wet screening method)	45c
Louisiana	20% or more P_2O_5 and ground so 80% will pass through a 100-mesh sieve	30c
Michigan	30% or more P_2O_5	35c
Minnesota	30% or more P_2O_5	35c
Missouri	30% or more P_2O_5	40c
Ohio	30% or more P_2O_5	40c
Oklahoma	28% or more P_2O_5 and ground so 80% will pass through a 200-mesh sieve	50c
Washington	30% or more P_2O_5	1c per unit P_2O_5
Wisconsin	28% or more P_2O_5	50c

It is apparent that finely-ground phosphate rock is a suitable fertilizer for certain soil improvement programs and that a market for such a fertilizer exists in the mid-west. Several factors need to be considered, however, in determining to what extent phosphate rock from the north Arkansas deposits can compete for this market. The most important consideration is the grade of the rock. As mentioned before, the phosphate rock from the Hickory Valley deposit as mined would average 18.8 percent P_2O_5 , washing would improve the grade to 24.8 percent P_2O_5 , and additional beneficiation by flotation would raise the grade to 32 percent P_2O_5 . The unwashed ground rock could possibly be marketed in competition with the higher grade commercial rocks now available, but in order to furnish an equal amount of phosphorus to the soil it would be necessary to use 164 pounds of the Hickory Valley rock as compared to 100 pounds of 30 percent P_2O_5 rock.

Most purchasers of the finely-ground phosphate rock now being used receive assistance under the Agriculture Conservation Program. Reference to Table VIII shows that there is no assistance given on raw rock that averages less than 20 percent in P_2O_5 content, and most states require a grade of 28 percent P_2O_5 or greater. Hence, the Arkansas phosphate in order to compete in the present market, would have to have a cost low enough not only to offset the higher grade of the present commercial ground rock but also to offset the amount of assistance given under the Agriculture Conservation Program in those states where this type of fertilizer receives assistance. Insofar as the present market in Arkansas is concerned, there is no assistance in the purchase of finely-ground phosphate rock regardless of grade, and only a small amount (270 tons during the fiscal year ending in June 1948) is used in the state.

Washing the Hickory Valley phosphate rock prior to crushing would increase the grade to 24.8 percent P_2O_5 and make the rock eligible for assistance in Louisiana under their present specifications, and concentration by flotation would increase the P_2O_5 content to 32 percent, enabling it to receive assistance in all the states now giving assistance for this conservation practice. It seems likely, however, that

the expense of installing and operating a flotation mill would make the cost of the product excessive, thus preventing it from competing with the finely ground rock now on the market.

The economic possibilities of the phosphate rock from the north Arkansas deposits can be summarized as follows:

1. Current possibilities:

- A. Finely-ground, unbeneficiated Arkansas phosphate (18-20 percent P_2O_5) could be used as an inexpensive source of phosphorus in certain long range soil improvement programs.
- B. Finely-ground Arkansas phosphate rock, the P_2O_5 content of which has been raised by beneficiation to 30 percent, could be used in the same program as in "A" above. This higher grade product would have a more extensive market, however, because it would be eligible for Agricultural Conservation subsidies in several states adjacent to Arkansas.

2. Future possibilities:

- A. The Arkansas rock could be a source of phosphate for an elemental phosphorus plant with the advent of cheap electricity from the proposed power installations on the White River.
- B. More research on the beneficiation of the north Arkansas phosphate may ultimately develop an ore dressing process that will yield a high-grade concentrate usable in the manufacture of superphosphate.

SELECTED BIBLIOGRAPHY

- 1896 Branner, J. C., "The Phosphate Deposit of Arkansas": A paper read before the American Institute of Mining Engineers at the Colorado Meeting, p. 6, 1896.
- 1902 Branner, J. C., and Newsom, J. F., "The Phosphate Rocks of Arkansas": Ark. Agric. Exp. Sta. Bull. No. 74, pp. 69-71, 1902.
- 1907 Purdue, A. H., "Developed phosphate deposits of northern Arkansas": U. S. Geol. Surv. Bull. 315, pp. 463-473.
- 1922 Miser, H. D., "Deposits of Manganese Ore in the Batesville District, Arkansas": U. S. Geol. Surv. Bull. 734, 223p., 1922.
- 1932 Harper, H. J., "Wide Row Spacing and Row Application of Limestone and Phosphate for Sweet Clover Production": Okla. Agric. Exp. Sta. Bull. No. B-248, p. 11, 1932.
- 1933 Nelson, M., "Soil Fertility Studies": Ark. Agric. Exp. Sta. Bull. No. 290, 1933.
- 1937 "Phosphorus Plant of Monsanto Chemical": Industrial Engineering Chemical, vol. 15, 1937.
- 1940 Smith, R. H. and Whitlach, G. I., "The Phosphate Resources of Tennessee," Tenn. Division of Geology Bull. 38, pp. 127-129, 1940.
- 1941 Miser, H. D., "Manganese Carbonate in the Batesville District, Arkansas": U. S. Geol. Surv. Bull. 921-A, pp. 10-11, 1941.