THE PHOSPHATE DEPOSITS OF SOUTH CAROLINA.

By G. Sherburne Rogers.

INTRODUCTION.

The deposits of phosphate rock in the vicinity of Charleston, S. C., were among the first discovered in the United States, and until about 20 years ago the field was one of the largest producers in the world. The workable deposits are confined to the region lying in general between Charleston and Beaufort and extending about 25 miles back from the coast. The phosphate rock occurs in a thin bed which underlies irregular areas within the region defined. This bed is commonly less than 18 feet below the surface, and is thus comparatively easy to mine, but, owing to the rather low grade of the rock and the exploitation of richer and more easily accessible deposits in Florida and Tennessee, production in the South Carolina field has now almost ceased. A number of papers describing this field have been published, most of them 20 years or more ago, but in view of the present more extended geologic information concerning this region it has been thought advisable to prepare this account, which is based on a brief field study by the writer.

The examination of the field was made in January, 1914. The writer is indebted to Mr. Earle Sloan, formerly State geologist of South Carolina, for many courtesies and for some unpublished information concerning the geology. Mr. John Hertz, who has long been engaged in phosphate mining, kindly contributed several maps and furnished valuable data, and Messrs. William Gaillard, Bachman Smith, and William Alston assisted in many ways. In addition to information privately communicated, several of the earlier reports on the field have been freely drawn upon for pertinent facts.

The earliest report on the phosphate deposits was published in 1868 by N. A. Pratt,[1] and this was followed in 1870 by a more extended account by F. S. Holmes.[2] Both of these papers are written in narrative and more or less popular form. In 1870 N. S. Shaler[3] contributed a short scientific description. In 1880 C. U. Shepard, jr.,[4]

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[1] Ashley River phosphates, Philadelphia, 1868.

[2] Phosphate rocks of South Carolina, Charleston, 1870.

[3] On the phosphate beds of South Carolina: Boston Soc. Nat. Hist. Proc., vol. 13, pp. 222–235, 1870: U. S. Coast Survey Rept., pp. 182–189, 1870.

[4] South Carolina phosphates, Charleston, 1880.

published the most complete and valuable of the earlier reports on the field. In 1888 R. A. F. Penrose, jr.,[1] wrote for the United States Geological Survey a bulletin on phosphate which contains a good though brief account of the South Carolina deposits. In 1891 a book on American phosphate by Francis Wyatt[2] appeared, in 1892 a book on phosphate by C. C. H. Millar,[3] and in 1895 a study of the phosphate industry by David Levat,[4] all three of which deal with the South Carolina field at greater or less length, but discuss chiefly the mining and product costs. Charles L. Reese[5] published a short paper on the region of the deposits based on a series of chemical experiments. An extended account of the field and narrative of its discovery and history, prepared primarily for newspaper publication, was written by P. E. Chazal[6] in 1904. In 1908 Earle Sloan,[7] State geologist, published a "Catalogue of the mineral localities of South Carolina," which contains geologic sections measured at a number of places and a short account of the phosphate. In 1913 William H. Waggaman,[8] of the United States Department of Agriculture, wrote a brief report on the field, dealing chiefly with the state of the industry and methods of production. In addition to these general papers, an elaborate description by Joseph Leidy[9] of the vertebrate fossils found in the phosphate beds appeared in 1881, and a brief account of some of the invertebrate forms by W. H. Dall[10] in 1894.

GEOGRAPHY AND TOPOGRAPHY.

The phosphate deposits are confined to a seaboard zone, most of it less than 30 miles in width, which extends from Beaufort on the south to a point about 20 miles beyond Charleston on the north. (See Pl. II.) The most important deposits, however, are situated between the mouth of Broad River and a point near the source of Wando River and lie within a rough arc terminating at these points and extending farthest back along Edisto River. Within this segment the phosphate underlies irregular areas whose boundaries have not been exactly defined but which are approximately delimited on the accompanying map.

The principal cities within this area are Charleston and Beaufort, the former being the center of the phosphate and fertilizer industry.

1 Nature and origin of deposits of phosphate of lime: U. S. Geol. Survey Bull. 46, pp. 60–70, 1888.

2 Phosphates of America, pp. 44–61, New York, 1891.

3 Florida, South Carolina, and Canadian phosphates, pp. 123–178, London, 1892.

4 Industrie des phosphates et superphosphates, pp. 83–90, Paris, 1895.

5 On the influence of swamp waters in the formation of the phosphate nodules of South Carolina: Am. Jour. Sci., 3d ser., vol. 43, pp. 402–406, 1892.

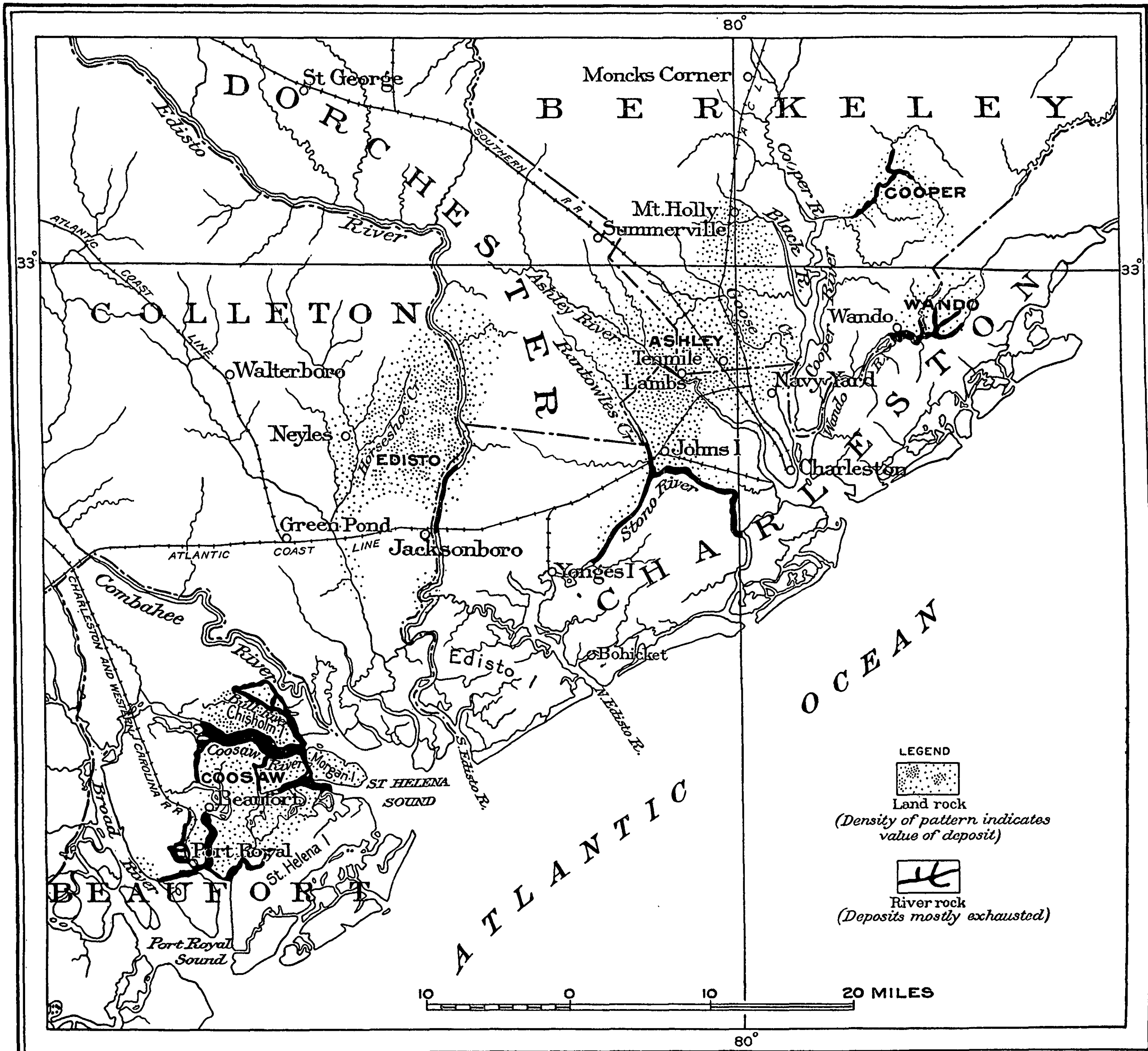
6 Sketch of the South Carolina phosphate industry, Charleston, 1904.

7 South Carolina Geol. Survey, 4th ser., Bull. 2, 1908.

8 Report on the phosphate fields of South Carolina: U. S. Dept. Agr. Bull. 18, 1913.

9 Description of vertebrate remains, chiefly from the phosphate beds of South Carolina: Jour. Acad. Nat. Sci. Philadelphia, vol. 8, 2d ser., pp. 209–262, 1874–1881.

10 Notes on the "land phosphate" of the Ashley River district, S. C.: Am. Jour. Sci., 3d ser., vol. 48, pp. 300–301, 1894.



MAP SHOWING APPROXIMATE ORIGINAL DISTRIBUTION OF SOUTH CAROLINA PHOSPHATE DEPOSITS.

In previous years a large amount of phosphate rock was shipped from these points or from docks located farther up the rivers in their vicinity. The Atlantic Coast Line, the Southern Railway, and the Charleston & Western Carolina Railway cross the area, and most of the phosphate properties are located either on the main lines or on short spurs of these roads.

The coast in this vicinity is low and extremely irregular in outline and is bordered by numerous islands. It is intersected in the most intricate manner by numberless tidewater channels which range in width from a few feet up to several miles, one of the widest being Broad River at Port Royal. Many of these channels run almost parallel to the coast and thus form islands, and in some localities they have intersected the coast to such an extent that two or three tiers of islands have been formed.[1] In addition to these arms of the sea, many of which extend considerable distances back from the coast proper, some of the streams and rivers that traverse this region have developed a system of tidewater distributaries. Edisto, Ashepoo, and Broad rivers are conspicuous examples of streams of this type, which, in conjunction with the waterways mentioned above, have intricately dissected the general coastal region. (See Pl. II.) Most of the rivers are broad, sluggish streams and are navigable for considerable distances above their mouths, affording ready means of transportation for the phosphate.

The topography within the whole phosphate-bearing area is very uniform, being everywhere of the Coastal Plain type. The land is almost flat and is for the most part less than 15 feet above tide; elevations of more than 25 feet are uncommon. Most of it is wooded and is swampy in character, being practically covered with water for at least part of the year. In the course of the phosphate mining during the last 45 years many large areas have been worked over with steam shovel or by hand, and these tracts, in which the surface is broken, swampy, and covered with dense thickets, are now practically impassable.

GEOLOGY.

STRATIGRAPHY.

SEQUENCE OF THE STRATA.

Owing to the wealth of fossil remains which some of the strata in this region contain they have attracted the attention of many observers. Ruffin,[2] Tuomey,[3] Pratt,[4] Holmes,[5] and Shepard,[6] all give more

[1] A good account of the configuration of the coast, the submarine topography, etc., is given by N. S. Shaler in U. S. Coast Survey Rept., 1870, pp. 182–185.

[2] Ruffin, Edmund, Agricultural survey of South Carolina, Columbia, 1843.

[3] Tuomey, Michael, Report on the geology of South Carolina, Columbia, 1848.

[4] Pratt, N. A., Ashley River phosphates, Philadelphia, 1868.

[5] Holmes, F. S., Phosphate rocks of South Carolina, Charleston, 1870.

[6] Shepard, C. U., jr., South Carolina phosphates, Charleston, 1880.

or less extended descriptions of the geology. Their work has been largely superseded, however, by the detailed investigations of Sloan[1] and the broad areal studies of Vaughan.[2] In conformity with the results of this recent work the following classification has been adopted by the United States Geological Survey for the formations treated in this report:

Geologic formations related to the phosphate deposits of the Charleston region, S. C.

System.	Series.	Formation.	Approximate thickness.	Character.
Quaternary.	Pleistocene.	Undifferentiated.	*Feet.* Variable.	Sand, gravel, loam, etc.
		Unconformity		
Tertiary.	Pliocene.	Waccamaw marl.	11	Compact granular marl; upper part brownish yellow, lower part gray.
		Unconformity		
	Miocene.	Duplin marl.	35	Yellow marl; upper part very hard, characterized by *Pecten eboreus;* middle compact to porous, containing *Chama striata* and *Arca incile;* lower friable and porous, containing *Amusium mortoni.*
		Unconformity		
		Edisto marl.	0–4	Marl, commonly more or less phosphatized; compact in texture, but containing many large cavities; color light where unaltered, darker where phosphatized; source of the commercial phosphate.
		Unconformity		
	Oligocene.	Apparently unrepresented in this area.		
	Eocene.	Cooper marl.	100+	Marl, light grayish green to dark greenish drab.

TERTIARY SYSTEM.

EOCENE SERIES.

Cooper marl.—The Cooper marl is the lowest formation here considered, though earlier Eocene is well developed within the general phosphate-bearing area. The Cooper conformably overlies the Barnwell sand (equivalent in part to the Mount Hope marl of Sloan), which is the highest formation of the Claiborne group in this region. The Cooper is therefore in whole or in part referable to the Jackson group, the highest division of the Eocene, but diagnostic fossils are rare and the exact age of the upper part of the formation has not yet been determined. The Cooper is, however, almost entirely late Eocene, but its higher strata may have been deposited in early Oligocene time.

The formation consists of over a hundred feet of grayish-green marl; the lower part (the Cooper marl of Sloan) is greenish drab in color and somewhat plastic when wet, but lighter colored and fairly

[1] Sloan, Earle, South Carolina Geol. Survey, 4th ser., Bull. 2, 1908.

[2] For discussion by Vaughan see Willis, Bailey, Index to the stratigraphy of North America: U. S. Geol. Survey Prof. Paper 71, pp. 806–813, 1912.

hard when dry. It commonly contains about 75 per cent lime carbonate and about 2 per cent lime phosphate. The upper part of the formation (the Ashley marl of Sloan) is dull olive green and semiplastic when wet and drab when dry. The content of lime carbonate is somewhat lower than that of the lower division of the formation, but the phosphate is considerably higher, commonly exceeding 5 per cent. (See analyses, p. 208.)

Shepard[1] gives an interesting well section made at Sineaths station, which presumably includes the greater part of the Cooper and probably also part of the underlying Claiborne group. The section is, unfortunately, not complete, but gives only the depth of certain strata which Shepard analyzed for phosphate. (See analyses, p.208.) It shows, however, that thin layers of large nodules containing 50 per cent or more of phosphate occur at depths of 26, 70, and 110 feet below the surface, and that the inclosing marl contains phosphate in amounts varying from a trace to 3 per cent.

The exact thickness of the Cooper marl has not been determined. The Cooper is being quarried at Woodstock, about 15 miles north of Charleston. At the time of the writer's visit only about 65 feet was exposed, but it is reported that the base of the marl had been reached by drilling to a depth of 140 feet. It is possible, however, that this may include part of an underlying formation. An excellent section of the Cooper is exposed at the Woodstock pit, from which about 5,000 tons a year is quarried for use as a base or "filler" for the commercial fertilizer. The marl is sufficiently coherent to form the vertical walls of the deep pit, yet soft enough to be worked with pick and shovel. It is blasted out, broken up, and transported by bucket hoist to the shed, where it is burned and ground. The marl is compact and impervious to water, so that the pit is fairly dry. Invertebrate fossils are rather scarce, but fragments of bone are not uncommon.

OLIGOCENE SERIES.

In the phosphate area the Oligocene is apparently not represented, and the Edisto marl (Miocene), the source of the phosphate with which this paper is primarily concerned, rests directly on the Cooper marl (Eocene).

It may be pointed out, however, that the absence of Oligocene strata does not necessarily imply that they were never deposited. The Cooper marl may overlap slightly into Oligocene time (see p. 186), and this suggests that there may have been no marked break at the

[1] Shepard, C. U., jr., Rural Carolinian, August, 1873. See also Chazal, P. E., loc. cit., and Waggaman, W. H., loc. cit.

end of the Ecoene and that deposition may have continued for some time. If it did, then all the strata down to the present top of the Cooper must have been eroded during the subsequent elevation of the land.

MIOCENE SERIES.

Edisto marl.—In this region the Edisto marl, the source of the phosphate rock, rests directly and unconformably on the Cooper marl, the hiatus representing all or nearly all of the Oligocene as well as the lowest Miocene. Similarly, the Edisto is commonly overlain directly by the Quaternary, although two higher Tertiary formations are well recognized in this general area. Although its identifiable fossils are few the Edisto is believed by Vaughan [1] to be middle Miocene—about equivalent to the St. Marys formation of Maryland and Virginia. The opinions of the older workers as to the age of the Edisto differed widely. Tuomey [2] referred it to the Eocene; Holmes, Shepard, and Chazal considered it an altered conglomerate of Eocene marl deposited in post-Pliocene time; and Pratt believed it to be Recent. Dall [3] in 1894 first definitely established its age as Miocene.

According to Sloan [4] the Edisto in its unaltered form is a yellow-white marl, commonly 4 to 5 feet thick. Although compact in texture it is penetrated in many places by tortuous cavities, some organic in origin and others apparently due to solution. It has been found in its unaltered form at only a few localities, being commonly phosphatized. The two forms may be observed in close proximity in the bed of Stono River near the mouth of Wappoo Cut. In the phosphatized form the bed is generally thinner, averaging about 1 foot and at few places exceeding 2½ feet. The phosphatized mass is fairly hard and is irregular in outline and honeycombed with many cavities. These may reach 4 inches or more in diameter and in some localities are so large that the rock is mostly broken up into irregular nodules. The filling of the cavities (or of the matrix when the bed is separated into fragments) is a black sandy clay, generally calcareous and phosphatic and in many places carrying abundant vertebrate remains. These are chiefly cetacean bones and sharks' teeth and vertebræ, but the coprolites and bones of late Miocene, Pliocene, and Quaternary land animals are also plentiful. A few distinctively Eocene shells, generally waterworn, are also found in this material. The phosphate rock itself, however, contains numerous casts and molds of the same shells that characterize the unaltered Edisto marl.[5]

In addition to this regularly stratified form the phosphate rock is also found in irregular deposits in the beds of many of the rivers.

[1] U. S. Geol. Survey Prof. Paper 71, p. 807, 1912.
[2] Tuomey, Michael, op. cit., pp. 164-165.
[3] Am. Jour. Sci., 3d ser., vol. 48, pp. 300-301, 1898.
[4] Sloan, Earle, op. cit., p. 470.
[5] Idem, p. 299.

This river rock generally consists of rounded pebbles, and is commonly darker in color and higher in specific gravity than the ordinary land rock. It is probable that these deposits were in part laid down during Edisto time, but that they were subsequently worked over by river action and were increased in thickness by the erosion and concentration of the land deposits.

Duplin marl.—The Duplin marl, an extension of the marl of the same name in North Carolina, includes the "Peedee" and "Goose Creek" marls of Sloan. It is upper Miocene in age. The lower part of the Duplin marl (the "Goose Creek marl" of Sloan) is a soft yellow porous marl containing over 80 per cent of carbonate of lime. According to Sloan it overlies the unphosphatized Edisto[1] at Givhams Ferry, and its outcrop near Goodrich station sharply delimits on the south that of the phosphatized Edisto.[2] At the latter place it contains near the contact nodules of phosphate rock that prove it to be younger, but although it presumably overlies the phosphate to the south it was not actually observed in this position. Except for these two localities the Edisto and Duplin marls have not been observed in the same section and in the main appear to occupy different areas.

The soft yellow porous marl is overlain in places by 25 feet of harder and more compact yellow marl, to which Sloan has applied the name "Peedee marl." There appears to be no significant faunal or lithologic differences between the two, however, and they are therefore grouped by Vaughan under the name Duplin marl. The upper member ("Peedee marl" of Sloan) has not been observed in contact with the Edisto.

PLIOCENE SERIES.

Waccamaw marl.—The Pliocene series in South Carolina is represented by the Waccamaw marl, which occurs only in Horry County near the North Carolina-South Carolina State line. It is not found in contact with the Edisto, the phosphate-bearing formation, and is here included for the sake of completeness. It is described by Sloan as a compact granular marl about 11 feet thick, brownish yellow at the top and gray beneath.

QUATERNARY SYSTEM.

PLEISTOCENE SERIES.

The Pleistocene deposits have been differentiated by Sloan into a number of subdivisions, but as their broader relations are not well established they are here treated as a unit. Because of the conditions described above, the Pleistocene generally rests directly on the Edisto within the phosphate-bearing area and constitutes the overburden

[1] Sloan, Earle, op. cit., p. 283. [2] Idem, p. 291.

which must be removed in mining. It consists of clay, marl, sand, and gravel, 20 feet or more in thickness. This material has been divided by Sloan [1] as follows:

5. Sea Island loams. Fine, glauconitic sand and silt, probably derived from the reworking of the Bohicket marl sands.

4. Wando clays and sands. White sand overlain by drab to red clay.

3. Accabee gravels, generally absent. Pebbles of quartz and phosphate rock derived from the reworking of the Edisto marl.

2. Bohicket marl sands. Fine-grained, greenish to bluish-green glauconitic sand.

1. Wadmalaw marl. Greenish-gray sandy marl inclosing large numbers of Pleistocene shells.

This classification appears to hold within the phosphate-bearing area, although the complete section is probably not exposed at any one place. In addition Sloan differentiates what he calls the Tenmile sands, which were deposited in early Pleistocene time in the form of a barrier ridge, on the seaward side of which the above-mentioned deposits were laid down.

Sloan's Wadmalaw marl is in general only 2 to 3 feet thick and is fairly persistent. It is overlapped by his Bohicket marl sands, which extend several miles beyond it to the north and are almost invariably present in the material overlying the phosphate and in places are 10 feet or more thick. These deposits are somewhat glauconitic and at the Bolton mines contain 2.19 per cent of potash. The Accabee gravels of Sloan form an interesting example of the reworking of an older bed. According to Sloan the material was derived from the partial disruption of the shoreward edge of the Edisto marl by wave action, especially in the Wando and Cooper basins. The area of the gravel is very small; where present it is generally less than a foot thick, though in places it attains a thickness of 4 feet. It has afforded a limited supply of phosphate and is known to the miners as the "Flying Rock bed." The Wando clays and sands of Sloan overlie the gravel in places, the sands being widely distributed. Sloan's Sea Island loams are best developed along the zone of the sands to which he applied the name "Bohicket" and are probably derived from them.

The character of the Pleistocene deposits that overlie the Edisto is illustrated by the following sections:

Section at Bolton mine, Charleston County.[2]

	Feet.
Vegetable muck	4
Clay, green, sandy, glauconitic (Bohicket of Sloan)	5
Sand (Bohicket of Sloan)	3
Marl, highly fossiliferous (Wadmalaw of Sloan)	2
Phosphate rock (Edisto)	2
	16

[1] Sloan, Earle, op. cit., pp. 480–484.

[2] Idem, p. 298.

Section near Lambs, Charleston County.

[Measured by G. S. Rogers.]

	Feet.
Vegetable muck	1
Sand, white, brownish at top (Wando (?) of Sloan)	6
Sand, yellow	1
Sand, bluish-green, clayey (Bohicket of Sloan)	3
Phosphate rock (Edisto)	1
	12

Section at Simmons Bluff, Youngs Island, Colleton County.[1]

	Ft.	in.
Soil, sandy	2	0
Wando (?) of Sloan:		
Loam, red, becoming clayey toward base	6	0
Clay, white, sandy, plastic	1	6
Sand, white, fine	1	6
Bohicket of Sloan:		
Clay, green, glauconitic	3	0
Wadmalaw of Sloan:		
Loose shells	3+	
	17+	

STRUCTURE.

The strata in the South Carolina phosphate area have undergone little or no tilting and for the most part lie almost flat. Such variations from the horizontal as they exhibit are due chiefly to the character of the old surface on which they were deposited. All the formations have a slight but gentle dip toward the sea owing to the shelving character of the old surface; and as this surface was in places irregular most of the formations vary considerably in thickness and in some localities are absent.

GEOLOGIC HISTORY.

During late Eocene time the region here considered was covered by the sea and the submergence may have extended into early Oligocene time. During this period the Cooper marl was laid down to a thickness of over 125 feet. At some time during the Oligocene the land was elevated and remained above the sea for a long time, during which a portion of the upper part of the Cooper was removed by erosion. According to Sloan the shore line during this period was roughly coincident with the present position of Wando and Stono rivers. (See Pl. II.) At the opening of the middle Miocene the land was again partly submerged, and the Edisto was deposited on the irregular upper surface of the Cooper. The hills of the old surface were perhaps in part submerged and in part formed low islands, on which the Edisto was never laid down. This formation thus appears to be entirely

[1] Sloan, Earle, op. cit., p. 300.

lacking in the area between Ashepoo and Combahee rivers and in several smaller districts. The old surface was somewhat shelving, as is indicated by the present slight dip (3.3 feet to the mile) of the Edisto toward the sea. Farther seaward this inclination of course increased, and the Edisto therefore dips sharply below the present surface along the southern boundary of the phosphate area, as indicated roughly on the map (Pl. II). Thus, according to Shepard,[1] the Edisto at Charleston is about 60 feet below the surface. After its deposition the Edisto marl underwent certain chemical changes, which increased its phosphate content. (See p. 206.)

At the end of Edisto time a slight elevation of the land took place and the Duplin marl was laid down within the area which still remained below water. A further elevation of land occurred at the end of Miocene time, and no more marine sediment was laid down in the immediate phosphate area until the Pleistocene.

According to Sloan the earliest Pleistocene formation is his Tenmile sands, which were deposited in the form of a barrier ridge along a zone near the north border of the phosphate area. During the gradual subsidence which followed, the deposits called by Sloan the Wadmalaw, Bohicket, and Accabee were deposited against the seaward side of this ridge as a progressively overlapping series. The relations of the deposits to which he gave the names Wando and Sea Island are less clear, but they appear to have been laid down during the gradual reelevation which doubtless brought the land to its present altitude.

PHOSPHATE ROCK.

PHYSICAL CHARACTER.

The phosphate was described by Pratt in 1868 and by Shepard in 1880 as essentially nodular in character, and this description has apparently been followed by most subsequent writers. From a commercial standpoint this description is sufficient, for the land phosphate as mined generally occurs in small and more or less rounded fragments, and the river rock, which was extensively mined in the early days of the industry when the term was first used, is decidedly nodular in appearance. Geologically, however, the term is unfortunate, for it implies much in the way of genesis and history that is probably incorrect.

The two varieties of the phosphate, land rock and river rock, differ somewhat in character. The land rock occurs in a more or less irregular bed which represents the undisturbed phosphatized Edisto marl; the river rock probably consists in part of the original phosphatized Edisto and in part of fragments derived from the land deposits and

[1] Shepard, C. U., jr., South Carolina phosphates, p. 20, Charleston, 1880.

concentrated on the river bottom, the whole deposit having been more or less worked over by river action. To these may be added a third kind, the Accabee gravels of Sloan, which are a later deposit formed by the reworking of the original bed.

The land rock occurs in a bed which has a maximum thickness of 30 inches, but averages probably between 8 and 16 inches, and is in many places absent. It generally consists of an irregular or even jagged mass of rock honeycombed by many tortuous cavities, but its upper surface is in many places smoother and more compact than the lower. In places the cavities are as much as 4 inches in diameter and thus afford lines of weakness which cause the bed to break up easily when disturbed in mining. The cavities are probably due chiefly to solution; their interiors are generally smooth, and when the rock is broken up a fragment resembles a very irregular nodule, the surface of which is partly smooth and partly rough and broken. Associated with the rock is a black sandy clay which contains a minor amount of small rounded phosphate nodules.

The term nodule was applied by the earlier writers to the whole mass, and even the large pieces removed in mining were described as "made up of nodules cemented together." Loosely scattered nodules are referred to by some of the older writers,[1] however, and it is probable that the solvent action was sometimes strong enough to enlarge the cavities until the mass was actually broken up. Some of the fragments are described as coated with a hard and lustrous enamel, but so far as can now be ascertained such fragments were of the river variety. No instance of concretionary structure in land rock is mentioned by any of the earlier writers. Moreover, the rock contains many casts and molds of the same species that characterize the unaltered Edisto marl,[2] and there seems little doubt that it is really a bed of irregularly phosphatized marl rather than a mass of concretionary nodules.

The rock varies considerably in color, hardness, and specific gravity, these characters being partly dependent on the degree of phosphatization. Much of the material now being mined is light yellowish brown in color and is soft and chalky. All variations in color from light brown to very dark gray are exhibited, and as the color deepens the hardness and specific gravity increase. A dark rock generally contains more lime phosphate per unit volume than a light-colored one and is therefore considered more valuable.

The cavities in the phosphate rock are filled with sandy clay, which is generally calcareous and somewhat phosphatic. Its color appears to depend largely on that of the rock with which it is associated. In

[1] Shaler, N. S., On the phosphate beds of South Carolina: Boston Soc. Nat. Hist. Proc., vol. 13, pp. 222-235, 1870.

[2] Sloan, Earle, op. cit., p. 299.

places this material contains quartz pebbles and pebbles or small nodules of phosphate rock. It also carries the abundant remains of many species of vertebrates which are not found within the rock mass itself.

The river rock occurs generally in loose and more or less rounded fragments of nodular aspect, which have accumulated in irregular banks on the river bottoms. In many localities they are well rounded and are inclosed by hard lustrous enamel. Penrose [1] distinguishes six different varieties of the river rock by their color and the presence or absence of enamel. The river rock is generally darker in color than the common land variety, being dark brown or gray or even jet-black. It is higher in specific gravity than the ordinary land rock and is generally harder, especially when inclosed by enamel. Some varieties are highly siliceous, the grains of sand being visible to the naked eye. According to Penrose some of the rock from Bull River exhibits a distinct concretionary structure, but this is very uncommon. In Morgan River and elsewhere the river rock has been found in a thin and more or less continuous bed like that of the ordinary land deposits, but it generally occurs in thick but irregular banks. Some of these deposits are fairly free from mud and sand and yield a product which requires little washing. In others the proportion of matrix is greater and may increase laterally until the phosphate is too sparsely scattered to allow mining. As would be expected in a river deposit, the distribution of the rock is generally very irregular, as is also the character of the overlying and underlying material. Where the river rock occurs as a more or less continuous and undisturbed bed it appears to rest upon the Cooper marl, but in its more common reworked condition it is generally separated from the marl by clay or sand.

Some writers have differentiated a third type which they call marsh deposits. These occur in a bed similar to the ordinary land deposits, but have the dark color and higher specific gravity of the river rock. They represent merely the undisturbed phosphate bed which has undergone certain changes. (See p. 209.)

The irregular deposits of phosphate and quartz pebbles known to the miners as the "Flying Rock bed" (the Accabee gravels of Sloan) are derived from the reworking of the original land deposits. They are chiefly of scientific interest, although at some places they have yielded a limited amount of phosphate.

[1] Penrose, R. A. F., jr., Nature and origin of deposits of phosphates of lime: U. S. Geol. Survey Bull. 46, pp. 60-70, 1888.

CHEMICAL COMPOSITION.

The commercial rock varies greatly in phosphate content, but at no place does it contain more than 64 per cent in the washed but unburned condition. Waggaman[1] states that isolated fragments have been found which contain as much as 75 per cent, but these do not occur in commercial quantity. Some of the rock mined in the Edisto district averages 62 per cent (see analysis 7, p. 196), but it is probable that the general average for the South Carolina area would approximate 58 per cent. There are many districts in which the phosphate content is as low as 55 or 53 per cent.

According to Shepard,[2] who made many hundred analyses of the South Carolina phosphate, the composition varies greatly in even one piece of rock. Thus the upper portion of the bed, which is generally flat and compact, is commonly somewhat higher in phosphate than the lower, more irregular, honeycombed portion. Similarly the exterior of a river nodule, especially when coated with enamel, may run 2 per cent or more higher in phosphate than the interior. The composition of the rock from a broad district is naturally even more variable, and irregular areas are sometimes found in mining in which the rock is of too low grade to work. The composition of the average commercial product, however, is fairly uniform.

In the following table are given fourteen analyses of the average commercial South Carolina product compiled from various sources, and three type analyses of the commercial Florida rock, inserted for comparison:

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[1] Waggaman, W. H., Report on the phosphate fields of South Carolina: U. S. Dept. Agr. Bull. 18, p. 6, 1913.

[2] Shepard, C. U., jr., South Carolina phosphates, p. 21, Charleston, 1880.

Analyses of phosphate rock from South Carolina and Florida.

	South Carolina.														Florida.		
	Land rock.							River rock.									
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Insoluble	11.37	11.89	9.06	13.03	9.70	9.16	7.75	11.55	12.41	13.30	9.06	12.06	24.02	22.27	3.90	8.49	9.28
Al_2O_3				.40		3.62									1.73	1.49	1.63
Fe_2O_3				1.38											.52	.65	1.19
MgO				Trace.												.26	5.37
CaO				39.10											51.20	47.07	45.82
P_2O_5	27.01	26.68	27.26	27.23	26.98		28.47	25.61	26.68	25.14	27.26	25.14	22.36	24.51	36.80	35.11	33.07
SO_3				1.45													
CO_2	4.47	3.51	3.54	3.05			3.78	4.68	4.28	3.61	3.79	4.89	3.36	1.71		5.54	1.64
H_2O at 100°	.00		.84	2.43	.91			3.68		.79	.57	3.85	4.79			.00	.45
H_2O combined	5.26	6.58	4.22	5.68			5.87	4.78		5.80	4.31					1.39	1.55
Organic matter												4.81	3.45	3.42			
Undetermined				5.25											5.85		
Equivalent $Ca_3(PO_4)_2$	58.95	58.25	59.51	59.44	58.92	60.46	62.14	55.91	58.24	54.88	59.51	54.88	48.81	53.51	80.33	76.65	72.19
Equivalent $CaCO_3$	10.16	7.98	8.04			9.64	8.59	10.64	9.73	8.20	8.61	11.11	7.64	3.90			3.72

1. Ashley River district; cargo sample. Shepard (Chazal, op. cit., p. 13).
2. Ashley district (between Junction and Tenmile Hill). Chazal (op. cit., p. 15).
3. Chisholms Island (Coosaw River district). Shepard (Chazal, op. cit., p. 13).
4. Bulow mines. Chazal (op. cit., p. 11).
5. Cooper district; average of four analyses. Chazal (op. cit., p. 14).
6. Edisto district (west of Edisto River); average of over 100 analyses. Chazal (op. cit., p. 15).
7. Edisto district (near Ashepoo River); average of 5 analyses. Chazal (idem).
8. Stono River—light-colored rock. Shepard (Chazal, op. cit., p. 13).
9. Stono River—dark-colored rock. Shepard (idem).
10. Bull River; cargo sample. Shepard (idem).
11. Coosaw River; cargo sample. Shepard (idem).
12. Upper Wando River. Chazal (op. cit., p. 14).
13. Wando River at Wando. Chazal (idem).
14. Beaufort River; average of 2 analyses. Chazal (op. cit., p. 16).
15. Hard-rock phosphate; Dunnellon district, Fla. Cargo sample. Millar (op. cit., p. 89).
16. Hard-rock phosphate; Pemberton Ferry district, Fla.; cargo sample. Millar (op. cit., p. 90).
17. Pebble phosphate, Phosphoria, Fla.; large average sample. Millar (op. cit., p. 36).

The analyses show that the percentage of phosphoric acid in the land rock is very uniform, ranging from 26.68 to 28.47, and that in the river rock it is generally lower, ranging from 22.36 to 27.26. The insoluble matter (chiefly sand) is generally higher in the river rock and reaches 24 per cent in the Wando product, though it is only 9.06 per cent in the Coosaw River product. Chazal says that the river rock generally contains more organic matter than the land rock, and Shepard says that it contains less iron and alumina, but the above analyses do not establish these differences. Despite its lower percentage of phosphate the river rock was strongly preferred in the early days of the industry, partly because of its low content of iron and alumina, which made it more attractive to the foreign trade, but chiefly because of the greater ease with which it could be mined and washed and because of its higher specific gravity, which meant a higher percentage of phosphate per unit volume handled. The difference in grade between dark and light colored rock is illustrated by analyses 8 and 9, which respectively show 55.91 per cent and 58.24 per cent of lime phosphate. The land rock of the Ashley district (analyses 1 and 2) may be taken as the general type for the whole area and as closely representing the product now being mined; that of the Edisto district (6 and 7) is exceptionally good. The river rock of the Stono and the Coosaw (analyses 8, 9, and 11) constituted the bulk of the river rock mined, but it is somewhat higher in grade than that of the other rivers.

In interpreting these analyses in a commercial way it must be borne in mind that most of them represent crude unburned rock or rock that has only been partly dried (air dried). In the calcination to which the rock is now subjected before it is sold the moisture and organic matter and part of the carbon dioxide are eliminated and the proportion of phosphate is generally increased 4 or 5 per cent thereby.

The analyses given in the table indicate that the South Carolina product can not compete with the Florida rock in quality. The present guaranties for the Florida export product are 78 per cent or more of lime phosphate and 3 per cent or less of iron and alumina. The very highest grade specimen of the South Carolina rock probably does not contain as much as 80 per cent of phosphate and the customary export guaranty in 1880 was only 55 per cent.[1] It later rose to 58 per cent and is now 60 per cent, but this is nearly as high as the South Carolina field can be expected to average, although the product of the Edisto district would approximate 61 per cent. On the other hand, however, the South Carolina rock makes an excellent acid phosphate which is in good mechanical condition for mixing purposes, and many consumers are said to prefer it on the ground that it makes a better fertilizer.

[1] Shepard, C. U., jr., South Carolina phosphates, p. 16, Charleston, 1880.

PERSISTENCE OF BED.

In the fields and districts roughly defined below there are many small areas in which the phosphate bed is lacking or is too thin to be of value or is overlain by cover too thick to remove. Owing to the length of time over which mining operations have extended and to the large amount of phosphate already removed it is impossible to prepare a large map showing in detail the distribution of the workable rock. Considerable prospecting has been done throughout the general area, however, and maps have been prepared showing the exact thickness and distribution of the phosphate in certain tracts. The accompanying map (fig. 55), which was kindly placed at the writer's disposal by Mr. John Hertz, shows the irregularity of the phosphate stratum.

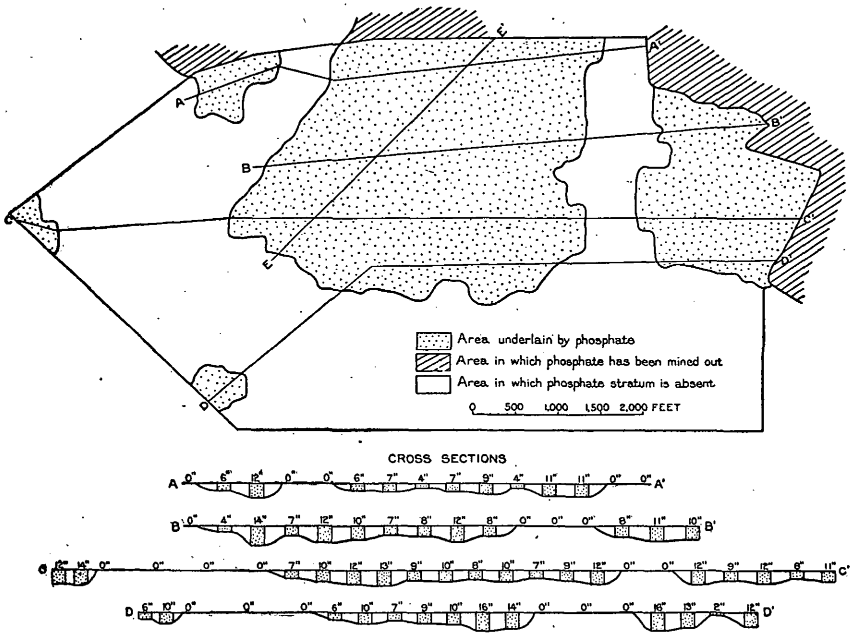

FIGURE 55.—Sketch map and sections showing irregularity of phosphate stratum near north branch of Stono River, S. C.

The tract shown on figure 55 is located near the north branch of Stono River, or on the southern border of the Ashley-Cooper field, described below. The extent of the workable phosphate is shown on the map, and the thickness of the stratum is shown by sections at intervals of 400 feet, obtained in bore holes and test pits. The sections suggest that although in some places the phosphate decreases regularly in thickness and feathers out, in most places it breaks off abruptly. This general irregularity in the thickness of the stratum is probably typical of the whole area, although in places the average thickness of the rock is much greater. The irregularity is further emphasized by the difference in average thickness of phosphate under the small areas; thus the average for the small area shown at the extreme left of the map is 12 inches, that for the small area shown near the bottom of the map is only 5½ inches, and that for the largest area is 9 inches. An estimate based on these thicknesses shows that the average yield per acre in these areas would be 1,080, 316, and 675 tons, respectively. In the whole tract shown on the map the proportion of "blank" area—that in which the Edisto marl is unphosphatized or is absent—is probably larger than that in most of the Ashley-Cooper field. Thus the area prospected is 926 acres, of which only 321 acres is underlain by phosphate rock, which averages 9 inches in thickness, whereas in a tract 1½ miles to the east the 200 acres prospected proved to be all underlain by workable rock of an average thickness of 10¾ inches. On the other hand, however, random borings made at three localities

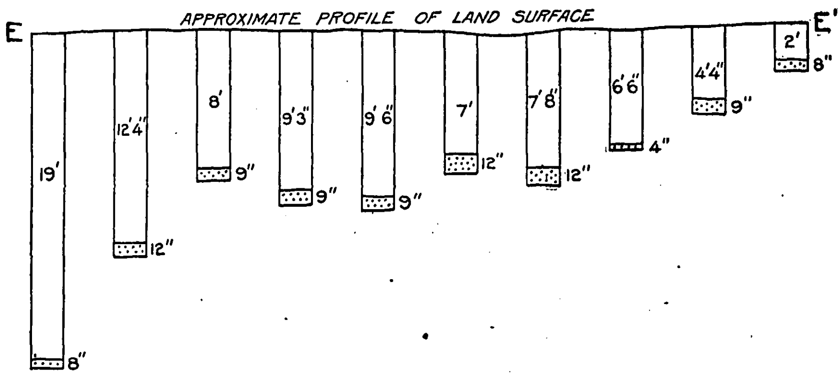

FIGURE 56.—Sections showing depth of phosphate bed below surface along line E–E′ on figure 55.

several miles northeast of the first tract showed no phosphate within 20 feet of the surface.

In figure 56 are given ten sections measured along the line E–E′ on figure 55 at intervals of about 360 feet. These sections show the depth of the phosphate below the surface to vary from 2 to 19 feet. Unfortunately, the absolute altitude of the surface along this line is not known, but a study of the drainage indicates that the variation in the depth of the stratum is due chiefly to the variation in its own altitude rather than to that of the land surface. This is to be expected because of the unconformable contact between the phosphate-bearing Edisto marl and the underlying Cooper marl, and affords a good example of the irregular and uneven character of the old surface on which the Edisto was laid down. In general this old surface is probably much more level than is here indicated, but in some localities, notably along Edisto River, its irregularity is even more pronounced.

The unevenness of the old Cooper surface, as shown by figure 56, suggests that in some of the areas in which the phosphate bed is thought to be absent it is merely covered by a greater thickness of overburden, and that it may therefore be somewhat more persistent than has hitherto been supposed. Owing to the fact that 20 feet is about the maximum thickness of overburden that can profitably be removed, the prospecting is generally carried only to this depth, and if the bed is not encountered it is reported absent. In some localities the operators can say with certainty that the old marl surface was reached, but in others the work done proves only that the phosphate bed does not lie within 20 or 25 feet of the surface. The presence of the bed at a greater depth has no commercial interest unless improved machinery capable of removing cheaply a greater thickness of cover is installed, but it is of distinct scientific interest in connection with the origin and geologic relations of the phosphate.

DISTRIBUTION.

All the commercially important deposits of phosphate rock lie on the seaward side of a rough arc drawn from a point near the source of Wando River to the mouth of Broad River. This area is approximately that underlain by the Edisto marl; but, as stated above, the distribution of this formation is somewhat irregular and the rock varies considerably in phosphate content, in some places being practically unphosphatized. Furthermore, in the course of mining operations during the last 45 years the phosphate has been entirely removed from tracts many square miles in extent. It is therefore impossible accurately to define the workable phosphate-bearing areas and they can be referred to only in more or less general terms.

On the map (Pl. II), however, an attempt has been made to show approximately the distribution of the phosphate. This map is based on that compiled by Shepard in 1870, but is modified because Shepard included only those areas in which the rock is within about 6 feet of the surface, whereas it has since been mined to depths of more than 15 feet. It must be borne in mind, however, that within the areas shown are many smaller districts in which the phosphate is lacking or is present at too great a depth to be workable, and many others, including practically all of the river deposits, in which it has been mined out.

In a general way the area may be divided into five fields. The Wando field contains chiefly a river deposit of rather small extent, which is now mostly worked out, but which has yielded a large quantity of fair-grade rock of the nodular form, black color, and high specific gravity characteristic of the river rock. Small areas of land rock occur along Wando River, but attempts to mine them have been unsatisfactory.

Northeast of the Wando field is the Cooper field, containing both land and river rock. The rock in this locality is of rather low grade and very little of it has been mined.

The Ashley field, a short distance northeast of Charleston, comprises about 150 square miles and is the largest and most important of all. The best deposits lie in the district along Ashley River and as far south as Rantowles Creek and Stono River. This district has been under continuous development since 1868 and has furnished by far the largest output of the land rock, having been practically the sole producer in South Carolina since 1904. The deposits on the western edge of this district are of less value than the rest, being thin, irregularly phosphatized, and in many places under considerable cover. Farther down the river, however, the rock is uniformly good, and the overburden is very regular in thickness over large areas. On the north side of Ashley River the workable phosphate has been largely mined out, but between it and Rantowles Creek large deposits still remain. In the district along the Atlantic Coast Line Railroad, especially near Mount Holly, a considerable amount of mining has been done. The best deposits are probably exhausted, for much of this area is known to be underlain by deposits which are poor or variable in character and irregular in extent. This is especially true in the district along Black and Cooper rivers, in which very little mining has been attempted.

The Stono River district, along the southern edge of the Ashley-Cooper field, has produced considerable quantities of river rock, which was of fairly high grade but which was mixed with marl and shells that were difficult to separate. Some of the earliest river mining was done on Stono River, and although the best deposits have been removed, it is possible from the more or less irregular character of the mining that some workable phosphate still remains.

The area west of Rantowles Creek almost as far as Edisto River is barren of workable phosphate, although thin deposits have been discovered at several places. Along the east bank of the Edisto a little north of the railroad a considerable amount of mining has been done, but it is reported that valuable deposits still remain.[1] Farther up the river on the east bank the rock is fairly thick and is easily accessible but is of rather low grade. River deposits occur in the Edisto itself but are so irregular that practically no mining has ever been done. The most important district of the Edisto field is that lying between Edisto and Ashepoo rivers, where many deposits of uncommonly high grade rock have been worked. According to Chazal some of the rock mined in this district contained as much as 64 per cent of lime phosphate and owing to the uniform thinness of the overburden was

[1] Chazal, P. E., Sketch of the South Carolina phosphate industry, p. 5, 1904.

very easy to mine. The rich deposits are irregular in extent, however, and there are many small areas in which the phosphate content is rather low. The chief obstacle to the thorough development of this district has been its relative inaccessibility, in consequence of which many fairly rich areas remain untouched.

The Coosaw field marks the southern extremity of the general phosphate area. Land deposits in this field are confined to the islands inclosed by Coosaw, Bull, Morgan, Johnson, and Beaufort rivers, and smaller channels. Owing to the somewhat inferior character of the rock and to the irregularity of the overburden these deposits have never been very extensively worked. By far the largest part of the great output of this field was obtained from the river deposits of the Coosaw and its smaller connecting channels. The deposits of the Coosaw itself covered 12 square miles with an average thickness of 22 inches and consisted of high-grade rock;[1] they apparently represent the concentration of the land deposits of a considerable area. Along the sides of the channels they grade into marsh deposits which were also extensively worked. The rock of Morgan River is also reported to have been high grade, and to have occurred in part as a layer 15 inches thick, similar to the land deposits. The phosphate of this district had been largely worked out by 1900, although some mining continued in the Coosaw itself until a few years later. The river deposits of Beaufort, Broad, and Johnson rivers are somewhat inferior in grade and have not contributed very extensively to the production.

QUANTITY.

Owing to the very irregular distribution of the South Carolina phosphate it is impossible to make an accurate estimate of the amount still available. Very little prospecting was done in the early days of the industry and although in recent years a large amount of exploration work has been done there are still many large areas concerning which the information is only approximate.

Shepard, in 1880, estimated the total available supply to be less than 5,000,000 tons, but over twice that amount has already been mined. Chazal, in 1904, estimated the supply still available at between 9,000,000 and 11,000,000 tons. Since that time less than 2,000,000 tons has been mined, which, according to this estimate, leaves between 7,000,000 and 9,000,000 tons. Some of this is under rather heavy cover and can not be mined at the ordinary cost, but much of it is probably comparable in accessibility and quality to that successfully mined in the past. The bulk of this phosphate is of the land variety, and is located in the areas between Ashley River and Rantowles Creek and between Edisto and Ashepoo rivers.

[1] Millar, C. C. H., Florida, South Carolina, and Canadian phosphates, p. 156, London, 1892.

ORIGIN.

EARLIER THEORIES.

All previous observers have advanced theories of the origin of these phosphate deposits, but all the theories except Sloan's were founded on what now appears to be a misconception of the geologic relations of the deposits. However, the essential idea of most of the earlier writers, namely, that the phosphate deposits are due to a concentration of the phosphate disseminated through the Cooper marl, is probably correct, although more geologic work is required before any hypothesis can be definitely accepted or rejected. Before reviewing the earlier theories it may be well to reiterate that the phosphate deposit is not essentially a collection of nodules, but is rather a more or less continuous bed of Miocene age, which is irregular in thickness and honeycombed by cavities, and is in places found unphosphatized. (See p. 193.)

Pratt advanced the earliest theory, which ascribed the phosphate to the accumulation of bone and the other remains of vertebrate animals. This material, he thought, had accumulated somewhere in the central part of the State and after the soluble portion had been leached away and the whole mass consolidated it was brought to its present position by streams. The mechanics of the consolidating process is not clear, nor the method by which the mass could have been transported by streams and laid down as a fairly pure bed.

Holmes in 1870 advanced a theory, which was generally accepted at that time, based on the view that the bed is a collection of nodules. According to Holmes the old surface of the Eocene marl was submerged and numerous fragments were broken off by the waves and deposited in irregular basins below sea level. After the elevation of the land the sea water caught in these basins evaporated, leaving salt licks, which were visited by numerous land animals. These animals deposited in the basins their fecal, remains, bones, and bodies, and the phosphoric acid derived from this mass of organic matter later replaced the carbonate in the underlying bed of marl nodules. The chemistry of this reaction is well established, but it is difficult to understand the regular deposition of the "marl nodules" themselves or their conversion into a fairly continuous bed. Moreover, this theory is refuted by the fact that the phosphate fragments are rich in Miocene fossils, whereas the underlying marl contains Eocene fossils in much smaller numbers.

Shaler in the same year (1870) advanced a theory which is much more reasonable geologically and which fundamentally is probably correct. According to Shaler the phosphate rock is a residual crust formed by the gradual removal of the underlying marl, the carbonate having been carried away in solution while most of the phosphate remained in place. The phosphate bed would therefore be merely the topmost layer of the Eocene marl. That the theory as stated is not entirely adequate is indicated by the Miocene fossils in the phosphate.

Shepard in 1880 accepted the nodule theory of Holmes, and Penrose in 1888 followed Shaler.

Levat in 1895[1] stated that the phosphate was formed "by the transportation, after disaggregation, of the phosphatic Eocene marl and its deposition in a shallow Miocene estuary together with a variable proportion of sand and clay." He also emphasizes the fact that the bones associated with the phosphate could not have supplied the phosphoric acid, for they themselves contain more than the normal amount.

Chazal in 1904 propounded a theory essentially like that of Holmes. He believed that fragments of the Eocene marl were torn from the old surface by tidal action and were later subjected to the action of solvent waters, which dissolved away the carbonate and replaced it with phosphate. After formation the nodules "were caught up and transported by the agency of the enormous tides of the post-Pliocene seas and deposited in valleys, hollows, or old waterways." Aside from the somewhat unusual nature of this transportational process, the presence of Miocene fossils in the phosphate is incompatible with this theory.

Sloan in 1908 was the first observer, with the possible exception of Levat, to take into account the true geologic relations of the deposit. According to Sloan the land surface (Cooper marl) was submerged in Miocene time and the Edisto deposited on it as an unphosphatized marl. After the deposition of the Edisto, phosphatic sediment was laid down upon it, which ultimately phosphatized it. The phosphatic sediment was derived chiefly from the disintegration, partial solution, and erosion of the Cooper marl, but also from phosphatic organisms stranded on the coast by the Gulf Stream, and to a lesser extent from bones and other remains which accumulated after the coast was elevated above sea level. However, as the Edisto in its unphosphatized condition must have been formed of sediment derived from the Cooper marl, it is difficult to understand why so much phosphatic sediment was brought down from the same land surface immediately after its deposition. Furthermore, it seems probable that the leachings of this old surface were chiefly calcareous, and that the phosphate, being coarser, remained to a considerable extent as a residual soil, according to Shaler's view.

[1] Levat, David, Industrie des phosphates et superphosphates, p. 83, Paris, 1895.

RESIDUAL-SOIL THEORY.

The writer's theory differs somewhat from any hitherto formulated, although involving the central idea of several of the earlier views. The fact that the phosphate is not a collection of Eocene nodules vitiates the arguments of Holmes, Shepard, and Chazal. Shaler's theory is similarly injured; for, as the Edisto is known to be marine Miocene, it must have been deposited during a distinct period of submergence. Sloan's hypothesis is unsatisfactory to the writer in that it involves the derivation of unphosphatized marl from an old land surface and a later derivation of richly phosphatic sediment from the same source. Levat's theory is not clearly expounded, but seems to approach most closely to the views advanced below.

The general conditions of sedimentation in this area have already been set forth. (See p. 191.) It seems certain that the Cooper marl formed a land surface during much of Oligocene and early Miocene time, and during this period it must have suffered considerable weathering and erosion. As this surface was not far above sea level, the amount removed by actual stream erosion was probably small in comparison with that lost by leaching and solution. The analyses given below show that the Cooper marl contains a certain amount of phosphate, which is in part disseminated through it in the form of grains and in part more irregularly distributed as nodules and to a minor extent as bone fragments, and probably also as phosphatic shells and sharks' teeth. As the Cooper land surface was gradually worn down, much of this coarser and more insoluble phosphatic material probably accumulated as a residual soil, only a part of it being carried away as sediment. Sloan[1] estimates the average phosphate content of the upper part of the Cooper to be 3 per cent (see analyses, p. 208), which gives 121 tons of 60 per cent phosphate rock per acre-foot. In other words, the disintegration of 8 feet in every acre of Cooper marl would yield about as much phosphatic material as is contained in an average acre of the phosphate bed. As a matter of fact, much of this phosphatic material was doubtless carried away as sediment; but, on the other hand, it is probable that many times 8 feet of Cooper was disintegrated and partly removed during the long period in which it remained above the sea. It may safely be assumed, therefore, that at the end of early Miocene time the old Cooper land surface was covered with a residual soil which was probably highly phosphatic in many places, though much less so in others, owing to the irregular distribution of the phosphate in the marl from which the soil was derived.

[1] Sloan, Earle, op. cit., p. 333.

At the end of early Miocene time the region was depressed somewhat below the sea and, as indicated by the present topography and the distribution of the phosphate bed, became a great estuary or series of estuaries. As the water gradually encroached on the land the residual soil was disturbed by wave action and much of the intermixed vegetal débris removed. The areas in which the Edisto is lacking to-day were probably partly submerged islands on which wave action was sufficient to wash away the residual soil. The relief of the old surface was probably not great, however, and if certain areas were left high enough to form islands, it seems that the depression was not a great one and that the general surface was not covered with very deep water. W. C. Kerr[1] suggests that phosphatic bivalves whose shells were later broken up by wave action may have contributed phosphate. As an example, he points out that the shells of *Lingula pyramidata*, which are still found in large numbers along the coast, contain about 55 per cent of lime and magnesian phosphate. W. H. Dall, however, stated to the writer that in his opinion neither this organism nor any of the other phosphatic brachiopods were present in sufficient numbers in Miocene time to have enriched the deposit materially. At this time also fishes, amphibians, and reptiles flourished along the coast, and their fossil remains, which are now found in great numbers, probably added somewhat to the supply of phosphate. In addition to these sources, a certain amount of sediment was being received from the land during this period, and this probably also contained some phosphate. By the end of middle Miocene time, when gradual reelevation of the coast began, a deposit aggregating 5 to 10 feet thick had probably accumulated. This deposit was in general richly phosphatic, but the phosphate was probably distributed through it irregularly and in some places was present only in minor amount.

The reelevation of the land progressed until most of the areas now underlain by phosphate became a series of marshes, in which it seems certain, as Shepard, Shaler, and Chazal contend, a chemical alteration of the phosphatic marl (Edisto) would take place. The most extensive alteration would be the leaching out of the carbonate of the marl by carbonated waters, leaving most of the phosphate intact, and this process would ultimately result in converting the original 5 or 10 feet of Edisto into a thin but highly phosphatic crust. Concomitantly with this process, however, a partial replacement of carbonate by phosphate took place. Reese[2] has shown that swamp water readily dissolves phosphate, but that the phosphate is reprecipitated when the water stands in contact with lime carbonate.

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[1] Am. Naturalist, vol. 4, p. 571, 1871.

[2] Reese, C. L., On the influence of swamp waters in the formation of the phosphate nodules of South Carolina: Am. Jour. Sci., vol. 43, pp. 402–406, 1892.

This would also tend to concentrate the phosphate at the bottom of the Edisto, where the waters came in contact with the purer underlying marl, and would furthermore tend to destroy the original forms in which the phosphatic material was scattered through the Edisto. The original Edisto marl was thus largely removed by solvent action, but most of its phosphatic material, chiefly in a reworked condition, was retained. Reptiles and amphibians continued to flourish during this period and in addition a few land animals frequented the marshes. Their bones are found to-day on the phosphate bed and intermingled with it but not actually incorporated in the mass. These bones have themselves been phosphatized, perhaps in part through the agency of other bones now entirely dissolved, and probably only a minor amount of the phosphate in the Edisto itself can be attributed to these remains.

The theory above outlined seems to account for all of the known facts. The presence of a few worn Eocene shells in the phosphate is due to its derivation in part from the residual soil. The presence of the rich marine Miocene fauna is accounted for by the submergence of the old surface during the Miocene. The vertebrate remains, which are Pliocene, Pleistocene, and Recent, are evidently later than the formation of the phosphate itself. According to this view, the black sandy clay which fills the cavities of the phosphate rock and in which many of the vertebrate remains are found, is also later than the phosphate. The originally irregular distribution of the phosphate, which was probably further increased by its later solution and reprecipitation, seems to explain the fact that the bed now varies greatly and rather abruptly in thickness. It also throws light on the fact that the phosphate bed is not generally thicker in the depressions of the old surface but appears to vary irregularly. The supposition that the Edisto as originally deposited was much thicker than the present phosphate bed is borne out by the fact that in the unaltered condition it is generally 4 or 5 feet thick, according to Sloan. The areas in which it is thus found were presumably islands in the old marsh where it was not subjected to the leaching and concentrating process, and the areas in which the Edisto was entirely lacking probably represent wave-swept islands in the estuaries in which the formation was deposited. This idea is partly borne out by the fact that the Edisto is lacking or is unphosphatized on the higher portions of the present interstream areas, as, for example, on that between Rantowles Creek and Edisto River and between the Ashepoo and the Combahee.

The experiments of Reese indicate that the leaching and concentrating process is possible, and that it has actually taken place is strongly suggested by the irregular shape of the phosphatized mass. Moreover, the Cooper marl immediately beneath the Edisto generally contains about 15 per cent of phosphate and for a distance of almost 30 feet commonly shows some enrichment. Below this the percentage of phosphate varies but seems to average about 3 per cent. The enrichment of the marl beneath the phosphate has been noted by several observers and is well shown in the first four analyses given below; the general composition of the marl at other, and probably lower, horizons is shown by the last six analyses.

Analyses of the Cooper marl.

	1	2	3	4	5	6	7	8	9	10
SiO_2 (and insoluble)	......	8.56	15.45	15.61	12.80	37.06	17.13	21.14	15.04	31.77
Al_2O_3	......	1.11	1.88	2.74	1.34	.83	......	......	......	} 11.75
Fe_2O_3	......	.95	.95	1.10	.79	1.38	......	......	......	
Na_2O	......	......	......	......	.35	.29	......	......	......	......
K_2O	......	......	......	......	.32	.39	......	......	......	......
MgO	0.65	......	.31	1.20	.43	3.91	Undet.	.56	Trace.	.45
CaO	29.44	48.80	43.41	41.80	45.68	26.80	......	33.76	43.52	39.80
SO_3	.58	......	......	......	......	.34	......	......	......	......
P_2O_5	7.00	4.13	1.76	.45	1.29	3.03	3.01	1.26	10.65	2.98
CO_2	16.29	34.50	32.79	33.74	35.17	21.88	26.64	24.78	15.67	8.32
Ignition	......	.62	1.68	1.31	.91	1.65	......	......	......	1.80
Moisture	......	1.19	1.29	2.46	.96	2.07	......	......	......	.25
	......	99.86	99.52	100.41	100.04	99.63	......	......	......	......
Equivalent $Ca_3(PO_4)_2$	15.28	9.02	3.85	.98	2.82	6.62	6.57	2.74	23.24	6.51
Equivalent $CaCO_3$	37.04	78.41	73.77	73.70	78.85	40.99	60.54	56.32	44.70	18.89

1. Marl immediately beneath phosphate bed; Bees Ferry, Ashley River. Sloan (op. cit., p. 385).
2. Marl 10 feet below phosphate bed; average sample; Ashley works, Ashley River. Sloan (op. cit., p. 384).
3. Marl 10 to 28 feet below phosphate bed; average sample; Ashley works, Ashley River. Sloan (idem).
4. Marl 28 to 50 feet below phosphate bed; average sample; Ashley works, Ashley River. Sloan (idem).
5. Average Cooper marl, exact horizon unknown; Steep Bluff, Biggin Creek. Sloan (op. cit., p. 386).
6. Average Cooper marl, exact horizon unknown; near Saxon, Goose Creek. Sloan (op. cit., p. 387).
7. Marl 34 feet below surface at Sineaths station. Chazal (op. cit., p. 26).
8. Marl 85 feet below surface at Sineaths station. Chazal (idem).
9. Marl containing phosphate nodules, 110 to 112 feet below surface at Sineaths station. Chazal (idem).
10. Average Cooper marl, exact horizon unknown; quarry at Woodstock (privately communicated).

Samples 1, 2, 3, and 4, taken at successively greater depths below the phosphate bed, show a gradual decrease in phosphoric acid. This would be expected from the experiments of Reese, which show that lime phosphate is precipitated slowly when in contact with lime carbonate. Owing to the moderate proportion of carbonate in the Edisto when it was first elevated above the sea and to the fact that this salt was constantly being removed by leaching and the proportion of phosphate thus increased, it is probable that phosphatic solutions were soon able to move freely in the mass. At first these solutions were weak because of the mass action of the carbonate present, and the phosphate was easily precipitated along the upper surface of the Cooper. With continuous decrease in the Edisto carbonate, however, the solutions increased in strength, were less easily precipitated, and finally penetrated some distance into the underlying Cooper before all of their phosphate was removed. The enrichment of the Cooper in phosphoric acid is well shown by analyses 1 and 2, of samples taken within 10 feet of the phosphate bed. Analyses 3 and 4, of samples taken between 10 and 50 feet below, show a decrease, 3 apparently representing about the original average composition of the marl, and 4 being abnormally low in phosphate.

The exact horizons of samples 5 and 6 are not known. They may represent the true average composition of the Cooper, but analysis 6, especially, shows a high proportion of phosphate, which is probably due to secondary enrichment. Samples 7, 8, and 9 were taken from the deep well at Sineaths station described above (p. 187); but their horizons are not stated by Shepard, and it is possible that sample 7 has undergone some enrichment. Sample 8 must be more than 50 feet below the phosphate bed, however, and probably represents the general average composition of the marl. Analysis 7 is of interest, as it shows the composition of one of the more highly phosphatic layers of the Cooper. The horizon of sample 10 is unknown, but as the phosphate bed is not present in the immediate locality from which it was taken the marl has probably not been directly enriched. It is difficult to ascertain the original average composition of the marl where not secondarily enriched, but it seems certain that it contains an average of at least 3 per cent of phosphate and is thus abundantly able to have contributed extensively to the formation of the Edisto.

The physical and chemical characters of the marsh and river deposits seem also to accord with the theory above outlined. The marsh deposits occur in a bed like the ordinary land deposits, but the rock is generally somewhat higher in specific gravity and is darker in color. As is generally the case, the darkest rock is commonly the richest in phosphate and the marsh deposits as a whole consist of high-grade rock. This is explained by the fact that it has been subjected to the action of swamp water longer than the land rock and that therefore the concentrating process has been longer continued. The result is a rock that is more compact and is richer in phosphate than much of the land rock. The darker color seems to be due chiefly to the inclusion of more carbonaceous matter during the longer period of association with swamp water. The color is therefore not directly connected with the phosphate content, but is nevertheless an indirect indication of it, for it is a rough measure of the length of time during which the concentrating process has gone on. Similarly the river deposits are darker and higher in specific gravity, although generally lower in phosphate, owing to the intermixture of sand. The rounded character of the fragments of river rock is doubtless due partly to the mechanical but chiefly to the solvent action of running water.

PHOSPHATE INDUSTRY.

PROSPECTING AND MINING METHODS.

Land mining.—Extensive prospecting and exploration work has been done in this area during the last 25 years, and it is reported that the location and extent of all of the workable deposits are known.

Much of this work has led only to outlining the deposits and gaining some idea of their thickness and the grade of the rock, but a great deal of detailed prospecting has also been done. Thus in the area shown on figure 55 (p. 198) one bore hole was sunk in each half-acre tract, or at intervals of less than 200 feet, and these were supplemented by a number of test pits. The information thus obtained affords a means of making a fairly accurate estimate of the quantity of minable phosphate in the ground in this area.

The greater part of the exploratory work has been done by boring with a long rod or auger or with a pipe. The auger used is an octagonal steel rod with a sharp point and a small shoulder just above the point. This rod is worked down through the unconsolidated sand and clay (see fig. 56) until it reaches the hard phosphate layer, when the distance traversed is measured. The rod is then forced through the phosphate layer into the soft marl below and is then withdrawn until the shoulder catches on the bottom of the hard layer. Another measurement is made, and the difference between the two gives the thickness of the phosphate. For more accurate work some operators use a 4½-inch pipe, which takes a core of rock that may be weighed or analyzed.

Mining is now done entirely by steam shovel, hand labor being impracticable where the overburden is thicker than about 8 feet. The tract to be mined is first thoroughly prospected, and in some tracts levels are run and drainage ditches are dug. Along one edge of the tract a canal about 20 feet wide and of sufficient depth to remove all the material above the phosphate is dug by a dredge or steam shovel. The dredge is, of course, preceded by a gang of laborers to clear the timber and blow out the stumps. The canal is extended in a straight line to the border of the property, the material removed being piled up on one bank and a movable steel track laid on the other. The phosphate layer is generally broken and dug with pick and shovel and thrown into buckets operated by a hoist that runs on the track and dumps the phosphate into flat cars. Some companies, however, remove the rock by a second steam shovel, of the clamshell type, which follows immediately behind the dredge. By the use of this second shovel the phosphate is broken up, hoisted, and loaded on cars in one motion, and hand labor is almost entirely dispensed with. It is said that one of these machines can load as many as 21 flat cars a day, although the average work of a machine is to load about 18 cars. Unless a system of lateral drainage ditches is developed one or two steam pumps are necessary to keep the canal dry, and these commonly follow the second shovel. When the border of the tract is reached the dredges are turned and a second canal immediately adjacent to the first is excavated, the overburden being thrown over into the old ditch. By this method practically all the phosphate is removed, and large areas that can not be mined by hand have thus been completely worked out. The marsh deposits are mined in a similar way, except that banks or levees are generally constructed to keep out water at high tide.

Hand mining can be practiced only where the overburden is less than 8 feet, and, as the more accessible deposits have been largely exhausted, very little hand work has been done during the last few years. Such work is generally performed on contract, the price being paid for the rock delivered at the washer. The contractor generally sublets to the laborer, assigning each man a section of about 18 feet along the sides of a common canal, from which he removes the overburden and digs and loads the phosphate.

River mining.—River mining was extensively practiced in the early days of the industry, but steadily declined after 1887 and practically ceased about 1904. (See p. 219.) The first river mining was done by hand in deposits that were nearly or quite uncovered at low tide. Shepard states that large quantities of rock were mined in this way, though the favorable deposits were few. In somewhat deeper water oyster tongs were used, especially on Wando River; and a small quantity of the rock was even dislodged and brought up by divers. The deposits in water sufficiently shallow for hand mining were soon exhausted, however, and steam dredges were introduced. The earliest models were adapted to working in water less than 20 feet deep, but with the exhaustion of the more accessible deposits the dredging was continued into deeper water until, according to Sloan, an extreme limit of 52 feet was reached. In most of this mining the clamshell type of dredge was used, but at least one large bucket dredge, carrying 38 buckets with a capacity of one-third ton each, was successfully used on Morgan River, where the rock occurred in a hard, compact layer. Much of the river rock occurs in more or less irregular banks, however, and some of the rock is probably overlooked. The tendency to dredge only the richest part of the deposit was strengthened by the practice of some of the companies of offering the dredge captain a bonus for a weekly production above a certain figure.[1] Most of the river mining was therefore very irregular and showed a marked contrast with the land mining, much of the river rock being lost.

PREPARATION OF THE ROCK.

After mining, the land rock must be washed and burned before it is shipped. As received from the dredge the phosphate is mixed with wet sand and mud derived partly from the overlying and underlying material, but chiefly from the stiff sandy clay which fills the cavities in the rock itself. It is reported that in the early days of

[1] Millar, C. C. H., op. cit., p. 162.

the industry the rock was picked over by hand and scrubbed with a brush in some convenient creek and that the resultant product was so impure that the land rock acquired a bad reputation and was long regarded with disfavor.

Hand washing was soon discarded as entirely inadequate and mechanical washers were introduced. At present the work is done almost entirely by machinery. The product is received on flat cars from the dredge and scraped off into a hopper that discharges into a mechanical conveyor. The conveyor buckets empty automatically into a crusher, where the rock is partly washed and is broken into fragments. It is then delivered through a trough to the lower end of a cylinder washer. This washer is a cylinder 27 feet long by 5 feet in diameter and is tilted so that the discharge end is a foot or more higher than the receiving end. The interior of the cylinder is fitted with plates arranged in the form of a spiral, so that as the cylinder revolves the phosphate is carried forward to the upper end. A stream of water under a pressure of 60 pounds enters the upper end of the cylinder and plays against the advancing phosphate, washing the finer material toward the lower end. This finer waste passes out through a heavy screen into a trough, through which it is carried by the water to the waste heap. The clean phosphate is discharged through the upper end of the cylinder on to a belt which transports it to the wet bins. While on the belt it is generally picked over by hand and any clay balls or fragments of marl are removed.

Much phosphate is lost in this grinding and washing. The operators estimate that 60 per cent of the material mined is sand, clay, and finely divided phosphate which escapes through the screens. Waggaman[1] says that an analysis of the material on the dumps showed about 13 per cent phosphate of lime, which is almost 8 per cent of the product as mined, or 20 per cent of the phosphate actually utilized. This may probably be taken as an average, though some phosphate deposits near Tenmile Hill are said by Chazal to be so friable and easily pulverized that a very large proportion is lost in handling and washing.

After washing, the rock is dried before being shipped in order to take advantage of the very material reduction in weight. In the early days of the industry the drying was accomplished by piling the rock in bins over perforated pipes carrying hot air, or in some places merely by exposure to the sun. The latter method was wholly inadequate and the former was only partly satisfactory, for 2 per cent or more of the moisture as well as most of the organic matter and carbon dioxide were still retained. Some operators, therefore, built expensive brickkilns in which the rock could be thoroughly calcined, but it was

[1] Waggaman, W. H., op. cit., p. 9.

later found that these were unnecessary and that the rock could be satisfactorily burned over cordwood in open sheds. The present practice is, therefore, to pile the rock over ricks of cordwood, 6 cords being allowed for 100 tons of rock. The heat generated by the combustion of the wood is increased by that of the organic matter in the rock and also by the formation and combustion of water gas, so that the rock is popularly said to "burn itself." By this process the moisture content of the rock, which, after washing, is from 10 to 15 per cent, is reduced to about 0.5 per cent, and the organic matter and part of the carbon dioxide are also expelled. The burned rock is soft and easily ground and is light gray, yellow, or red.

The river rock was purified in a somewhat different manner. According to Shepard, a lighter accompanied each dredge and all the washing was done before the material was taken ashore. The dredge emptied the rock directly into a conical washer, where it was cleaned by heavy streams of water. After leaving this conical washer the rock entered a crusher, through which it passed into a cylindrical washer for the final cleansing. This cylindrical washer discharged upon a second lighter on which the rock was towed ashore. The procedure varied somewhat according to the character of the rock and in many cases the first washing and the crushing were omitted. Owing to the more compact form of the river rock, many operators considered calcination unnecessary and dried it by hot air.

After the final drying the rock is shipped in closed cars—in former years it was shipped by vessel—to the fertilizer factories. After it has been calcined it is easily ground and is then mixed with sulphuric acid to produce an acid phosphate. The customary specification is 16 per cent soluble phosphate, although it is reported that a special method has been used to some extent by which a very high grade or double superphosphate is made. It is then generally mixed with calcined and finely ground marl, which acts as a base or filler and also as a drying agent, and with tankage, bone, potash, and ammonia salts, etc., in proportions which are varied according to the grade of fertilizer desired.

ECONOMIC FACTORS.

Workability.—In the South Carolina phosphate field, as in most other producing mineral fields, the gradually increasing cost of production has been met by the introduction of machinery and of improved methods of mining. Thus, in the early days of the industry, it was not considered practicable to remove an overburden of more than 6 feet on land or to dredge in water more than 15 feet deep. Yet in the last 10 years as much as 22 feet of overburden has been profitably removed, and river rock has been dredged from a depth of 52 feet, including a cover of 16 feet of sand and mud. It is thus difficult to define a workable deposit, especially at the present time, when the competition of the Florida and Tennessee rock prohibits the mining of deposits which 10 years ago were considered very favorable.

The most important factors are, of course, the thickness of the overburden and the thickness and compactness of the rock stratum. Under the conditions which have prevailed during the last decade 15 feet of overburden may be removed without excessive cost, but a greater thickness must be offset by an exceptionally high yield of phosphate. The amount of overburden that can profitably be removed also depends somewhat on the natural drainage of the property, for this affects the extent to which steam pumps must be used. The yield of the phosphate itself depends not only on the thickness of the stratum but also upon its compactness and its hardness. Other conditions being equal a 12-inch stratum is good, and a 10 or even an 8-inch stratum can be profitably worked. In some places, however, the cavities in the phosphate are exceptionally large and may reduce the yield of a 12-inch stratum below the workable limit. In some localities the rock is so soft and friable that it can not stand transportation and washing, for even the hardest rock generally suffers in the washing process. When the stratum is exceptionally thin its hardness may be very important, because the heavy dredge travels directly on it and must use it as a floor.

The composition of the rock is also important. The guaranty of lime phosphate has steadily risen from 55 per cent in 1880 (Shepard) to 60 per cent at the present day. This rise is not absolute, however, and has been largely met by improved methods of preparing the rock. Under the present method of calcining the rock nearly all of the moisture and organic matter and part of the carbon dioxide are eliminated, so that a rock which would have yielded 55 per cent under the old conditions of washing and air drying may now yield over 60 per cent. Even with this improvement in methods, however, the rock at many localities, especially along the northern and western borders of the fields, is too low in phosphate to be marketed under the present guaranty.

Cost of production.—Notwithstanding the extension of the workable deposits brought about by improved methods the industry has suffered seriously because of the increasing cost of production. The great increase in the price of labor and the exhaustion of the shallower deposits have practically put an end to hand mining. In consequence an elaborate and expensive plant is now necessary and the small operators have been forced out of the business.

Waggaman[1] estimates that under average conditions, when the plant is working to its full capacity, the cost per ton of mining,

[1] Waggaman, W. H., loc. cit.

washing, and drying the rock is $3.46. The rainy seasons, which involve extra pumping, and the difficulty of obtaining labor, which frequently prevents the plant working to its full capacity, must also be taken into account. The present price, which is controlled largely by the higher-grade Florida product, is about $4 a ton. This leaves a very small margin of profit and in consequence mining operations have fallen off greatly.

Grade of product.—The South Carolina rock is distinctly lower in phosphate content than the Florida product. (See p. 196.) The price of phosphate rock is fixed chiefly by the percentage of lime phosphate it contains, and the foreign trade generally specifies also a maximum percentage of iron and alumina. Before the exploitation of the high-grade Florida deposits the South Carolina river rock was very popular with the foreign trade, being fairly clean and low in iron and alumina. The appearance of the Florida rock on the market, however, injured and finally destroyed its export sale and for many years the South Carolina product has been sold only in the domestic market.

Although in this country the rock is priced largely according to its content of phosphate, certain factors seem to have aided the South Carolina product in competition with the higher-grade Florida rock. The fertilizer manufacturers find that after calcining it grinds readily and cheaply into an impalpable powder, which allows the sulphuric acid to act uniformly on the whole mass. The superphosphate formed is light and dries readily, and remains in good mechanical condition for mixing. Many planters, moreover, prefer fertilizer made from the South Carolina rock to that made from the Florida or Tennessee rock. There appears to be no chemical basis for this preference and it is probably due chiefly to the excellent physical condition of the South Carolina fertilizer.

HISTORY OF FIELD.

DISCOVERY.

It is interesting to note that the existence of the phosphate stratum was known long before its true nature and value were recognized. As far back as 1795[1] interest was attracted to the strata associated with the phosphate bed by the discovery in them of large numbers of teeth and bones. In 1837 F. S. Holmes collected a number of phosphate nodules from an old rice field on the west shore of Ashley River, but his interest was occasioned only by the fossil shells preserved in them. In 1842 Edmund Ruffin made a partial geologic survey of the State with special reference to marl and limestone for use as fertilizer; and in his description of the marl on Ashley River

[1] Millar, C. C. H., op. cit., p. 125.

he mentions "lumps of stony hardness full of impressions of shells."[1] It is remarkable that he actually determined the percentage of lime carbonate in these rocks, but finding it to be only 6 per cent did not complete the analysis. In 1884 Holmes published a brief description of the fossiliferous rocks which he had found seven years before, describing them as a "remarkable bed of nodules or conglomerates 12 inches thick, embedded in clay";[2] and in 1860 again referred to them as a bed of silicified fragments of the underlying marl.[3] In 1848 Tuomey[4] described the nodules as "marl stones," from which the lime carbonate had been largely removed, leaving chiefly silica and alumina. Tuomey evidently relied on Ruffin's determination of these nodules, for although he presents numerous analyses of the underlying Eocene marl and points out especially the presence of phosphate in it, he gives no analysis showing the phosphate in the nodules.

In a lecture delivered in 1859 before the Medical Association of South Carolina, C. U. Shepard referred vaguely to the presence of "phosphatic stone" near Charleston. Although he did not specify the rock in question, it appears from information quoted by Chazal[5] that he was acquainted with the true nature of the phosphate stratum and endeavored to organize a company to mine and utilize it as fertilizer. The Civil War put an end to these plans, however, and nothing definite was done until 1867, when St. Julian Ravenel made an apparently independent discovery of the nature of the rock. N. A. Pratt at about the same time recognized its value, and in company with F. S. Holmes immediately made an effort to organize a company. As a result of their efforts the Charleston Mining & Manufacturing Co. was formed in 1867 and a large area of excellent phosphate land on both sides of Ashley River near Tenmile Hill was secured. In the meantime Ravenel organized the first manufacturing concern, which was known as the Wando Fertilizer Co.

DEVELOPMENT.[6]

The first small cargoes of hard rock were shipped in April, 1868, but it was several years before adequate mining methods were developed and the work was properly organized. The first washer was built at Lambs in 1868, but until 1879 all of the product was shipped undried. Moreover, much of the early product was imperfectly washed and the land rock acquired a bad reputation, especially in the European market, which demanded a low percentage of iron and

[1] Ruffin, Edmund, Agricultural survey of South Carolina, p. 35, Columbia, 1843.
[2] Holmes, F. S., South Carolina Agriculturist, 1844.
[3] Holmes, F. S., Post-Pleiocene fossils of South Carolina, p. ii, Charleston, 1860.
[4] Tuomey, Michael, Report on the geology of South Carolina, Columbia, 1848.
[5] Chazal, P. E., op. cit., p. 40.
[6] This account is taken in large part from the works of Chazal and Millar.

alumina. It was therefore practically excluded from the early foreign trade and has always found its best market in this country. The hot-air system of drying was begun in 1879 but was abandoned in 1882 for the present method of burning over cordwood. Up to 1888 mining was done almost entirely by hand, and steam shovels did not come into general use until about 1895. The Charleston Mining & Manufacturing Co., the pioneer concern, had a large working capital and acquired some of the best phosphate lands in the field. In 1868 this company built the first washing plant at Lambs and established headquarters there. It has always been the largest and one of the most prosperous companies, although it has had many competitors. Five companies were in the field in 1870, 16 companies in 1884, and 22 companies in 1891. Many of these, however, were small private enterprises and most of them have either ceased operations or have been absorbed by the Charleston Mining Co. In 1892 there was a change of management in this company, which resulted in the abandonment of the old plant at Lambs and the erection of a more costly one at Bees Ferry, a few miles farther down the Ashley. This apparently did not lead to the expected decrease in cost of production, however, and when the concern sold out to the Virginia-Carolina Chemical Co. in 1901 the new owners abandoned the Bees Ferry plant and returned to Lambs. In 1904 they completed a new plant which had a capacity of 1,200 tons a day and which was then the largest in the world.

The river mining industry, dealing as it did with deposits in navigable streams under the jurisdiction of the State, early became involved in litigation, which hampered it for many years. Owing to the fact that expensive machinery was needed for the dredging, the operations were carried on by a few large companies, whereas the land mining was done by a number of small operators. In 1870 the general assembly of the State passed an act giving the Marine & River Phosphate Mining & Manufacturing Co. the right to mine phosphate rock from the navigable streams of the State for a term of 21 years, under a royalty of $1 a ton. This company, which began operations in 1870, immediately claimed exclusive rights and transferred exclusive rights to mine in Coosaw River to a new concern, the Coosaw Mining Co. The courts, however, later decided that no exclusive grant had been made and several other companies were formed. In 1876 another act was passed by which the Coosaw Mining Co. and all other concerns were granted exclusive rights within the territory in which their operations had been carried on prior to the passage of the act. By the close of 1878 ten river companies had been organized and six more were in process of organization. The Marine & River Phosphate Mining & Manufacturing Co.

ceased operations in 1882, but the Coosaw Mining Co., which had exclusive rights to the largest and highest-grade river deposits in the whole field, was extremely successful. By 1894 it had produced nearly half of the total amount of river rock mined and had paid the State about $1,500,000 in royalties. The original lease expired in 1891, however, and despite the claim that perpetual rights had been granted by the act of 1876, the State, after prolonged litigation, finally threw its territory open. During this litigation the company was forced to suspend operations and was unable to fill or renew its foreign contracts. Up to this time the rock from Coosaw River had enjoyed a high reputation in Europe, but when the supply was stopped the foreign consumers were forced to use Florida rock, which thus gained its first foothold and whose superiority became so apparent that the South Carolina rock was no longer preferred. The Coosaw Mining Co. resumed operations in 1892, but in 1893 a disastrous cyclone destroyed the plants of practically all the river companies and paralyzed the industry for some time. The richer deposits had by this time been exhausted, and the competition of the Florida, Tennessee, and Algiers phosphate had become keen; the cyclone therefore came at a particularly critical time and injured the river mining beyond hope of recovery. The industry rapidly declined during the next 10 years, and by 1904 all the large river companies had failed or ceased operations. Since 1904 a small amount of river rock has been intermittently mined, but the industry as a whole is practically dead.

In the following table is given the amount of South Carolina phosphate rock marketed in each year from 1867 to 1913.[1] The actual amount mined differs slightly from the amount marketed and is generally higher. The prices during this period have ranged from $10 to less than $3.50 a ton, depending partly on cost of production and partly on the market, which fluctuated considerably according to the condition of the crops. The prices paid for the river rock were generally about $1 lower than those paid for the land rock. In connection with the following table it may be noted that the Florida rock first appeared on the market about 1889 and that its production exceeded that of the South Carolina rock in 1894; and that the Tennessee rock first appeared about 1893, increased greatly in 1897, and exceeded the South Carolina rock in 1899. Until about 1885 South Carolina furnished over 95 per cent of the phosphate marketed in the United States; at present it furnishes 4 per cent or less.

[1] For statistics of production, prices, market, labor conditions, etc., in each year see U. S. Geol. Survey Mineral Resources, 1882–1913.

Production of marketed phosphate rock in South Carolina, 1867–1912, in long tons.[a]

Year.	Land rock.	River rock.	Total.
ENDING MAY 31.			
1867	6	....	6
1868	12,262	....	12,262
1869	31,958	....	31,958
1870	63,252	1,989	65,241
1871	56,533	17,655	74,188
1872	36,258	22,502	58,760
1873	33,426	45,777	79,203
1874	51,624	57,716	109,340
1875	54,821	67,969	122,790
1876	50,566	81,912	132,478
1877	36,431	126,569	163,000
1878	112,622	97,700	210,322
1879	100,779	98,586	199,365
1880	125,601	65,162	190,763
1881	142,193	124,541	266,734
1882	191,305	140,772	332,077
1883	219,202	159,178	378,380
1884	250,297	181,482	431,779
1885	225,913	169,490	395,403
ENDING DEC. 31.			
1885	149,400	128,389	277,789
1886	253,484	177,065	430,549
1887	261,658	218,900	480,558
1888	290,689	157,878	448,567
1889	329,543	212,102	541,645
ENDING DEC. 31—Continued.			
1890	353,757	110,241	463,998
1891	344,978	130,528	475,506
1892	243,653	150,575	394,228
1893	308,435	194,129	502,564
1894	307,305	142,803	450,108
1895	270,560	161,415	431,975
1896	267,072	135,351	402,423
1897	267,380	90,900	358,280
1898	298,610	101,274	399,884
1899	223,949	132,701	356,650
1900	266,186	62,987	329,173
1901	225,189	95,992	321,181
1902	245,243	68,122	313,365
1903	233,540	25,000	258,540
1904	258,806	12,000	270,806
1905	234,676	35,549	270,225
1906	190,180	33,495	223,675
1907	228,354	28,867	257,221
1908	192,263	33,232	225,495
1909	201,254	6,700	207,954
1910	179,659	0	179,659
1911	169,156	0	169,156
1912	131,490	0	131,490
	8,721,518	4,105,195	12,826,713

[a] U. S. Geol. Survey Mineral Resources, 1892, p. 782, 1893.

PRESENT CONDITION.

As shown in the table, the production of the South Carolina field has fallen off greatly within the last few years and is now about equal to the production between 1875 and 1880. No river rock has been mined since 1910 and very little in the five years previous to that time. Land mining is confined chiefly to the Ashley district, but at the time of the writer's visit only one dredge was operating on the north side of the river and two on the south side. The Virginia-Carolina Chemical Co. is the principal producer, and only one other company is operating. The large washing plant at Lambs is the only one now in operation, although in the fall of 1913 three other plants were working, two on Stono River and one on Chisholms Island, near Beaufort. Under present conditions the price of rock is controlled largely by the Florida product, and the margin of profit in the South Carolina field is so small that mining is practicable only with the use of machinery capable of handling large quantities of material.

FUTURE OF THE FIELD.

The prospects of a marked revival of mining operations in this field are poor. The field attained its importance at a time when no other commercial deposits in this country were known and when, on the other hand, the widespread need of fertilizer was first being felt.

The increased cost of production, the exhaustion of the richer and more accessible deposits, and finally the extensive exploitation of the cheap and high-grade Tennessee and Florida deposits have proved a combination which the operators have not been able to withstand. The foreign trade has been completely lost, and under present conditions the rock can not be shipped out of the State.

It must be remembered, however, that there are probably at least 5,000,000 tons of 60 per cent phosphate still in the ground and that improved machinery may at some later time render these deposits workable. Furthermore, the South Carolina phosphate enjoys two advantages. First, the former importance of the field led to the building of a group of large fertilizer factories at Charleston, and the expense of shipping is therefore almost negligible; second, the rock makes an excellent superphosphate, and many planters prefer it to the higher-grade rock of the neighboring fields.

On the other hand, the highest grade rock that the field can be expected to produce does not average more than 61 per cent phosphate and generally exceeds 3 per cent iron and alumina. The cost of production is considerably higher than that in the Florida and Tennessee fields, so that the 70 per cent phosphate rock from those States can be delivered at Charleston at a price only slightly above that of the local product. This offsets the saving due to local manufacture, and the excellence of the superphosphate can scarcely compensate permanently for a difference of 10 per cent in phosphate content. The preference for the South Carolina rock is chiefly local, and although the demand within the State may continue for some time it probably can not affect the general phosphate industry.

It is probable, therefore, that only a small amount of mining will be done for some time. However, as the Florida and Tennessee deposits become exhausted prices may advance sufficiently to permit the profitable mining of the remaining South Carolina rock. On the other hand, the presence of great deposits of high-grade rock in Wyoming and Idaho points to an undiminished supply for many years and insures crushing competition in the interior part of the United States. All considerations, therefore, seem to indicate that the South Carolina field has passed its period of maximum production, and that despite the quantity and the favored location of the remaining deposits the field will not for a very long time be an important factor in the phosphate industry.