PHOSPHATES.

PHOSPHATE DEPOSITS IN SOUTHWESTERN VIRGINIA.

By George W. Stose.

INTRODUCTION.

Commercial phosphate rock is not known to occur in Virginia, the nearest deposits of consequence being those at Columbia, in central Tennessee, where high-grade phosphate is mined on a large scale. The phosphate bed here described is probably not of work-

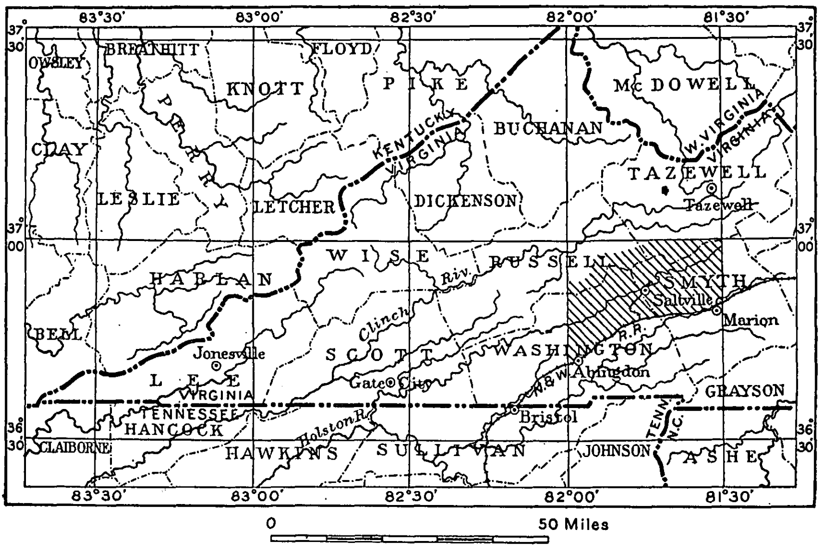

Figure 34.—Map of southwestern Virginia, showing by ruled pattern the area described and mapped in this report. Railroad connections for this area only are shown.

able size and is therefore rather of scientific interest than of practical value, although its discovery may lead to the finding of workable deposits. The location of the area is shown in figure 34.

Phosphate deposits have been observed at two localities in the area mapped by the United States Geological Survey as the Abingdon quadrangle, in southwestern Virginia—at the foot of the southeast slope of Clinch Mountain, 5 miles west of Saltville, and in Walker

Valley at the east end of Brushy Mountain, 5 miles west of Marion. The horizon at which the phosphate occurs has been traced from the Clinch Mountain locality for 20 miles northeast and southwest across the Abingdon quadrangle, and for about 2 miles in the Brushy Mountain locality, as shown on the geologic map, figure 35. It has also been mapped along the east slope of Walker Mountain for about 15 miles in the quadrangle, but the phosphate was not seen there.

TOPOGRAPHY OF THE REGION.

Clinch Mountain is a massive ridge trending northeast and southwest across southwestern Virginia into Tennessee. In the Abingdon quadrangle it comprises several nearly parallel high ridges which accompany an offset in the mountain in this vicinity. Its general altitude in the quadrangle is between 4,000 and 4,500 feet, attaining a maximum of 4,550 feet in Whiterock Mountain.

Walker Mountain, which begins as a low ridge about 8 miles northeast of Abingdon, runs northeastward parallel to Clinch Mountain and in the eastern part of the quadrangle reaches an altitude of 3,800 feet. Brushy Mountain is a local outlying ridge on the southeast side of Walker Mountain having an altitude of 3,500 feet.

The area between Clinch Mountain and Walker Mountain comprises alternate longitudinal valleys and hills. Along the southeast foot of Clinch Mountain is a valley whose soil is so barren that it is called Poor Valley. It is drained by several short streams which cut through Pine Mountain, a high ridge that lies to the southeast, between it and the valley of the North Fork of Holston River. Pine Mountain is a narrow, nearly straight ridge parallel with Clinch Mountain, having an elevation ranging from 2,500 feet to 3,000 feet in the area mapped. As the North Fork of Holston River lies directly at the foot of Pine Mountain and has an altitude of 1,600 feet, its tributaries are short and steep and are actively scouring the adjacent mountain. They have also cut deep ravines and coves in the side of Clinch Mountain. To the east of the Holston Valley lie rounded and irregular hills about 2,000 to 2,500 feet in elevation, which are remnants of a former plain that has been dissected by short transverse branches of the North Fork. Between these hills and Walker Mountain lies a broad, open valley, with fertile limestone soil, called Rich Valley.

Much of this area is either timbered or is cleared for pasture. Rich Valley and portions of the fertile lowlands bordering the North Fork are cultivated. A great number of export cattle are raised on the fertile western slopes of Clinch Mountain and in the adjacent valleys, and some are pastured in the valleys on the eastern slope and on the hills adjacent to the river, although the soil here is poorer and the grass not so luxuriant. The higher parts of the mountains and the rocky portions of the slopes are timbered, mostly with second growth, although a few patches of virgin forest, largely evergreen, still remain in the more inaccessible areas.

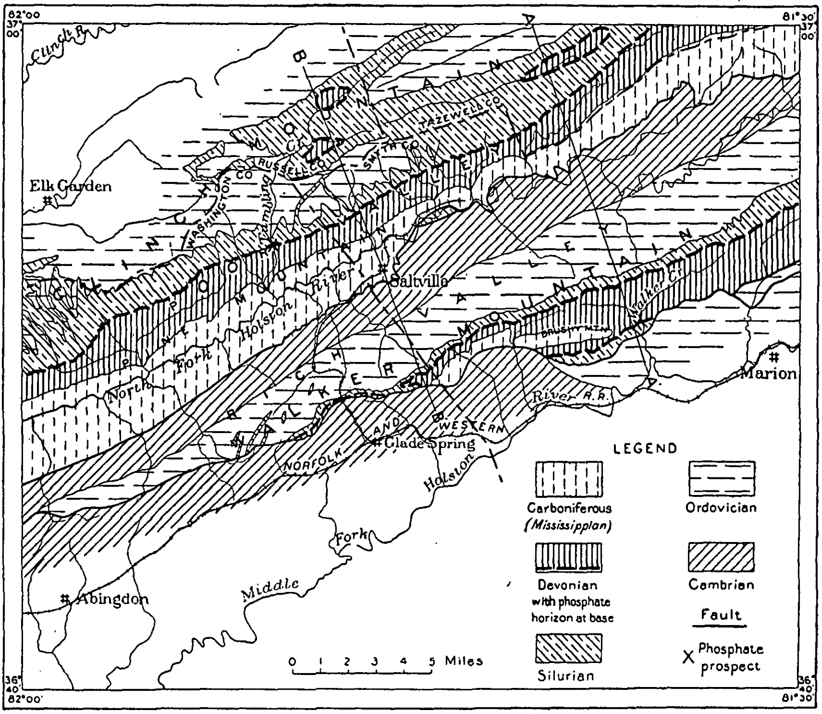

FIGURE 35.—Geologic map of part of the Abingdon quadrangle, Virginia, showing the distribution of the phosphate-bearing rock.

GEOLOGY OF THE REGION.

GENERAL SECTION.

The rocks of the area herein described comprise all the Paleozoic systems from the Cambrian at the base to the Carboniferous at the top, as represented on the geologic map (fig. 35). Those northwest of the great Rome fault, which passes through the area, differ somewhat in lithology, thickness, and faunal content from those on the southeast, so that the section given in the following table is representative of the whole area only in a general way.

Section of rocks in part of the Abingdon quadrangle, Virginia, and correlations with formations of adjacent areas.

System.	Bristol quadrangle, southwest of this area.	Part of Abingdon quadrangle, Virginia. Character.	Thickness.	Pocahontas and Tazewell quadrangles, northeast of this area.
			Feet.	
Carboniferous (Mississippian series).	Newman limestone.	Calcareous gray shale.	400+	Greenbrier limestone.
		Red calcareous crinoidal sandstone. Few fossils of Mississippian age.	70	
		Calcareous bluish-gray shale and laminated earthy limestone.	1,150	
		Massive blue and gray fossiliferous limestone, in part grano-crystalline and containing some chert. Numerous fossils of lower Mississippian age.	250	
	Grainger formation.	Black and red shales, earthy calcareous sandstone, impure limestone, and red clay with gypsum and salt beds. (Maccrady formation.) Large molluscan fauna of lower Mississippian age.	765	Pulaski shale.
		Thin-bedded, irregular-layered coarse white to bluish-gray sandstone. Small fauna, probably of Pocono age.	420	Price sandstone.
Devonian.		Massive reddish and gray arkosic sandstone with scattered quartz pebbles. Chemung fauna.	1,800	Kimberling shale.
		Sandy shale with thin fine-grained sandstones, coarser toward the top. Chemung fauna.		
		Olive colored to gray fissile shale, with interbedded black shale toward the base. Portage (Manticoceras) fauna.	735	Romney shale.
	Chattanooga shale.	Black carbonaceous fissile shale. Characteristic small Genesee fossils.	175	
	Hancock limestone.	Massive light and dark chert layers. Large Oriskany fauna.	125	Giles formation.
Silurian.		Impure finely laminated magnesian limestones; calcareous gray sandstone, weathering porous, at the base. Cayuga ostracodes and other shells.	0–145	
	Rockwood formation.	Soft greenish-gray shale and rusty to red ferruginous sandstone. Numerous Clinton fossils in places.	0–235	Rockwood formation.
	Clinch sandstone.	Pure white quartzose sandstone of upper Medina age.	0–180	Clinch sandstone.
Ordovician.	Bays sandstone.	Coarse, loose-textured red to brown sandstone and shale. Numerous fossils of Maysville age in lower part.	500	Bays sandstone.

Section of rocks in part of the Abingdon quadrangle, Virginia, and correlations with formations of adjacent areas—Continued.

System.	Bristol quadrangle, southwest of this area.	Part of Abingdon quadrangle, Virginia.		Pocahontas and Tazewell quadrangles, northeast of this area.
		Character.	Thickness.	
			Feet.	
Ordovician.	Sevier shale.	Light-gray to buff soft shale containing thin crystalline fossiliferous limestones, with sandstone beds toward the top. Eden fossils in upper part and Trenton fossils in lower part.	800	Sevier shale.
Ordovician.	Moccasin limestone.	Red to greenish-gray finely banded argillaceous limestone, sandstone, and shale.	400	Moccasin limestone.
Ordovician.	[Not present.]	Light-gray granular crystalline and compact dark-blue shaly limestones and calcareous shale. Fossils of uppermost Chazy age.	200	
Ordovician.	Athens shale.	Platy calcareous shale and dark-blue shaly limestone in upper part; dark-gray fissile shale below. Normanskill graptolite fauna.	500–600	Chickamauga limestone.
Ordovician.	Chickamauga limestone.	Fine-grained to coarse granular light-gray limestone. Numerous fossils of Stones River age.	400	
Ordovician.	Knox dolomite.	Interbedded impure gray laminated magnesian limestone and blue limestone, with thin sandstones and chert layers. Gastropods of Beekmantown age.	2,371	Knox dolomite.
Cambrian.		Coarse dolomite, generally weathered to red granular soil, some light-gray impure limestone, and chert with cryptozoans.	1,500±	
Cambrian.	Nolichucky shale.	Interbedded finely banded limestone and dark-gray shale. Trilobites and other fossils of Upper Cambrian age.	400–580	Nolichucky shale.
Cambrian.	Honaker limestone.	Coarse gray dolomite, thin-bedded fine-grained dolomite, and dolomite conglomerate, with round banded cherts. Closely resembles dolomite of Elbrook formation of northern areas.	600±	Honaker limestone.
Cambrian.	Russell formation.	Red shale and rusty-gray sandstone, with large rough cherts at the top. Equivalent to Watauga shale southwest of the area.	460	Russell formation.

CAMBRIAN SYSTEM.

Cambrian rocks are exposed in this area only southeast of the Rome fault. They are chiefly dolomite and limestone, with subordinate amounts of shale and sandstone. They comprise formations which have been described and mapped in adjacent areas as the Russell formation (lowest), Honaker limestone, Nolichucky shale, and the lower part of the Knox dolomite. Only the red shales, sandstones, and large rough cherts of the upper part of the Russell formation are known to be exposed in the area here described. To the southwest these beds have been called the Watauga shale. The Honaker limestone and Nolichucky shale are not readily distinguishable as separate formations in many parts of the area, but in general comprise a lower series of about 600 feet of coarse dolomite and thin-bedded finer-grained dolomite, with round banded cherts and dolomite conglomerate at the base, closely resembling the dolomite of the Elbrook formation of northern areas, and an upper series of about 500 feet of interbedded finely banded dark-blue limestone and shale. The shale decreases toward the east and is probably entirely absent at the east edge of the quadrangle, but even there the Nolichucky can generally be recognized by the marked finely siliceous banded character of some of the limestone beds and the flat-pebble "edgewise" limestone conglomerates.

The lower part of the Knox is largely a coarse dolomite which weathers to a deep-red granular soil but contains many harder light gray to blue impure limestone beds and cryptozoan-bearing cherts with wavy banding.

ORDOVICIAN SYSTEM.

The Ordovician rocks are largely limestones in the lower part and shales and sandstones above and form valleys and the slopes of mountains. The valleys, of which Rich Valley is the most important, are generally fertile. As described in reports on adjacent areas, these rocks comprise the upper part of the Knox dolomite and the Chickamauga limestone, Athens shale, Moccasin limestone, Sevier shale, and Bays sandstone, Only the Sevier and Bays formations occur northwest of the Rome fault in the area here described.

The upper part of the Knox is a thick series of interbedded hard, finely laminated light-gray impure magnesian limestone and purer blue limestones, with thin calcareous sandstones and massive white chert layers. It can generally be recognized by its rather meager fauna, chiefly gastropods, which indicate Beekmantown age. The Chickamauga limestone is largely a pure light-gray fine to coarse-grained limestone, about 400 feet thick, and is the best rock in the region for lime burning. Its fossils are of Stones River age. The lower part of the Athens shale is a dark-gray fissile shale, with thin limestone beds, containing a graptolite fauna, correlated by Ulrich with the Normanskill shale. Above these beds are dark-blue shaly limestones and calcareous shale with a meager graptolite fauna.

Overlying the Athens shale are dark-blue shaly and light-gray granular crystalline limestones containing numerous fossils, correlated by Ulrich with the uppermost part of the Chazy, which is called by him the Ottosee limestone. These beds are apparently not present to the southwest in the Bristol area. The beds at this horizon, together with the Athens shale, which becomes increasingly calcareous toward the northeast, have heretofore been included with the Chickamauga limestone in the Tazewell and Pocahontas quadrangles. The overlying Moccasin limestone is made up of finely banded argillaceous limestone, fine-grained marble, sandstone, and shale, is usually red and greenish in color, and contains few fossils. It is about 400 feet thick. The Sevier shale, a thick, soft light greenish-gray to buff shale, has thin-bedded limestones in the lower part and sandy beds and sandstones toward the top. The fossils of the limestones are correlated by Ulrich with the Trenton and those of the upper beds with the Eden, so that the formation closely resembles the Martinsburg shale of northern areas. The sandy beds grade into the Bays sandstone, a formation of coarse, loose-textured red to brown sandstone and red shale. Its lower portion contains numerous fossils of Maysville age, and the overlying apparently barren red beds may represent the Juniata or lower part of the Medina. As the Bays sandstone directly underlies the hard Clinch sandstone, it occurs chiefly in the upper slopes of the sandstone ridges.

SILURIAN SYSTEM.

The Silurian rocks are largely sandstones and sandy shales included in the formations previously mapped as Clinch sandstone and Rockwood formation. The Clinch, the mountain-making formation of the region, is a pure white quartzose sandstone or quartzite, about 200 feet thick in Clinch Mountain, where some of its massive layers are 25 feet thick. In Walker Mountain, on the southeast, it has a maximum thickness of 90 feet and thins out toward the southwest. No fossils were found in it except the supposed plant *Arthophycus harlani*, which in places covers large surfaces of the white rock. Above the sandstone are soft greenish-gray shale and red ferruginous sandstone, about 235 feet thick, which contain a typical Clinton fauna. Overlying these rocks are about 150 feet of sandy magnesian limestones and porous calcareous sandstones, which contain small ostracode and other shells characteristic of the Cayuga formation of the northern Appalachians. These two softer formations are not known to be exposed southeast of the Rome fault and are probably not present on the southeast slope of Walker Mountain.

DEVONIAN SYSTEM.

The Devonian rocks are largely shales and sandstones, but the lowest formation of this age is a massive chert. The sandstones form a high straight ridge named Pine Mountain and the shales the barren valley called Poor Valley. These strata, in the region to the north, have been described in ascending order as the Giles formation, Romney shale, and Kimberling shale and in the region to the south as the Hancock limestone, Chattanooga shale, and Grainger formation. The massive chert, 125 feet thick west of the fault, in part represents the Hancock limestone of the Bristol area and the Giles formation of the northern area, these formations apparently including also the underlying limestones of Cayugan age. The chert is generally very fossiliferous at the base, where it contains a well-recognized Oriskany fauna. Directly overlying the chert is a black coaly shale followed by fissile black shale, the whole 175 feet thick west of the fault, correlated by some geologists with the Chattanooga shale. It was found to contain a characteristic Genesee fauna and has the lithologic character and stratigraphic position of the Genesee shale. The black shale grades upward by gradual transition into olive-colored and gray fissile shale having a thickness of over 700 feet and containing a fine development of the Manticoceras fauna of the Portage formation. Beautifully preserved coiled cephalopods, 2 to 3 inches in diameter were collected from this shale. It is followed by sandy shales with thin beds of fine-grained sandstone, which becomes coarser and more abundant higher in the section. The fossiliferous coarser beds yield a characteristic Chemung fauna. The Devonian culminates in heavy, irregularly bedded, somewhat arkosic reddish sandstones, which also contain a meager Chemung fauna and probably represent a phase similar to the Catskill formation of New York. The strata of Chemung age are about 1,800 feet thick.

CARBONIFEROUS SYSTEM.

The Carboniferous strata exposed in the area include sandstone and shale in the lower part and limestone above. They comprise the Price sandstone, Maccrady ("Pulaski") formation, and Newman limestone of published reports. The Price sandstone, 400 feet thick, caps a high wooded mountain ridge and the limestone and shale form low rounded hills and valleys, which are generally cleared and used as pasture for cattle. In the upper layers of the Price sandstone are thin coal seams which increase in size, thickness, and range northeast of the area. Fossil shells at its base are of Mississippian age.

The Price is overlain by about 750 feet of dark shale, soft earthy sandstone, and thin impure limestone, which locally contain gypsiferous and saline clays that are of commercial value at several places along the great Rome fault. This formation is called the Maccrady. It contains numerous fossil shells and plants of Mississippian age, which find their closest ally, according to G. H. Girty, in the Moorefield shale of Arkansas. The Maccrady is followed by massive, highly fossiliferous limestones which grade upward into argillaceous or earthy limestones that weather to shales, the whole constituting the Newman limestone. The fauna is reported by Girty to be closely related to that of the Batesville sandstone of Arkansas. Near the top of the Newman limestone as exposed in the area is a red calcareous crinoidal sandstone. The exposed thickness of the Newman is 1,600 feet. The Pennington shale, also of Mississippian age, which overlies the Newman limestone in adjacent regions, is not present in this area.

STRUCTURE AND DISTRIBUTION OF THE FORMATIONS.

Southwestern Virginia lies within the closely folded belt of the Appalachian Mountains. The rocks occur in great elongated folds with axes trending northeast and southwest, their length being measurable in miles, some in hundreds of miles, and their height in hundreds and even thousands of feet. They are cut here and there by great longitudinal breaks or faults along which the strata have been displaced. (See fig. 36.)

The rocks were once sediments of various kinds deposited nearly horizontally in the sea and later consolidated, and the beds attained their present attitude by being compressed by powerful earth forces that bent the strata into great elongated folds at right angles to the direction of compression. The axial planes of the folds generally dip southeast, indicating that the compressive force near the surface acted from that direction. The faults also show this same direction

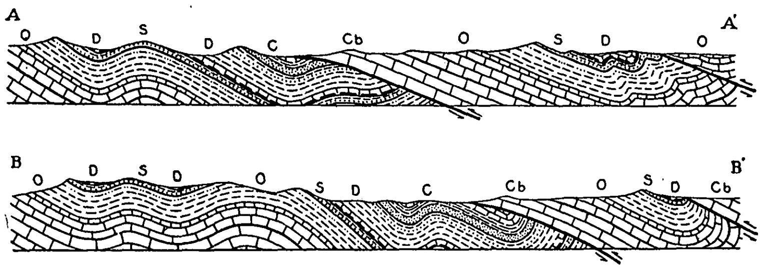

FIGURE 36.—Structure sections along lines A–A′ and B–B′, figure 35, showing the probable extent underground and relation of the phosphate-bearing rock. Cb, Cambrian rocks; O, Ordovician rocks; S, Silurian rocks; D, Devonian rocks; C, Carboniferous rocks. Horizon of the phosphate-bearing rock shown by heavy dashes. Scale, twice the scale of the map (fig. 35).

of movement, the rocks on the southeast of nearly every fault having been pushed or thrust over those on the northwest, in some places several thousand feet. Most of the faults originated in folds that were compressed to a degree beyond the shearing strength of the rocks, which thereupon yielded by fracture and by sliding along the fracture or fault plane.

Two such great faults cross the area here described. The larger one, called the Rome fault because it is continuous with the fault at Rome, Ga., passes through Plasterco, Saltville, Maccrady, and Broad Ford. On the northwest side of the fault is a compressed syncline of Carboniferous limestone and shale, whose axis pitches southwestward, and the syncline correspondingly deepens in that direction. Toward the northeast the Carboniferous rocks along the fault are partly hidden beneath the overthrust mass. Following the Carboniferous limestone and shale in monoclinal sequence northwestward are the basal Carboniferous sandstone and Devonian sandstone forming Pine Ridge, the Devonian interbedded shales and thin sandstones and chert underlying Poor Valley, the Silurian shales and sandstones forming the east slope and crest of Clinch Mountain, and the softer Ordovician rocks occupying most of the western slope of Clinch Mountain and coves on the eastern slope. Near the north edge of the area an anticline plunging northeastward causes the mountain-making Clinch sandstone and associated rocks to swing back, producing the offset of the mountain previously mentioned and a corresponding multiplication of ridges.

Directly adjacent to the Rome fault on the southeast are the lowest Cambrian strata exposed in the area. They are followed southeastward by successively higher strata through the Cambrian and Ordovician to the Clinch sandstone of the Silurian, forming Walker Mountain, and the Devonian shales in the valley on the southeast. Carboniferous sandstones, the highest rocks locally preserved in this syncline, form Brushy Mountain.

The second great fault, called the Walker Mountain fault, follows an irregular line at the east foot of Brushy Mountain and to the southwest cuts diagonally across the rocks of Walker Mountain until the mountain-making beds are cut off and the mountain terminates. Cambrian and Ordovician rocks form the front of the overthrust mass southeast of the fault. In the vicinity of Brushy Mountain some Silurian and basal Devonian beds are infolded next to the fault and are of special economic importance because of their content of phosphate.

PHOSPHATE ROCK.

OCCURRENCE.

The phosphate rock occurs at the base of strata of known Oriskany age and is probably basal Devonian. It has thus far been observed at only two places in the Abingdon quadrangle, but the horizon at which it occurs has been traced across the area, and its several bands are shown on the map. Careful search along these lines of outcrop will no doubt reveal the presence of the phosphate rock at many other places, although it seems to be represented by red ferruginous sandstone in certain sections.

TUMBLING CREEK.

One of the tributaries of North Fork of Holston River descends the steep southeastern slope of Clinch Mountain in Tumbling Creek and has bared the lower Devonian and upper Silurian rocks so that they are now exposed in the floor and cliffs of the narrow gorge at Henderson's mill. At no other place in the area were these rocks so well displayed for examination. Generally the slopes of the mountain are mantled by sandstone débris from above, and the chert formation is visible only in small scattered outcrops or is represented merely by loose fragments of chert, although better outcrops may be seen in some stream gorges. The general absence of good exposures of the soft rocks beneath the chert accounts for the lack of recognition of the phosphate bed at other points along the foot of Clinch Mountain.

The following detailed section was measured at Henderson's mill on Tumbling Creek:

Detailed section of the rocks containing the phosphate bed at Tumbling Creek, 5 miles west of Saltville.

	Feet.
Massive beds, 1 to 3 feet thick, of hard black and white flint and chert-bearing limestone, with numerous characteristic Oriskany fossils	24
Fine greenish conglomerate of small, rounded white quartz pebbles and limestone pebbles cemented by white calcite, and containing grains and large nodules of dark phosphate. About	1
Gray and reddish, finely laminated, porous, calcareous sandstone, greenish toward the top, with trace of calcium phosphate	14
Concretionary calcareous sandstone with shaly limestone, and wavy banding at the base	2
Thinly laminated drab limestone, weathering light gray, containing characteristic Cayuga Leperditia	12

Although the bed containing the phosphate nodules and grains in sufficient quantity to be called phosphate rock is a little less than a foot thick in this section, the sandstones just beneath seem also to contain a small amount of phosphate. From the nature of the deposit it probably varies in thickness more or less, and in the concealed portion it may be slightly thicker or thinner than where measured.

WALKER CREEK.

The other observed occurrence of phosphate rock is on Walker Creek at the east end of Brushy Mountain, 5 miles west of Marion, where the following section is exposed in the new roadway recently cut in the hillside west of the stream:

Detailed section on Walker Creek.

	Feet.
Nodular black flint with shaly partings. Contains characteristic Oriskany fossils	40
Fine rounded grains of shiny dark green glauconite, with phosphatic matrix, and nodules and layers of dense fine-grained phosphate rock	$1\frac{1}{3}$
Largely covered. Sandy limestone and chert with Oriskany fossils at the top	15
Thin-bedded light-green sandstone	15

Here also the concentrated phosphate rock is only a little over 1 foot thick, but the underlying sandstone is apparently also more or less phosphatic.

EXTENT.

As previously stated, although the phosphate bed has been observed at only two places, it probably has considerable extent along the outcrop of the beds at its horizon, shown on the map by the heavy dashed line. These beds lie along the southeast slope of Clinch Mountain between Devonian chert above and Silurian sandstone and shales below. From Tumbling Creek they follow the foot of Redrock Mountain and Flattop Mountain to the vicinity of Tannersville, where they swing back around the end of Flattop Mountain into Little Valley and then on northeast again, following the southeast foot of the offset Clinch Mountain. Two outliers of the horizon occur on the mountain top around Brier Cove and Laurel Bed.

Another line of outcrop of these beds was traced along the southeast side of Walker Mountain from a point near Emory northeastward as far as the edge of the area shown in figure 35. In this belt, however, the phosphate rock was not observed, although careful search will probably reveal its presence in places.

The belt along the outcrop of phosphate rock on Walker Creek is of small extent, perhaps 2 or 3 miles in length, as it is cut off in both directions by the Walker Mountain fault.

The extent of the phosphate rock underground can be only surmised, but as it is found at two points widely separated across the strike of the beds, it is probably more or less continuous underground between them. The rocks dip about 25° SE. along Clinch Mountain and the phosphate-bearing bed therefore descends in this direction at 25° from the horizontal for an indefinite distance and is eventually cut off by the Rome fault. About the same dip prevails on the east side of Walker Mountain, where the rocks at the phosphate horizon descend southeastward in the same way. At Walker Creek the dip is 55° SE., but as the chert is on the west and the sandstone on the east, the relations are inverted and the dips are overturned, as shown at the right in section A–A′, figure 36. The beds containing the phosphate therefore descend at 55° from the horizontal toward the southeast for a short distance, then steepen, and at no great depth turn back at the bottom of the syncline and connect with the Walker Mountain outcrop of these beds.

APPEARANCE AND CHEMICAL COMPOSITION.

The phosphate rock collected in this area is of four types. One, a conglomerate of white quartz pebbles a quarter of an inch in diameter and larger light-colored limestone pebbles, with black calcium phosphate nodules of similar size, in a dark greenish-gray phosphatic matrix, occurs at Tumbling Creek. The exposed surface of the rock is coated by the characteristic faint bluish-white film of calcium phosphate. Analysis of a phosphate nodule from this rock showed

16.72 per cent of P_2O_5, equivalent to 36.5 per cent of tricalcium phosphate.

Another type that occurs at Tumbling Creek is a granular sandstone of rounded quartz grains with calcareous and phosphatic cement containing scattered grains and larger nodules of calcium phosphate. The rock has a greenish color that is due apparently to the disseminated phosphate, and on weathering it becomes coated with the characteristic milk-white film. Analysis of the granular rock without phosphate nodules showed only 0.22 per cent of P_2O_5; 34 per cent was $CaCO_3$ and the rest largely insoluble silica.

The phosphatic glauconite rock from the Walker Creek area is composed of fine shiny grains of greenish-black glauconite in a light-gray phosphatic cement. The glauconite weathers rusty brown, which gives the weathered rock a mottled rusty color. Analysis of the glauconitic rock with little visible phosphatic matrix gave 1.17 per cent P_2O_5.

The phosphatic glauconite rock of Walker Creek grades into a very compact fine-grained gray phosphate by the gradual diminution of the glauconite grains and increase of the phosphatic matrix. It weathers at the surface to a thick white coating, which also forms along the smooth joint planes that cut through it. This is the richest phosphate rock collected, and its analysis shows 25.17 per cent of P_2O_5, equivalent to 54.97 per cent of tricalcium phosphate.

AGE AND ORIGIN.

The phosphate bed, as previously stated, occurs below chert containing Oriskany fossils and above rocks containing Cayuga fossils, the limestone of Helderberg age apparently being entirely absent. The phosphate bed, composed of grains and small pebbles of quartz, glauconite, and phosphate nodules, probably represents the beginning of Oriskany sedimentation after an interval of land conditions during Helderberg time.

The area was probably but slightly raised above the sea during this brief interval, so that erosion did not carry away the products of disintegration of the recently deposited sandy limestone of Cayugan age. As the lime was dissolved it left a regolith of quartz sand with scattered quartz pebbles, rounded fragments of partly dissolved impure limestone, and probably innumerable small shells of ostracodes which crowded the limestone. On the reinvasion by the sea glauconite grains were formed, possibly by the action of decomposing animal matter upon the iron and other minerals in the sea water, and phosphate nodules were formed by the concentration around organic centers of calcium phosphate probably dissolved from numerous phosphatic shells, possibly ostracodes. These were intermixed with the siliceous sediment to form the basal deposit of the Oriskany epoch.

During the rest of Oriskany time the land conditions were such that detrital material was not carried into this part of the sea, the deposits consisting of fine calcareous and siliceous ooze in which calcareous shells of mollusks and other marine animals that lived in the sea were buried. Later this ooze hardened to massive chert, and the fossil shells were also altered to silica.

TRANSPORTATION AND MARKET.

Although the deposits of phosphate here described are probably not of commercial value, those on Walker Creek are most favorably located for transportation, being but 3 miles by road down a gentle grade through an open country to the main line of the Norfolk & Western Railway, and but 5 miles from Marion. If deposits are found along the southeast slope of Walker Mountain at the horizon indicated, they will be almost as advantageously located, the railroad paralleling the mountain at a distance of about 4 miles. The Clinch Mountain locality is less accessible. The Tumbling Creek exposure is about 4 miles in an air line from the Saltville branch of the Norfolk & Western Railway, but the construction of a contemplated branch railroad up Poor Valley, which has already been surveyed, would make the east foot of Clinch Mountain readily accessible.

USES AND TREATMENT OF PHOSPHATE ROCK.

Phosphate rock is the most important source of phosphorus, which is one of the three necessary elements of plant food in all soils, the others being nitrogen and potash. Many soils that contain relatively large amounts of nitrogen and potash, but are deficient in phosphorus, are greatly benefited by the application of phosphate rock alone. The usual method of preparing phosphate rock for use as fertilizer is to dissolve it in an equal weight of sulphuric acid, a treatment that makes the phosphorus immediately available for the use of plants. The product is called superphosphate. Raw phosphate rock, either finely ground or roasted and ground, is used successfully on the heavier humus-bearing soils without further treatment or in combination with barnyard manure. If raw ground phosphate is applied to land, the phosphorus thus added to the soil is liberated for the use of the plant more gradually than if superphosphate is applied, but the amount of phosphorus eventually supplied to the soil from a ton of the raw phosphate is about double the amount supplied from a ton of superphosphate and the effects are said to be more lasting, though not so intense.

SURVEY PUBLICATIONS ON PHOSPHATES AND OTHER MINERAL FERTILIZERS.

The following papers relating to phosphates and other mineral materials used as fertilizers have been published by the United States Geological Survey or by members of its staff. Further references will be found under the head of "Gypsum."

The Government publications, except those to which a price is affixed, may be obtained free by applying to the Director, United States Geological Survey, Washington, D. C. The priced publications may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C. The one marked "Exhausted" is not available for distribution but may be seen at the larger libraries of the country.

Blackwelder, Eliot, Phosphate deposits east of Ogden, Utah: Bull. 430, 1910, pp. 536–551.

——— A reconnaissance of the phosphate deposits in western Wyoming: Bull. 470, 1911, pp. 452–481.

Darton, N. H., and Siebenthal, C. E., Geology and mineral resources of the Laramie Basin, Wyoming; a preliminary report: Bull. 364, 1909, 81 pp.

Eckel, E. C., Recently discovered extension of Tennessee white-phosphate field: Mineral Resources U. S. for 1900, 1901, pp. 812–813. 70c.

——— Utilization of iron and steel slags: Bull. 213, 1903, pp. 221–231. 25c.

——— The white phosphates of Decatur County, Tenn.: Bull. 213, 1903, pp. 424–425. 25c.

Eldridge, G. H., A preliminary sketch of the phosphates of Florida: Trans. Am. Inst. Min. Eng., vol. 21, 1893, pp. 196–231.

Gale, H. S., Rock phosphate near Melrose, Mont.: Bull. 470, 1911, pp. 440–451.

Gale, H. S., and Richards, R. W., Preliminary report on the phosphate deposits in southeastern Idaho and adjacent parts of Wyoming and Utah: Bull. 430, 1910, pp. 457–535.

Girty, G. H., The fauna of the phosphate beds of the Park City formation of Idaho, Utah, and Wyoming: Bull. 436, 1910, 82 pp.

Hayes, C. W., The Tennessee phosphates: Sixteenth Ann. Rept., pt. 4, 1895, pp. 610–630. $1.20. Also Seventeenth Ann. Rept., pt. 2, 1896, pp. 519–550. $2.35.

——— The white phosphates of Tennessee: Trans. Am. Inst. Min. Eng., vol. 25, 1896, pp. 19–28.

——— A brief reconnaissance of the Tennessee phosphate field: Twentieth Ann. Rept., pt. 6, 1899, pp. 633–638. $1.

——— The geological relations of the Tennessee brown phosphates: Science, vol. 12, 1900, p. 1005.

——— Tennessee white phosphate: Twenty-first Ann. Rept., pt. 3, 1901, pp. 473–485. $1.75.

HAYES, C. W., Origin and extent of the Tennessee white phosphates: Bull. 213, 1903, pp. 418–423. 25c.

IHLSENG, M. C., A phosphate prospect in Pennsylvania: Seventeenth Ann. Rept., pt. 3, 1896, pp. 955–957. $1.

MEMMINGER, C. G., Commercial development of the Tennessee phosphates: Sixteenth Ann. Rept., pt. 4, 1895, pp. 631–635. $1.20.

MOSES, O. A., The phosphate deposits of South Carolina: Mineral Resources U. S. for 1882, 1883, pp. 504–521. 50c.

ORTON, EDWARD, Gypsum or land plaster in Ohio: Mineral Resources U. S. for 1887, 1888, pp. 596–601. 50c.

PENROSE, R. A. F., Nature and origin of deposits of phosphate of lime: Bull. 46, 1888, 143 pp. Exhausted.

PARDEE, J. T., Some further discoveries of rock phosphate in Montana: Bull. 530, 1913, pp. 285–291.

PHALEN, W. C., Phosphate rock in 1912: Mineral Resources U. S. for 1912, 1913.

PURDUE, A. H., Developed phosphate deposits of northern Arkansas: Bull. 315, 1907, pp. 463–473. 50c.

RICHARDS, R. W., and MANSFIELD, G. R., Preliminary report on a portion of the Idaho phosphate reserve: Bull. 470, 1911, pp. 371–439.

——— Geology of the phosphate deposits northeast of Georgetown, Idaho: Bull. 577 (in preparation).

SCHULTZ, A. R., Geology and geography of a portion of Lincoln County, Wyoming: Bull. 543, 1914, 141 pp.

SCHULTZ, A. R., and RICHARDS, R. W., A geologic reconnaissance in southeastern Idaho: Bull. 530, 1913, pp. 267–284.

STOSE, G. W., Phosphorus ore at Mount Holly Springs, Pennsylvania: Bull. 315, 1907, 474–483. 50c.

——— Phosphorus: Mineral Resources U. S. for 1906, 1907, pp. 1084–1090. 50c.

STUBBS, W. C., Phosphates of Alabama: Mineral Resources U. S. for 1883–84, 1885, pp. 794–803. 60c.

VAN HORN, F. B., The phosphate deposits of the United States: Bull. 394, 1909, pp. 157–171.

——— Phosphate rock: Mineral Resources U. S. for 1911, pt. 2, 1912, pp. 877–888.

WEEKS, F. B., Phosphate deposits in the western United States: Bull. 340, 1908, pp. 441–447. 30c.

WEEKS, F. B., and FERRIER, W. F., Phosphate deposits in western United States: Bull. 315, 1907, pp. 449–462. 50c.

WILBER, F. A., Greensand marls in the United States: Mineral Resources U. S. for 1882, 1883, pp. 522–526. 50c.