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THE PHOSPHATE DEPOSITS OF FLORIDA

BY

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THE PHOSPHATE DEPOSITS OF FLORIDA.

By George Charlton Matson.

CLASSES AND GENERAL FORM AND FEATURES.

The phosphates of Florida are of three distinct types—rock phosphate, pebble phosphate, and soft phosphate. The rock phosphate consists of bowlders and pebbles, of many sizes and shapes, embedded in a mass of sand, clay, and soft phosphate, the whole being usually intermingled in varying proportions. In a few deposits the coarse and fine fragments of phosphate are more or less definitely separated, the large pieces, comprising cobbles and bowlders, being aggregated near the bottom, but even where there is a general separation the larger pieces are likely to be scattered sporadically through the whole deposit, and fine materials may be found in any part of a bed. The rock phosphate ranges in color from light gray or white, the usual colors, to yellow, brown, or dark blue.

The pebble phosphates are composed of rounded or subangular pebbles embedded in a matrix of sand, clay, or soft phosphate. The materials show more or less assortment into alternating layers of coarse and fine pebbles in a matrix which is in most places sandy, but in some deposits consists of fine clay or soft phosphate. The color of the pebbles ranges from light gray to blue or black.

The soft phosphate is in fine powder or in soft masses that crumble to dust when dry but are very plastic when wet. Phosphate of this type is commonly white, though it may be colored yellow or brown by ferric hydroxide or other substances. Soft phosphate forms a large portion of the matrix enveloping the fragments of rock in the rock-phosphate deposits. A part of the matrix in many deposits of pebble phosphate consists of soft phosphate, but the percentage of sand and clay in such deposits is usually larger than in those of rock phosphate. Some deposits in regions underlain by limestones contain few pebbles of rock phosphate, but such deposits are small.

HISTORY AND PRODUCTION.

Phosphate has been mined in Florida since 1888, and for many years the State has been an important source of phosphate for the manufacture of high-grade fertilizer, which has been made and used both in this country and abroad. Mines have recently been opened on some of the ocean islands, but notwithstanding this fact the exploitation of Florida phosphate has continued with only temporary fluctuations, which were probably due largely to fluctuations in the demand. During 1909 some of the mines reduced their output and others suspended work, but early in 1910 many mines were reopened and nearly all the large mining companies began prospecting to discover new deposits of high-grade rock. By the summer of 1911 the number of active mines had increased, and during that year more phosphate was mined in Florida than in any preceding year.

River-pebble phosphate was mined as early as 1888 on Peace River near Arcadia, the principal mines being along the river, though some mining was done along other streams. The amount of rock produced annually reached a maximum of nearly 125,000 tons in 1893 and then declined until operations were suspended in 1908.

The exploitation of rock and land-pebble phosphate deposits began about 1889 or 1890. During the earlier years of the industry in Florida the quantity of land-pebble phosphate mined was rather small, the mines being nearly all on low-grade deposits, some of them containing less than 70 per cent tricalcium phosphate, but in recent years the discovery of high-grade land-pebble phosphate containing 75 to 80 per cent tricalcium phosphate has led to a considerable increase in the amount of rock mined. There has also been a marked increase in the demand for the lower grade rock, so that the production in 1910 was more than a million and a half tons.

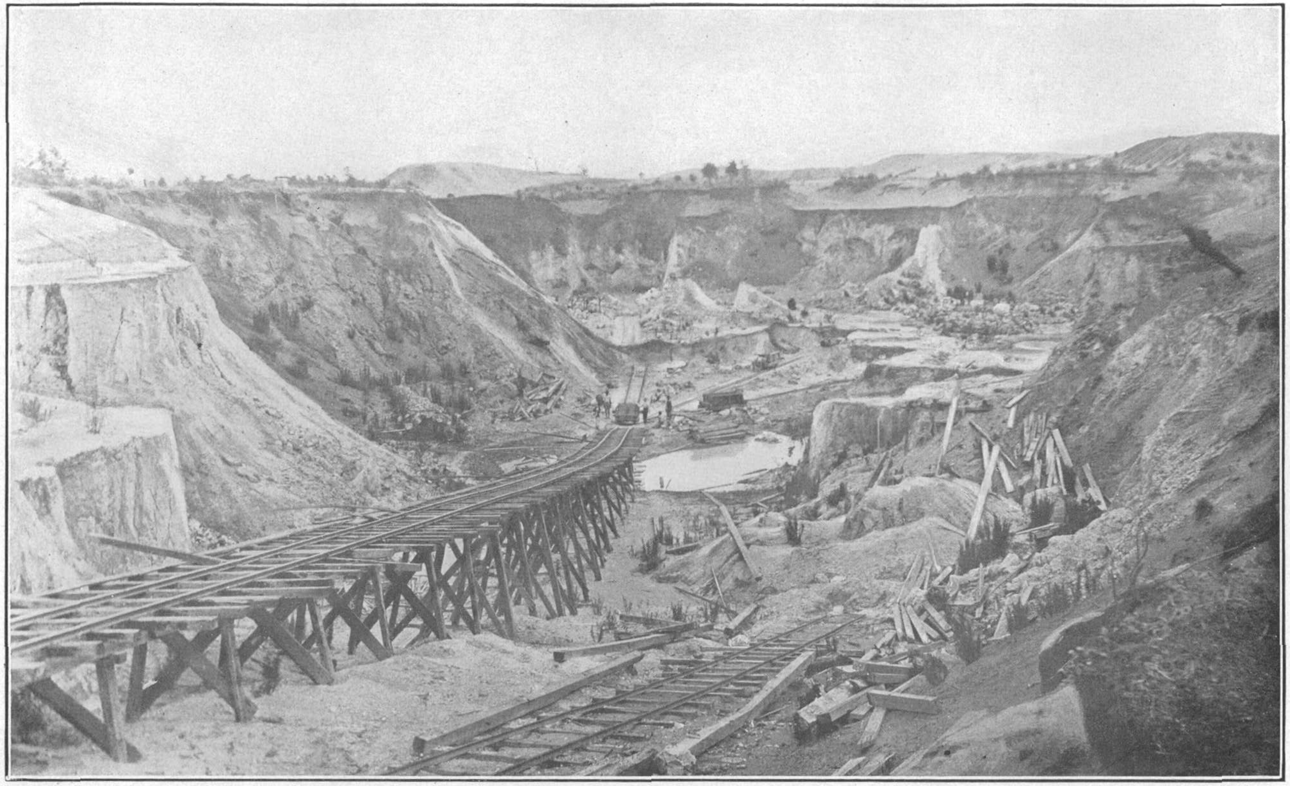
The rock phosphate was formerly guaranteed to contain not less than 75 per cent tricalcium phosphate and not more than 5 per cent of iron oxide and alumina. The demand for rock of this grade was large enough to cause the opening of a number of mines to furnish phosphate for exportation, but later the minimum standard was raised from 75 to 77 per cent tricalcium phosphate, and the maximum of iron and alumina was fixed at 3 instead of 5 per cent. This change led to the abandonment of some mines but stimulated the working of high-grade deposits (See Pl. II) until the output is now more than two and a half million tons annually.

The quantity of phosphate rock marketed in Florida during the years 1909–1913 is shown in the table below:

Phosphate rock marketed in Florida, 1909–1913, classified by grades, in long tons.

Year.	Hard rock.		Land pebble.		River pebble.		Total.	
	Quantity.	Value.	Quantity.	Value.	Quantity.	Value.	Quantity.	Value.
1909	513,585	$4,026,333	1,266,117	$4,514,968	....	....	1,779,702	$8,541,301
1910	438,347	3,051,827	1,629,160	5,595,947	....	....	2,067,507	8,647,774
1911	443,511	2,761,449	[a] 1,992,737	6,712,189	([b])	([b])	2,436,248	9,473,638
1912	493,481	3,293,168	[a] 1,913,418	6,168,129	([b])	([b])	2,406,899	9,461,297
1913	489,794	2,987,274	[a] 2,055,482	6,575,810	([b])	([b])	2,545,276	9,563,084

[a] Includes a small quantity of river pebble. [b] Included in land pebble.



GENERAL VIEW OF ROCK-PHOSPHATE MINE.

Photograph by W. L. Martin.

DISTRIBUTION OF PHOSPHATE DEPOSITS.

General conditions.—Small deposits of phosphate and phosphatic rock occur at many places in Florida; in fact, phosphate appears to be very widely distributed in the northern and central parts of the peninsula, and deposits are found on the west side of Apalachicola River in western Florida. (See Pl. III.) The areas of workable phosphate, however, are confined to certain parts of the peninsula, and even in areas that are usually included in the phosphate region only a very small percentage of the land actually contains enough phosphate to warrant exploitation.

Rock phosphate.—Deposits of rock phosphate occur on Wacissa, Aucilla, Fenholloway, and Suwannee rivers, in Jefferson and Taylor counties, and though none of these deposits are now mined, some of them might be exploited if better facilities for transportation were provided. Near Luraville there are rich deposits of rock phosphate, but attempts to mine them have been abandoned because the percentage of iron oxide and alumina in the phosphate exceeds the present limit prescribed by the purchasers. In these deposits the alumina is in the interior of the pebbles and bowlders and consequently is not readily removed by washing. The rock-phosphate region, where mining has been most active, forms a narrow belt beginning in southeastern Suwannee and southern Columbia counties and extending southeastward to High Springs, where it bends southward across western Alachua and Marion and eastern Citrus and Hernando counties.

Many active mines are located along Barr's tramroad, a few miles west of the Atlantic Coast Line Railroad, extending from a point near Clark southward beyond Newberry. The number of mines decreases southward toward Archer, and mining has been discontinued at Albion, in Levy County. The Early Bird and Eagle mines were long ago abandoned, but two mines are in operation near Standard and one near Juliette, in western Marion County. Dunnellon, in southwestern Marion County, is an important center of rock-phosphate mining, several mines being located near that place on terraces bordering Withlacoochee River and others on a terrace bordering the west side of Tsala Apopka Lake. There is a rock-phosphate mine a few miles west of Istachatta, in northeastern Hernando County, and another just south of Croom, in the east-central part of the same county. The rock-phosphate deposits extend into western Sumter County and southward a few miles beyond Richland, in eastern Pasco County, but the rock in Sumter and Pasco counties is of low grade and is not being mined.

Phosphate that has generally been classed as plate rock is found in central Marion County. Several mines were opened in the plate-rock region along the Seaboard Air Line Railway, northeast of Ocala, but all have been closed for some time. The best deposits of this rock are near Sparr and Anthony and 5 or 6 miles east of Ocala. Bowlders of phosphate were at one time mined near Welshton, but operations were suspended many years ago, when the introduction of log washers made it possible to mine finer material, and no mines are now being operated in the plate-rock region.

Land-pebble phosphate.—The extent of the land-pebble phosphate (Bone Valley gravel) is discussed in the geologic résumé, on page 22. The principal centers of mining are at Mulberry and Fort Meade, but mines are located as far north as Plant City and Medulla, and it is rumored that one is soon to be opened between Medulla and Winston. Mulberry is an important center for pebble-phosphate mining and there are a number of mines along the Atlantic Coast Line Railroad between Mulberry and Fort Meade. South of Fort Meade there are mines at Jane Jay and near Bowling Green. Some prospecting has been done near Turkey Creek, and mines will probably be opened farther west than those now in operation. There are also rumors of impending development southeast of Fort Meade.

River-pebble phosphate.—River-pebble phosphate was formerly mined along Peace River from Mulberry southward. Arcadia was at one time the principal center for the exploitation of this kind of phosphate rock, but in recent years there has been considerable mining near Fort Ogden and Hull. Pebble rock was also mined on Alafia River and on Black Creek, a tributary of St. Johns River. Since 1908 no river-pebble phosphate has been mined in Florida. In addition to the localities already mentioned, pebble phosphate has been reported on Manatee, Miakka, Kissimmee, and Caloosahatchee rivers and at the mouth of Fisheating Creek, but none of these streams is known to afford workable deposits.

Pebble phosphates were collected by Eldridge in T. 1 N., R. 12 E., and T. 2 N., Rs. 13 and 14 E., all of the meridian of Tallahassee. Specimens of similar character were obtained also from T. 1 S., R. 14 E. of the Tallahassee meridian. It is not certain that these deposits are of the river-pebble type, but in any event there is evidence of the presence of rock phosphate in that part of the State, and the pebble phosphate has probably been derived from the rock phosphate by erosion and redeposition either by streams or by wave action during a period of submergence.

Soft phosphate.—Soft phosphate forms a variable proportion of the matrix that surrounds the fragments of rock phosphate in all the deposits of the hard-rock type. It also incloses pebbles of phosphate in the land-pebble region, but it is less important there because the deposits are prevailingly coarse and much of the matrix is sandy. In addition to its occurrence with the other types soft phosphate occurs

MAP SHOWING THE PHOSPHATE DEPOSITS OF FLORIDA.

in small, more or less isolated pockets in the limestones of the Vicksburg group, and in larger areas, scattered over several square miles, south of Greer and northwest of Ocala. Soft phosphate is found also southwest of Richland, in Pasco County. There is practically no demand for this kind of phosphate, though it should be a valuable fertilizer for use on soils of certain types.

GEOLOGY.

NOMENCLATURE AND LITHOLOGY OF THE FORMATIONS.

The geology and topography of Florida have been discussed by many writers, and the detailed consideration of these subjects may therefore be omitted from this report. It is necessary to give a brief summary of the geology of the northern part of the peninsula, however, in order to furnish a basis for the discussion of the mode of occurrence, geologic relations, and origin of the phosphates. A comprehensive summary of the geology is given in a table published in the Second Annual Report of the Florida Geological Survey,[1] which is here reproduced (opp. p. 12) after revision to conform to the present state of knowledge of the geology of Florida. The deposits called the Hawthorn formation have for a long time been known to be the equivalent of a part of the Alum Bluff formation, and the deposits heretofore described under that name are in this report included in the Alum Bluff formation. The evidence for the abandonment of the name "Hawthorn formation" has recently been briefly discussed by Messrs. Vaughan and Cooke,[2] and will be fully presented in a detailed report to be published later.

The map accompanying this report is in part a reprint of one prepared for a report on the geology and ground waters of Florida,[3] but it has been revised and corrected by means of studies made subsequent to the publication of the earlier report. The map is constructed with special reference to the Tertiary geology, for the commercial deposits of phosphate are associated with rocks of Tertiary age.

TERTIARY SYSTEM.

OLIGOCENE SERIES.

VICKSBURG GROUP.

Definition and subdivisions.—The oldest rocks known in Florida belong to the Oligocene system, and the oldest Oligocene rocks belong to the Vicksburg group, which comprises a large part of what was

[1] Matson, G. C., and Clapp, F. G., A preliminary report on the geology of Florida, with special reference to the stratigraphy: Florida Geol. Survey Second Ann. Rept., 1909.

[2] Vaughan, T. W., and Cooke, C. W., Correlation of the Hawthorn formation: Washington Acad. Sci. Jour., vol. 4, No. 10, pp. 250–253, 1914.

[3] Matson, G. C., and Sanford, Samuel, Geology and ground waters of Florida: U. S. Geol. Survey Water-Supply Paper 319, 1913.

once called the Vicksburg limestone. However, some of the deposits that were formerly included in the Vicksburg have for several years been classed with post-Vicksburg formations. The Vicksburg group in Florida has been divided into three formations, known as the Marianna limestone, the "Peninsular" limestone, and the Ocala limestone. These three formations are similar in lithologic character and will therefore be discussed here as a single group. These limestones are of especial interest because they underlie all the rock phosphate now mined in Florida.

Lithologic character.—The Vicksburg group includes white or light-colored porous limestones, which are generally soft and crumble so easily that it is difficult to obtain good specimens. On exposure to the air, however, the surface of the limestone hardens as a result of the deposition of calcium carbonate in the outer pores of the rock. Samples obtained in drilling deep wells show that these rocks are remarkably uniform in color and texture to a depth of several hundred feet beneath the surface in the peninsula of Florida. However, the upper part of the limestones of the peninsula include a slight admixture of land-derived sediments, such as clay and fine sand, and well records indicate that similar conditions exist in western Florida. Layers of light-blue or gray chert, ranging in thickness from a fraction of an inch to several feet, occur in the limestones of this group. Irregular masses and bowlders of flint are found at many places where the rocks belonging to this group are at the surface, and the shells embedded in this flint serve as a valuable guide to determine the areal extent of the rocks of Vicksburg age.

Distribution.—The limestones of the Vicksburg group underlie all of Florida, but except in small areas in the peninsula and in western Florida they are covered by younger beds of sand, clay, or limestone. In the peninsula the principal area in which these limestones lie at or near the surface extends from a point near Sutherland, Hillsboro County, and Dade City, Pasco County, northward nearly to Fort White and Lake City Junction, Columbia County. The best exposures are in Pasco, Sumter, Lake, Citrus, Hernando, Marion, Levy, Lafayette, Alachua, Suwannee, and Columbia counties. Near the margin of the area of the Vicksburg (see map, Pl. I, in pocket) there are many more or less isolated exposures, the best known being the outliers in Taylor, Jefferson, Columbia, and Suwannee counties.

APALACHICOLA GROUP.

SUBDIVISIONS.

The Apalachicola group (see table opposite) is now divided into three formations—the Tampa, Chattahoochee, and Alum Bluff—the Chattahoochee and Tampa formations being probably in part

Geologic formations in Florida.

System.	Series.	Group.	Formation.	Lithologic features of the formations.	Member.	Lithologic features of the members.	Old names.
Quaternary.	Recent.			Human remains, "Vermetus rock," beach sands, coquina, eolian deposits, lacustrine deposits, chemical deposits, alluvial deposits.			
Quaternary.	Pleistocene.			Yellow sand. "Vermetus rock." Coquina. "Planorbis rock." Gray sand. Fossiliferous marls.			"Everglades limestone"; includes part of Palm Beach limestone, Miami oolite, and Lostmans River limestone.
			Palm Beach limestone	Light-colored limestone, with sandy beds and loose sand.			
			Miami oolite	Light gray to white oolitic limestone, sandy in places.			
			Key Largo limestone	Coral limestone; reef rock.			
			Key West oolite	Light gray to white oolitic limestone.			
			Lostmans River limestone.	Dark to light, hard to friable limestone, sandy or marly in places.			
			Unconformity				
Tertiary.	Pliocene.		Bone Valley gravel (Probably largely contemporaneous deposition.)	Light-colored gravel and marl, containing phosphatic pebbles.			Land-pebble phosphates=Bone Valley gravel.
			Alachua clay	Greenish sandy clay, weathering yellow or red.			"Archer beds"=Alachua clay.
			Nashua marl	Light-colored sandy shell marl.			"De Soto beds"="Arcadia marl," "Peace Creek bone bed," and Alachua clay. "Arcadia marl" regarded as a phase of the Caloosahatchee. "Floridian group," proposed for Pliocene beds of Atlantic and Gulf States.
			Caloosahatchee marl.	Light-colored sandy shell marl.			
			Unconformity (?)				
	Miocene.		Jacksonville formation (eastern coast). (Contemporaneous deposition.)	Light-gray to white limestone, weathering light yellow; light-gray to yellow clay and gray sand; some chert beds.			
			Choctawhatchee marl (western Florida and St. Johns Valley).	Greenish to light-gray sandy shell marl or greenish-gray clay.			
			Unconformity				
	Oligocene.	Apalachicola.	Alum Bluff formation	Gray to green sands, clays, and fuller's earth; limestone occurs in some localities, but it is usually impure.	Shoal River marl. Oak Grove sand. Chipola marl.	Greenish to gray sands and marls, very fossiliferous. Light-gray sand and marl, very fossiliferous. Gray to yellow shell marl.	"Chipola group" and "Chipolan stage"—Apalachicola group. "Sopchoppy limestone"; included in Alum Bluff formation. "Manatee River marl"; included in Alum Bluff formation.
			Chattahoochee formation (western Florida). (Probably deposited contemporaneously.)	Light yellow to gray earthy and siliceous limestones; in places cherty; sand and clay rare.			"Aspalaga marl"; part of Chattahoochee formation. "Ocheesee beds"=Chattahoochee formation and may include the upper limestone of the Tampa formation.
			Tampa formation (southern Florida).	Yellow limestones and greenish clays; some chert nodules and layers.			"Waldo formation"; exact position doubtful.
			Unconformity				
		Vicksburg	Ocala limestone	Soft, porous light-gray to white limestone with beds of marl and layers of chert.			"Levyville formation," probably=Ocala limestone.
			"Peninsular" limestone (central Florida).	Soft, porous light-gray to white limestone containing marl beds and layers of chert.			
			Marianna limestone (western Florida).	Soft, porous light-gray to white limestones containing some marl and more rarely clay beds; layers of chert common.			

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contemporaneous and the Alum Bluff formation being younger. The deposits heretofore described under the name "Hawthorn formation" have been found to be the same as the Alum Bluff formation, and they are therefore here included in that formation, as explained on page 11.

CHATTAHOOCHEE FORMATION.

The Chattahoochee formation consists of light-colored limestones and marls and lies mostly in western Florida. It rests upon an eroded surface of the Vicksburg group and occupies the northern part of the area of the Apalachicola group as it is outlined on the map (Pl. I, in pocket).

TAMPA FORMATION.

Lithologic character.—Like the Alum Bluff formation, the Tampa formation contains both limestone and clastic materials. At the base of the formation at the type locality near Tampa is a tough blue clay, over 40 feet thick, containing more or less sand, probably in the form of thin laminæ. Above the clay is a limestone having a thickness of over 25 feet and containing a silicified layer ranging in thickness from a few inches to over 10 feet. This layer of silicified limestone is very fossiliferous and has been called the Orthaulax zone because it contains a certain shell belonging to that genus. Some clays that overlie the upper limestone of the Tampa formation were formerly included in it, but recent investigations have shown that they belong to the Alum Bluff formation.

Distribution.—The Tampa formation is exposed along the shores of old Tampa Bay and lies beneath the surface of the peninsula west of the bay. The limestones of this formation probably extend northeastward into Pasco and Polk counties, and the formation has been recognized as far south as Manatee River, on the west coast. Its occurrence in the interior of the peninsula has not yet been determined, but it probably extends some distance up the north prong of Hillsboro River.

ALUM BLUFF FORMATION.

General features.—The Alum Bluff formation is one of the most interesting and widespread formations in Florida. It includes a great variety of sediments, ranging from pure, fine-grained clays to sands, marls, and limestones. It is of considerable economic importance because it supplies all the fuller's earth and a little of the phosphate now being mined in the State. As explained on page 11, it includes the deposits heretofore described under the name "Hawthorn formation," recent work having proved that those deposits are the same as the typical Alum Bluff formation.

Lithologic character.—The most prominent constituent of this formation, especially where it is at the surface, is a coarse gray sand, which, where thick, is covered by a growth of stunted timber known as "scrub." The "big scrub" that lies east of Oklawaha River is a good example of the stunted vegetation found in some places on the sands of the Alum Bluff formation. Shell marls (sand containing shells) are common at certain geologic horizons, especially near the top of the formation in the western part of the State. Clays are locally abundant, among them being deposits of fuller's earth. These deposits are now being mined in the vicinity of Quincy and near Ellenton, on Manatee River, but similar deposits are found in other parts of the State, especially in Gadsden County. Limestones are not numerous in the Alum Bluff formation, but thin beds occur in the upper portion. These limestones are shallow-water deposits, generally more or less earthy, containing shells of marine animals that inhabit shoal water. The Florida Geological Survey [1] recognizes three members of this formation—the Chipola marl, the Oak Grove sand, and the Shoal River marl. The "Sopchoppy limestone"[2] was also tentatively included in the Alum Bluff formation and the propriety of including it is shown by the fact that for this report a basis of correlation was found in the collections of fossils obtained from a light-gray to yellow phosphatic limestone that underlies the pebble phosphate and is known locally as "bedrock." In connection with the discussion of the phosphate deposits a more detailed description of this "bedrock" will be given. Its faunal relations to the Oak Grove sand member indicate that it belongs to the upper part of the Alum Bluff formation, and its similar relation to the "Sopchoppy limestone" strengthens the belief that the limestone lies at about the same geologic horizon as the Oak Grove sand. The collections made from the limestones of the Alum Bluff formation represent several localities, but the largest number of well-preserved specimens came from the pit of the Coronet Phosphate Co., about 5 miles southeast of Plant City. W. H. Dall selected some of these specimens for examination and in a letter to the author gave the results of his studies as follows:

I have made a very careful and particular examination of the most characteristic fossils I could find in the material from 5 miles southeast of Plant City, Fla., with the following results:

Busycon n. sp.
Pecten sayanus Dall (Oak Grove up).
Pecten (almost certainly) poulsoni Morton.
Arca santarosana Dall (Chipola, "Sopchoppy," Oak Grove).
Arca (probably) dodona Dall (Oak Grove).

[1] Matson, G. C., and Clapp, F. G., A preliminary report on the geology of Florida, with special reference to the stratigraphy: Florida Geol. Survey Second Ann. Rept., pp. 102-106, 1909.

[2] Idem, p. 103.

Arca umbonata Lamarck (Chipola to Recent).
Chione glyptocyma Dall (Oak Grove).
Cardita tegea Dall (Chipola, "silex beds").
Mytiloconcha incurva Conrad (lower Miocene of New Jersey and Maryland, "Sopchoppy limestone").

I have added the distribution, which shows that the horizon is upper Oligocene, probably near the Oak Grove, Santa Rosa County, Fla., horizon. It is a "beach" deposit, as shown by the way in which the shells are tumbled together and by the presence of shore barnacles. The Pecten (?*P. poulsoni*) is a fragment and may be rémanié. I think the species is not known to have survived the era of the "Peninsular" limestone.

In the pebble-phosphate region the limestones of the Alum Bluff formation contain numerous pebbles of phosphate and some clay and sand and are interbedded with layers of clay containing pebbles.

Distribution.—The Alum Bluff formation lies near the surface over a large part of the north end of the State, whence it extends southward in a belt between Oklawaha and St. Johns rivers. It extends across Central Lake County, but near the headwaters of Withlacoochee and Kissimmee rivers its distribution has not been determined. From the vicinity of Haines City it extends southwestward, passing beneath the younger formations. The sandy phase of this formation may be represented in a ridge bordering the west side of Kissimmee Valley, somewhat farther south than the latitude of Fort Meade. This part of the State has not been examined carefully, but descriptions furnished by casual visitors and residents suggest the occurrence here of sands of the Alum Bluff formation.

MIOCENE SERIES.

SUBDIVISIONS.

Two formations of Miocene age, known as the Choctawhatchee marl and the Jacksonville formation, have been recognized in Florida, and it is possible that the Bone Valley gravel and the Alachua clay, after eliminating the "Peace Creek bone bed," may also be Miocene.

CHOCTAWHATCHEE MARL.

Lithologic character.—The Choctawhatchee marl consists of gray to green or blue sands and shell marls and, in some localities, of clays. The sands are moderately coarse and in many places contain fine glistening scales of mica. Locally they show a slight tendency to induration because of the presence of a small amount of calcium carbonate, which acts as a cement, binding the sand grains together. Intermingled with the sands there is usually a little dark-colored earthy matter, and the presence of iron compounds is indicated by the red and yellow stains that appear where the surface of the sands has been exposed to the weather.

Some layers contain a large number of shells of marine animals such as lived in shallow water during the deposition of the beds of Miocene age. In many places these shells are almost perfectly preserved, but the occurrence of broken and worn fragments indicate that some of the animal remains were subjected to more or less disturbance by the waves of the Miocene sea. At a few places a deposit of clay has been observed in the upper part of the formation.

Distribution.—The distribution of the Choctawhatchee marl has been indicated on the map, but owing to poor exposures the details of the occurrence of this and other formations are not known. The principal area of this marl stretches from a point near the northwest corner of Florida eastward nearly to Tallahassee. The exposures occupy a narrow belt and the formation dips seaward beneath the younger deposits that fringe the Gulf coast. Small patches of marl similar to that already described are found in the St. Johns Valley and as far west as Brooker, giving additional evidence of the possibility of the existence of a Miocene strait across the northern end of the peninsula. Similar marl has been observed in drillings from the wells at Kissimmee and it doubtless underlies the southern end of the peninsula.

JACKSONVILLE FORMATION.

Lithologic character.—The Jacksonville formation consists of a thick deposit of interbedded sand, sandstones, and clays, with some layers of limestone near the top. No good exposures of the sands and clays have been observed, but the character of these deposits is shown by samples obtained in drilling a well at Jacksonville. The log of this well, supplied by Mr. R. N. Ellis, follows:

Log of well at Jacksonville, Fla.

	Feet.
Filled ground and sand	0 - 15
Varicolored gray to red sand	15 - 34
Gravel	34 - 34½
Yellowish fossiliferous rock	34½- 40
Gravel with water	40 - 44
Gray fossiliferous rock	44 - 53
Clay, with thin layers of white rock	53 - 58
Blue clay, with black gravel at 58–70 and 82–89 feet	58 - 89
Rock	89 - 94
Blue clay and black gravel	94 -100
Rock, 2 inches thick	100
Blue clay with quartz sand and very fine black gravel	100 -130
Very hard compact clay and sand	130 -142
Greenish sandy clay	142 -204
Greenish sandy clay with more or less black gravel and occasional streaks of pure clay	204 -250
Sticky clay and sand and fine gravel	250 -263
Rock	263 -263½
Greenish sandy clay and heavy gravel bed	263½-272

	Feet.
Blue clay containing very fine sand	272 –287
Sand rock	287 –289
Bed of shells, oysters, etc., living types	289 –290
White clay	290 –294
Sand with clay enough to hold it	294 –298
Compact greenish sandy clay with streaks of nearly pure clay	298 –314
Sand containing shells; just enough clay to hold them	314 –320
Shells with scraps of fossil bone	320 –330
"Coquina" rock	330 –331
Clay	331 –340
Blue clay and sand	340 –350
Sticky blue clay; very little sand	350 –358
Clay with black gravel	358 –365
Blue clay with gravel and shell casts	365 –368
White clay with gravel	368 –375
White marl with very little sand	375 –385
Light-colored clay	385 –390
Greenish clay	390 –400
Greenish sandy clay	400 –410
Sticky clay	410 –428
Clay with very little sand	428 –434
Nearly pure clay; very light when dry	434 –443
Bluish sandy clay with gravel and streaks of sticky clay with some nodules of rock	443 –470
Rock	470 –470½
Greenish clay with fine sand above and coarse sand below; small flow of water at 487 feet	470½–487
Rock bowlder (siliceous concretion) in blue sandy clay	487 –492
Compact blue clay	492 –496
White clay	496 –497
Conglomerate rock	497 –499
Hard brownish rock	499 –504
Very hard compact rock (siliceous limestone)	504 –510
Soft white rock with some water	510 –519
Hard compact rock	519 –524
Very soft white rock in layers 1 to 5 feet thick, with strata of more compact rock 3 to 12 inches thick; increase in the flow of water on breaking each hard stratum. Gaged flow at 632 feet 1,000,000 gallons in 24 hours	524 –727
Compact brown rock; no water	727 –758
Alternate hard and soft strata of grayish rock with very little water	758 –865
Soft white rock with hard brown layers 1 to 3 feet thick every few feet; a slight increase of flow from each soft layer	865 –930
Very hard brown rock	930 –935
Soft brownish rock with hard layers, flow increasing as each hard layer is broken	935 –950
Alternate layers of hard and soft rock; small increase in flow	950 –970
More compact rock; no water	970 –980

The sands and gravels from the surface to 34½ feet are probably Pleistocene, though they may include some Pliocene beds.

The fossiliferous limestone encountered at 35 feet belongs to the Jacksonville formation, which is thought to extend to a depth of at least 496 feet, though it is possible that this measurement may include some sands and clays of the Alum Bluff formation.

The limestones of the Jacksonville formation range in color from white or light gray where they are fresh to pale yellow or yellowish-gray where they have been exposed to the weather. When examined with an ordinary hand lens the limestone is seen to be prevailingly coarse grained and to contain a large proportion of sand, and a more careful examination shows the presence of considerable clay. Some layers of this rock are abundantly fossiliferous, but the animal remains consist of casts and molds left after the original shell had been removed by solution.

Distribution.—The distribution of the Jacksonville formation is imperfectly known, but similar rock is exposed near Zellwood, in Orange County, and the artesian wells at St. Augustine pass through sands and clays that resemble those at Jacksonville. Possibly the deposits of Miocene age encountered in the deep well at Palm Beach should be referred to this formation. The Jacksonville formation is known as far west as Waldo, and either it or the Choctawhatchee marl may extend entirely across the north end of the peninsula, as Miocene fossils have been reported from the valley of Suwannee River.

PLIOCENE SERIES.

SUBDIVISIONS.

The Pliocene deposits of Florida have heretofore been divided into five formations—the Caloosahatchee and Nashua marls, the Alachua clay, the Bone Valley gravel, and the Lafayette formation. Heretofore the first four of these formations have been regarded as largely contemporaneous. Recent work, however, has shown that the Alachua clay and Bone Valley gravel are perhaps older and that they may be even of Miocene age, but until conclusive evidence of their age has been discovered they are for the present retained in the Pliocene.

In the report on the geology and ground waters of Florida,[1] attention was called to the fact that the materials included in the assemblage called the Lafayette formation in Florida did not comprise a distinct formation, but are in part upper Oligocene, in part Miocene, and in part Pliocene.

The collection of vertebrate fossils obtained from the rock-phosphate mines along Withlacoochee River in the vicinity of Dunnellon

[1] Matson, G. C., and Sanford, Samuel, Geology and ground waters of Florida: U. S. Geol. Survey Water-Supply Paper 319, p. 147, 1913.

was submitted to J. W. Gidley, of the United States National Museum, and his report on these specimens follows:

The vertebrates from the Dunnellon, Fla., localities, which include one and possibly two species of mastodon and a tooth of *Elephas primigenius* (?), represent a considerably later phase than the beds at Mulberry, being probably nearly the equivalent of the "Loup River beds" (upper Pliocene or lower Pleistocene) of Nebraska.

It is intended in the near future to give these collections a more detailed study, when a complete list of the species represented will be given.

CALOOSAHATCHEE MARL AND NASHUA MARL.

Age.—The Caloosahatchee marl and the Nashua marl are lithologically similar and are probably contemporaneous, hence they are here discussed together. Neither of them includes any commercially important deposits of phosphate, though pebbles of phosphate have been reported from the Caloosahatchee marl on Caloosahatchee River. It is not probable, however, that these pebbles are sufficiently numerous to have any economic value.

Lithologic character.—The Caloosahatchee and Nashua marls consist of light-gray and blue sandy shell marls interbedded with more or less sand. The shells in these formations, many of which are beautifully preserved, are generally embedded in a matrix consisting of sand and fragments of shells. The only difference between the two formations is the presence in the Nashua marl of some shells not found in the Caloosahatchee.

Distribution.—The known exposures of the Nashua marl are in the vicinity of St. Johns River, between Palatka and Sanford, but the formation is no doubt much more widely distributed and additional field work may disclose many other exposures. The Caloosahatchee marl is best known on Caloosahatchee River but is also exposed on the other streams that enter Charlotte Harbor. The best exposures are along Peace River and its tributaries, but other exposures may occur along Miakka River, Prairie Creek, and some smaller streams. The marl probably forms a nearly continuous deposit between these isolated exposures, and the presence of Pliocene shells in some of the samples obtained from deep wells at Kissimmee suggests that Pliocene marl stretches entirely around the eastern side of the exposures of older formations. It is doubtful whether this can be confirmed by direct observation, because heavy deposits of younger sands obscure the Pliocene beds in the south-central part of the peninsula.

The deposits of Peace Creek and the fossils obtained from Ocala (see p. 20) may be Pliocene or even Pleistocene, but little is known concerning the relations of the "Peace Creek bone bed." It may be either the Pleistocene or Recent deposits formerly mined for river-pebble phosphate, or it may be an older deposit exposed by erosion of the stream.

The vertebrate fossils from Ocala were obtained from the overburden at the pits of the Ocala Lime Co. The bones were embedded in the sand and clay which at that locality overlies the Vicksburg group and extends into depressions in its surface. Their mode of occurrence indicates that these bones may represent parts of the skeletons of animals that were mired in local marshes or lakes, and this and their situation near the level of the uppermost Pleistocene terrace suggest that they may be of early Pleistocene age.

ALACHUA CLAY.

Age.—The reason for believing that the Bone Valley gravel may be Miocene has already been given. The age of the Alachua clay is also in doubt because the fossils may be either late Miocene or early Pliocene. The occurrence of these clays in the interior of the peninsula, remote from exposures of known Pliocene and at altitudes high enough to correspond better with the Miocene, is in favor of their inclusion in the Miocene. Concerning the vertebrate fossils from the Alachua clay, J. W. Gidley, who has recently studied the lists already published, makes the following report:

> The faunas of the beds at Archer and Ocala indicate strata at two distinct horizons, the later being much newer than the earlier. With the possible exception of *Elephas columbi*, from Ocala and Peace Creek, none of the beds in Florida contain any species in common with beds of the Western Plains region, hence an accurate estimate regarding the age of these beds relative to those of the West is not yet possible.
>
> The presence of Elephas and true Equus, as well as specimens referred to Bison, Cervus, and Megalonyx, in the deposits of Ocala and Peace Creek suggest a Pleistocene age for these beds, although they may just as well be late Pliocene. Judging from the less advanced stage of development of the species, these beds seem to be older than the deposits at Hay Springs, Nebr., which have been considered as representing nearly the beginning of the Pleistocene, and may be about the equivalent of the Loup River, Nebr., deposits, which are held to be either late Pliocene or early Pleistocene.
>
> The beds at Archer and those at Mixon's contain a fauna which in point of development seems to correspond closely with that of the "Republican River formation" of Kansas and Nebraska, thus bringing them near the dividing line between the Miocene and Pliocene, and they may be, with good reason, placed in either the upper Miocene or lower Pliocene.
>
> The horses are represented by Miocene genera, but the species seem in general to be more highly specialized. This does not necessarily mean a later phase or horizon but suggests it.
>
> From the evidence furnished by vertebrate fossils, therefore, it may be concluded that the beds at Archer and those at Mixon's, 10 miles east of Archer, are in age near the transition from the Miocene to the Pliocene and that the newer beds at Ocala and Peace Creek, Fla., may be placed in time very near the beginning of the Pleistocene.

Lithologic character.—The Alachua clay consists of a light-blue sandy clay, weathering to yellow or red on exposure to the atmosphere. Angular sand is usually a rather large constituent of the formation, which, however, generally contains enough clay to hold the material together and make it plastic. The formation is destitute of fossils except at a few localities, where bones and teeth of large land animals are abundant.

Distribution.—Exposures of the Alachua clay occur in the central part of the peninsula, from Gainesville northwestward. The formation occupies depressions in the surface of the "peninsular" limestone and is probably not continuous over very large areas. Owing to its close resemblance to other clays this formation is not readily differentiated except where it contains fossils.

BONE VALLEY GRAVEL.

Age.—The Bone Valley gravel has generally been regarded as Pliocene and it is so classified here, but recent field work has shown that in some places the formation lies more than 125 feet above sea level. Assuming that changes in level in the peninsula of Florida have been general, as indicated by the attitude of the other formations, this altitude seems too high for Pliocene beds, but it corresponds roughly with the altitude of beds of Miocene age. A collection of vertebrate remains from the phosphate mines was submitted to J. W. Gidley, whose report follows:

A preliminary examination of the vertebrate remains from localities in Florida leads to the following conclusions regarding the age of the deposits in which they were found.

The mammal remains from Mulberry and other localities in Florida, except those east of Dunnellon, are Miocene in aspect, but the advanced stage of development of the species indicate an upper horizon of this series. They may even be as late as early Pliocene. In the collection is a portion of an upper jaw of a mastodon of the Tetrabelodon type, which very much resembles the species found in the "Clarendon beds" (upper Miocene) of Texas, suggesting a higher horizon than the top of the Miocene, but there is also in the lot a second upper molar tooth which differs but slightly from the corresponding tooth of *Teleoceras fossiger*, a typical species of the "Republican River formation" of Nebraska and Kansas. It seems, therefore, that the beds in Florida are about the equivalent of the "Republican River formation," or perhaps somewhat older. The few horse teeth in the collection, representing small but highly specialized species of Merychippus and Neohipparion, like some of those found in the "Republican River formation," bear out this conclusion. The numerous shark teeth seem to include a mixture of Eocene, Oligocene, and Miocene species, hence they are of little value in drawing conclusions regarding the age of the beds.

Lithologic character.—The Bone Valley gravel comprises gray, brown, or mottled sand and phosphate conglomerate, in a sand matrix. The brown sands are locally cemented into a hard ferruginous sandstone, and slight induration is common. In places a phosphatic marl containing many sand grains lies just above the conglomerate, and though it is not possible to be sure whether this material belongs with the Bone Valley gravel or is part of an overlying formation its relation to the conglomerate is apparently conformable. The conglomerate is made up of pebbles and granules of phosphate embedded in clay or sand. The Bone Valley gravel is the formation that furnishes nearly all the land-pebble phosphate, and its age is discussed more fully elsewhere in this report. (See p. 69.)

Distribution.—The extent of the Bone Valley gravel is difficult to determine because the sands are not distinctive and the gravel is exposed at few places except mines and prospect holes. From the vicinity of Plant City and Lakeland this formation stretches southward to the latitude of Zolfo Springs, and perhaps even farther, though information concerning its extent in that direction is lacking. Theoretically, the eastern boundary of this formation should be near the west side of the upland that stretches southward from the vicinity of Lakeland, but further study is necessary to determine its eastern limits. Its western boundary has not yet been determined, but it is known to be some distance beyond the mines now being operated.

QUATERNARY SYSTEM.

PLEISTOCENE SERIES.

Subdivisions.—The Pleistocene deposits in Florida have been divided into five distinct formations [1] and a number of deposits, of different lithologic character, that are not designated by specific formation names. In this report the separate discussion of these various subdivisions does not appear to be necessary, as they have little bearing on the occurrence or character of the important deposits of phosphate.

Lithologic character.—The deposits of Pleistocene age consist very largely of sand, most of it moderately coarse, though it contains in some places a slight admixture of clay, and lenses of fine-grained Pleistocene clay have been encountered in well drillings. Shell marls and limestones are common on the lowest Pleistocene terrace, especially in the southern part of the peninsula, but they are not extensively developed on either of the upper terraces. Except in the southern part of the State the thickness of the sand does not usually exceed 40 feet.

Distribution.—Attention has already been called to the fact that the Pleistocene sands are in the form of terraces of marine origin. One of these terraces, having an altitude of 20 to 25 feet above sea level, is not important in the phosphate region, but the higher terraces are well developed in certain parts of the rock-phosphate region. In the vicinity of Dunnellon a terrace that has been observed in many places extends along Withlacoochee River in a narrow belt having an altitude of 40 to 60 feet above sea level. Farther up the river, in the vicinity of Gum Swamp and of Tsala Apopka Lake, this terrace

[1] Matson, G. C., and Clapp, F. G., A preliminary report on the geology of Florida, with special reference to the stratigraphy: Florida Geol. Survey Second Ann. Rept., p. 171, 1909.

becomes much broader, and it is apparently extensively developed in the south-central part of the peninsula. The large prairie just south of Gainesville lies only a little higher than this terrace and was probably formed about the same time, though the basin in which the prairie lies is older than the terrace. Some of the other prairies and lakes, and the broad area that stretches southwestward from Paynes Prairie, probably correspond to the next higher terrace. This terrace extends around the entire peninsula and along the coast of western Florida.

A terrace that rises 70 to 100 feet above sea level extends around the inner border of the terrace just described. Near Dunnellon it is more or less dissected and its surface has been lowered somewhat by the solution of the underlying limestone. In general this terrace is narrower than the one below, but in some places it is several miles wide. In the rock-phosphate region this terrace is extensively developed, its eastern margin stretching across western Marion and Alachua counties and including the important phosphate belt in the vicinity of Newberry. In the area south of Dunnellon nearly all the mines except those that are close to the river are on the surface or on the margins of this terrace. In the southern part of the peninsula also this terrace is extensively developed, but it lies mostly west and south of the pebble-phosphate region and the details of its distribution have not yet been determined. It extends northward across the southern part of the peninsula as far as Center Hill and along the west side of the St. Johns River valley.

The Pleistocene formations of southern Florida have been discussed elsewhere.[1]

RECENT SERIES.

The deposits classed as Recent include clays, sands, marls, sand rock, and coquina. They resemble similar deposits of Pleistocene age and their differentiation, in many places, is therefore difficult. They are found along the beach in the valleys of the principal streams, in the lake basins, and on the uplands where the wind has built sand hills and ridges. There are no recent phosphate deposits except in the valleys of some of the streams that flow across phosphate beds, and the recent accumulations of phosphate are insignificant when compared with those of former periods.

CHARACTER AND OCCURRENCE OF THE DEPOSITS.

There are several different types of phosphate in Florida, but only two of them—rock phosphate and land-pebble phosphate—are commercially important. Practically all knowledge concerning the

[1] Matson, G. C., and Sanford, Samuel, Geology and ground waters of Florida: U. S. Geol. Survey Water-Supply Paper 319, 1913.

phosphate deposits has been obtained by examining mines or by boring prospect holes, and consequently the information available relates to the two types that are now being exploited, which are therefore the deposits here chiefly considered.

ROCK PHOSPHATE.

FORM AND GENERAL FEATURES.

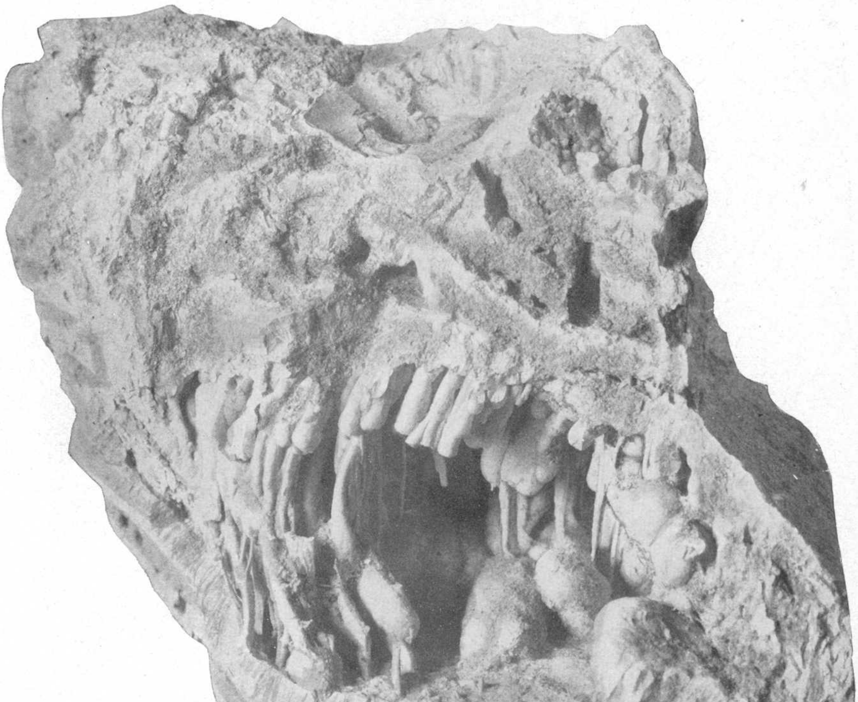
The rock phosphate usually lies beneath a varying thickness of sands and clays and the deposits show great diversity of composition, the commercially valuable phosphate consisting as a rule of pebbles or bowlders, or both, embedded in a matrix of fine material. Large bowlders and small pebbles may be mixed indiscriminately in some parts of a deposit, whereas elsewhere they may occur in different parts of the same section, though more or less segregated. Where there is any marked separation the coarse material usually occurs near the bottoms of the pits. (See Pl. IV, *A*.) In many of the mines, especially along Withlacoochee River, bowlders predominate, some of them being so large that they must be blasted before they can be put on the cars and elevated to the washers. Large masses of phosphate rock are by no means uncommon in the upland mines; for example, at the mine south of Croom they are so numerous that a great deal of blasting is necessary in order to prepare them for handling.

In many of the deposits the pebbles are angular, but in a few they are partly rounded. Some are light and porous, some hard and dense, and others show laminæ that vary slightly in color and density.

The bowlders are generally rounded or oval, but irregular shapes are not uncommon. They may be solid or hollow, the cavities being lined by minerals that were evidently formed by deposition from solution. The most common lining of these cavities is a fibrous crystalline phosphate mineral (see Pls. IV, *B*, and V) of undetermined composition, but in a few cavities calcite, quartz, or other minerals are found. A common structure is a solid shell surrounding a series of parallel plates, usually less than an inch thick, separated by narrow, discontinuous crevices. (See Pl. VI, *A*.) The lamellæ are connected by irregular deposits and many of them show evidence of having been broken and recemented by phosphate of a slightly different color from the original rock. (See Pl. VI, *B*.) The outer shell of many of the bowlders is made up of a dense phosphate showing more or less distinct bands of different colors.

Plates of phosphate ranging in breadth from a few inches to several feet are found in many mines. Few of these plates are more than a few inches thick, and, because of their elasticity, many of them have been distorted by movements in the phosphate rock. They com-

A. BOWLDERS OF ROCK PHOSPHATE EMBEDDED IN A MATRIX OF CLAY AND SOFT PHOSPHATE, NEWBERRY REGION.



B. FRAGMENT OF A BOWLDER OF ROCK PHOSPHATE SHOWING CAVITIES LINED WITH CRYSTALLINE PHOSPHATE MINERALS AND CONTAINING PHOSPHATIC STALACTITES.

U. S. National Museum Catalogue No. 77373.

FRAGMENT OF A BOWLDER OF ROCK PHOSPHATE SHOWING PART OF A CAVITY LINED WITH CRYSTALLINE PHOSPHATE MINERALS.

U. S. National Museum Catalogue No. 66739.

monly include more or less clay, which brings the percentage of aluminum and iron above the maximum amount permissible, so that it is difficult for the miners to maintain the required standard. In the vicinity of Anthony and Sparr and east of Ocala the deposits contain many plates of phosphate and are known as "plate rock," to distinguish them from the hard-rock deposits found elsewhere, but plates of phosphate occur in hard-rock mines in other parts of the rock-phosphate region. (See Pl. XIV, *A*, p. 51.)

Long pendants of phosphate, resembling the stalactites formed in caverns, have been reported in some phosphate deposits. Doubtless their origin was similar to that of limestone stalactites (see Pl. IV, *B*), and though they are of considerable scientific interest they are too rare to have any economic interest or value.

In color rock phosphate ranges from white, gray, or cream to yellow, brown, or black. The pebbles of the upland deposits are usually light colored, ranging from white to light yellow or brown, though a few of them are dark brown or even black. Most of the rock mined near Withlacoochee River is dark blue or black, though some light-colored pebbles occur in nearly all the river mines. The character of the coloring matter has not been determined, but the color is probably due to both organic and inorganic material, the organic being doubtless more important than the inorganic.

It should not be inferred that phosphate is the most abundant constituent of the deposits, for the phosphate is embedded in a fine-grained matrix, and a deposit that will yield 25 per cent of rock of commercial value is regarded as very rich. In some mines the proportion of phosphate is higher, rising nearly to 50 per cent, but in many others it falls as low as 12 or 15 per cent, and in a part of one deposit the amount of rock obtained was reported to be only about 4 per cent of the whole. Probably not more than 15 per cent of the material mined in the rock-phosphate region is now commercially valuable.

MATRIX.

The phosphate rock is embedded in a matrix composed of varying percentages of clay, soft phosphate, and sand. The proportions of these materials vary in different mines and in different parts of the same mine, but certain generalizations will apply to the deposits in different parts of the rock-phosphate region. From Dunnellon southward clay and soft phosphate predominate in the matrix, which includes only a rather small percentage of sand, whereas in the area north of Dunnellon a sandy matrix is most common, though some clay and soft phosphate occur in nearly all the mines. The phosphate is removed from the matrix by washing, and in this process the soft phosphate is carried away with the accompanying sand and clay.

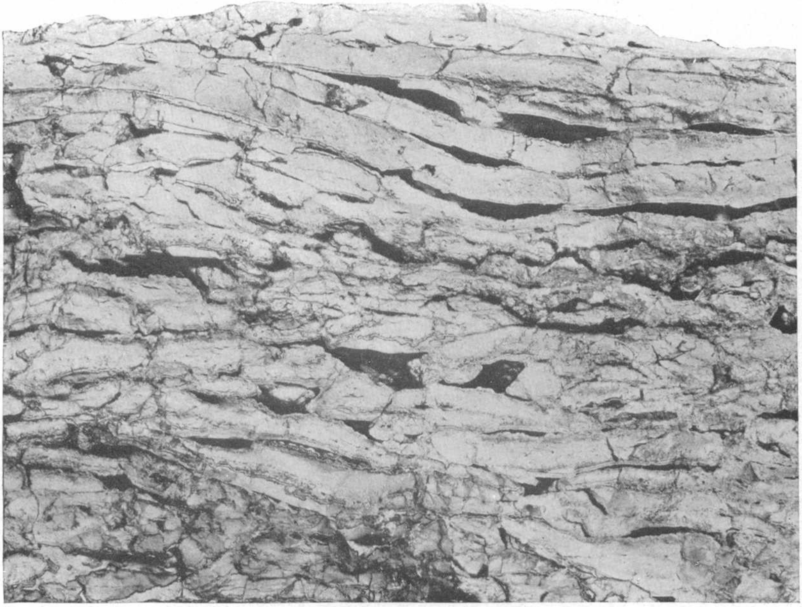
This results in the loss of a large amount of phosphoric acid in the form of soft phosphate, which should be a useful fertilizer for some types of soil.

FLINT AND LIMESTONE.

Intermingled with the rock phosphate are many pebbles and bowlders of flint, ranging in diameter from a fraction of an inch to several feet. In general they have a rounded form, which appears to be original and not the result of mechanical wear. Many of the bowlders are hollow, the interior being lined with quartz crystals; some of them have a more or less lamellar structure, similar to that found in the phosphate; others consist of a core of silicified limestone containing characteristic fossils of the underlying formation. The outer shells of some of the bowlders are laminated, the laminæ being visible because of slight variations in color; the interiors are usually dark blue, though lighter shades are not uncommon. The flint bowlders and pebbles do not appear to be restricted to any particular part of the phosphate deposit, for they may be aggregated in one place or they may be distributed through the entire deposit. In one mine near Holder a large mass of flint surrounded by phosphate was found near the base of the deposit. It measured 30 feet in length and about 5 feet in diameter. The number of bowlders differs in different mines and in some places they have been so numerous that mining was unprofitable. The phosphate deposits contain scattered pebbles of limestone belonging to the underlying formation. A few of them show progressive alteration from calcium carbonate to calcium phosphate as a result of the action of phosphoric acid upon the limestone.

OVERBURDEN.

The deposits of rock phosphate are everywhere covered by a varying thickness of coarse, angular sand, which is generally light gray or brown in color, is either incoherent or only slightly indurated, and is locally separated from the phosphate rock by a thin deposit of blue or gray clay, which assumes a red or yellow color after exposure to the weather. The sand conceals the underlying materials so effectually that it is seldom possible to discover the phosphate deposits by the surface indications. In a few places phosphatic pebbles lie on the surface, but their presence does not necessarily indicate that there is a valuable deposit underground. It is necessary to bore numerous holes through the mantle of surface sand in order to locate a phosphate deposit and to determine its size and thickness. Borings made for this purpose have shown that the surface sands range in thickness from a few inches to over 50 feet, and, owing to inequalities in the altitude of the surface and irregularities in the phosphate deposits, differences in thickness of several feet may be found within a radius of a few yards.

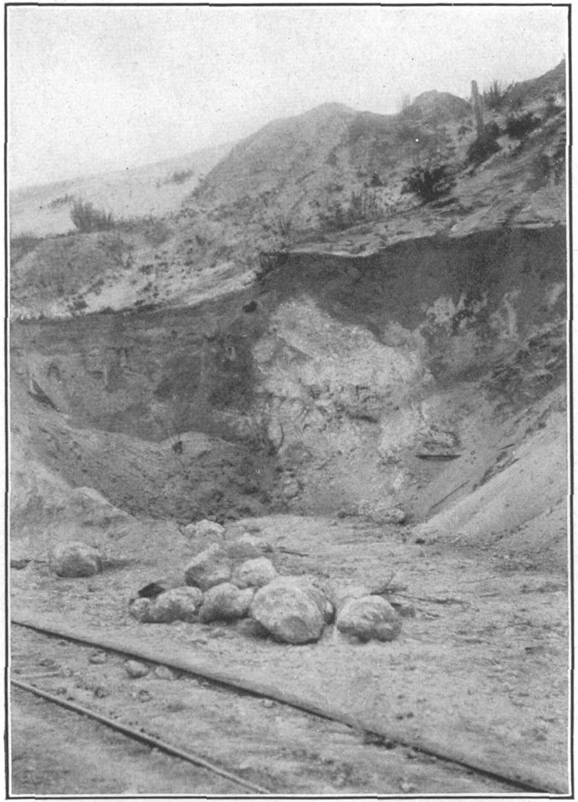


A. FRAGMENT OF ROCK PHOSPHATE COMPOSED OF PLATES.

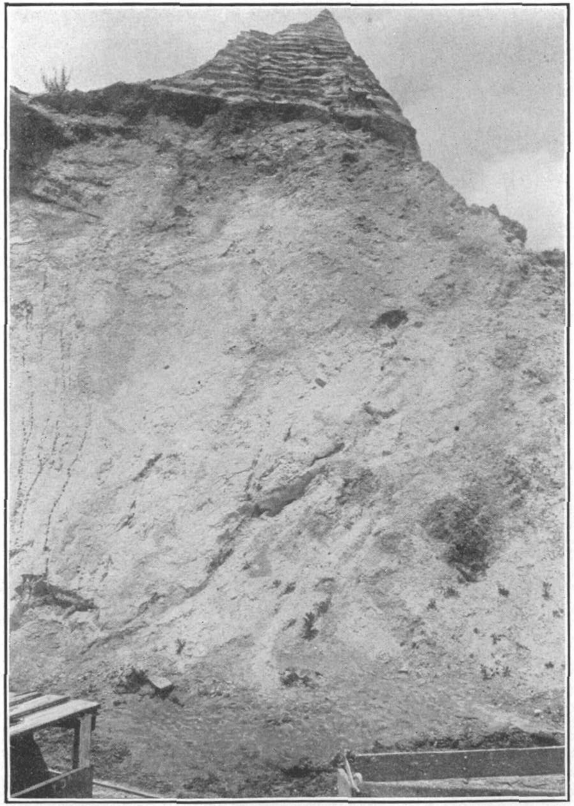
Photograph by U. S. National Museum. U. S. National Museum Catalogue No. 66736.

B. BROKEN PLATES OF ROCK PHOSPHATE CEMENTED BY PHOSPHATE.

U. S. National Museum Catalogue No. 77351.



A. PHOSPHATE DEPOSIT CONTAINING BOWLDERS OF FLINT AND PILLARS OF LIMESTONE, THE WHOLE COVERED BY PLEISTOCENE SANDS.



B. STRATIFIED PLEISTOCENE SANDS RESTING UNCONFORMABLY ON PHOSPHATE AND SEMI-INDURATED SANDS THAT HAVE BEEN BROKEN AND DISTORTED.

In some mines stratified sands lie above the rock-phosphate deposits and their associated sands and clays. These sands are shown on Plate VII, *A* and *B*, and though they are not everywhere horizontal, the layers seldom show more than slight undulations, which usually conform to the outlines of the underlying phosphate and its associated materials. They show less induration than the sands associated with the phosphate, and their general freedom from disturbance, together with the fact that the stratification is parallel to the irregular surface of the underlying beds, indicate that they are younger than those beds. The stratification is sufficiently regular to show that the sands are subaqueous, and their position on a terrace having an altitude of 70 to 100 feet above sea level fixes their age as Pleistocene and serves to correlate them with the uppermost Pleistocene terrace recognized elsewhere in the State.

This terrace has a fairly level surface, its minor irregularities having doubtless been produced by the removal of the underlying limestone by solution since the terrace was formed. The Pleistocene sands are likely to be lighter colored near the surface than the sands at greater depths, the difference in color being due in part to the leaching action of surface waters and in part to mechanical wear where the surface sands have been slightly disturbed. Near the surface there is a general absence of lamination, which is attributed to the fact that the roots of plants have destroyed the original stratification. The transition from the surface sands to those below is locally so abrupt that they were formerly thought to be a distinct formation, but recent investigations show that they belong to the underlying formation.

DEFORMATION.

In most of the rock-phosphate mines portions of the phosphate and associated sands have been considerably disturbed, as is shown by the distortion of layers of phosphatic pebbles and by breaks in the phosphate deposits where the materials have been faulted, one portion having slipped downward. In many places the planes along which the slipping occurred are smoothed and polished, though the amount of movement is usually small. The distortion and faulting has locally resulted in enough movement to bring down into the deposits sands and friable sandstones that originally lay above the phosphate. (See Pl. VII, *B*.) This movement has produced sand "horses" in many mines and the sands in many places show evidence of the violence of the movement, their stratification having been destroyed and the material having been reduced to a heterogeneous mass.

The faulting and other disturbances were doubtless caused by the same agencies that produce ordinary sink holes in limestone. The water that percolates into the ground carries with it carbonic acid, derived chiefly from decaying organic matter. This acid enables the water to dissolve the limestone. In the rock-phosphate region the process of solution is rapid, because the underlying limestone of the Vicksburg group is very porous and is readily attacked by the carbonated waters. Solution continues until underground channels or caverns are formed, and after a time it weakens the roofs of these caverns so much that the weight of the overlying rock causes them to collapse, the downfall involving also the superincumbent phosphate and sands. This process is so active in the limestones of the central and western parts of the peninsula that newly formed sink holes are common, and the present topography has been shaped by solution and consequent collapse of roofs of underground channels. At one point south of Albion the bottom of a phosphate pit that lay above such a cavern is reported to have fallen 4 or 5 feet. Open channels that extend downward to caverns may be seen in some of the phosphate mines near Newberry, and subsidence caused by the breaking of cavern roofs may occur at any time, though there is little danger that such a cave-in will occur during the short time a mine is operated.

SIZE AND SHAPE OF DEPOSITS.

The deposits of rock phosphate differ greatly in size, ranging from single masses containing less than a ton to irregular bodies including many thousands of tons. The outlines of the deposits are so irregular that it is frequently necessary to remove inclosed pillars of limestone in order to gain access to small accumulations of phosphate. In many places mining reveals the fact that the phosphate occupies irregular pockets in the limestone and is distributed over areas ranging in size from a few square feet to several acres. (See Pl. XIII, *A*, p. 50). Most of the pits in the rock-phosphate region cover only a few acres, but at the Cummer Lumber Co.'s mine, No. 25, near Newberry, a single pit has an area of more than 35 acres. Elsewhere in the Newberry district the average size of the phosphaet pits is probably less than 5 acres.

Some large deposits of phosphate are reported to lie near Dunnellon, but none of the pits are as large as the one just described. Deposits covering more than 40 acres have been reported at Dunnellon, and other large deposits have been found farther south.

THICKNESS.

The thickness of the rock phosphate varies greatly, reaching a maximum of about 100 feet in the vicinity of Dunnellon and decreasing rapidly toward the northern end of the region and more gradually toward the southern end. Experienced prospectors say that the maximum thickness in the vicinity of Newberry is probably not over 50 or 60 feet, and that the average thickness is less than 30 feet. In the area south of Dunnellon the deposits are uniformly much thicker than they are farther north, and the amount of barren sand overlying the phosphate is generally greater. Sellards[1] states that the thickness of the deposit on the Southern Phosphate Development Co.'s properties near Inverness ranges from 50 to 100 feet and averages 70 feet, but these estimates included the thickness of the sand above the phosphate rock.

LOCAL DETAILS OF ROCK-PHOSPHATE DEPOSITS.

The individual phosphate deposits are so diverse that it is difficult to present adequate general descriptions that will apply to all of them. The sections and descriptions that follow are generalized so far as possible, but the same deposits may present many variations during the progress of mining, so that a section of a deposit as it appears at one stage of mining may be very different from a section of the same deposit after it has been mined for a longer time.

NEWBERRY DISTRICT.

The relation of some of the rock-phosphate deposits to the underlying rock is shown at a mine near Newberry. The pit here shows a very uneven surface of limestone of the Vicksburg group, which rises in peaks and ridges 2 to 15 feet high, separated by narrow, irregular channels ranging in width from 10 or 15 feet near the top to 3 or 4 feet near the bottom. Most of these channels in the limestone are not very deep, and from some of them rounded cavities or "wells" (see Pl. XIII) containing phosphate extend into the peaks of limestone. The surface of the limestone appears to be smooth, but a soft, porous layer lies at the contact of the limestone with the phosphate, and this layer in places contains fragments of shells that are characteristic of the limestone.

At one point in the pit is an open cavity that extends downward into the limestone and doubtless reaches an underground channel. The average thickness of the phosphate deposit in this mine does not exceed 15 feet, and it varies from zero where the limestone peaks are near the surface to its maximum thickness in the depressions between the peaks. The overburden is a light-yellow sand having an average thickness of about 4 feet. The commercially valuable phosphate consists largely of small gray pebbles, many of them less than an inch in diameter, and some bowlders, few of them weighing more than 1,000 pounds. The largest bowlder reported in this mine made 15 carloads, the car being of the sort used in conveying the phosphate from the

[1] Sellards, E. H., A preliminary paper on the Florida phosphate deposits: Florida Geol. Survey Third Ann. Rept., p. 30, 1910.

pit to the washer and having a capacity of about 1½ tons. This bowlder lay in the upper part of the deposit immediately below the overburden. There is a gradation from soft, friable phosphate near the limestone to denser and harder phosphate in the form of plates, bowlders, and pebbles at some distance from the peaks. In many places plates of phosphate lie parallel or roughly parallel to the surface of the deposit, but elsewhere they are broken or bent downward, the amount of slumping increasing toward the center of the channels between the peaks of limestone. At one point a depression in the surface of the phosphate, having a depth of about 20 feet, was filled with sand, which was separated from the adjacent limestone by only about 3 feet of phosphate.

In some places near the limestone the phosphate shows smooth planes (slickensides), caused by slumping of the deposit where the underlying limestone has been partly removed by solution. Most of these surfaces have a very steep inclination which is more or less parallel to the surface of the limestone peaks. (See fig. 2, p. 53.)

Bowlders of flint are not numerous in this mine, though a few, more or less rounded, were seen. The deposits contain a few shark teeth and some fragments of bones, apparently parts of the ribs of some animal.

The following section was measured in one of the mines of the Newberry district:

	Feet.
Light-yellow sand with dark sandy loam near the top	10–15
Purplish-brown sand	0–5
Matrix of soft phosphate and clay containing angular pebbles and rounded bowlders of rock phosphate	20

At a depth of 37 feet below the surface a bowlder weighing about a ton was found. It was surrounded by about 4 feet of sand, which was entirely free from phosphate and was inclosed in a matrix containing phosphate pebbles. Probably this bowlder and its envelope of sand was carried down into the phosphate by slumping when the supporting limestone was removed by solution. This mine also yielded a mass of flint weighing about 10 tons. Many of the bowlders lie near the top of the phosphate deposit, and some that were observed in this position weighed not less than 3 tons.

Another mine in the Newberry district showed certain features not found in those previously described. At this mine the peaks and ridges of limestone of the Vicksburg group are comparatively rare. The deposit consists of a light-gray matrix of clay and soft phosphate, locally somewhat sandy and containing angular pebbles and rounded bowlders of rock phosphate. The phosphate near the surface is in places stained yellow by a surficial coating of iron oxide. Most of the pebbles and bowlders are light gray, but some are light yellow. A few bowlders have a lamellar structure, and the lamellæ are either light or dark blue. The phosphate exposed above water level is 16 to 20 feet thick, but in places it extends far below water level, and its maximum thickness has not been determined.

There is evidence of subsidence in this pit, for local bodies of sand are found at the same level as the phosphate, their presence being explained by the fact that they have sunk into the pit from above. Wavy and distorted layers occur in the phosphate and there are examples of slipping, and many of the planes along which the movement occurs show polished surfaces. Above the phosphate and its included bodies of sand is an overburden of light-yellow sand, which shows horizontal bedding and is clearly younger than the sand and phosphate below. At one point a "sand horse," in which the layers are considerably broken and stand nearly vertical, is overlain by horizontally bedded sands. The upper part of the overburden consists of 2 to 4 feet of lighter-colored sands showing no traces of stratification. Here and at many other localities the stratification of the surficial sand has been destroyed by the roots of plants. The contact of the stratified sand in the overburden with the beds below is clearly defined and the layers of the sand are essentially horizontal though they show slight undulations parallel to the surface of the underlying deposits.

Section of a phosphate mine in the Newberry district.

	Feet.
Yellow sand, locally indurated, about	10
Light-yellow and gray soft phosphate and clay matrix containing pebbles and occasional bowlders of phosphate	15
Yellow clay and soft phosphate containing large bowlders of phosphate	10

A few peaks of limestone of Vicksburg age and some bowlders of flint may be seen in the deposit.

DUNNELLON DISTRICT.

A deposit at one of the mines in the Dunnellon district consists of 15 to 20 feet of gray phosphate matrix composed of clay, very fine sand, and soft phosphate containing pebbles and bowlders of gray and yellow phosphate. The pebbles are angular and are of many sizes; some of them exceed 6 inches in diameter, but most of them measure less than an inch. Some bowlders of chert have a diameter of 3 or 4 feet. The overburden consists of 10 to 15 feet of yellow sand, locally somewhat indurated, and 6 feet of underlying blue clay, weathering light yellow.

At a point about 8 feet above the bottom of this pit there are rounded bowlders of fossiliferous rock resembling the "Peninsular" limestone in texture and containing similar fossils. The shells have been removed by solution, so that nothing but the casts and molds remain, and the entire rock has been altered to a low-grade phosphate containing no trace of the original carbonate of lime. These bowlders form a layer about 18 inches thick and 4 feet long. The fossiliferous bowlders are coated with soft phosphate, which is partly coherent but crumbles easily. Above the bowlders is a hard, dense plate of phosphate about 2 inches thick, composed of layers of different colors.

It is reported that the phosphate below water level is poorer than that above, falling on the average below 60 per cent tricalcium phosphate. The rock below water level also contains more carbonate of lime, alumina, and iron oxide.

The composition of the phosphate that lies entirely below water level can be determined only by examining materials raised by the dredge. One mine of this kind, near Withlacoochee River, stands only a few feet above water level and the rock is obtained by dredging to a depth of over 40 feet. The deposit is prevailingly coarse and contains many large bowlders. The rock ranges in color from black to light gray, but most of it is dark. Many of the fragments of rock that come from the washer are pieces of large bowlders, and some of them consist of a series of parallel plates of dark phosphate rock separated by narrow discontinuous crevices.

The matrix is nearly all clay but in some places includes a little sand. Many of the large bowlders are of very high grade, containing 80 per cent or more of tricalcium phosphate, and a composite sample obtained by mixing small samples from 290 tons analyzed a fraction more than 80 per cent.

This mine has supplied a great many fragments of bones and some teeth of sharks, mastodons, and elephants. The best informed miners say the bones and teeth of the large animals come from near the edge of the phosphate deposit.

HERNANDO AND VICINITY.

A typical deposit in this part of the rock-phosphate region shows gray phosphate pebbles and bowlders embedded in a soft phosphate and clay matrix. Some of the phosphate bowlders are hollow, others have a lamellar structure, and still others are composed of layers of different colors. The phosphate pebbles in this deposit are nearly all angular, but they show some tendency toward stratification, forming layers which are in places bent by unequal subsidence. Associated with the phosphate are a few bowlders of flint 1 to 2 feet in diameter. Most of the flint bowlders are rounded or oval and those that are broken show concentric layers of shades varying from dark to light blue. Some of them are hollow and the cavities are lined with crystals of quartz. Most of the pebbles and bowlders are light yellow to gray, but some are dark. Other bowlders have a core of silicified limestone containing many shells and an outer shell

2 to 4 inches thick, formed of concentric bands of flint, differing slightly in color but usually some shade of blue.

The overburden at this pit consists of about 10 feet of coarse, yellow sand, which is locally slightly indurated but is sufficiently friable to break up easily.

Another mine in this vicinity consists of two branches, about 150 yards long and 50 yards wide, with short lateral projections where the miners have been excavating. This rock is reported to average more than 77 per cent tricalcium phosphate and to overlie 7 to 8 feet of rock ranging from 61 to 65 per cent. This lower rock in turn rests upon limestone of the Vicksburg group, the contact between the two being very irregular.

At one point a mass of sand rock (sand horse) about 25 yards across was left after the phosphate rock was removed from around it. The pit is about 25 to 30 feet deep and the overburden consists of 10 to 12 feet of yellow stratified sand, which is slightly indurated except in the upper 3 to 4 feet.

Some of the mines in this part of the rock-phosphate region contain plate rock. One pit shows about 20 feet of phosphate consisting of small angular pebbles and some large bowlders and plates embedded in a matrix of fine clay, mixed with more or less soft phosphate. The pit contains several large plates of phosphate, some of them being 8 or 10 feet wide before they are broken. In places the plates have been bent downward by movements in the phosphate deposit.

The overburden consists of 12 to 15 feet of yellow sand, slightly indurated near the base, containing some lenses and irregular masses of clay. The position of the lenses indicates that the deposit has been more or less disturbed, probably as a result of the solution of the underlying limestone and the falling of the roofs of caverns, resulting in slumping of the overlying phosphate. Fragments and bowlders of flint 1½ to 3 feet in diameter occur at several levels.

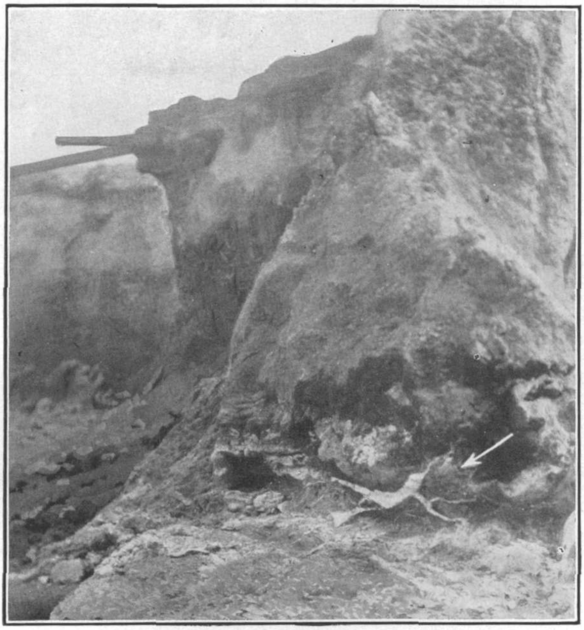
PHOSPHATE OF ALUM BLUFF FORMATION ("BEDROCK").

The uppermost formation of Oligocene age in southern Florida is the Alum Bluff, which is represented in the pebble-phosphate region by a magnesian limestone and marl containing granules and nodules of phosphate interbedded with more or less clay and pebble phosphate. This formation, especially the limestone portion, is known to the miners as "bedrock." The exposures in the phosphate mines are seldom more than 5 or 6 feet thick, though in the Coronet mine a well penetrated limestone of the Alum Bluff formation to a depth of nearly 30 feet. In this well a thin bed of clay was encountered, and a layer of flint near the surface which contained a great many fossils, those listed on pages 14 and 15 having been identified from selected specimens collected at this locality. One or more small exposures of the "bedrock" can be found in practically every pit in the land-pebble phosphate region, and these numerous exposures show that the rock is a moderately hard limestone or marl containing many dark-colored nodules and granules of phosphate, a few shark teeth, and many casts of shells. The limestone changes to a light-yellow sticky marl on weathering because of the presence of considerable earthy matter in the original rock. Beds of clay and pebble phosphate that accumulated during the deposition of the "bedrock" are interstratified with the limestone and marl and in some places rest upon them. (See Pl. VIII, *A* and *B*.) The best section of this portion of the Alum Bluff formation was obtained in drilling a well at the phosphate mine near Medulla. The following record of this well was supplied by Mr. North, foreman of the mine:

Section of well at phosphate mine near Medulla.

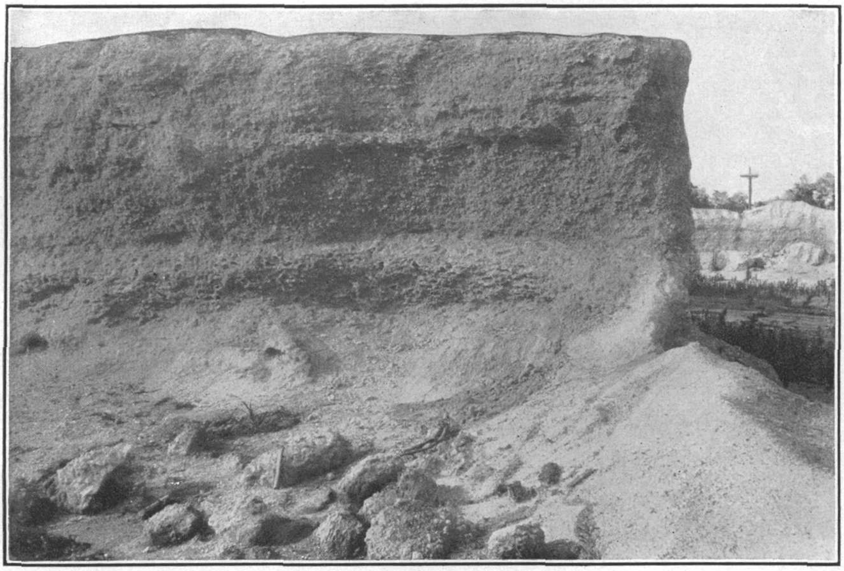
	Feet.
Overburden:	
Sand	22
Marl	6
Pebble phosphate:	
Phosphate	17
"Bedrock":	
"Yellow joint clay" (yellow marl)	32
Blue limestone	30
Phosphate interbedded with clay	60–70
Undetermined:	
Blue marl, clay, and rock alternating to a depth of 760 feet.	

Reference to this section will show that in the Alum Bluff formation ("bedrock") a thick interbedded layer of clay and phosphate was encountered. This phosphate has no commercial value, because it is too deeply buried to be mined, but it is of considerable scientific interest, for it shows that a great deal of phosphate accumulated as an original deposit in the Alum Bluff formation. In one of the pits of the Phosphate Mining Co., west of Mulberry, a thin, irregular layer of blue clay containing phosphate nodules was observed interbedded with the limestone of the Alum Bluff formation (see Pl. VI, *A* and *B*), and a similar section was seen in one of the pits of the Pierce Phosphate Co., where the phosphate bed had a thickness of nearly 10 feet and had been mined to a depth of 6 feet below the superincumbent bed of limestone of the Alum Bluff. This rock was of lower grade than that obtained from the overlying Bone Valley gravel, and considerable carbonate of lime was mixed with the phosphate. In one of the pits at Christina a phosphatized portion of limestone of the Alum Bluff formation projects 8 or 10 feet above the floor of the mine. In appearance it is much like the rock phosphate, and the fact that it was altered from the limestone



A. PHOSPHATIZED LIMESTONE BELONGING TO THE ALUM BLUFF FORMATION ("BEDROCK").

The arrow indicates a vein of phosphate that was deposited in a crevice.



B. COARSE SEMI-INDURATED PEBBLE PHOSPHATE.

is evident, because the texture of the original rock is preserved. Veins of phosphate that were evidently deposited in cracks in the rock may be seen in this phosphatized limestone. (See Pl. VIII, *A*.) Although the phosphatic limestone and phosphate nodules of the Alum Bluff formation are commercially important only in small areas, they are of considerable interest because of their relation to the overlying Bone Valley gravel, which is the source of the land-pebble phosphate. Detailed information concerning this "bedrock" is given on pages 39–44.

PHOSPHATE OF BONE VALLEY GRAVEL OR LAND-PEBBLE PHOSPHATE.

DISTINCTIVE FEATURES.

The Bone Valley gravel as the term was used in the Second Annual Report of the Florida Geological Survey[1] was intended to include the coarse, sandy land-pebble phosphate and the associated sands. The name is used in a similar sense by Sellards [2] in his report on the phosphates of Florida. At the time of the publication of the earlier report the fact that there was another phosphate-bearing formation in the land-pebble region was not definitely recognized. During the progress of recent field work it has become evident that, though the Bone Valley gravel is the source of the phosphate in nearly all the mines, there are a few mines that obtain a small amount of phosphate from the formation lying unconformably beneath the Bone Valley gravel. It seems best to draw the line as sharply as possible between these two formations, as the periods of their deposition were unquestionably separated by a considerable interval of time, and therefore it should be understood that the name Bone Valley gravel does not include these older phosphate-bearing beds.

The surface of the land-pebble phosphate region is comparatively level, though minor undulations amounting to 15 or 20 feet are not uncommon and variations of 50 feet in the altitude occur near the larger streams. This upland lies generally between 125 and 150 feet above sea level. At many places in the phosphate region the sand associated with the pebble phosphate, and in some localities the phosphate itself is overlain by younger sands. These sands resemble those below so closely that the two can with difficulty be distinguished except where there is some marked unconformity between them. In the Phosphate Mining Co.'s pit, west of Mulberry, the line of demarcation between the upper sands and the Bone Valley gravel below is marked by a lens of dark-colored organic matter. According to the

[1] Matson, G. C., and Clapp, F. G., A preliminary report on the geology of Florida, with special reference to the stratigraphy: Florida Geol. Survey Second Ann. Rept., pp. 138-141, 1909.

[2] Sellards, E. H., A preliminary paper on the Florida phosphate deposits: Florida Geol. Survey Third Ann. Rept., p. 33, 1910.

account given by the foreman at this pit the lens had a maximum thickness of about 2½ feet and measured several feet across. Similar evidences of unconformity between the Bone Valley gravel and an overlying formation are seen at other points.

The pit at Christina shows several feet of interlaminated sands and clays between the phosphate and the overlying sand. The contact of the bed of clay and sand with the underlying phosphate is more or less irregular, but the fact that the plane of contact is roughly parallel to the planes of stratification of the phosphate suggests that there may have been continuous deposition with merely slight change in the character of the sediments. In some of the mines erosion has proceeded far enough to remove the phosphate and a portion of the "bedrock," forming channels that have subsequently been filled with younger sands.

The Bone Valley gravel consists of rounded pebbles of phosphate embedded in a matrix of sand or clay overlain by varying thicknesses of loose or semi-indurated sand. The maximum thickness of this formation is probably more than 50 feet, but only about one-third of this thickness should be assigned to the phosphate.

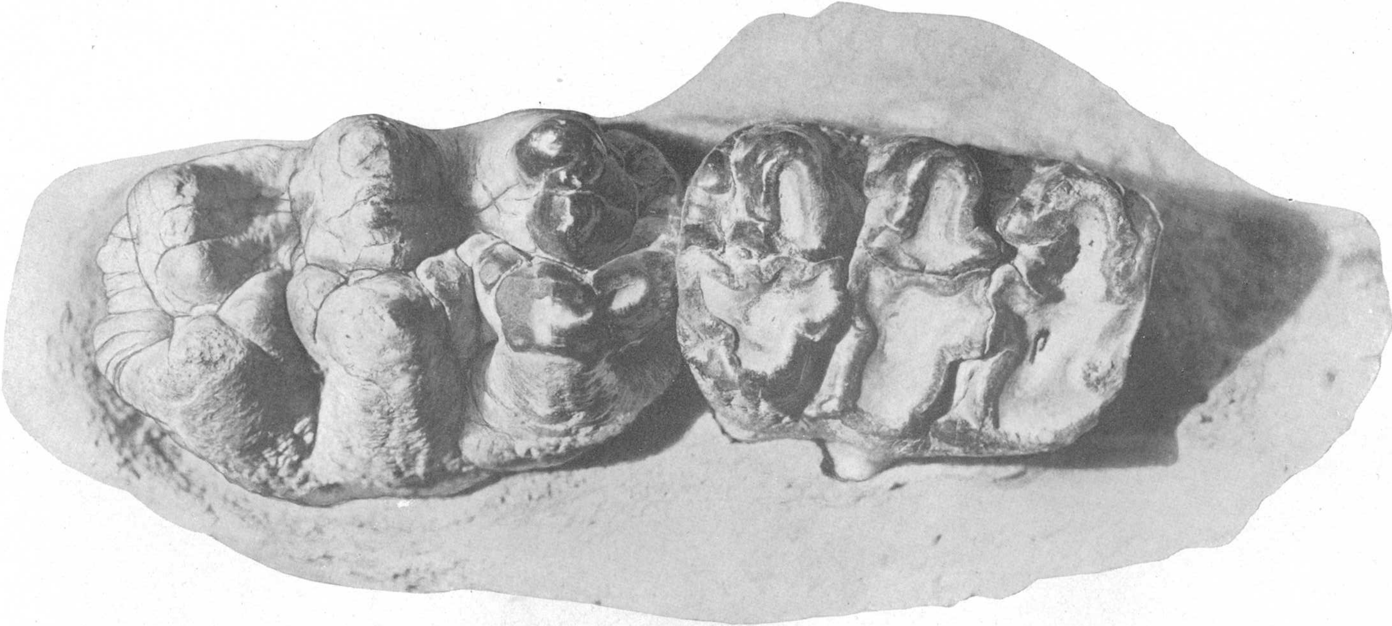
The phosphate-bearing portion of the Bone Valley formation is a gravel containing rounded and subangular pebbles of phosphate of varying degrees of coarseness intermingled with more or less sand and clay. In general the deposit shows distinct stratification, some beds being wonderfully persistent over a distance of several hundred yards though others are lenticular and extend only short distances. There are numerous alternations of coarse and fine material and many of the layers are distinctly undulating. (See Pl. VIII, *B*.) The wavy character of the stratification appears to be original, though in one or two mines there are evidences of sufficient deformation to cause slight faulting, which has brought the overlying sand into juxtaposition with the phosphate. The entire formation bears evidence of having been deposited in shallow water where conflicting currents gave rise to irregular bedding and rapid alternations of sediments of varying coarseness. The color of the phosphate-bearing portion of the Bone Valley gravel varies from nearly white to dark gray and the individual pebbles are white, yellow, brown, or black.

ANIMAL REMAINS.

Practically all the mines contain fragments of bones of both land and marine animals. There are many vertebræ, both large and small, and in a few places these are found in juxtaposition, suggesting that they were articulated and were probably still held together by ligaments at the time of their deposition. In one mine four of these

PART OF THE JAWBONE OF A MASTODON.

U. S. National Museum Catalogue No. 7204.



SPECIMEN SHOWN IN PLATE IX, VIEWED FROM ABOVE.

U. S. National Museum Catalogue No. 7204.

vertebræ were found, end to end, and a fifth was only slightly displaced. Reports of finding complete skeletons of marine animals are common, but many inquiries have been made without bringing to light a single instance where a skull has been associated with a skeleton. The most common animal remains are the teeth of sharks and fish, but in addition the teeth of the horse, mastodon, rhinoceros, and manatee have been found. (See Pls. IX to XII, inclusive.) Several fragments of tusks of mastodons were observed, among them being one that measured over 13 inches in circumference. Waterworn fragments of phosphatized casts of shells, apparently derived from the erosion of the underlying formation, are common in many mines.

QUARTZ AND CHERT.

Pebbles of quartz and chert occur throughout the Bone Valley gravel. Many of these pebbles are perfectly rounded and are composed of pellucid quartz; others are partly rounded fragments of dark chert, such as may be found in many parts of the peninsula of Florida. In the pits of the Coronet Phosphate Co. worn fragments of silicified corals occur in the phosphate. Among these a single fragment weighing over 25 pounds was observed, but most of them are much smaller. They show very little evidence of wear, which indicates that they have probably not been transported far from their sources; they were evidently derived by weathering and erosion from some portion of the Alum Bluff formation.

OVERBURDEN.

The overburden, as it is commonly termed, consists of brown to gray coarse sand, usually resting directly on the phosphate. It varies in thickness from 3 to 4 feet in the northern part of the region to over 30 feet in the southern part. This sand locally shows some induration, the cementing material varying in different places. In some mines it is largely iron oxide, which locally accumulates to form a coarse sandstone that is known as "hardpan." In many mines it is necessary to blast this hardpan in order to break it up so that it may be removed.

SIZE AND SHAPE OF THE DEPOSITS.

The mined areas of Bone Valley gravel form only a small part of the whole deposit. The gravel is rather widely distributed, forming a continuous mantle for several miles, but it is not mined except in small areas of various shapes. The factors that determine the locations of mines are the quantity of phosphate that can be obtained, the amount of waste material that must be handled in exploitation, the quality of the phosphate, and the distance of the deposit from a railroad.

The quantity of phosphate obtainable is determined before plans are made to install machinery for mining, and as there is considerable difference in the thickness of the beds at different places, as well as pronounced variations in the percentage of phosphate pebbles, both the thickness and the pebble content of the gravel are carefully considered. In addition it is necessary to take into account the amount and character of the overburden. The cost of removing the overburden varies greatly. Soft sand is most easily removed because it can be handled by hydraulic processes; indurated sand is more difficult to excavate, as it may require blasting, and if the fragments are too large to pass through the pumps used in the hydraulic process it is necessary to use steam shovels, which increases the cost.

The price obtained for the phosphate will be governed largely by its quality, for, other things being equal, the value of the phosphate will depend upon its content of phosphoric acid. The presence of considerable sand that can not readily be removed by washing the pebbles will lessen value, and if a large percentage of the oxides of iron and aluminum are present the value of the phosphate will be lowered by them.

After all these factors have been considered it is usually found that the area of material which can be profitably mined is rather small. However, the average size of the pits in the land-pebble phosphate region is several acres, and the maximum size exceeds 40 acres.

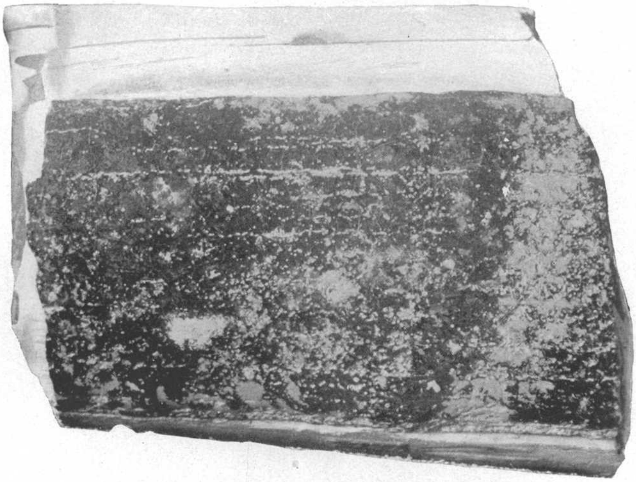
THICKNESS.

The pebble phosphate varies in thickness but not so much as the rock phosphate. The thickness of the workable deposits ranges from a few feet to 20 or 25 feet, and probably averages 10 to 12 feet. The thickness of the sands that overlie the phosphate ranges from a few feet to over 40 feet, and probably averages more than 15 feet.

LOCAL DETAILS.

NORTHERN PART OF REGION.

In the rock-phosphate region detailed sections of the deposits have very little significance, but in the land-pebble phosphate region, where the phosphate is in the form of a conglomerate, there is much greater uniformity in both the character and the thickness of the materials. The details of sections taken in different parts of a single mine may be unlike, but the major features are similar and in most places the relations of the deposits to both the overlying and the sub-

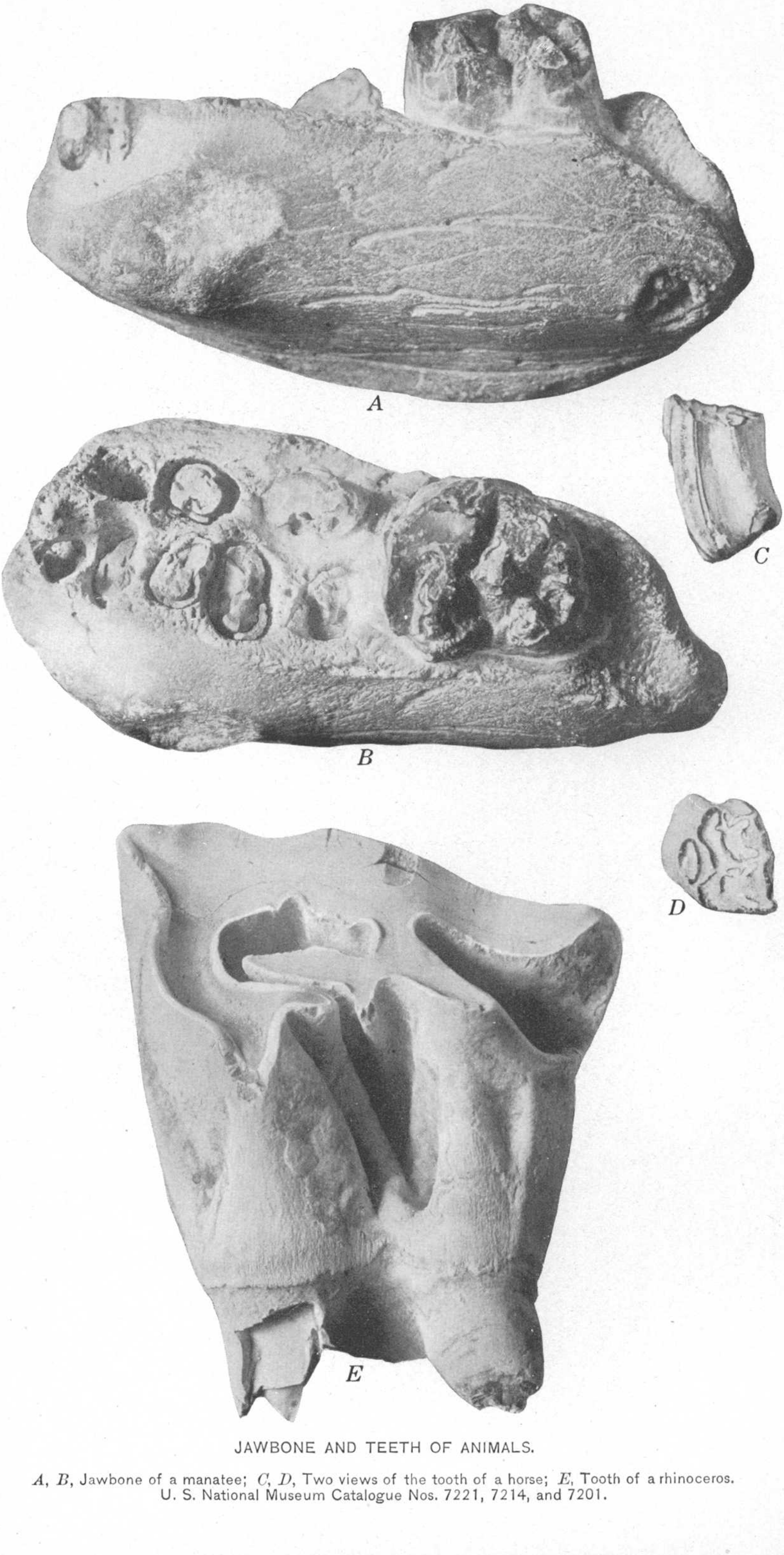


A. PART OF THE TUSK OF A MASTODON.

U. S. National Museum Catalogue No. 7203.

B. TOOTH OF A MASTODON.

U. S. National Museum Catalogue No. 7207.



JAWBONE AND TEETH OF ANIMALS.

A, *B*, Jawbone of a manatee; *C*, *D*, Two views of the tooth of a horse; *E*, Tooth of a rhinoceros.
U. S. National Museum Catalogue Nos. 7221, 7214, and 7201.

jacent materials are constant. The following sections illustrate the occurrence and relations of the land-pebble phosphate in different parts of the region.

Sections in northern parts of region.

1.

	Feet.
Overburden:	
Dark-brown to black sand	2- 3
Brown sand with pebbles stained by iron oxide	3
Fine, white, sandy phosphatic marl	0- 2
Phosphate:	
Arranged in well-defined layers interbedded with lenses of coarser material. Associated with the phosphate are many fragments of bones and a few shark teeth.	
Fine white clay with coarse pebbles of phosphate	2
Sandy white clay with medium pebbles of phosphate	1½
Blue clay with fine pebbles of phosphate	4- 5
Brownish clay with coarse pebbles of phosphate	2
Soft blue clay with small grains of dark-colored phosphate	2- 4
"Bedrock": Light-gray marl weathering yellow or brown and containing numerous pebbles of phosphate and casts of shells. Upper surface irregular	2+

2.

Overburden:	
Yellow sand	2- 4
Indurated gray sand	4- 6
Phosphate:	
Containing many shark teeth and worn fragments of corals.	
Coarse phosphatic gravel with layers of varying texture	3- 6
Olive-green clay with fine grains and small pebbles of phosphate	½- 3
"Bedrock": Light-gray to yellow limestone containing many pebbles of phosphate, merging to a soft, sticky marl containing similar pebbles and fossils. Some layers of the limestone are silicified	4-10+

3.

Overburden:	
Incoherent gray sand	3- 4
Semi-indurated yellow sand	12
Lens of interlaminated blue clay and gray indurated sand	0- 6
Phosphate:	
Sandy light-gray matrix containing many pebbles of phosphate	10
Fine blue clay with small pebbles and granules of phosphate	2
"Bedrock": Sandy yellow marl and limestone	2+

In this pit the surface of the bedrock is very uneven but less fossiliferous than at some other localities. At one point the bedrock rises several feet above the floor of the pit and has been altered to a rock phosphate containing light-colored, irregular veins of the same material. The rock phosphate has the texture and the pebbles characteristic of the underlying bedrock.

MULBERRY AND VICINITY.

Section in part of Prairie Pebble Phosphate Co.'s mine, at Mulberry.

	Feet.
Overburden:	
Gray sand containing some organic matter	2
Gray sand containing yellow and red stains	4– 5
Gray sand	5
Brown sand with some iron concretions	2
Phosphate:	
Alternating layers of fine and coarse sandy phosphate gravel	8–10
Fine greenish-gray sand and clay with numerous small granules and pebbles of phosphate	4
"Bedrock:" Light-yellow marl and limestone containing dark pebbles of phosphate	4+

A more detailed section of the lower part of the exposure in this pit is given below:

Section in lower part of pit at Mulberry.

	Feet.
Phosphate:	
Fine sandy phosphate with small pebbles	6
Coarse pebble phosphate, most of the pebbles dark colored	½–1
Alternating layers of gray and green sandy clay with fine phosphate pebbles	2
Gray sand with coarse phosphate	1–2
"Bedrock":	
Dark-yellow phosphatic marl	1–2
Pale-yellow friable limestone with pebbles of phosphate	3+

In the upper 4 feet of the phosphate there is some trace of induration and the beds are slightly undulating. The coarse layer is very persistent, having a horizontal extent of over 500 feet. Variations of 3 to 4 per cent, more rarely 5 to 6 per cent, in the amount of tricalcium phosphate have been noticed within a distance of 150 feet. Some of these variations accompany differences in color; the light-colored porous rock being usually of higher grade than the dark-colored heavy rock. However, the light-colored rock loses a much larger percentage of volume in washing than the dark.

Section in Phosphate Mining Co.'s pit No. 3, about 2 miles west of Mulberry.

	Feet.
Overburden:	
Gray sand with dark sandy loam at the top and locally a dark layer, containing organic matter, at the bottom	2
Gray and yellow semi-indurated sand	12
Gray sand with a few iron concretions	0– 3
Brown semi-indurated sand	2
Phosphate:	
Light-gray sandy pebble phosphate with alternating layers of coarse and fine material	6
Light-blue clay containing many small pebbles and granules of phosphate	6– 8
"Bedrock": Light-yellow limestone containing phosphate pebbles	4+

At one point in this pit a wedge of pink sand extends to a depth of over 5 feet into the phosphate. The upper portion of this body of sand is 10 feet across and it tapers to a few inches in width at the bottom. Many of the coarse layers of phosphate have marked inclinations, amounting to 3 or 4 feet in a horizontal distance of not more than 10 feet. The contact between the "bedrock" and the overlying phosphate is very uneven and apparently the "bedrock" was extensively weathered and eroded before the phosphate was deposited. There is a marked difference in the character of the overburden on the opposite sides of the pit. On the north side the sand shows distinct lamination and is stained yellow by streaks of iron oxide. This part of the overburden has in places a thickness of about 15 feet. On the south side of the pit the same kind of material has a thickness of only about 2 feet and it is overlain by about 10 feet of coarse gray, poorly stratified sand. In the north wall of the pit there is a lens of black clay containing thin laminæ of friable sand rock. This lens, which has a maximum thickness of about 6 inches, separates the overburden from the underlying phosphate. The lens is reported to have had a horizontal extent of over 15 feet and a maximum thickness of 2½ feet. In one corner of this pit the "bedrock" presents an unusual section, consisting of yellow limestone with pebbles of phosphate, 1 to 3 feet; blue clay and fine sand with pebbles and granules of dark-colored phosphate, 6 inches to 3 feet; hard yellow limestone, 2+ feet. At this locality the fine-grained phosphate is interbedded with the limestone that forms the "bedrock."

Section in the Pierce Phosphate Co.'s mine at Pierce.

	eet.
Overburden:	
Loose gray sand	3
Indurated gray sand	20–25
Phosphate: Gray phosphate rock with uniformly coarse pebbles in a fine sandy matrix	6–16
"Bedrock":	
Fossiliferous yellow limestone	0– 4
Light-blue clay with fine sand and small granules and pebbles of phosphate	6–10

In another pit near the one where the above section was observed the following section was exposed:

Section in the Pierce Phosphate Co.'s mine at Pierce.

	Feet.
Overburden:	
Light-yellow sand	3– 4
Indurated gray sand with siliceous concretions.	
Phosphate:	
Coarse pebble phosphate with gray sandy matrix and several large bone fragments	6– 8
Sandy blue clay with fine pebbles of dark-colored phosphate.	4+

	Feet.
"Bedrock":	
Marly yellow limestone with phosphate pebbles	3+
Clay containing many pebbles of phosphate	10

FORT MEADE AND VICINITY.

Section in Palmetto Phosphate Co.'s mine No. 2, at Tiger Bay.

	Feet.
Overburden:	
Loose gray sand dark colored near the top	4
Indurated brown sand with local layers of concretionary iron nodules near the top	10
Phosphate:	
Coarse sand containing large phosphate pebbles, bone fragments, and casts of shells	2– 4
Fine sandy matrix with small phosphate pebbles and local lenses of coarser material	8–10
Fine blue sand and clay with small phosphate pebbles	1– 2
"Bedrock": Yellow limestone containing phosphate pebbles	2+

Section in Palmetto Phosphate Co.'s mine No. 1, at Dominion.

	Feet.
Overburden: Gray sand stained yellow by iron oxide	15
Phosphate:	
Coarse sandy phosphate with some undulating layers	10
Fine blue to olive-green, thinly laminated clay containing phosphatic sand	4
"Bedrock": Yellow limestone containing many pebbles of phosphate and large shells	4+

At one point near the base of this section four vertebræ were found in place and the fifth was lying about 2 inches away. In one end of the pit the phosphate extends into the fine clay to a depth of over 5 feet.

Section in phosphate mine at Agricola.

	Feet.
Overburden:	
Loose gray sand	2
Semi-indurated yellow sand	10
Fine-grained, indurated brown sand containing a little phosphate	1– 6
Phosphate:	
Coarse gray sand with large pebbles of phosphate	2
Fine gray sand with small pebbles of phosphate	4
Coarse gray sand with large pebbles of phosphate	2
Fine blue clay and sand with small pebbles and granules of phosphate	2
"Bedrock": Hard yellow marl and limestone with phosphate pebbles and granules	2+

The upper surface of the bedrock is irregular and slopes as much as 4 or 5 feet in a horizontal distance of 50 feet.

Section in Charleston Mining Co.'s mine No. 1, at Fort Meade.

	Feet.
Overburden:	
Loose gray sand	2–4
Semi-indurated gray and brownish-gray sand with some iron concretions and local lenses of gray phosphatic marl	12–14
Phosphate: Light-blue and gray sand with numerous fine pebbles of phosphate and a few lenticular layers of coarser pebbles	12
"Bedrock": Coarse gray limestone weathering yellow and containing many casts of shells and pebbles of phosphate	5+

The upper surface of the limestone is irregular and at one point an old stream channel has been eroded across the deposit, removing the overburden, phosphate, and a portion of the "bedrock." The channel has subsequently been filled by a deposit of gray sand.

Section at Dominion Phosphate Co.'s mine, Dominion.

	Ft.	in.
Overburden:		
Loose gray sand	4	
Brown to yellow semi-indurated sand	6–12	
Blue clay containing iron stains and resting unconformably on the phosphate	0	4
Phosphate: Gray phosphatic conglomerate with a sandy matrix.	8–12	
This conglomerate shows frequent alternations of coarse and fine pebbles in layers ranging from 1 inch to 3 or 4 feet thick.		
"Bedrock": Yellow limestone	4+	

At one point in this pit there is about 4 feet of gray phosphatic sandy marl at the base of the overburden. A tooth of a mastodon was found in this marl. The line of contact between the marl and the phosphate is uneven, as though the latter had been eroded before the deposition of the former.

Section in mine of the Phosphate Mining Corporation at Royster.

	Feet.
Overburden:	
Loose gray sand	2–4
Semi-indurated brown sand with yellow stains due to iron oxide	10–12
Phosphate:	
Sandy gray conglomerate with phosphate pebbles and a few scattered bone fragments	6–8
Blue to gray sand containing small pebbles and granules of phosphate with some thin layers of coarser pebbles	5–6
"Bedrock": Sticky yellow marl with many pebbles of phosphate.	5+

The stratification of the phosphate conglomerate is wavy and its upper surface appears to have been slightly eroded, for it bears channels from 1 to 2 feet deep, which have been filled with the sand of the overburden. In some places there is a thin layer of marly clay at the contact between the overburden and the phosphate. A piece of the jawbone of a mastodon containing a single tooth was found in this conglomerate. At one place in this pit a small piece of charcoal was embedded in the phosphate conglomerate. The section of material overlying this charcoal included 6 feet of phosphate conglomerate and 16 feet of sand overburden.

Section in the Tilghman Phosphate Co.'s mine at Bowling Green.

	Ft.	in.
Overburden:		
Loose gray sand	2–4	
Indurated gray sand	10	
Thin, laminated blue clay		4
Phosphate:		
Gray sand with coarse pebbles of phosphate	4	
Gray phosphate conglomerate containing some sand	4	
Blue clay and fine sand with many granules and small pebbles of phosphate	1–2	
"Bedrock": Yellow limestone, locally phosphatic, and with some layers silicified	3+	

PHOSPHATIC MARL.

CHARACTER AND USES.

In some of the mines a soft, white phosphatic marl rests upon the Bone Valley gravel. The contact of the marl and the gravel is as a rule slightly irregular, and the marl itself is generally intermingled with more or less sand similar to that which forms the overburden. This marl has been mined in the vicinity of Fort Meade and, after burning, is reported to contain a high percentage of tricalcium phosphate. The output of this mine is used in making fertilizer. The marl in the pebble-phosphate mines is not regarded as valuable and is removed with the sand that forms the overburden. Animal remains are rare in this marl, but it was in material of this kind that Superintendent Campbell of the Dominion Phosphate Co. found the mastodon tooth mentioned by Sellards in his report.[1]

Section in the International Phosphate Co.'s mine, Jane Jay.

	Feet.
Overburden:	
Loose gray sand containing many pebbles and fragments of phosphatic marl	2–4
Sandy, gray phosphatic marl resting upon an uneven surface of phosphate gravel	2–4
Phosphate:	
Gray sand alternating with layers of coarse and fine phosphate pebbles	10
Thin, laminated, olive-green clay containing fine phosphate pebbles	4
"Bedrock": Light-yellow limestone and marl with phosphate pebbles	2+

[1] Sellards, E. H., A preliminary paper on the Florida phosphate deposits: Florida Geol. Survey Third Ann. Rept., p. 24, 1910.

The limestone has an irregular upper surface and was apparently extensively weathered before the deposition of the phosphate. Eroded casts of shells showing considerable abrasion, which were doubtless reworked from the "bedrock," are numerous in the upper portion of the phosphate deposit.

DEVELOPMENT AT FORT MEADE.

A deposit on the west bank of Peace River consists of coarse gray phosphatic marl containing a large amount of sand like that described as phosphatic marl in connection with the discussion of the overburden in the Pebble Phosphate Co.'s mines. The rock is quarried and burned for use in making fertilizer.

Section in pit on west bank of Peace River.

	Feet.
Overburden:	
Brownish-yellow sand containing fragments of phosphatic marl.	2
Yellow sand with pebbles and fragments of phosphatic marl..	2– 3
Phosphate: Sandy, gray phosphatic marl........................	10

RIVER-PEBBLE PHOSPHATE.

The river-pebble phosphate, as the name implies, is a fluviatile deposit consisting of pebbles of different sizes arranged in bars and lenses of various sizes and shapes. The fragments of phosphate show rounded outlines produced by mechanical abrasion and range from small granules to pebbles 2 inches or more in diameter, though the average diameter is less than an inch.

The phosphate is usually stained dark by a surficial coating of organic or, more rarely, inorganic matter, and the pebbles when broken show colors similar to those of the land-pebble phosphate. The deposits contained many fragments of bones and teeth of sharks and other animals. Presumably the "Peace Creek bone bed," already mentioned, belongs to the river-pebble phosphate, though there is little or no definite information concerning the source of the collections of vertebrate remains that were assigned to this bed.

The matrix of the river-pebble phosphate consists of sand and sandy clay of various colors. The sand predominates and is in places so coarse that it is difficult to separate from the phosphate. In some localities, as on Miakka and Caloosahatchee rivers, there are so many shells of marine organisms mixed with the phosphate pebbles that mining is impracticable.

ORIGIN AND AGE OF THE PHOSPHATES.

GENERAL CONCLUSIONS.

The phosphates of Florida occur in sedimentary rocks and with the exception of certain deposits southwest of Lakeland are of secondary origin, having been redeposited either by mechanical or chemical action. They are of Tertiary age, the rock phosphates occupying depressions in the surface of limestones of lower Oligocene age and the pebble phosphates being somewhat younger. The land-pebble phosphates have been assigned to the Miocene, though they may possibly be as late as early Pliocene. The river-pebble phosphates are in part Pleistocene and in part Recent. They occur in beds of streams that flow through the phosphate region or they lie beneath the low terraces that border these streams.

Phosphate deposits similar to those found in Florida have been reported from many other localities, and the studies of Sir John Murray [1] have shed much light on the origin of types of phosphate analogous to those occurring in some parts of the State. His discussion of the origin of marine phosphates is of unusual interest, and further reference to his work will be made on subsequent pages. Various theories have been advanced to explain the origin of the rock phosphate of Florida, and these will here be reviewed.

ROCK PHOSPHATES OF THE VICKSBURG GROUP.

THEORIES OF ORIGIN.

One of the early theories to account for the origin of the rock phosphate of the Vicksburg group was advanced by Millar,[2] who cites the opinions of Darton and others, with comment, as follows:

Mr. N. H. Darton, of the United States Geological Survey, is, among others, of opinion that guano was probably the original source of the phosphate deposits, and this theory seems to cover the conditions of the problem more completely than most of the hypotheses advanced. Others again consider that the underlying limestone rock originally contained a certain percentage of phosphate of lime, and that by the action of water the carbonate got leached out, leaving behind a crust of phosphate of lime. The objection to this theory is the tremendous leaching out of carbonate of lime which would have to have taken place in order to leave behind so thick a bed of phosphate. For, supposing even that the limestone actually did contain 5 per cent of phosphate of lime, this would mean a leaching of a thickness of 1,000 feet of limestone to produce 50 feet of phosphate.

A third theory is that the upper surface of the limestone rock, being continually washed with phosphate in solution, derived from the decomposition of animal remains, gradually lost its carbonic acid and became phosphatized. In this case one would expect to find phosphatized shells, which up to date have not been forthcoming.

Dr. Francis Wyatt considers that the phosphate formation was due to the evaporation of the Miocene waters.[3]

"During the Miocene submergence there was deposited upon the Upper Eocene limestones, more especially in the cracks or fissures resulting from their drying up, a soft, fine disintegrated calcareous sediment or mud.

"The gradual evaporation of these Miocene waters brought about the formation, principally in the neighborhood of the rock cavities and fissures, of large and small

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[1] Report on the specimens of bottom deposits dredged by U. S. Coast Survey steamer *Blake:* Mus. Comp. Zoology Bull., vol. 12, 1885–86, pp. 37–61. Deep-sea deposits: Report on the scientific results of the voyage of H. M. S. *Challenger*, pp. 391–400, London, 1891.

[2] Millar, C. C. H., Florida, South Carolina, and Canadian phosphates, pp. 116–118, 1892.

[3] Eng. and Min. Jour., Aug. 23, 1890.

estuaries. These estuaries were replete, swarming with life and vegetable matter—fish, mollusks, reptiles, and marine plants. They were, besides, heavily charged with gases and acids, and their continuous concentration ultimately induced a multiplicity of readily conceivable processes of decomposition and final metamorphism."

Dr. N. A. Pratt, on the other hand, is of opinion that the rock or bowlder phosphate had its immediate origin in animal life, and that the phosphate bowlder is a true fossil. He does not see any objection to the possibility of a species existing which secreted a skeleton of phosphate of lime, in the same way that the coral animal secretes carbonate of lime. He thinks, in fact, that such a species did exist, and that the fossil bowlder is the fossil remains of a huge foraminifer, which had identical composition in its skeleton with true bone deprived of all organic matter.

These are the principal theories as to the origin of the phosphates, and there are as many or more hypotheses accounting for the formation in which the phosphate is found to-day. Without discussing these in detail, it seems to be agreed that the deposits owe their present position and form to the agency of water; in other words, the phosphate is not found to-day in the position and shape in which it originally received its origin, but the beds or crusts or layers have been broken up, washed together, detrited, water-worn, and rolled by the action both of salt and fresh water until their present form and position were arrived at.

Dall [1] suggests that the rock phosphate is the result of the action of solutions bearing phosphoric acid upon limestone. He thinks the occurrence of bones and teeth in the phosphate has no bearing on the origin of the deposits, and the phosphoric acid, according to his theory, was supplied by the leaching of excreta of birds, seals, or other gregarious animals.

The local character of such rookeries would determine the local occurrence of phosphate rock, whose irregularities in this respect are notorious. The different forms under which the phosphates now present themselves would result from the different constitution of the rocks upon which the rookeries were originally situated; the difference in elevation and dryness or accessibility to occasional incursions of brackish or salt water; the existence or nonexistence of some subterranean water table in the particular localities; and subsequent solutionary or erosive action upon the rocks thus modified. The material of such rocks rearranged into later strata would preserve a certain proportion of phosphoric acid, even though no subsequent additions of that substance were received by the new beds. A tendency under certain circumstances for the phosphatized lime to concentrate in nodules, or as shells over harder nuclei, is very marked. In this process it would seem as if the traces of iron in the rocks followed and joined with the phosphoric acid, since these nodular concretions are almost invariably darker colored than the rest of the rock, and, when subjected to river action, frequently become blackened by the resulting chemical action on the contained iron.

Pratt, whose views are outlined in the report of Millar, already quoted, suggests that the bowlders are the skeletal remains of gigantic Foraminifera that flourished at the time the rock was being deposited. The rock phosphate was thought to have been derived from the skeletons of these animals, and the soft phosphate was attributed to the spawn.

[1] Dall, W. H., and Harris, G. D., Correlation papers—Neocene: U. S. Geol. Survey Bull. 84, pp. 134–140, 1892.

Eldridge,[1] in 1892, published a comprehensive discussion of the origin of the rock and soft phosphates. In considering Eldridge's paper it should be borne in mind that the rocks called Eocene are now placed in the Vicksburg group, and that his phosphatized "Miocene" is now included in the Apalachicola group; both therefore belong to the Oligocene. Eldridge divides the formation of the rock phosphate into three periods: (1) Formation of the primary rock by replacement of the carbonic acid of the original limestone by phosphoric acid, thus changing the calcium carbonate to calcium phosphate; (2) secondary deposition of phosphate both from solution and suspension in cavities in the primary rock; (3) disintegration and redeposition of the phosphate. This author mentions both the alterations of limestones by solutions bearing phosphoric acid from guano beds and by concentration of phosphate present in the limestone as an original constituent, but makes no attempt to discriminate between the two possible sources of the phosphoric acid. He believes that there is clearly evidence of downward percolation of surface waters—

> highly charged with carbonic and earth acids, and thus enabled to carry down into the mass of the limestone dissolved phosphate of lime, to be redeposited under conditions favorable to its separation. Such conditions might have been brought about by the simple interchange of bases between the phosphate and carbonate of lime thus brought together or by the lowering of the solvent power of the waters through loss of carbonic acid. The latter would happen whenever the acid was required for the solution of additional carbonate of lime, or when, through aeration, it should escape from the water. The zone of phosphate deposition was apparently one of double concentration, resulting from the removal of the soluble carbonate, thus raising the percentage of the less soluble phosphate, and from the acquirement of additional phosphate of lime from the overlying portions of the deposit. * * *
>
> Much of the primary rock, both Eocene and Miocene, has the appearance rather of deposition by precipitation than of alteration by replacement of the limestone by the phosphate, but either of these processes may have taken place under the conditions existing at that time.

The secondary period of Eldridge includes deposition by chemical precipitation either on exposed surfaces or in cavities and crevices, together with deposition of phosphatic sediment from suspension in the waters percolating through the phosphate deposits. During this period the incrustations in cavities and the laminated and plate-shaped deposits that now appear as bowlders were formed. Laminated phosphate is also attributed to repeated deposition of a thin coating of phosphate on a sea-washed shore, the precipitation being caused by aeration resulting in a slight loss of carbonic acid. In the period of secondary deposition are included the examples of recementation of broken fragments of phosphate giving rise to brecciated forms.

[1] Eldridge, G. H., A preliminary sketch of the phosphates of Florida: Am. Inst. Min. Eng. Trans., vol. 21, pp. 213-218, 1892.

During the third period of formation of rock phosphates, as outlined by Eldridge, the beds previously formed were broken up and redeposited in their present position with detritus from various sources. When this action occurred is uncertain, but it was probably during the time of the last submergence of the peninsula, when conditions were believed to have been especially favorable to the solution and abrasion of the limestone upon which the phosphate rested. The soft phosphate found associated with the bowlders is thought to have been derived from hard rock phosphate by processes of comminution of bowlders and pebbles.

TYPES OF ROCK PHOSPHATE DISCRIMINATED.

Failure to discriminate between the rock phosphates in the limestones of the Vicksburg group and those in the limestones of the Apalachicola group has led to much confusion, for these deposits differ not only in age but in mode of occurrence and origin. It has already been noted here that all the rock phosphate now mined rests on the limestones of the Vicksburg group, and it may be added that a large part of the soft phosphate either occurs with this rock phosphate or occupies depressions in the upper surface of limestones of the same age. In the previous discussion the rock phosphates of the Apalachicola group have been disregarded because the only deposits of that group that are now readily accessible are those belonging to the Alum Bluff formation ("bedrock" of the miners) of the pebble-phosphate region.

The phosphates described by Eldridge [1] as belonging to the Eocene system rest on the limestones of the Vicksburg group. A careful examination of these deposits shows that though they include materials of various kinds mixed together in a more or less heterogeneous mass, they can be separated into two types, which may either occur in different mines or be found together in a single mine.

ROCK PHOSPHATE FORMED IN PLACE.

Phosphate of the first type is represented by such deposits as the one at the Cummer Lumber Co.'s mine a mile south of Newberry. The phosphate at this mine consists of angular fragments, such as the miners ordinarily call pebbles, associated with bowlders, the largest having a diameter of more than 18 inches and the whole being inclosed in a matrix of soft phosphate and clay. Most of the pebbles and bowlders are phosphatic, though a few of the bowlders are of flint.

[1] Eldridge, G. H., A preliminary sketch of the phosphates of Florida: Am. Inst. Min. Eng. Trans., vol. 21, pp. 213-218, 1892.

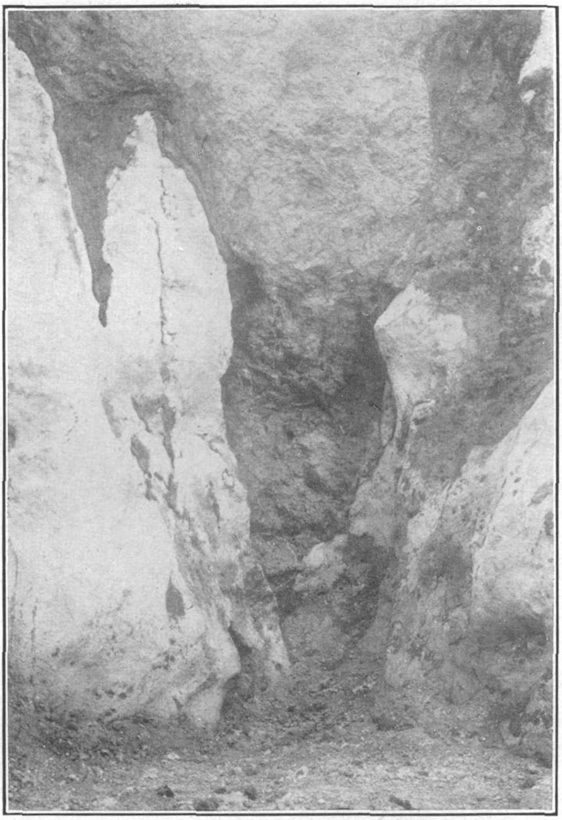
The deposit includes a few pebbles of partly phosphatized limestone, and in some places near the contact with the underlying rock there is a transition zone from the phosphate to the limestone. Fossils are rare in such deposits, though in a few places phosphate pebbles and bowlders containing Vicksburg fossils have been seen (see Pl. XIV, *B*), and fragments of bone and teeth of sharks are distributed sporadically throughout the phosphate. In the transition zone fragments of Orbitoides and other characteristic fossils of the limestone may be found, but owing to the pulverulent character of the partly phosphatized limestone the contact phenomena may easily be overlooked. The surface of the limestone appears smooth after the phosphate has been removed, and this fact led Sellards [1] to conclude that a portion of the limestone had been removed by erosion prior to the deposition of the phosphate. The irregular outline of the limestone bears some resemblance to an eroded surface, but the channels are not continuous, and the presence of rounded depressions of small diameter (see Pl. XIII, *A* and *B*), locally called "wells," some of which extend several feet into the limestone, can hardly be explained by assuming that they are due to erosion.

Deposits of the character just described appear to have been formed in place by alteration of calcium carbonate to calcium phosphate under the influence of solutions bearing phosphoric acid. In this process nearly all the fossils are destroyed and the texture of the original rock is at many places altered beyond recognition, though not everywhere, because at a few localities both the characteristic fossils and the texture of the rock have been preserved during the process of phosphatization. Apparently the phosphate accumulated in unusually large quantities about certain centers, producing phosphate pebbles.

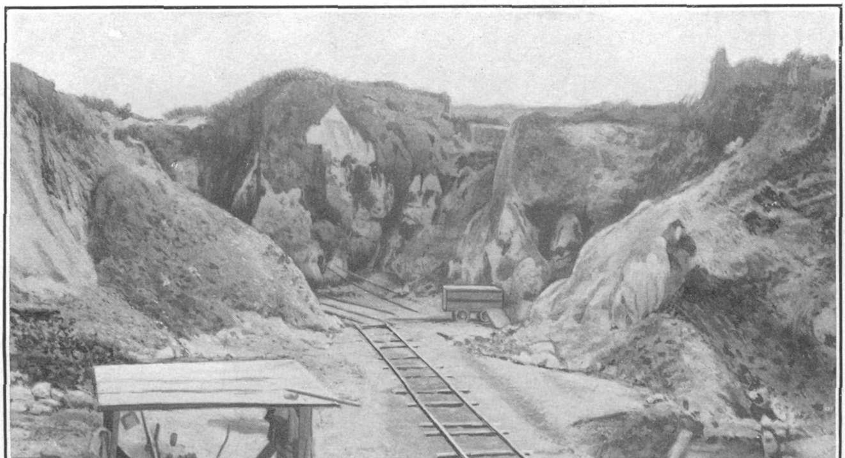
The nature of the process by which the formation of phosphate nodules was begun is not known, but after a nodule had been started the accumulation was due, in considerable measure, to the attraction of the material already deposited. Variations in the density of the limestone may have been the primary cause of the formation of centers of unusual accumulation, but as the texture of the original rock has been obliterated this theory can not be readily proved.

Some of the bowlders appear to have been formed by deposition of phosphate in preexisting cavities and channels in the limestone, the accumulation beginning as a coating on the walls of the openings, and therefore they conform in outline to the shape of the cavities in which they were deposited. At many places changes in the character of the solution produced successive layers of slightly different colors, and in many cavities the phosphate was more or less definitely arranged

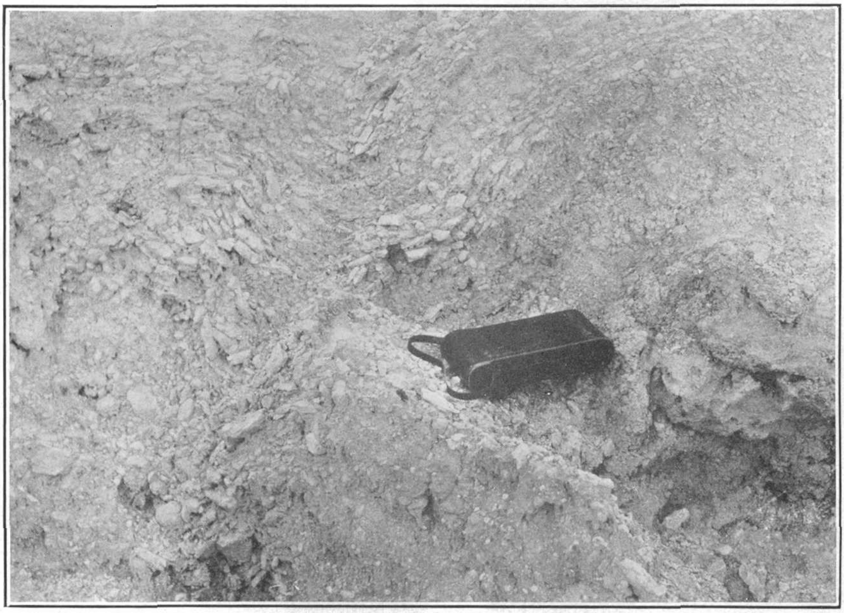
[1] Sellards, E. H., A preliminary paper on the Florida phosphate deposits: Florida Geol. Survey Third Ann. Rept., p. 24, 1910.



A. RELATIONS OF ROCK PHOSPHATE TO UNDERLYING LIMESTONE IN CUMMER LUMBER CO.'S MINE AT NEWBERRY.



B. GENERAL VIEW OF CUMMER LUMBER CO.'S MINE AT NEWBERRY.



A. PLATE-ROCK PHOSPHATE NEAR ANTHONY.

Reproduced from "A preliminary paper on the Florida phosphate deposits," by E. H. Sellards, in Third Annual Report Florida Geological Survey, 1910.

B. PHOSPHATIZED LIMESTONE OF VICKSBURG GROUP.

U. S. National Museum Catalogue No. 66793.

in plates connected by a network of the same material, forming bowlders that have been classed as skeletons of giant foraminifers. In many cavities the latest deposits are fibrous crystals forming stalactites (see Pl. XV), or mammillary coatings of phosphate minerals. In a few openings the phosphate is covered by subsequent deposits of fine silt, and, as already noted by Eldridge, there is evidence that secondary deposits of phosphates bound together fragments of the same material. The shattering of the phosphate that produced these fragments doubtless resulted from some of the movements described below.

Doubtless many bowlders were formed by the accumulation of phosphate in places where there were no preexisting cavities. These bowlders were produced by the replacement of the calcium carbonate of the limestone by calcium phosphate borne in solution by percolating waters. Many nodules and much soft phosphate were formed in the same way.

The nodules and bowlders of flint found in phosphate deposits of this type appear to have originated in a manner similar to the pebbles and bowlders of phosphate. Some bowlders show the same tendency toward banding and the same lamellar arrangement of plates. In many bowlders, especially those in some of the mines near Newberry, the texture of the original rock has been partly preserved, and in some of them the characteristic fossils of the underlying rock are represented as casts and molds. Apparently the process of silicification of a limestone does not result in the same wholesale destruction of fossils that occurs during phosphatization.

Movements in phosphate deposits formed thus in the places where they lie are confined to settling resulting from leaching of calcium carbonate and other substances by percolating waters and to slumping of the phosphate at localities where a part of the supporting limestone has been removed by solution. Movements of this kind, caused by collapse of roofs of underground channels, have been already described, and the resulting displacement of phosphate beds is shown in figure 1 (p. 52).

The fact that attrition of the pebbles would have rounded them precludes the possibility that they were eroded and redeposited in their present position. Moreover, the large bowlders of flint and phosphate scattered throughout the deposit indicates that the phosphate has not been redeposited, because some of the bowlders are too large to have been transported far from where they were formed.

The soft phosphate associated with the rock phosphate, as well as that found elsewhere in the Vicksburg group, appears to be largely the result of phosphatization of the soft porous limestone without solidification. Some soft phosphate may be due to partial phosphatization of the original rock and subsequent removal of the remaining calcium carbonate in solution, the phosphate already formed being left in an incoherent mass. Thus some of the soft phosphate is slightly coherent and its texture resembles that of the phosphate of the Vicksburg group, but this type is comparatively rare. Large quantities of soft phosphates can hardly be formed by mechanical destruction of rock phosphate except where the fragments of such phosphate have been subjected to enough attrition to produce rounded forms.

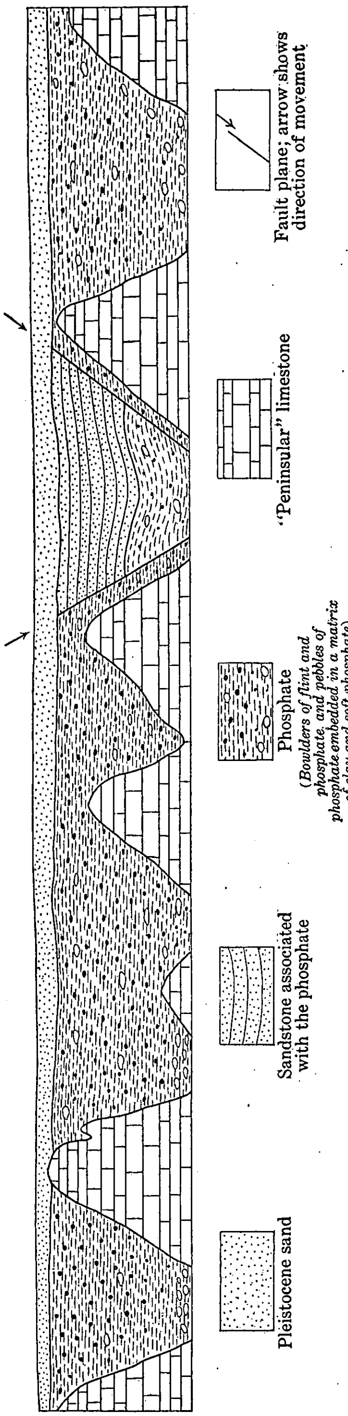
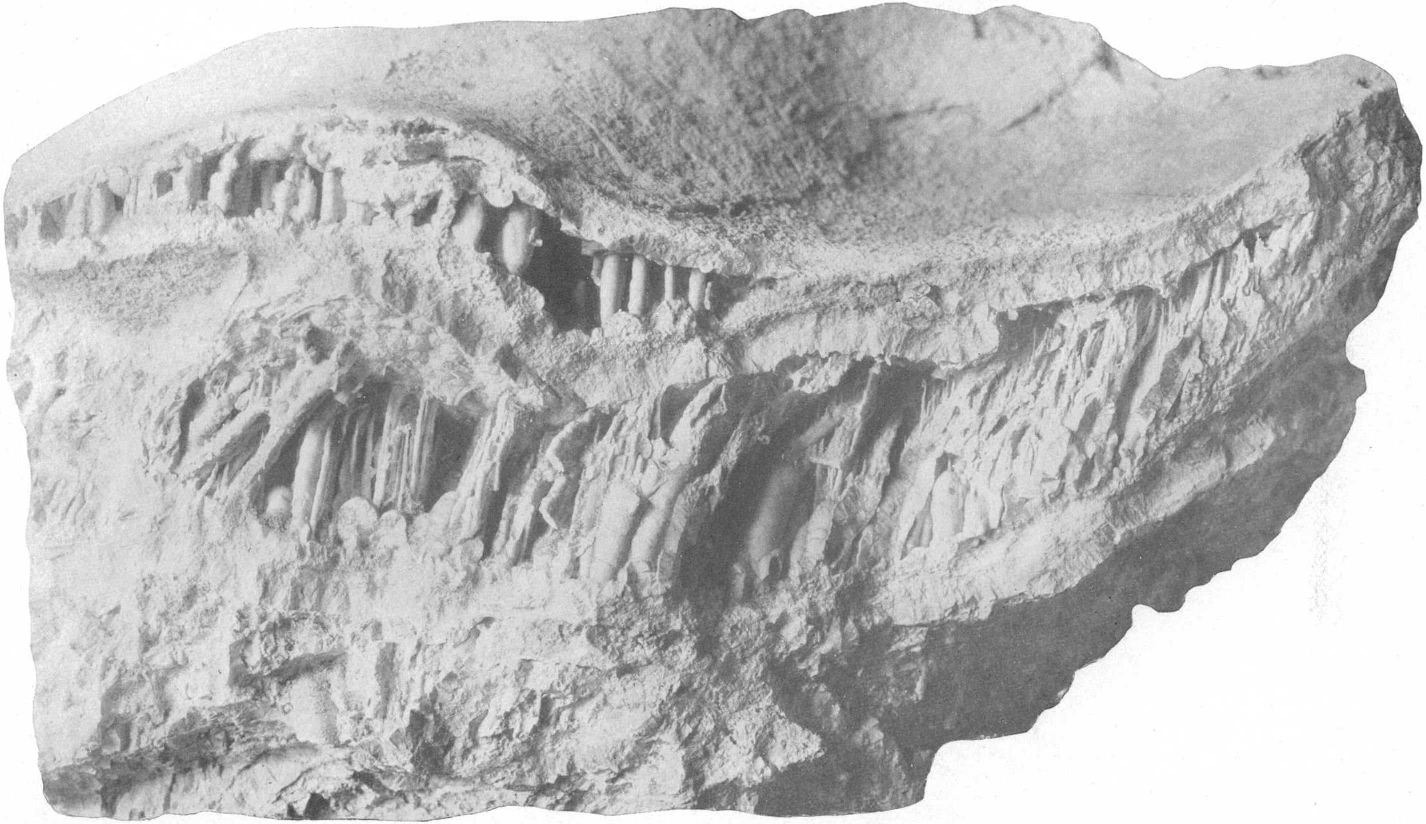


FIGURE 1.—Diagram showing relations of Peninsular limestone to sandstone, rock phosphate, and gray Pleistocene sand. Length, 100 feet; thickness, 20 feet.

REDEPOSITED PHOSPHATE.

Another type of rock-phosphate deposit found on the rocks of the Vicksburg group is illustrated by a section seen in a mine near Newberry. The phosphate pebbles at this mine show evidence of abrasion, and many of them are well rounded. There is an absence of large bowlders in the upper portion of the deposit, and the pebbles show a general arrangement in layers. The matrix is prevailingly sandy, though in places it contains much clay and soft phosphate. Thin layers of sand are interbedded with the phosphate. This type of deposit is shown in figure 2. That such a deposit is the result of erosion and redeposition of preexisting phosphates can hardly be questioned. There is little doubt that both soft phosphate and pebbles were derived from deposits formed in the places where they are found, though additional soft phosphate was formed by mechanical wear during the process of transportation of the pebbles, and some of the pebbles were derived from geologic formations younger than



FRAGMENT OF PHOSPHATE CONTAINING CAVITIES COATED WITH DEPOSITS OF CRYSTALLINE PHOSPHATE AND PARTLY FILLED WITH PHOSPHATIC STALACTITES.

U. S. National Museum Catalogue No. 77373.

the Vicksburg group. The relatively small proportion of soft phosphate and the large quantity of sand in the matrix is due to the fact that the soft phosphate was not deposited in the waters that laid down the phosphatic gravels but was transported to some point where quieter water favored the deposition of fine-grained material.

Though care has been taken to separate the discussions of the two types of phosphate, it should be clearly understood that both types may be found in the same mine, and even in a single section. Thus in many places the phosphate deposits are a composite of materials formed in place and other materials that have been redeposited. Where the two types occur in the same section the phosphates formed in place are naturally found beneath those that have been redeposited. Both types have been subjected to the same kinds of disturbance and their discrimination is in many places uncertain because at some localities where there has been considerable movement, resulting from solution and removal of the supporting limestone, the deposits have been reduced to a heterogeneous mass that preserves very little of the original structure.

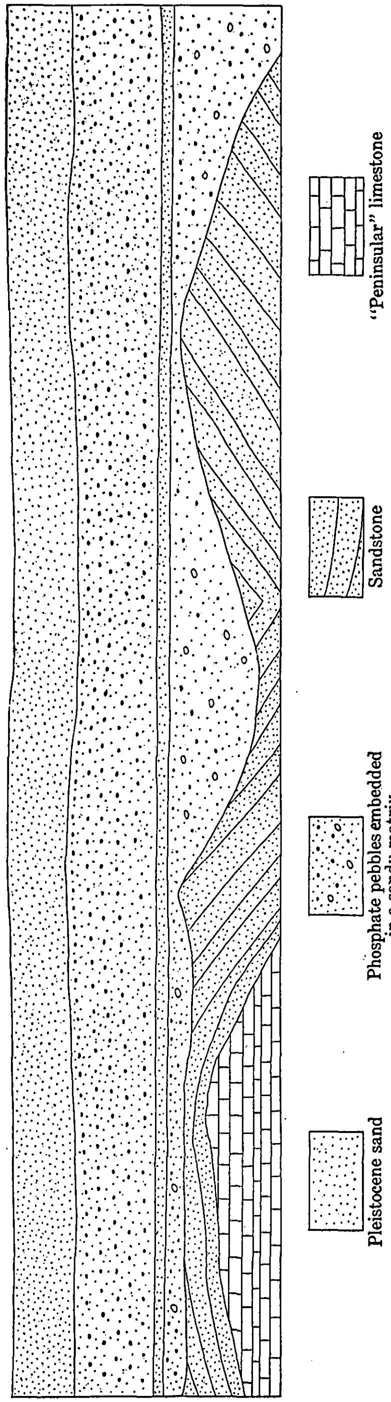


FIGURE 2.—Diagram showing relations of Peninsular limestone to sandstone, rock phosphate, and gray Pleistocene sand. Length, 100 feet; thickness, 30 feet.

SOURCE OF THE PHOSPHORIC ACID.

There are three probable sources of the phosphoric acid of the rock phosphate—first, the phosphate originally disseminated through the limestone; second, the phosphate contained in organic matter accumulated on the surface of the limestone; third, the phosphate derived from post-Vicksburg formations.

The best statement of the theory that the phosphoric acid was originally contained in the limestone of the Vicksburg group was made by Brown,[1] who argues that the phosphoric acid was originally disseminated through the limestone chiefly in the form of nodules and in shells of phosphate-secreting animals. He assigns to leaching of phosphoric acid from guano a subordinate place in the process of formation. Some of the phosphoric acid was concentrated by solution and redeposition, replacing the carbonic acid of the limestone. Disintegration of the rock containing the phosphate nodules freed them from the surrounding limestone, and they were subsequently washed into sinks and channels either by streams or ocean currents, or by both.

Cox[2] mentions the possibility that some of the phosphoric acid may be original but does not elaborate the theory, evidently believing that guano was a more abundant source.

Though analyses are not at hand it is well known that the Vicksburg rocks, as well as some of those belonging to the Apalachicola group, contain small quantities of phosphoric acid. An objection to this theory is offered by Millar,[3] who says that even if the limestone contained 5 per cent of phosphate of lime—a very large estimate—it would require the leaching of 1,000 feet of limestone to produce 50 feet of phosphate. Though the average thickness of the rock phosphate is small, a fatal objection to the theory of concentration is found in the sporadic distribution of the rock phosphate in patches a few acres in extent, unless the phosphates that remain are regarded as small remnants left by the erosion of deposits that once covered much larger areas. This theory would explain the present distribution of the phosphate if surface erosion had predominated, but the removal of the limestone of the Vicksburg group is now, and probably always has been, chiefly the result of solution, mechanical abrasion having been relatively unimportant. Thus it is necessary to seek some explanation of the concentration of the phosphate in deposits. If it is assumed that phosphate accumulated in large quantities at different places in the rock, its distribution would be accounted for, but the form of the deposits and their relation to the limestone would still be unexplained. The explanation of the mode of concentration given by Brown[4] seems plausible, but no such accumulation of

[1] Brown, L. P., Phosphate deposits of the Southern States: Eng. Assoc. of the South Trans., vol. 15, No. 8, pp. 63–66, 1904.

[2] Cox, E. T., Floridite: A new variety of phosphate of lime: Am. Assoc. Adv. Sci. Proc., vol. 39, pp. 260–262, 1891.

[3] Millar, C. C. H., Florida, South Carolina, and Canadian phosphates, p. 116, 1892.

[4] Op. cit., pp. 63–66.

nodules and phosphatic shells as would be necessary to supply the phosphoric acid has been noted in the Vicksburg group of limestone.

The geologic relations of the rock phosphate are explained by the theory advanced by Dall [1] and others that the phosphates are the result of phosphatization of limestone by percolating waters bearing phosphoric acid in solution. Such solutions would act more efficiently where the conditions governing the circulation of the water were favorable, and thus in some places the alteration would take place along irregular zones, whereas in other places the greatest change would occur along more or less rounded channels. That the fundamental movement of phosphate was downward is shown by the narrow bodies of phosphate that extend into the limestone, which indicates that the alteration occurred when the water table was below the level of the zone of phosphatization, as otherwise circulation would have been more nearly horizontal and the alteration would have produced nearly horizontal bodies of phosphate, which might easily have been mistaken for bedded deposits. Probably the presence near the surface of relatively impermeable argillaceous limestones explains the localization of some of the deposits.

The source of the phosphoric acid has been regarded as guano accumulated in the rookeries of birds, seals, or other gregarious animals.[2] Probably this theory would be strengthened by assuming that these rookeries were those of birds that occupied small islets when the land stood near sea level, though it is probable that marine animals, both by their excreta and by their remains, would be the source of some of the organic material.

The fact that a very large quantity of guano would be required to furnish the phosphoric acid in the extensive accumulations of rock phosphate has been urged as an objection to this theory; but though phosphoric acid forms only about one-eighth of undecomposed guano, the objection is not conclusive. The strongest argument against the theory is found in the relation of the phosphate to the Oligocene formations. If we assume that the guano accumulated on scattered islets or in embayments during the emergence of the limestones of the Vicksburg group before the deposition of the Apalachicola sediments it would have been buried beneath the formations of the Apalachicola group. This conclusion is necessitated by the fact that the entire area included in the rock-phosphate region was covered by these formations, for though they have since been removed their

[1] Dall, W. H., and Harris, G. D., Correlation papers—Neocene: U. S. Geol. Survey Bull. 84, pp. 134–140, 1892.

[2] Dall, W. H., op. cit. Wyatt, Francis, Notes on Florida phosphate beds: Eng. and Min. Jour., vol. 50, pp. 218–220, 1890. Darton, N. H., Notes on the geology of the Florida phosphate deposits: Am. Jour. Sci., 3d ser., vol. 41, pp. 102–105, 1891. Johnson, L. C., Notes on the geology of Florida; two of the lesser but typical phosphate fields: Am. Jour. Sci., 3d ser., vol. 45, pp. 497–503, 1893.

detritus covers the surface and their remnants form a nearly continuous rim around the phosphate region and rise from 50 to 100 feet above it. Well borings, however, do not show any accumulations of phosphate beneath these formations, and prospect holes show that near the contact of the Vicksburg group with the younger formations the phosphate deposits thin rapidly and the rock phosphate beneath the younger formations is the result of replacement such as might be expected where solutions bearing phosphoric acid penetrated the porous limestone. Any theory requiring the accumulation of guano upon islets during the period including the resubmergence of the Vicksburg group of limestone and the beginning of Apalachicola deposition would be subject to the same objection and would be further invalidated by the fact that at some localities the limestone was replaced to depths of 25 feet or more above the level of ground water. The islets of limestone must therefore have stood several feet high for a period long enough to permit the transformation of the original rock to phosphate.

There still remains the possibility that guano was deposited subsequent to the deposition of the Apalachicola sediments. Against this possibility it may be urged that the temperature in this region was lower, as shown by the fossils of the post-Oligocene Tertiary, being about the same as that now prevailing between the latitudes of Cape Hatteras and Chesapeake Bay, and the conditions were therefore less favorable to the existence of large numbers of birds or marine animals. A still greater obstacle is found in the fact that the localization of the deposits of guano requires that some condition, such as a nearly complete submergence, should restrict the area available for rookeries, if birds were the source of the guano, otherwise no large quantity would accumulate in one place. The fact that the limestone was exposed only where the overlying sands and clays had been removed, and once exposed was more readily removed than the sands and clays of adjacent areas, caused the Vicksburg rocks to occupy the depressions, whereas the later Oligocene formations occupied the higher lands. After a submergence the favorable situation for rookeries of birds would be on the hills, which would project as islands when the adjacent valleys were filled with water. But these islands would be composed of sands and clays of the Apalachicola group, and would not be subject to phosphatization such as we find in the rock-phosphate mines. The absence of a general submergence in post-Oligocene time would also be a fatal objection, for it would preclude the possibility that the phosphoric acid had been derived from the remains and excreta of gregarious marine animals.

A recent paper by Sellards[1] presents a somewhat different view of the source of the phosphoric acid. According to this author the upper Oligocene formations which formerly extended across the rock-phosphate region supplied the phosphoric acid. The deposits contain fragments of the younger formations, together with phosphatized portions of limestone of the Vicksburg group.

Concerning the validity of the conclusion that the upper Oligocene formations formerly covered the phosphate regions there should be unanimity of opinion among those who are familiar with the geology of Florida. The younger formations surround the phosphate region by nearly continuous outcrops on the east, the north, and the south and are represented by outliers on the west. They rise on the east to an altitude somewhat above the surface of the phosphate region, and residual products of them are found on the surface of limestone of the Vicksburg group in the area where the phosphate occurs. The upper Oligocene formations are phosphatic, a notable percentage of phosphate nodules being found in the Alum Bluff formation ("bedrock") of the pebble-phosphate region, in a quarry near Hawthorn, in a sink near Brandon, in the outcrops on Sopchoppy River, and at many other localities. The formation of the phosphate nodules in the upper Oligocene will be discussed in considering the phosphates of the Alum Bluff formation, but it may be said here that they are of marine origin.

A clear understanding of this theory concerning the source of the phosphoric acid in the hard-rock phosphate necessitates a brief consideration of the post-Oligocene history of the region. The upper Oligocene rocks were at first eroded by surface streams, but wherever the underlying limestone of the Vicksburg group was so near the surface that the ground water penetrated it freely, solution resulted in the formation of underground channels and sink holes. These depressions received the wash from the surrounding areas, which included some phosphate nodules, and at the same time some water containing phosphoric acid, dissolved from the overlying beds, percolated into the limestone of the Vicksburg group. The action of such solutions upon the limestones resulted in their alteration to calcium phosphate by an interchange of phosphoric acid for the carbonic acid of the limestone. Examination of thin sections of rock phosphate shows that some of the material contains much more quartz, in the form of sand grains, than is found in the limestone of the Vicksburg group. Such fragments resemble the phosphate nodules of the Alum Bluff formation. Other sections are relatively free from sand, and the rock is probably phosphatized limestone of

[1] Sellards, E. H., Origin of the hard-rock phosphate deposits of Florida: Florida Geol. Survey Fifth Ann. Rept., pp. 23-80, 1913.

the Vicksburg group. In addition, there are bowlders of more or less completely phosphatized limestone containing Vicksburg fossils. Some of the deposits appear to have been formed in the places where they lie, the phosphates being the result of alteration of the limestones; others have been reworked and are a composite of material derived from both Vicksburg and post-Vicksburg formations.

PHOSPHATE OF ALUM BLUFF FORMATION ("BEDROCK").

MARINE PHOSPHATIC NODULES.

While the Alum Bluff formation was being deposited a large amount of phosphate accumulated in some of the limestones and associated clays. The most valuable deposits of the Apalachicola group examined during the investigation made for this bulletin belong to the limestone and associated clays of the Alum Bluff formation ("bedrock") southwest of Lakeland, but phosphates of the Alum Bluff formation have been mined at Hawthorn, and at other places, as at the Devils Mill Hopper,[1] in Alachua County, and on Aucilla River southeast of Tallahassee.[2] Little is known, however, concerning any of these phosphates except those in the area southwest of Lakeland, and the discussion will therefore be confined to the deposits of that area.

The occurrence of phosphate granules and nodules embedded in the limestones and interbedded clays of the Alum Bluff formation has been noted in the discussion of the phosphates of the Alum Bluff formation, on pages 33–35. The amount of this material is large and it appears to be widely distributed, though it forms a relatively small proportion of the whole formation. The Alum Bluff formation ("bedrock") is found in every pebble-phosphate mine, and the well at Christina showed a thickness of phosphate beds exceeding 60 feet.

The phosphatic granules are very abundant at certain horizons and where granules of dark and light colors are mixed together they give the mottling that prospectors call "pepper and salt." In general these granules differ considerably in size, ranging from particles invisible without the aid of a lens to well-defined grains larger than a pea. Most of them are smooth ovules, though some are globular, or kidney shaped, or have other forms. The nodules of phosphate have the same general distribution as the granules, but differ from them both in size and shape. In addition to being larger most of the nodules have more or less irregular outlines, though they are not angular. They show many rounded protuberances and cavities,

[1] Dall, W. H., and Harris, G. D., Correlation papers—Neocene: U. S. Geol. Survey Bull. 84, p. 108, 1892.
[2] Eldridge, G. H., A preliminary sketch of the phosphates of Florida: Am. Inst. Min. Eng. Trans., vol. 21, p. 197, 1893.

but the surfaces of the nodules are usually so smooth that they appear to have been polished. Both light and dark nodules occur, but the dark ones predominate. On polished surfaces and in thin sections the nodules are seen to inclose granules of phosphate showing characteristic forms and colors, together with somewhat angular grains of quartz and, more rarely, of other silicate minerals. Some of the nodules consist of an outer shell of dense phosphate surrounding a bit of limestone that still retains its original texture and contains characteristic fossils, which may be either partly or wholly represented by casts of phosphate. Around this limestone and its inclusions is a thin shell of brown or yellow phosphate, which forms the outer surface of the nodule. The limestone in some nodules is penetrated by reticulated masses of phosphate, which project inward from the outer shell; the limestone in others has been entirely changed to phosphate. In thoroughly phosphatized nodules the texture of the limestone is not invariably preserved, and the fossils are usually destroyed, though in some nodules the imprints of shells may be seen. The inclusions of phosphate granules and quartz grains show a tendency to aggregation, but the aggregation probably occurred before the rock was phosphatized. Cracks or other openings in the limestone have usually been filled by a secondary deposit of phosphate that shows bands of slightly different colors, and some cavities that are not entirely filled have botryoidal surfaces.

The granules and nodules of phosphate are distributed through a considerable thickness of the Alum Bluff formation and are more abundant in some layers than in others, a fact indicating that phosphatic material was supplied intermittently. Their association with limestone, clay, and sand shows that they accumulated in both clear and muddy water.

The phosphate granules and nodules of the Alum Bluff formation ("bedrock") bear a striking resemblance to those described by Sir John Murray [1] as occurring on the sea bottom. Concerning specimens obtained from the sea floor between Cape Hatteras and lat. 31° 4′ N., this author says:

> Phosphate of lime and manganese concretions are present in all the deposits, and one remarkable concretion of these substances is described in detail from station 317, in a depth of 333 fathoms, immediately under the waters of the Gulf Stream.

In deposits dredged from the Gulf of Mexico and the Florida Strait concretions of calcium phosphate were very numerous. The character of these concretions is indicated by the following extract: [2]

> *Phosphatic concretions.*—The phosphatic concretions in the dredgings in Florida Strait are very interesting. In a great many deep-sea deposits there is usually a

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[1] Report on the specimens of bottom deposits: Harvard Coll. Mus. Comp. Zoology Bull., vol. 12, No. 27, p. 41, 1885.

[2] Idem, pp. 52–53.

small percentage of phosphate of lime, but near the shore, in some places, the quantity is very considerable. Sharples, who analyzed the ooze of the Gulf Stream, found—

Carbonate of lime	85.62
Carbonate of magnesium	4.26
Silica	1.32
Alumina	.20
Oxide of iron	.31
Phosphate of lime	.18
Loss on ignition	8.15
	100.04

In certain concretions found by the *Blake* in the Florida Strait, and by the *Challenger* in various parts of the world near land, the quantity of phosphate of lime is very much greater than in the deposits. These concretions appear always to be associated in an intimate way with organisms.

In 125 fathoms southwest of Land Key, Fla., a fragment of bone was obtained several centimeters in diameter. It was of a dirty brown color, of great hardness, and had a conchoidal fracture. A microscopic examination of thin sections showed that the bone structure was perfectly preserved.

The following is the result of an analysis of this specimen by M. Klement:

Phosphoric acid (P_2O_5)	33.42
Carbonic acid (CO_2)	5.80
Sulphuric acid (SO_3)	2.74
Fluorine	1.21
Lime (CaO)	51.90
Magnesia (MgO)	.70
Iron and alumina	1.56
Insoluble residue	.21
Loss on ignition	2.16
	99.70
Oxygen corresponding to fluorine	— .51
	99.19

There were also traces of silica and chlorine.

Atomic ratios.

P_2O_5	1,417	1814
CO_2	264	
SO_3	69	
F	64	
CaO	1,853	1888
MgO	35	

At the same place and depth there was a concretion of a brown color consisting of an aggregation of calcareous organisms cemented by a brownish-yellow matter, often showing concentric rings after the manner of agate. This yellowish-brown matter is isotropic; between crossed nicols only the calcite and the shells of the Foraminifera brighten up; the calcite lies crystallized in the interior of the Foraminifera. In treating the brown or yellow parts under the microscope with molybdate of ammonium and nitric acid, there is an abundant yellow precipitate characteristic of phosphoric acid.

At other stations small phosphatic concretions were also obtained by the *Blake*, all more or less resembling those described above. There are difficulties in understanding how phosphate of lime and carbonate of lime are deposited at the bottom of the sea, yet there is no doubt that such a deposition does take place under some special circumstances. Their solution is, however, an almost universal phenomenon in the ocean.

All the phosphate nodules described by Sir John Murray[1] were obtained at a depth of 125 fathoms or more, and many and possibly all of the nodules of the Alum Bluff formation were formed in much shallower water. Concerning the depth of water in Apalachicola time, Vaughan[2] says:

> The Plateau in early Apalachicolan time had practically the same outline as at present; the depth of water north of Tampa was probably in no place over 100 feet. Coral reefs were present in southern Georgia, across the base of the present peninsula, and around Tampa; the temperature was tropical, the minimum for the year being at least as high as 70° F.; the main movement of the ocean water was from the Tropics; the sediments consisted to a lesser degree of organic débris and were predominantly of terrigenous constituents.

It is doubtful whether the depth of water where the Alum Bluff deposits accumulated was greater than in the area around Tampa, and the character of the animal life and the aggregation of the animal remains indicate that it may have been less than 50 feet. Probably the conditions at that time over this part of the Florida Plateau were in some respects like those now existing between the Florida Keys and the mainland, for the Alum Bluff formation was deposited some distance from rivers bearing abundant sediments and the conditions were especially favorable to the existence of numerous marine animals. The possibility that phosphatic nodules may have accumulated rapidly should not be overlooked, because the shallow waters, having a high temperature, furnished conditions especially favorable to the development of marine life.

Phosphate nodules similar to those of the Alum Bluff formation were found in material obtained from the sea bottom by the *Challenger*,[3] and they were especially numerous near the border of the continent at places where large quantities of fresh water entered the ocean or where ocean currents of different temperatures met. Thus submarine phosphatic nodules were most abundant in the Atlantic Ocean off the eastern coast of North America and in the Pacific Ocean off Cape of Good Hope.

The similarity of the phosphate of the Alum Bluff formation to the nodules found in marine deposits off the continental shelf point to a similar mode of origin, and there is little doubt that the nodules of the Alum Bluff formation are marine phosphates. The arrangement of the phosphate nodules of Florida in layers of limestone and clay

[1] Report on the specimens of bottom deposits: Harvard Coll. Mus. Comp. Zoology Bull., vol. 12, No. 27, pp. 52-53, 1885.

[2] Vaughan, T. W., A contribution to the geologic history of the Floridian Plateau: Carnegie Inst. Washington Pub. 133, p. 182, 1910.

[3] Murray, Sir John, Deep-sea deposits: Report on the scientific results of the voyage of H. M. S. *Challenger*, pp. 391-400, London, 1891.

interbedded with barren clay indicates periodic accumulation. The many alternations of beds of clay containing phosphate nodules with beds of clay barren of nodules in the well at Christina show that there were many abrupt changes in conditions. That there was sudden destruction of a large number of animals is not clearly shown, for the same results might be obtained if the phosphate layers accumulated slowly enough to permit the formation of phosphate nodules and the barren clays were deposited too rapidly to allow such material to accumulate. In any event, if the animals were not destroyed by the conditions that resulted from an abrupt influx of sediment-laden water they were doubtless forced to abandon, for the time, their old habitat and to seek a new location where conditions for life were more favorable.

The area of the Alum Bluff formation is remote from points where large streams enter the sea and shows no signs of volcanism or of other source of gases inimical to animal life, so it is necessary to seek some other explanation of the conditions that were at intervals unfavorable to the existence of animals. The geologic history of the region during Apalachicola time furnishes a clue to the conditions resulting in the deposition of the phosphate. At the beginning of this epoch the peninsula of Florida was reduced to an island separated from the mainland by the Suwannee Strait. Somewhat later the entire peninsula was submerged. This submergence was followed by slight emergence of the central part of the peninsula, but in the meantime the Suwannee Strait was rapidly being filled with sediment. When the Alum Bluff formation was laid down the strait may have been so much filled that the passage of water through it was at times partly or wholly obstructed. The conditions may have been such that a slight change in level would have at times permitted the southward-moving cold current to pass through the Suwannee Strait, whereas at other times it was excluded. This current, sweeping across the area where clay and sand were being deposited, would bring with it terrigenous sediment, which would be deposited in the quiet waters of the Gulf coast, and frequent changes would produce the alternating layers of limestone and clays containing phosphate. The influx of mud would of itself have been sufficient to destroy some animals and to cause others to migrate to places where conditions were more favorable to their existence. Probably the difference in the temperature of the waters on the two sides of the peninsula was an additional factor in the formation of the phosphates. It was at about this time that the tropical Oligocene faunas were replaced by the colder water Miocene faunas, and the physical changes that produced the faunal differences may have been begun during the closing stage of the deposition of the upper portion of the Oligocene system. Thus it is thought that by a wholesale destruction of animal life, differences in temperature may have played a part in the origin of the phosphates of the Apalachicola group, though such changes of temperature are not believed to have been essential to their formation.

SOURCE OF THE PHOSPHORIC ACID.

In discussing the origin of marine phosphates, Murray[1] says the phosphate was first extracted from sea water by living organisms, and on their death was dissolved and redeposited. The chemical reactions causing the precipitation of the phosphoric acid as calcium phosphate and the arrangement of the material in nodular form is not fully understood. Murray continues:

> In that pulp formed by the calcareous and siliceous organic envelopes, by the fragments of rocks and minerals reduced to the state of muddy matter, and by albuminoid and other matters derived from higher organisms, the phosphates are rearranged, with the result that phosphate of lime in a nodular form is in some places found in considerable abundance. It may be supposed that this phosphatic matter, dissolved in the sea water impregnating the mud, is endowed with the properties of colloidal bodies, for we know that phosphate of lime presents incontestable analogies with certain colloids, for example, with hydrated silica. By admitting that phosphate of lime can effect this colloidal state, it is sufficient that a center of concretion should arise to initiate precipitation, and the nucleus once formed would subsequently enlarge by successive additions.[2]
>
> Many substances may have played, with respect to the phosphate, the rôle of center of attraction. It may have originated in the first instance, as we have shown, in the filling up of the hollow spaces of a Globigerina shell; afterwards it may be deposited around this shell and agglutinate the surrounding portions of the deposit into a more or less compact mass. The organic remains on the bottom of the sea often retain for a long time some of their sarcodic substance, and we are inclined to think that this exercises upon the phosphate an attraction which might be considered as a feeble echo of that exercised by living matter. This view might be supported by recalling the frequent incrustations of phosphate and its concretionary development upon the remains of plants and animals; at the same time it must be pointed out that phosphate of lime is sometimes formed around inert matters to which no affinity would appear to carry it. A solid body of any kind appears to serve as a nucleus, though phosphatic nodules are by preference formed around organic centers, but whatever the nature of the nucleus, once the first layer of the concretionary substance is deposited it no longer remains inert, acting in its turn as a center of attraction and grouping round it, just as the solvents furnish material, all the molecules of the same nature which are found within its radius of attraction.

The phosphates of the Alum Bluff formation are similar to the phosphatic nodules found by Sir John Murray[3] on the island of Malta. In both deposits the phosphates are in the form of granules and nodules, the nodules including portions of more or less altered

[1] Report on the specimens of bottom deposits: Harvard Coll. Mus. Comp. Zoology Bull., vol. 12, No. 27 pp. 52–53, 1885.

[2] The phosphate of lime may be held to be directly derived from the products of decaying bones of dead animals, upon which carbonic acid exerts a powerful solvent action. At the same time the organic nitrogenous matter of the bones is decomposed into ammoniacal salts, which would readily dissolve in water containing free carbonic acid and form a solution exceedingly prone to redeposit the phosphate of lime held in solution on any nucleus or in any cavities or shells.

[3] The Maltese Islands, with special reference to their geological structure: Scottish Geog. Mag., vol. 6, pp. 449–488, 1890.

country rock. The phosphate nodules of Malta are aggregated in some beds but in others they form extensive layers of nodules. The great accumulation of phosphatic nodules at certain horizons are attributed by Sir John Murray [1] to disturbances—

either in the neighboring continent, or in the ocean, or both. The emission of gases from submarine volcanoes, or an abnormal outflow of river water from the land frequently kills large numbers of pelagic creatures, and their dead bodies may at such times form a vast layer on the bottom. The phosphate of ammonia thus arising would, in the deposits in process of formation, be decomposed in the presence of carbonate of lime, giving rise to phosphate of lime and alkaline carbonates. The former, being insoluble, would accumulate by pseudomorphism and mechanically in nodular form in the deposits accumulating on the sea floor.

Animal life was abundant while the beds containing the phosphates of Malta were deposited, for many fossils are found in those beds. Among these fossils are numerous sharks' teeth, which, like those associated with the marine-phosphate nodules, have been well preserved by having their softer portions phosphatized. These phosphatized teeth present a striking contrast to the many sharks' teeth dredged from the bottom of the deep sea, where phosphate nodules are rare, for these unphosphatized teeth are represented only by the outer shell of dentine, their more soluble parts having been removed by the corrosive action of the salt water.

The phosphoric acid of the Alum Bluff deposits was doubtless derived from remains of animals that extracted it from the sea water or that fed upon plants having power to obtain phosphoric acid from the same source. These plants may have supplied some phosphate directly to the deposits, though there is an absence of evidence on this point, but the abundant animal fossils show clearly that the animals were very numerous. The most prominent remains of organisms associated with the phosphate nodules are the shells of marine pelecypods and gastropods that inhabited shallow water. Attached to some of the shells are barnacles, and the whole deposit is aggregated in such a way as to indicate wave action. The fossils are so abundant that they are found in small exposures at the bottom of nearly all the phosphate mines in the land-pebble phosphate region.

Sharks' teeth have been observed at many points, but they are much more abundant in the overlying beds, which were derived largely from the Alum Bluff by weathering and erosion. Nearly all the teeth found in the "bedrock" (Alum Bluff formation) are well preserved, showing no trace of corrosion by the water in which they were deposited. Bones of large animals are occasionally found and they also show no evidence of corrosion, though many of them have been broken.

[1] The Maltese Islands, with special reference to their geological structure: Scottish Geog. Mag., vol. 6, p. 481, 1890.

PHOSPHATE OF BONE VALLEY GRAVEL (LAND-PEBBLE PHOSPHATE).

The Bone Valley gravel is apparently of secondary origin, though some phosphatic material may have been added to it during its deposition. The source of the phosphate was the subjacent bedrock, as is shown by the facts that some of the phosphate pebbles are rounded nodules of phosphate derived from the underlying formation, having been merely reworked from the phosphatic layers, and that other pebbles are eroded and rounded fragments of the phosphatized limestone. Many of these fragments still retain the texture of the original limestone, which contains small granules and pebbles of phosphate, and though a few of them are slightly calcareous, many of them have been entirely altered to phosphate.

The uneven surface of the Alum Bluff formation and the marked change from fine clays, containing small phosphate pebbles interbedded with limestones, to the coarser, more sandy conglomerates of the Bone Valley gravel (see Pl. XVI, *A*) indicate a pronounced difference in the conditions under which these two formations were deposited and show that the period in which the Bone Valley gravel was laid down was preceded by a period in which there was considerable weathering and erosion of the older formation. During this interval a large amount of gravel, sand, and clay must have accumulated on the surface as a product of the weathering of the Alum Bluff formation and, with the incursion of the sea, with which the deposition of the Bone Valley gravel began, this material was eroded, roughly assorted, and redeposited in its present position. The proportion of phosphate pebbles in the Alum Bluff formation varies from place to place and different layers of the formation are near the surface at different points. Consequently the richness of the residual material in phosphate nodules and gravel was not uniform. In the process of redeposition the phosphate pebbles may have been at some places concentrated, whereas at other places they were more or less distributed, this difference accounting for the present variations in the thickness and character of the phosphate-bearing part of the Bone Valley gravel.

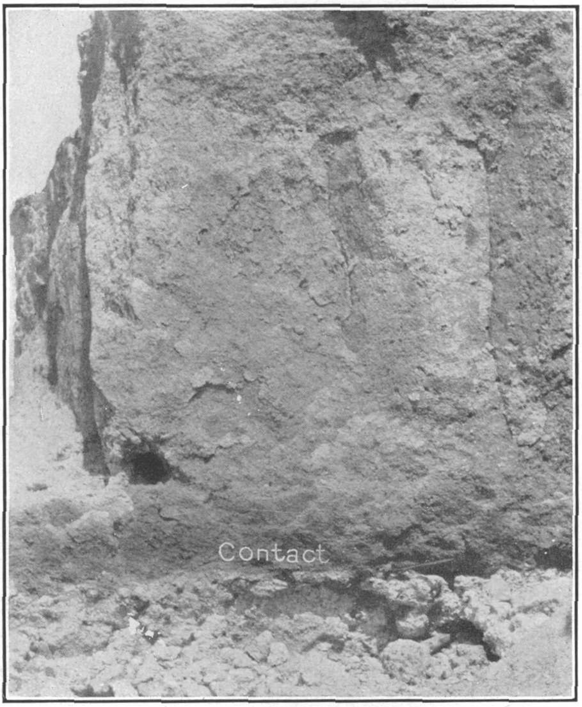
The abundance of animal remains in the phosphate deposits suggests that some of the pebbles may represent original phosphatic nodules of organic origin that were deposited while the Bone Valley gravel was accumulating. Some of the pebbles appear to have been formed by the union of two or more smaller ones, and many of them contain minute phosphatic granules embedded in a matrix of phosphate, but the phosphate nodules of the underlying formation have the same characteristics. Considerable attention was devoted to the pebbles of phosphate, as it was believed that the original granules and small pebbles might be oolitic. None of the thin sections prepared, however, showed any evidence of oolitic texture, but some of them showed variations in density. The texture of the pebbles examined indicated that they were in part the result of phosphatization of the limestone of the Alum Bluff formation and in part the result of accretions of phosphatic material. Partly rounded or angular grains of quartz sand are common in the phosphate pebbles and usually show a tendency to accumulate or segregate, but they appear to show no uniform arrangement, for in one pebble these grains may be aggregated near the center, whereas in another they lie near the surface. Many fragments of bone are found in the Bone Valley gravel and these are, of course, phosphatic, but they form so small a proportion of the whole deposit that they are not commercially important.

The Bone Valley gravel consists of a conglomerate of varying coarseness embedded in a matrix of sand or clay. At some localities the lower part of the phosphate is composed of blue to olive-green clay containing many dark-colored granules and small nodules of phosphate. At some places this clay forms the upper member of the Alum Bluff formation, but at others it has been eroded and redeposited in the lower part of the Bone Valley gravel. Above this fine material lies a varying thickness of the coarse sandy conglomerate that is characteristic of the formation. These two materials show the difference in the conditions of deposition, ranging from sedimentation in quiet water to deposition of coarser beds whose texture varied under the influence of waves and shifting currents. Throughout the region there is frequent alternation of coarse and fine material, and though many layers have considerable horizontal extent, others are of lenticular shape. The general character and arrangement of the gravels and the frequent alternation of coarse and fine material showing gentle undulations, as represented in Plate XVI, *B*, indicates deposition in shallow water, and the presence of fossils of marine animals shows that the material is of marine origin.

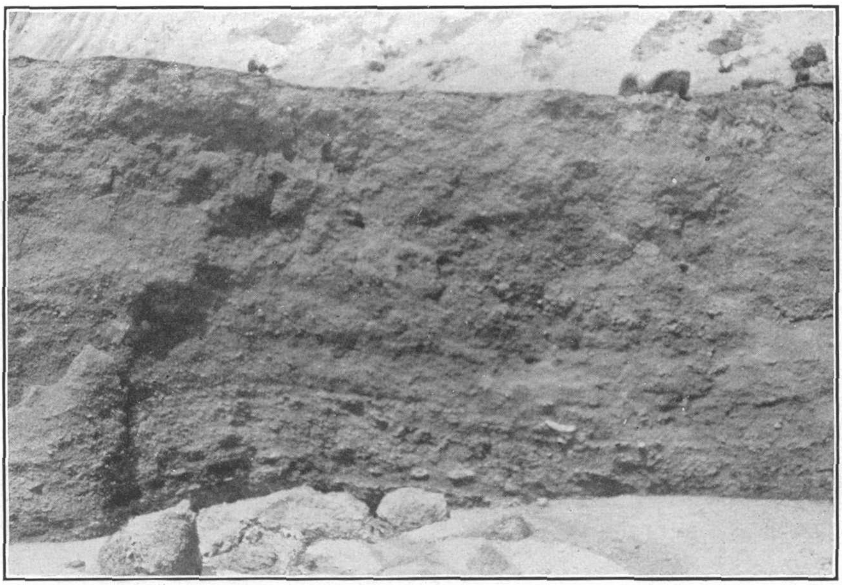
RIVER-PEBBLE PHOSPHATE.

Topographic position.—The situation of the river-pebble phosphate points unmistakably to its fluviatile origin. The deposits lie beneath the flood plains and terraces of streams, where they form bars and irregular beds in the ancient stream channels. There is no question that they have been deposited in their present positions at times of flood, when the swollen streams were able to transport coarse material.

Source of phosphate.—In southern Florida the river-pebble phosphate was largely eroded from the Bone Valley gravel, though some part of it may have been derived from the phosphatic nodules of the



A. CONTACT OF ALUM BLUFF FORMATION ("BEDROCK") AND OVERLYING BONE VALLEY GRAVEL.



B. UNDULATING LAYERS OF PEBBLE PHOSPHATE OF VARYING TEXTURE, CONTAINING FRAGMENTS OF BONES.

Alum Bluff formation ("bedrock"). In northern Florida some of the river pebbles appear to have been nodules similar in structure to those of the Alum Bluff, but in the absence of good specimens from the rivers of southern Florida it can only be surmised that similar pebbles exist there. The existence of such nodules near the northern end of the State is of unusual interest because they indicate the presence in that area of a formation similar to the "bedrock" of the southern end of the peninsula.

According to Sellards,[1] the phosphates on Black Creek and other tributaries entering St. Johns River were derived from a phosphatic bed in the northern part of the peninsula. The exposure described by him is about 3 miles southeast of Brooker, where a phosphate bed underlies a marl containing Miocene fossils. A recent visit to this locality disclosed the fact that the phosphate consisted of a marl containing nodules similar to those found in the Alum Bluff formation ("bedrock") of the pebble-phosphate region. Doubtless the erosion of rock phosphate has resulted in the formation of river-pebble deposits in some localities, but as the rock-phosphate region is largely drained underground this process has not been active in recent geologic time.

ROCK PHOSPHATE.

Organic remains collected from the beds by Sellards [2] were assigned by him to two groups—those derived from the original rock and those incorporated with the phosphates during redeposition. The most common fossils belonging to the original rock are invertebrate remains derived from the beds of the Vicksburg group, with which are associated at many places shark teeth and fragments of bones from the same beds. The fossils incorporated with the redeposited phosphates are in part residual and in part contemporaneous. Sellards gives the following localities:

> Of the fossils that are accepted as contemporaneous with the phosphate formation the best authenticated is a species of mastodon, probably *M. floridanus*. This mastodon has been obtained in the hard-rock phosphate section from the following mines: T. A. Thompson, Neals, Alachua County; Dutton Phosphate Co., plant No. 22, Juliette, Marion County; Cullen River Mine, Dunnellon, and Dunnellon Phosphate Co., plant No. 5, Hernando, Citrus County. That the mastodon is actually embedded in the phosphate-bearing formation is not only vouched for by the miners who have personally taken specimens from the pits but is evident from the specimens themselves, some of which have the gray phosphatic sands of the phosphate formation adhering to them. Associated with the mastodon is found the small three-toed horse Hipparion. The remains of the horse have been obtained only from the picker belt, but notwithstanding the fact that they have gone through the washer some of the teeth still have bits of the phosphate matrix clinging to them. The horse remains

[1] Sellards, E. H., Mineral industries: Florida Geol. Survey Second Ann. Rept., p. 240, 1909.

[2] Sellards, E. H., Origin of the hard-rock phosphate deposits of Florida: Florida Geol. Survey Fifth Ann. Rept., pp. 56–58, 1913.

have been obtained from the following mines: Franklin Phosphate Co. mine No. 2, Newberry, and T. A. Thompson, Neals, both in Alachua County; Dunnellon Phosphate Co., plant No. 6, Dunnellon, Marion County, and Dunnellon Phosphate Co., plant No. 5, Hernando, Citrus County. A number of other fossils have been obtained, which remain to be determined. Among these are teeth of an early camel from Dunnellon Phosphate Co., plant No. 5, Hernando, Citrus County, and Cullen River mine, Dunnellon.

Concerning the vertebrate fossils figured by Sellards, Mr. J. W. Gidley, of the United States National Museum, has furnished the following note:

In answer to your inquiry regarding the mammal remains figured in the Fifth Annual Report of the Florida Geological Survey, I can only say that the horse teeth figured on plate 5 represent two genera and are apparently referable to Leidy's species, the two on the left and the toe bone being *Hipparion plicatile*, the others *Equus fraternus*. The status of neither of these species is well established, they being known only from teeth and isolated bones, hence their value as horizon markers is limited. The Hipparion species indicates a Miocene or possibly a Pliocene age, while the Equus indicates a Pleistocene phase. Yet there is no proof that these species may not have been contemporaneous, the former being a later survival of Hipparion than is recorded in the fossil-bearing deposits of the West, or, possibly but not so likely, the latter may be an earlier representative of Equus than is known in the fossil beds of the West.

Like the horses of the Coastal Plain deposits, the mastodons also are known only from teeth and fragments, representing probably three or four species, and the material, to make it of any great value in determining horizons, should receive much more careful study than has ever been given it.

The suggestion made by Eldridge[1] that the phosphate may have been redeposited when the peninsula was last submerged applies to only a few deposits. The latest submergence occurred during the Pleistocene epoch, and the major part of the deposits of that epoch is sand, but in a few places phosphate was eroded, assorted, and redeposited.

Some fossils collected at the mines along Withlacoochee River were identified by Gidley as Pleistocene, this determination indicating more or less redeposition at that locality since the beginning of the Pleistocene epoch. Doubtless the material in the Pleistocene terraces was more or less reworked during their formation, but it is not easy to determine the amount of redeposition in places where there are no characteristic fossils.

PHOSPHATES OF APALACHICOLA GROUP.

The phosphates occurring in the Alum Bluff formation ("bedrock") are believed to be an original constituent of the formation, and their age, as indicated by the accompanying fossils, is about the same as

[1] Eldridge, G. H., A preliminary sketch of the phosphates of Florida: Am. Inst. Min. Eng. Trans., vol. 21, pp. 217-218, 1892.

that of the Oak Grove sand member of the Alum Bluff formation of Santa Rosa County. This member lies near the top of the Alum Bluff formation, a fact that correlates the phosphates of the Apalachicola group of the southern part of the peninsula with the uppermost part of the Oligocene series. It is not yet possible to decide the relations of some of the Apalachicola phosphates in other parts of Florida to those in the Alum Bluff formation, though at several places there are phosphatic pebbles eroded from the Vicksburg deposits and at other localities there are nodules similar to those found in the Alum Bluff formation.

BONE VALLEY GRAVEL (LAND-PEBBLE PHOSPHATE).

The age of the Bone Valley gravel has been discussed in connection with the geology. (See pp. 21–22.) To sum up, it is clear that these phosphate beds are somewhat younger than the underlying Alum Bluff formation, from which they are separated by a distinct unconformity. The abundant animal remains, except those derived from the underlying formation by erosion and redeposition, are largely vertebrate and are not sufficiently distinctive to differentiate between uppermost Miocene and lowermost Pliocene, though they are probably Miocene. The altitude of the beds accords more nearly with that of the marine Miocene than with the marine Pliocene of the peninsula of Florida, and in the absence of marked deformation this fact is thought to strengthen the evidence of the Miocene age of the phosphate.

RIVER-PEBBLE PHOSPHATE.

The deposits of river-pebble phosphate form parts of extensive accumulations of detritus in the valleys of some of the streams flowing through regions containing other types of phosphate. The erosion of the stream valleys began about the close of the Pliocene epoch and the deposition of the terraces occurred during late Pleistocene time. Those phosphates that underlie the terraces may therefore be correlated with the younger Pleistocene. After the Pleistocene terraces were formed considerable phosphate was deposited in the flood plains and bars along the present streams. These phosphates are Recent and their deposition is still in progress, though the rate of their accumulation is very slow.

COMPOSITION OF THE PHOSPHATES.

COMMERCIAL REQUIREMENTS.

In considering the composition of phosphate for commercial uses only a few substances need to be taken into account. These are insoluble matter (largely sand), iron oxide, alumina, carbonic acid, and phosphoric acid. Of these substances the phosphoric acid only is valuable, the others being more or less deleterious or suggesting the presence of objectionable compounds.

The least objectionable of these substances is the sand or insoluble matter, which is unimportant except that it adds a certain amount of weight, thus diminishing the proportion of valuable material in the phosphate. The carbonic acid is not in itself important, but it may indicate the presence of calcite or other carbonates. In the process of making superphosphates sulphuric acid combines with the bases of these carbonates, so that a larger amount of acid is required to produce superphosphates from a rock that contains carbonates than from one that contains no carbonates. Both the iron and the aluminum oxide are troublesome, because in the process used in making superphosphates they cause some of the phosphates to become insoluble, and if they are present in considerable quantities they greatly retard the drying of the superphosphates.

The contracts made for the purchase or sale of large quantities of phosphate rock prescribe certain standards of purity or enrichment, specifying a minimum percentage of phosphoric acid, usually estimated as tricalcium phosphate (bone phosphate of lime), and a maximum percentage of aluminum and iron, estimated as oxides. Rock phosphate, for example, is sold under a fixed standard or guaranty of at least 77 per cent tricalcium phosphate and not more than 3 per cent of both iron and aluminum oxides. If the rock does not conform to these requirements it must be mixed with material of higher grade until it reaches the standard, otherwise it may be rejected; or, if accepted, its price may be reduced in proportion to the amount the analysis shows the rock to be below the standard agreed upon. No fixed standards have been established for pebble phosphate and presumably each contract for the sale of rock is made in accordance with standards fixed by agreement between buyer and seller.

ROCK PHOSPHATE.

Owing to the variability in the composition of the Florida phosphates composite samples of large quantities of rock give the most reliable information concerning values. The accompanying table gives analyses of rock from different parts of the rock-phosphate region and of plate rock from the area east of Ocala. No. 1, from the Newberry district, shows slightly less tricalcium phosphate than No. 2, from the southern end of the rock-phosphate region; but the conditions might be reversed by other analyses. No analyses have been given of composite samples taken at Dunnellon, but analyses of some composite samples obtained in that vicinity give over 82 per cent tricalcium phosphate and only small quantities of oxides of iron and aluminum. However, the average grade may not be higher than that of the phosphate mined some distance north and south of Dunnellon, a fact illustrated by three analyses given by Jumeau,[1] showing, respectively, 78.90, 78.42, and 81.06 per cent tricalcium phosphate and 3.09, 2.56, and 2.96 per cent oxides of iron and aluminum.

Analyses of phosphates from Florida.

	1	2	3	4	5
Insoluble (SiO_2)	2.03	4.79	3.62	4.78	5.34
Oxide of iron (Fe_2O_3)	.10	1.56	3.01	4.15	2.91
Alumina (Al_2O_3)	2.30				
Calcium oxide (CaO)	51.45	......	......	......	......
Carbonic acid (CO_2)	2.45	......	......	......	......
Phosphoric acid (P_2O_5)	35.52	......	......	......	......
Tricalcium phosphate (bone phosphate of lime) ($Ca_3P_2O_8$)	77.5	78.19	65.98	74.85	75.26

1. From the Newberry district. Analyzed by J. G. Fairchild.
2. From the southern end of the rock-phosphate region.
3. Composite sample from several prospect holes in SW. ¼ SE. ¼ sec. 7, T. 15 S., R. 23 E. Tallahassee meridian.
4. Composite sample from several prospect holes in SE. ¼ SW. ¼ sec. 19, T. 15 S., R. 23 E. Tallahassee meridian.
5. Composite sample from several prospect holes in SW. ¼ SE. ¼ sec. 19, T. 15 S., R. 23 E. Tallahassee meridian.

3, 4, and 5 analyzed by H. Herzog, jr.

The samples taken east of Ocala were obtained from prospect holes. To illustrate the variation in grade samples of borings taken from holes in the NW. ¼ NW. ¼ sec. 30, T. 15 S., R. 23 E., Tallahassee meridian, were analyzed by Mr. W. H. Waggaman, of the United States Bureau of Soils. One sample contained 79.3 per cent tricalcium phosphate; another contained only 75.3 per cent. Still greater differences were noted in samples taken from only one or two prospect holes. Samples 4 and 5 are composites from several prospect holes on the same phosphate deposit on adjoining tracts of land, and though they contain about the same percentages of tricalcium phosphate they show considerable variation in the percentages of oxides of iron and aluminum. Sample 3 was taken from a deposit in which considerable calcium carbonate was mixed with the phosphate. Differences of this sort are found in all parts of the rock-phosphate region, and some are much greater than those shown by these analyses.

A large number of analyses of various types of Florida phosphates have been made. The following analyses, republished from Survey Bulletin 491,[2] show the percentages of a large number of substances found in the rock phosphate and the great difference in the composition of different samples.

[1] Jumeau, L. P., Le phosphate de chaux et les exploitations aux États-Unis en 1905, p. 138, Paris, 1905.
[2] Clarke, F. W., The data of geochemistry: U. S. Geol. Survey Bull. 491, p. 503, 1911.

Analyses of phosphate from Florida.

[Analyses by George Steiger.]

	6	7	8	9
SiO_2	3.44	5.36	10.63	10.51
TiO_2	.13	.26	.86	.58
Al_2O_3	1.49	5.41	12.42	21.17
Fe_2O_3	1.43	2.86	2.90	3.10
CaO	48.81	42.13	30.93	23.95
MgO	.23	.47	.29	.15
K_2O	Trace.	None.	.20	} .40
Na_2O	Trace.	None.	.27	
P_2O_5	35.93	33.37	30.35	25.38
CO_2	2.71	2.15	1.72	2.14
SO_3	.10	.09	.13	.15
F	2.55	2.10	1.95	1.42
H_2O at 105°	.90	1.84	1.27	1.27
Ignition	1.98	4.76	7.69	10.35
	99.70	100.80	101.61	100.57
Less O	1.05	.88	.82	.60
	98.65	99.92	100.79	99.97
Organic C	....	.18	.12	.22

6. From near Sunnyside, Taylor County.
7, 8. From Luraville district, Suwannee County.
9. From Albion district, Levy County.

These analyses have an additional interest because the samples were obtained from localities where mining has been abandoned.

A table given by Eldridge[1] and reprinted below shows the composition of some different types of rock phosphate. As most of the analyses were made from small specimens they may not truly represent the character of the rock of such types.

Chemical analyses of phosphates from Florida.

[Analyses by T. M. Chatard.]

	10	11	12	13
Loss (H_2O) at 105° C	....	0.51	0.20	1.05
Loss (H_2O) at red heat	....	....	1.31	2.42
CO_2	....	2.78	3.15	2.28
F	....	....	1.94	2.40
Insoluble residue (in HCl, HNO_3)	0.10 } 0.17	0.82 } .83	.05	5.73 } 5.85
Insoluble residue (in HNO_3)	.25	.84		5.98
$(Al_2Fe_2)O_3$	2.19, 2.29, 2.32 } 2.27	3.22, 3.39 } 3.30	0.91, .95 } .93	5.13, 5.10, 5.16 } 5.13
Al_2O_3	....	....	....	3.88
Fe_2O_3	....	....	....	.56
CaO	....	....	54.46, 54.42 } 54.44	46.16, 46.12 } 46.14
MgO	....	....	2.00	.21
P_2O_5	36.50	36.62, 36.63 } 36.62	37.70, 37.77 } 37.73	34.04, 33.93 } 33.98

10. Typical gray phosphate.
11. Mottled brown and white phosphate.
12. Mammillary incrustation.
13. A fossiliferous phosphate, containing cavities with sand.

[1] Eldridge, G. H., A preliminary sketch of the phosphates of Florida: Am. Inst. Min. Eng. Trans., vol. 21, p. 225, 1893.

Chemical analyses of phosphates from Florida—Continued.

	14	15	16	17	18
Loss (H_2O) at 105° C				0.17	
Loss (H_2O) at red heat					
CO_2				1.62	
Insoluble residue (in HCl, HNO_3) / Insoluble residue (in HNO_3)	{0.08, .08} 0.08	{0.05, .06} 0.05	0.21	{0.26, .26} .26	{0.05, .06} 0.06
$(Al_2Fe_2)O_3$	{1.39, 1.38, 1.35} 1.37	{1.22, 1.25, 1.25} 1.24	{4.12, 4.85} 4.48	{2.25, 2.31, 2.41} 2.32	{.32, .35, .32} .34
Al_2O_3				1.47	
Fe_2O_3				1.13	
CaO			{52.01, 52.02} 52.02		
MgO			.28		
P_2O_5	{38.40, 38.38} 38.39	{37.75, 37.78} 37.76	{38.78, 38.79} 38.79	{38.81, 38.83} 38.82	{39.66, 39.62} 39.64

14. White, coarsely laminated phosphate, with clay in cavities.
15. Gray variety of No. 80, typical.
16. Typical laminated phosphate from same locality as 98.
17. A granular-looking phosphate, light gray.
18. The coarser portion of 100, after separation on a 20-mesh sieve.

In exploiting a deposit of phosphate composed of fragments of different sizes, the composition of material of the several grades of fineness is an important guide to the miner in determining how the material shall be separated. Several years ago studies were begun by Dr. Chatard[1] to determine the quality of particles of various sizes. Of a sample of rock phosphate from Florida, screened dry (A in table), 64.62 per cent was left on a 20-mesh sieve. The remaining 35.38 per cent (B) of the sample was assorted by water in a Thoulet tube into four grades: B_1 (coarsest), 12.06 per cent of original material; B_2 (middle), 5.31 per cent; B_3 (finest), 16.31 per cent; lost by remaining in suspension, 1.70 per cent. Dr. Chatard's[2] analyses of the materials obtained by this method are given in the following table:

Analyses of particles of phosphates of different sizes (No. 19).

	Total sample.	A.	B.	B_1.	B_2.	B_3.
Insoluble	5.85	0.53	8.56	0.51	6.26	14.53
$(Al_2Fe_2)O_3$	5.13	3.36	6.32	2.41	3.54	7.79
P_2O_5	33.98	37.83	32.60	37.44	34.69	29.98
$Ca_3P_2O_8$	74.20	82.38	71.18	81.70	75.75	65.63

From these analyses Dr. Chatard concluded that 82 per cent of the original sample comprised in portions A, B_1, and B_2 contained the high-grade rock, and that the finest material, B_3, contained too much ferric oxide and alumina to be marketable.

[1] Chatard, T. M., Phosphate chemistry as it concerns the miner: Am. Inst. Min. Eng. Trans., vol. 21, 1892–93, pp. 160–175.

[2] Op. cit., p. 164

Dr. Chatard made similar experiments with a phosphatic sand rock from the Itchetucknee region in Florida. The results, shown in the table below, gave (A) 20.74 per cent of sample on a 20-mesh sieve. The use of the Thoulet tube on the remaining 79.26 per cent (B) of the sample gave B_1 37.83 per cent, B_2 20.87 per cent, B_3 17.75 per cent, and loss 2.81 per cent. The analyses of the materials of different grades given in the accompanying table[1] show that this method of separation does not give satisfactory results where there is an intimate mixture of phosphate and clay.

Analyses of phosphate and rock from Florida (No. 20).

	Total sample.	A.	B.	B_1.	B_2.	B_3.
Insoluble	34.77	18.13	44.19	62.55	38.11	10.50
$(Al_2Fe_2)O_3$	7.09	6.53	7.70	2.96	7.97	15.57
P_2O_5	24.08	30.49	20.36	13.75	25.02	31.90
$Ca_3P_2O_8$	52.49	65.46	43.38	29.97	54.54	69.54

Unfortunately Dr. Chatard's work was interrupted and he had no opportunity to carry it to completion, but the results he obtained indicated the practical value of his study.

A similar investigation was made by Waggaman,[2] who, however, used samples that had been burned. His results are given below. He says:

In some sections of the hard-rock region, where considerable phosphate of alumina occurs, the rock is screened after burning. It is claimed that this screening reduces the percentage of iron and alumina and raises the grade of the rock. In order to see if this would hold true under ordinary conditions where the deposit contained no abnormal amount of aluminum phosphate, the author collected samples both of medium-sized and of small fragments (not larger than a pea) from the same pile of burned rock and analyzed them. The results are given in the table below.

Chemical analyses of samples of large and small pieces of hard-rock phosphate after burning.

Sample.	Location.	Description.	Analyses.				
			SiO_2.	Fe_2O_3.	Al_2O_3.	P_2O_5.	$Ca_3(PO_4)_2$.
21	Dunnellon	Nodular, hard, fairly large lumps	1.70	0.33	1.16	37.1	81.25
22	...do	Small fragments	4.37	.33	1.36	35.8	78.40

It will be seen from inspection of this table that both the silica and the iron and alumina are higher in the sample of small fragments than in that composed of larger pieces. The difference in the quality of the two samples is not only due to the disintegration of the aluminum phosphate but also to the fact that the larger pieces are sorted and many impure pieces thus eliminated.

[1] Chatard, T. M., op. cit.

[2] Waggaman, W. H., A review of the phosphate fields of Florida: U. S. Dept. Agr. Bur. Soils Bull. 76, p. 12, 1911.

Mr. Waggaman also made analyses of two types of rock to determine the effect of burning, and his results are given below.[1]

Chemical analyses of samples of hard-rock phosphate before and after burning.

[All the samples were dried in the laboratory at 100° C. for at least four hours.]

Sample number.	Description.	Analysis.	
		P_2O_5.	$Ca_3(PO_4)_2$.
23	Blue rock, hard, not burned	37.5	82.12
23A	Blue rock, hard, burned	37.5	82.12
24	White rock, hard, not burned	37.1	81.25
24A	White rock, hard, burned	38.5	84.32

WASTE FROM ROCK PHOSPHATE.

In the discussion of the methods of mining (pp. 89–98) mention is made of the material lost in preparing the phosphate for market. This waste is variable in composition and not many analyses of it were made, so that it is impossible to determine accurately how much phosphoric acid is being thrown away. Most of the valuable material lost is soft phosphate of lime, though doubtless some phosphate of aluminum and iron is mixed with this phosphate.

Concerning soft phosphate Jumeau[2] says that its content of tricalcium phosphate ranges from 50 to 60 per cent, and that some pockets contain material yielding 65 per cent. Its content of iron and aluminum oxides, according to this author, range from 5 to 10 per cent and may rise above 15 per cent or fall below 3 per cent.

The following analysis given by Eldridge[3] shows the composition of a sample of soft-clay phosphate.

Chemical analysis of typical soft-clay phosphate from Florida (No. 25).

[Analysis by T. M. Chatard.]

Loss (H_2O) at 105° C	.....	0.46
Loss (H_2O) at red heat	.....	4.76
CO_2	.....	2.33
F	2.55 2.59 2.59	2.58
Insoluble residuum (in HCl, HNO_3)	.....	.....
Insoluble residuum (in HNO_3)	.....	4.25
$(Al_2Fe_2)O_3$	7.93 7.78	7.85
Al_2O_3	.....	7.01
Fe_2O_3	.....	1.46
CaO	44.05 44.04	44.05
MgO	.....	.....
P_2O_5	35.28 35.11	35.19

[1] Waggaman, W. H., A review of the phosphate fields of Florida: U. S. Dept. Agr. Bur. Soils Bull. 76, p. 12, 1911.

[2] Jumeau, L. P., Le phosphate de chaux et les exploitations aux États-Unis en 1905, p. 147, Paris, 1905.

[3] Eldridge, G. H., A preliminary sketch of the phosphates of Florida: Am. Inst. Min. Eng. Trans., vol. 21, p. 229, 1893.

Waggaman[1] estimates the amount of phosphoric acid lost in mining at twice the quantity saved. There is no question that some of this material might be utilized advantageously on soils devoted to general farming, and if a cheaper method of producing acid phosphate could be devised it might be possible to use much of this low-grade material. Analyses of waste materials are given by Waggaman, who says:

Samples taken from various parts of the waste pile differ greatly in composition, as considerable mechanical separation takes place when the stream of water carrying this detritus is discharged upon the waste heap, because the clay and soft phosphates being held in suspension longest are carried some distance, while the sand and heavier particles are deposited more rapidly.

In order to get a better idea of its actual composition the author carefully washed some of the phosphatic detritus as it was brought from a prospect hole. The wash water and all material finer than 1 millimeter were saved, and after evaporating the water the sample was thoroughly dried and mixed. The analyses of this material, together with some made by other chemists, are given below.

Chemical analyses of material washed away in preparing hard rock for the market.

Sample No.	Location.	Analyst.	Analysis.				
			SiO_2.	Al_2O_3.	Fe_2O_3.	P_2O_5.	$Ca_3(PO_4)_2$.
26	SW. ¼ sec. 30, T. 15, R. 23 E.	W. H. Waggaman	38.40	19.17	2.95	18.00	39.42
27	Anthony	P. Jumeau	58.95	11.70		12.70	28.21
28	do	do	60.10	11.20		12.20	26.72
29	Newberry, 5 miles southeast of Dunnellon.	In office of Florida State chemist.				9.99	21.78
						12.14	26.59

In the process of sorting rock phosphate on the "picking belt" considerable phosphatic material is rejected by inexperienced workmen and some is removed by skilled laborers, because it is not always possible to distinguish the good material from the poor. The following analysis of refuse from the picking belt was made by Waggaman:[2]

Chemical analysis of a sample of material thrown from picking table.

Sample No.	Location.	Description.	Analysis.				
			SiO_2.	Al_2O_3.	Fe_2O_3.	P_2O_5.	$Ca_3(PO_4)_2$.
30	Dunnellon	Clay balls, limestone, etc	68.02	3.80	0.48	11.6	25.40

PHOSPHATES OF THE ALUM BLUFF FORMATION.

Few samples of phosphate from the Alum Bluff formation have been analyzed, though phosphatic nodules are abundant in some layers in both northern and southern Florida, being found at many

[1] Waggaman, W. H., A review of the phosphate fields of Florida: U. S. Dept. Agr. Bur. Soils Bull. 76, p. 14, 1911.

[2] Idem, p. 15.

places in the "bedrock" of the pebble-phosphate region, on Sopchoppy River near Sopchoppy, and at other widely scattered localities. The following analyses [1] by A. B. Howe are of samples of Alum Bluff rock from a quarry formerly operated near Hawthorn:

Analysis of first sample (No. 31).

	I.	II.	Mean.
SiO_2	46.70	46.83	46.765
Al_2O_3	19.53	19.61	19.57
Fe_2O_3	1.79	1.64	1.715
CaO	2.91	2.75	2.83
MgO	.16	.27	.215
P_2O_5	16.12	16.02	16.07
H_2O	14.28	(14.28)	14.28
	101.49	101.40	101.445

The second specimen was like the first, porous and slightly yellowish in color, but it was softer, a circumstance due to the fact that it had been lately quarried. Its composition was as follows:

Analysis of second sample (No. 32).

	I.	II.	Mean.
SiO_2	50.70	50.76	50.73
Al_2O_3	12.84	12.86	12.85
Fe_2O_3	1.81	1.85	1.83
CaO	12.07	11.96	12.015
MgO	.36	.33	.345
Na_2O	.32	.32	.32
K_2O	.33	.33	.33
P_2O_5	12.97	13.12	13.045
H_2O	8.39	8.39	8.39
CO_2	.86	.86	.86

In order to determine the composition of the "bedrock" analyses of samples were made in the laboratory of the United States Geological Survey. The results are given below, and they show some interesting peculiarities:

Sample No. 33 was obtained from a mine near Mulberry. This rock is a light-yellow limestone or dolomite containing many brown nodules of phosphate. Mr. J. G. Fairchild, who made the analyses, removed the phosphate nodules from the matrix and analyzed each separately. Because of the intimate mixture of the two portions of the rock complete separation was not possible, but the results indicate the general composition of the two constituents.

The matrix (No 33A) contained a little phosphate, probably in the form of minute granules, and the high percentage of magnesia present shows that the rock has very nearly the composition of a dolomite. The percentage of phosphate in the nodules (No. 33B) is relatively high, and magnesia is present in small quantities. These nodules have the same general characteristics as the ones described in the discussion

[1] U. S. Nat. Mus. Proc., vol. 5, pp. 47, 48, 1882.

of the phosphates of the Alum Bluff formation ("bedrock"), (pp. 33–35), and are doubtless nodules of marine origin. The presence of the magnesia in the phosphate nodules indicates that dolomitization was in progress during the process of the deposition of the phosphate and was marine. The presence of a much higher percentage of material insoluble in nitric acid in the matrix than in the phosphate nodules probably indicates that phosphatization was influenced by the composition of the rock, nodules forming where the limestone was relatively pure, though the sample had been subjected to the action of surface water and the matrix had doubtless been leached of a part of its soluble calcium carbonate, thus increasing the proportion of relatively insoluble material, such as sand and magnesium carbonate, while the phosphate suffered little loss because it was much less soluble than the calcium carbonate.

Sample No. 34, a pebble phosphate from the central part of the region, is classed with limestone of the Alum Bluff formation, though the matrix is sandy. This sample contains less phosphate than No. 1B and more magnesia and other relatively insoluble matter.

Sample No. 35 is a phosphatized portion of the "bedrock" at Christina, in which considerable insoluble material represents the large percentage of impurities in the original limestone. In this sample phosphatization has been nearly complete and there is very little magnesia, but the limestone at this locality may contain less than that farther south. In any event there is no reason to suppose that the replacement of carbonic acid by phosphoric acid would be accompanied by the removal of magnesia. The alteration of this rock had resulted in considerable increase in its contents of phosphoric acid but the change had not been complete, as is shown by the presence of some carbonic acid.

Analyses of Florida phosphate.

[Analyses by J. G. Fairchild, United States Geological Survey.]

	33		34	35
	A	B		
Insoluble in HNO_3	14.26	3.51	13.21	14.45
SiO (acid soluble)	....	....	.32	.10
$(Al_2Fe_2)O_3$	1.32	3.79	6.33	8.08
CaO	26.38	45.07	29.98	38.73
MgO	....	....	11.62	.24
P_2O_5	1.70	24.60	9.05	30.58
CO_2	36.18	7.94	26.20	1.96
MnO	....	....	.05	.08
	79.84	84.91	96.76	94.22
$CaCO_3$ (calculated)	43.32	22.25	....	....
$Ca_3P_2O_8$ (calculated)	3.74	60.17	....	....
$MgCO_3$ (calculated)	32.87	[a] 4.	....	....

[a] Probably.

33. Bedrock from Prairie Pebble Phosphate Co.'s mine near Mulberry: A, matrix; B, nodules.
34. Pebble phosphate from Alum Bluff formation.
35. Phosphatic limestone from Alum Bluff formation at Christina.

On page 81 there is given a partial analysis of a sample of the "bedrock," taken at a locality a mile north of Bartow, which contained 75 per cent of calcium carbonate and only 5 per cent of tricalcium phosphate. Thus the rock at that place is comparatively poor in phosphoric acid. It is remarkable, moreover, for its small contents (0.5 per cent) of iron oxide and alumina.

LAND-PEBBLE PHOSPHATE.

Though few analyses are available for publication enough information has been gathered to indicate that the average content of tricalcium phosphate in land-pebble phosphate ranges from about 65 to 75 per cent. The better grades of phosphate near the north end of the region may contain over 77 per cent tricalcium phosphate, for some analyses show a content of over 80 per cent. The average percentage of tricalcium phosphate declines toward the south, but there are so many local variations that this generalization will not apply to all places.

The accompanying analyses were made from composite samples of material taken from several prospect holes distributed with some degree of uniformity over 40-acre tracts of land. The tracts lie within a few miles of the north end of the region, and it is worthy of note that these two samples, which contained, respectively, 74.85 and 75.26 per cent of tricalcium phosphate and only 4.15 per cent and 2.91 per cent of aluminum and iron oxides, compare favorably with some of the lower grades of rock phosphate.

Analyses of samples of phosphate taken from prospect holes at north end of phosphate region of Florida.

[Dried at 212° Apr. 12, 1911, F. H. Herzog, jr., analyst.]

	36	37
Sand (SiO_2)	4.78	5.34
Iron oxide (Fe_2O_3) / Aluminum oxide (Al_2O_3)	4.15	2.91
Tricalcium phosphate (bone phosphate of lime) ($Ca_3P_2O_8$)	74.85	75.26

36. From the SE. ¼ SW. ¼ sec. 19, T. 15 S., R. 23 E. Tallahassee Meridian.
37. From the SW. ¼ SE. ¼ sec. 19, T. 15 S., R. 23 E. Tallahassee Meridian.

The samples represented by the following analyses were taken from mines in the central part of the pebble-phosphate region, 38 being from the vicinity of Bartow. The exact locality at which the other sample was taken is somewhat uncertain.

Chemical analyses of washed pebble phosphates from Florida.[a]

[Analyses by T. M. Chatard.]

	38	39
Loss (H_2O) at 105° C	0.63	0.79
Loss (H_2O) at red heat	3.15	3.47
CO_2	2.19	3.93
F	{2.73, 2.72} 2.72	{1.87, 1.86} 1.86
Insoluble residuum (in HCl, HNO_3)	4.34	....
Insoluble residuum (in HNO_3)		6.69
Al_2O_3	2.53	2.14
Fe_2O_3	1.35	.61
CaO	{47.96, 47.94} 47.95	{46.06, 46.00} 46.03
MgO	{.19, .22} .21	{.32, .34} .33
P_2O_5	{34.77, 34.67} 34.72	{31.49, 31.51} 31.50

[a] Eldridge, G. H., A preliminary sketch of the phosphates of Florida: Am. Inst. Min. Eng. Trans., vol. 21, pp. 230-231, 1893.

Chatard [1] examined some samples of pebble phosphate taken from a mine near Bartow to determine the best method of treating the product. A sample disintegrated in water was washed on a 20-mesh sieve, which retained 54.54 per cent of the original sample in the form of pebbles, the matrix, which had passed through the sieve, comprising the remaining 45.46 per cent. The analysis given below indicates that although a large percentage of the best material is held on a sieve of 20 meshes to the inch, some phosphate passes through. This loss might be avoided by using a sieve with smaller openings, but the grade of the material held by a finer screen would probably be lowered.

Analyses of pebble phosphate from a mine near Bartow.

	No. 40, pebble.	No. 41, matrix.
Insoluble	4.34	49.78
$(Al_2Fe_2)O_3$	4.05	9.38
P_2O_5	34.72	13.58
$Ca_3P_2O_8$	75.69	29.60

In order to determine the relative values of pebbles of different colors, Waggaman [2] made the analyses given below. He says:

In the table below are given the analyses of three different-colored samples. It will be noted that the black pebbles and white pebbles are richer in phosphoric acid than the brown or yellow. This same appears to be true in the hard-rock regions.

[1] Chatard, T. M., Am. Inst. Min. Eng. Trans., vol. 21, pp. 164-165, 1893.

[2] Waggaman, W. H., A review of the phosphate fields of Florida: U. S. Dept. Agr. Bur. Soils Bull. 76, p. 19, 1911.

Chemical analyses of samples of different-colored pebble phosphate from Mulberry, Fla.

Sample.	Location.	Description.	Analyses.				
			SiO_2.	Al_2O_3.	Fe_2O_3.	P_2O_5.	$Ca_3(PO_4)_2$.
42	Mulberry.....	Small black pebbles................	4.66	0.34	0.96	35.40	77.53
43	.....do........	Small white pebbles................	4.16	.60	.80	34.60	75.77
44	.....do........	Small brown pebbles...............	3.81	.84	2.24	31.30	68.55

The generalization made by Waggaman is doubtless subject to some exceptions, for the best rock varies in color at different places.

Differences in the grade of the phosphate in different layers have been noted in many of the mines. In some mines, in a vertical thickness of 10 or 12 feet, there may be variations of 4 or 5 per cent in the amount of tricalcium phosphate in the coarse and the fine material or in the light, porous pebbles and the hard, dense pebbles. The size of the material does not appear to indicate its grade, for in one mine the coarse material, in another the fine material, and in still another the medium-sized pebbles may be the high-grade rock. In addition to abrupt variations in the quality of the rock in a single vertical section, there are horizontal differences, which are so marked that within a distance of 50 feet the content of tricalcium phosphate may vary 4 or 5 per cent, and extreme variations of nearly 30 per cent have been noted.

A detailed section, supplied to Eldridge by Dr. Chazal, is given below:

Section 1 mile north of Bartow.

	Feet.
Surface soil and sand..	2
Phosphate gravel containing a few pebbles of sand, the whole embedded in a matrix of ferruginous sand. The phosphate pebbles are nearly all white, but are coated with a brown stain. These pebbles comprise 33 per cent of the whole bed and contain 70 per cent tricalcium phosphate and 5 per cent oxides of iron and aluminum..	1–2
Clay containing some layers of sand near the top; phosphate pebbles 33 per cent of the whole, containing 64 to 72 per cent tricalcium phosphate and 4.5 to 6 per cent of oxides of iron and aluminum. The clay in this layer gave considerable trouble in washing because of its tendency to form balls..............................	6
Clay containing 10 per cent of phosphate pebbles, which showed on analysis 72 per cent tricalcium phosphate and 4.5 per cent oxides of iron and aluminum....................................	6
"Bone bed" containing 30 per cent phosphate pebbles, which on analysis showed 72 per cent tricalcium phosphate and 4.5 per cent oxides of iron and aluminum	3
"Bedrock," consisting of hard marl and limestone, which on analysis showed 75 per cent calcium carbonate, 5 per cent tricalcium phosphate, and 0.5 per cent oxides of iron and aluminum.	

WASTE FROM LAND-PEBBLE PHOSPHATE.

The amount of phosphoric acid lost in preparing the land-pebble phosphate for market has not been determined, but it probably does not exceed one-half the quantity mined. Few analyses are available to show the composition of the matrix that is rejected in mining. The analysis already quoted (p. 80) shows the composition of material passing a 20-mesh sieve, but a somewhat coarser screen is employed in mining. The following analysis given by Eldridge [1] is probably open to the objection that it may not be representative of this type of material because the sample was small. However, if instead of taking the matrix from a single small sample the chemist had been furnished a composite sample from many tons of such material, the average composition at the locality at which the sample was taken might have been determined.

Chemical analyses of matrix of land-pebble phosphate (No. 45).

[Analysis by T. M. Chatard.]

Loss (H_2O) at 105° C		3.34
Loss (H_2O) at red heat		6.88
CO_2		.82
F		.88
Insoluble residuum (in HCl, HNO_3)		0.00
Insoluble residuum (in HNO_3)		49.78
Al_2O_3		6.85
Fe_2O_3		1.05
CaO	15.95 15.89	15.92
MgO	0.37 .37	.37
P_2O_5	13.55 13.61	13.58

In washing pebble phosphate a large number of clay balls are screened out and carried to the waste heap. The clay that makes up the bulk of these balls contains some pebbles of phosphate, most of which are similar to the pebbles saved in mining. In addition to the phosphate lost in balls removed by screening some material is lost from "picking belts" at a few mines. The composition of these two types of waste, as determined by Waggaman,[2] is given in the table below.

An analysis was made of the material having a diameter greater than 2½ inches discarded before the material containing the phosphate goes through the washing process. The composition of a sample thrown from the picking table at one of the plants was also determined. These analyses are given in the following table:

[1] Eldridge, G. H., A preliminary sketch of the phosphates of Florida: Am. Inst. Min. Eng. Trans., vol. 21, p. 231, 1893.

[2] Waggaman, W. H., A review of the phosphate fields of Florida: U. S. Dept. Agr. Bur. Soils Bull. 76; p. 22, 1911.

Chemical analyses of waste or discarded material at phosphate mines in Florida.

Sample No.	Description.	Analyses.				
		SiO_2.	Al_2O_3.	Fe_2O_3.	P_2O_5.	$Ca_3(PO_4)_2$.
46	Clay balls, 2½ inches in diameter, containing phosphate pebbles from discard	44.10	5.24	1.78	17.6	38.54
47	Material from picking table	50.58	5.18	12.96	7.2	17.68

PHOSPHATIC MARL.

The phosphatic marl in the overburden of the pebble-phosphate region is relatively unimportant commercially, being mined at Fort Meade only, and there in a primitive fashion. The product of this mine is said to be high-grade phosphate rock, but no analyses are available for publication. A sample from the overburden of one of the pebble-phosphate mines near Fort Meade was submitted to Mr. Fairchild and the result of his analysis is given below. The marl contained a large amount of fine sand, the presence of which accounts, in part, for the high percentage of material insoluble in nitric acid (HNO_3). There was also a relatively high percentage of iron oxide (Fe_2O_3) and alumina and iron (Al_2O_3), and this fact, together with the small percentages of lime (CaO) and magnesia (MgO), suggests that the phosphoric acid was probably combined with the iron and alumina.

Analysis of phosphatic marl (No. 48).

[Analyzed in the laboratory of the U. S. Geological Survey by J. G. Fairchild.]

Insoluble in HNO_3	70.74
SiO_2 (acid soluble)	.10
$(Al_2Fe_2)O_3$	11.84
CaO	.78
MgO	.11
P_2O_5	10.05
CO_2	.09
MnO	Trace.
	93.71

RIVER-PEBBLE PHOSPHATE.

River-pebble phosphate is not now mined, and there is no indication that its exploitation will be renewed, but it was the first rock marketed from Florida, and for a number of years its recovery was a profitable industry. The quality of the phosphate was lower than that obtained from the land-pebble and rock-phosphate mines, the proportion of phosphoric acid usually falling below 30 per cent, which is equivalent to about 65.5 per cent tricalcium phosphate. The general range in composition for this type of rock was from 55 to 65 per cent tricalcium phosphate, though in some places the rock averaged less than 55 per cent and a few analyses gave results somewhat higher than 65 per cent. The following analyses of this type of rock are given by Eldridge:[1]

Chemical analyses of river-pebble phosphates from Florida.

[Analyses by T. M. Chatard.]

	Numbers of samples.		
	49	50	51
Loss (H_2O) at 105° C	0.56	0.77	0.96
Loss (H_2O) at red heat	4.90	4.88	7.90
CO_2	3.90	6.37	.40
F	{2.48, 2.41} 2.44	{2.45, 2.54} 2.49	3.17
Insoluble residuum (in HCl, HNO_3)	....	....	....
Insoluble residuum (in HNO_3)	12.23	6.02	10.19
Al_2O_3	2.01	1.37	1.60
Fe_2O_3	1.05	.83	.78
CaO	{42.74, 42.75} 42.75	{45.68, 45.69} 45.69	{33.10, 33.03} 33.06
MgO	{.49, .40} .44	{.79, .77} .78	{.62, .68} .65
P_2O_5	{28.33, 28.38} 28.36	{28.49, 28.45} 28.47	{21.05, 21.06} 21.06

49. Peace River; dried pebble, from a bin.
50. Caloosahatchee River; picked pebbles from a lighter load.
51. Black Creek; air-dried pebble.

MINERALOGY.

The phosphate deposits of Florida consist of more or less earthy phosphorites whose physical characteristics vary, depending roughly on the proportion of their content of calcium phosphate to their impurities. They contain one or more phosphates of calcium intimately intermingled with other substances of both organic and inorganic origin. The organic substances are distinct fragments of skeletons of animals or diffused pigments that impart a more or less definite color to the inorganic materials.

Some deposits contain a very small proportion of the phosphates, consisting in large part of other minerals, which are classed as impurities. Chemical analyses show that the most common impurities are the oxides of aluminum and iron, which occur in different forms, the most prominent aluminum-bearing mineral being the hydrosilicate kaolinite. The large proportion of phosphoric acid shown by many of the analyses suggests that some of the alumina may be combined to form aluminum phosphates, either with or without iron.

Limonite is the most common iron-bearing mineral, though in the pebble-phosphate region glauconite is a constituent of the "bedrock" (Alum Bluff formation). In many of the deposits the iron probably occurs in the form of ferrous silicate at depths where oxidation

[1] Eldridge, G. H., A preliminary sketch of the phosphates of Florida: Am. Inst. Min. Eng. Trans., vol. 21, p. 231, 1893.

has not been very effective. The limonite is usually disseminated through the other materials in such a way as to give them a slight yellow or orange color, but in the overburden of some of the pebble-phosphate mines it is concentrated in the form of nodules that include more or less sand.

Vivianite ($Fe_3P_2O_8.8H_2O$) has been noted at some places, but it is probably rare, for its blue color would cause it to be recognized at once where it occurred in considerable quantity.

Silica is a very common constituent, occurring in coarse fragments that appear to have been more or less rounded by mechanical wear. In some parts of the phosphorites the silica is evenly distributed; in others it is aggregated.

Magnesium oxide, which is given in a large number of analyses of phosphate, probably occurs most commonly as magnesite, but in a few phosphorites the large proportion of phosphoric acid and the small proportion of carbonic acid suggest that the magnesia is combined with the phosphoric acid to form magnesian phosphate.

The percentages of other substances determined in analyses of phosphate are so small that they are of little consequence. In the most complete analyses small quantities of sodium and potassium are reported, and probably these elements occur either as carbonates or sulphates.

The minerals seen in thin sections of phosphorites are either isotropic or doubly refracting. The minerals that show double refraction occur as mammillary incrustations on the surface of the isotropic material or as veins that more or less completely fill crevices. More rarely stalactites and stalagmites are found in cavities in the phosphorite. The incrustations are white, brown, yellow, or greenish, have a resinous or vitreous luster, and appear either opaque or only slightly translucent when seen with the naked eye, but in thin sections they appear transparent and colorless or white. Their hardness is somewhat variable, though the purest materials are about as hard as apatite, being approximately 5 by the Mohs scale. The crystalline fragments decrepitate when heated and form a white powder when pulverized. The index of refraction is about 1.6; the double refraction of some of the minerals is low and that of others is high. Many sections contain alternate bands that show different birefringence, one band being low and the next about twice as strong. The crystals are in the form of microscopic fibers arranged in radiating groups or with their longest dimensions at about right angles to the surface of the incrustations. The basal sections of some of the fibers show an interference figure that indicates a mineral which is uniaxial and negative. Other basal sections appear to contain another mineral, which is optically positive.

In his discussion of the French phosphorites Lacroix[1] describes two doubly refracting minerals having about the same optical characters as some of those found in the Florida phosphates. These are called dahllite and francolite, which may be distinguished by the presence of fluorine in francolite and its absence in dahllite. Lacroix restricts the name staffelite to the fibrous variety of francolite. The presence of a third mineral, of unknown composition, was detected by the fact that it had a higher birefringence than dahllite and francolite and was optically positive instead of negative.

Florida phosphate contains a uniaxial mineral of low double refraction corresponding in this and other optical properties to francolite, and the presence of fluorine in the phosphate, as shown by the complete analyses, indicates that this mineral is francolite or its fibrous representative which Lacroix calls staffelite. The unknown mineral described by Lacroix may be represented by the crystals having a higher birefringence than francolite and a positive optical character.

The isotropic phosphorite of the French deposits has been called collophanite and the variety containing fluorine has been called fluocollophanite. Mixtures of the isotropic collophanite with crystalline minerals Lacroix[2] named quercyite, mixtures containing an optically negative mineral he called α-quercyite, and mixtures containing the unknown, optically positive mineral he called β-quercyite.

The molecular ratios of the minerals in a few Florida phosphates have been calculated, CaO being taken as 100, as shown in the table on page 85. The numbers of the analyses are the same as those used in the tables on pages 71–81. In making the calculations the silica (SiO_2) has been omitted from analyses in which it was impossible to determine whether the combined silica was included with the uncombined. The water (H_2O) driven off below 105° C. was assumed to be hygroscopic, though in the absence of definite information concerning some of the analyses it is not certain that some of the combined water in the phosphate minerals may not have been driven off at a lower temperature. It should also be remembered that theoretical combinations based on the analysis of impure material are more or less unreliable. For comparison there has been added to the table the average ratios obtained by calculating the analyses of the materials described by Lacroix.[3]

[1] Lacroix, A., Sur la constitution minéralogique des phosphorites françaises: Compt. Rend., vol. 150, p. 1213, 1910; Minéralogie de la France, vol. 4, pt. 2, p. 535, 1910.

[2] Op. cit.

[3] Schaller, W. T., Mineralogical notes, series 2: U. S. Geol. Survey Bull. 509, pp. 98–100, 1912.

Ratios computed from analyses of phosphates from Florida.

No.	Page of this bulletin.	CaO.	P_2O_5.	CO_2.	F.	H_2O.	Al_2O_3.	Fe_2O_3.	MgO.	SiO_2.	K_2O.	Na_2O.	TiO_2.	SO_3.
1....	71	100	27	6	....	......	2	(a)	......	4	......	......	......	......
6....	72	100	29	7	15	13	2	1	(a)	7	(a)	(a)	(a)	(a)
7....	72	100	31	6	14	32	7	2	(a)	12	(a)	(a)	(a)	(a)
8....	72	100	39	7	19	89	22	3	(a)	32	(a)	(a)	(a)	(a)
9....	72	100	41	12	17	135	48	4	(a)	41	(a)	(a)	(a)	(a)
12....	72	100	27	7	10	7	(a)	(a)	5	(a)	......	......	......	......
13....	72	100	29	5	15	16	5	(a)	(a)	(a)	......	......	......	......
25....	75	100	31	7	17	34	9	1	......	(a)	......	......	......	......
31....	77	100	222	......	....	1,555	376	22	1	1,527	......	......	......	......
32....	77	100	43	9	....	218	59	5	3	395	(a)	(a)	......	......
33A..	79	100	3	174	....	......	(a)	(a)	......	(a)	......	......	......	......
33B..	79	100	22	23	....	......	(a)	(a)	......	(a)	......	......	......	......
34....	79	100	12	111	....	......	(a)	(a)	54	(a)	......	......	......	......
35....	79	100	31	7	....	......	(a)	(a)	1	(a)	......	......	......	......
38....	80	100	28	56	16	23	29	9	......	......	......	......	......	......
39....	80	100	27	11	12	25	3	......	......	......	......	......	......	......
45....	82	100	34	7	16	134	24	2	......	......	......	......	......	......
49....	84	100	26	12	16	35	3	......	......	......	......	......	......	......
50....	84	100	25	18	16	33	1	......	......	......	......	......	......	......
51....	84	100	25	2	28	74	2	......	......	......	......	......	......	......
Dahllite[b].......		100	29	12	....	10	......	......	......	......	......	......	......	......
Francolite[b].....		100	29	7	18	9	......	......	......	......	......	......	......	......
Collophanite[b]..		100	30	10	5	44	......	......	......	......	......	......	......	......

[a] Not computed.
[b] Ratios computed by Schaller from analyses of phosphate minerals.

The phosphates represented by the first seven analyses are more or less impure rock phosphates, and with one exception probably consist very largely of amorphous material. The description of No. 12 indicates that the sample was an incrustation on a mass of phosphorite, and though the original sample is not now available for examination, there is little doubt that the incrustation, like all the others that have been examined, was largely crystalline.

The average ratios of analyses Nos. 1, 6, 7, 12, and 13 correspond to about $100CaO.29P_2O_5.13F.7CO_2.18H_2O$. For francolite Schaller[1] gives the ratios $100CaO.29P_2O_5.18F.7CO_2.9H_2O$ (minus 9O) and for the analysis of collophanite containing fluorine $100CaO.30P_2O_5.5F.10CO_2.44H_2O$. The analyses of the Florida rock phosphates agree in the ratios of the principal materials with the ratios of francolite and collophanite, the fluorine is more than that of the fluocollophanite and less than that of the francolite, and the proportion of H_2O is higher than in francolite and lower than in fluocollophanite. Many thin sections of the rock phosphates contain both isotropic and doubly refracting minerals, and this fact, taken in connection with the analyses, suggests that the phosphorites are a mixture of francolite and fluocollophanite, with formulas which may be written $9CaO.3P_2O_5.CO_2.H_2O.CaFe$ and $9CaO.3P_2O_5.CaO.CO_2.H_2O.nH_2O.2HF$. Analyses Nos. 8 and 9 show a higher ratio of P_2O_5 than is found in these minerals, and the presence of a large proportion of Al_2O_3 and Fe_2O_3 suggests the occurrence of compounds of phosphate containing iron or aluminum, or both, together with the mixture of francolite and fluocollophanite.

[1] Schaller, W. T., op. cit., p. 99.

Analysis No. 25 represents a soft phosphate having the ratios $100CaO.31P_2O_5.18F.7CO_2.34H_2O$, or approximately the same as fluocollophanite with a somewhat smaller proportion of H_2O because of the necessity of supplying some H_2O to the compounds of iron and aluminum present. The natural presumption is that the minerals francolite and fluocollophanite are present, and this presumption is strengthened by the intimate relation of the soft phosphate and the rock phosphate.

The ratios shown in analyses Nos. 31 and 32 do not admit of a close approximation to the formulas of any definite compounds, but the high proportions of P_2O_5, Al_2O_3, and Fe_2O_3 suggest the presence of aluminum or iron phosphates, or both. The analysis of phosphatized limestone (No. 35) gives ratios for CaO, P_2O_5, and CO_2 in about the proportions of dahllite, francolite, or collophanite, but in the absence of determinations of F and H_2O it is not possible to determine which of these minerals is present. Analyses of pebble phosphate (samples Nos. 33, 34, and 36) are also incomplete and differ from the preceding only in the relatively small proportion of P_2O_5 and large proportion of CO_2, which probably indicates the presence of calcium carbonate in addition to the phosphate minerals.

Analyses Nos. 38 and 39 represent pebble phosphates, the samples having been obtained by washing the matrix from the pebbles. The average values give $100CaO.28P_2O_5.14F.8CO_2.24H_2O$. This formula is approximately the same as that deduced from the analyses of rock phosphates. The examination of thin sections shows a high percentage of isotropic material, though a doubly refracting mineral is present in some sections. The natural inference is that the mineral composition is approximately the same as the rock phosphate and that the pebbles are probably a mixture of francolite and fluocollophanite. A slightly higher proportion of CO_2 in analysis No. 40 is doubtless explained by the presence of a carbonate of calcium.

The matrix of a pebble phosphate is represented by analysis No. 46, which shows nearly the same ratios as the pebbles. A high proportion of H_2O is explained by the fact that a portion of it was doubtless combined with the alumina and iron oxide.

The analyses of river-pebble phosphate Nos. 50, 51, and 52 give average values $100CaO.25P_2O_5.20F.11CO_2.47H_2O$. This formula is slightly lower in P_2O_5 and slightly higher in F and CO_2 than that deduced for the other phosphates. The assumption that some of the CaO is combined with the excess of CO_2 in analyses Nos. 50 and 51, and that some of the excess Ca is combined with the F in analysis No. 52 would permit the combination of the remaining substances as fluocollophanite or as a mixture of fluocollophanite and francolite.

In the foregoing discussion of the analyses included in the table no attention has been given to the unknown mineral described by

Lacroix,[1] though some of the thin sections of rock phosphate show a mineral that, from its high birefringence and optically positive (?) character, has been tentatively identified as the unknown mineral. If this identification is correct the rock phosphates consist of both α-quercyite and β-quercyite. The occurrence of francolite of the fibrous variety, staffelite,[1] and the unknown mineral intimately intermingled and associated with the isotropic fluocollophanite show that the rock phosphates are a mixture of α-quercyite and β-quercyite. A doubly refracting mineral occurs sparingly in the pebble phosphates, but it has a low birefringence and agrees in its other optical properties with dahllite and francolite. The presence of fluorine in the complete analyses indicates that this mineral is probably francolite. The pebble phosphates are therefore largely fluocollophanite or, where francolite is present, α-quercyite. Possibly further study will reveal the presence of the unknown mineral and thus the pebble phosphate may after further investigation be found to contain β-quercyite.

The relations of the isotropic and crystalline minerals in the thin sections of Florida phosphates are sufficiently clear to indicate the different stages of formation. As has already been stated, the crystalline minerals occur as incrustations on exposed surfaces of the isotropic mineral or as veins in small openings. After the deposition of the isotropic portion of the phosphorite the cavities were wholly or partly filled with the crystalline minerals. Reference to the analyses of the different phosphate samples will show that the proportion of impurities present is greater in the ordinary samples than in sample No. 12, which represents the comparatively pure incrustation found on the surface of the phosphorite. After the deposition of the isotropic portion of the phosphorite waters percolating through the deposit brought with them or dissolved a portion of the phosphate already formed and redeposited it in the form of crystalline material that was much freer from impurities than the original phosphorite. This material was doubtless formed slowly and was arranged in crystalline form partly because of the rate of deposition and partly because the materials in solution were relatively free from foreign substances.

PHOSPHATE MINING.

CLASSES OF PHOSPHATES MINED.

In Florida there are two classes of commercially important phosphate—the rock phosphate and the land-pebble phosphate. Both types are mined by means of open pits, but the processes employed in the rock-phosphate region differ greatly from those employed in the land-pebble phosphate region. Moreover, there are minor differ-

[1] Lacroix, A., op. cit.

ences in the methods of mining in different parts of a single region. In discussing mining methods only the general processes involved will be considered. Local modifications of the general processes of exploiting the phosphate and preparing it for the market are designed to meet the requirements of the varying conditions of occurrence, and the greater the degree of ingenuity and resourcefulness of the miner the more successful he will be in obtaining satisfactory results.

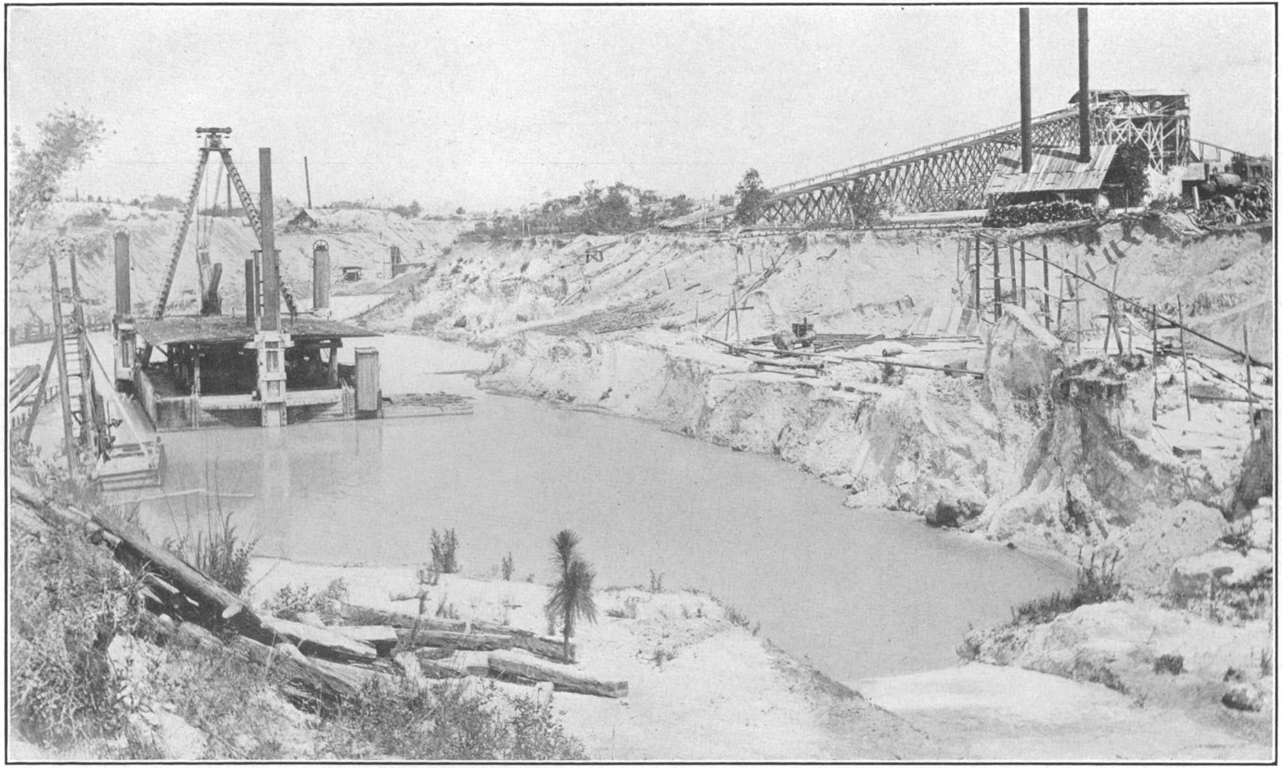
ROCK PHOSPHATE.

Stripping.—The first operation in mining rock phosphate is to remove the overburden of barren sand and clay—work that is usually done by horsepower scrapers, by picks and shovels, or, more rarely, by steam shovels. In some places hydraulic methods are employed, the overburden being first loosened by a hydraulic giant and washed into a pit, from which it is raised by a centrifugal pump and forced through pipes to the waste pile.

Excavating.—Rock phosphate was first mined by pick and shovel, and in some places nothing but the bowlders were saved. These, after being uncovered by the removal of soft phosphate, phosphatic pebbles, sand, and other débris, were broken up and the fragments were shipped to the market. Later some of the miners endeavored to recover a portion of the finer material. The phosphate was excavated with pick and shovel and thrown upon a screen of mesh that permitted the clay and soft phosphate to pass through and to retain the coarser pebbles. By this method it was possible to save some of the pebbles as well as the bowlders.

With the introduction of log washers the cruder methods first used were abandoned. However, the pick and shovel are still used in most places where the mining is done above the level of ground water, though in a few mines phosphate is excavated by steam shovels.

Soon after mining was begun it was discovered that much of the phosphate in the vicinity of Dunnellon and farther south was below the level of ground water. At first attempts were made to lower the water level in the mines by pumping, but owing to the porous character of the beds and the large volume of water they contained, the quantity of water entering the mines was large, so this method proved both difficult and expensive. Later steam dredges were mounted on wooden hulls and the phosphate was dredged from below water level. (See Pl. XVII.) This method of mining proved satisfactory, and is in use now wherever phosphate is mined below the ground-water level. In some places the deposits lie partly above water and it is possible to remove a part of the phosphate with pick and shovel before dredging is begun. By dry mining it is easier to follow the trend of small pockets of phosphate, and a smaller amount of worthless material is excavated than with a dredge.



GENERAL VIEW OF PIT IN THE ROCK-PHOSPHATE REGION, SHOWING MINING BY DREDGING.

Photograph by W. L. Martin.

Raising and washing.—After it has been excavated the phosphate and its matrix, consisting of a number of substances, is conveyed to the washer. Some phosphate was formerly raised from the pits by means of buckets attached to cables, but it is all now loaded on small cars and drawn up inclined railways by means of cables. The phosphate is dumped from these cars on a screen composed of parallel iron bars ("grizzly" bars), 2 to 2½ inches apart. The finer material, consisting of sand, clay, soft phosphate, and pebbles, is washed through the openings between the bars by a jet of water. Bowlders too large to pass between the "grizzly" bars are broken with a sledge hammer or with dynamite. Occasionally the steam shovel or dredge raises a bowlder too large to be dumped into the hoisting cars, and so it is broken by blasting with dynamite, a stick of which is placed on the bowlder, covered with mud or wet sand, and then exploded.

After passing through the grizzly bars the phosphate is broken in a crusher and then washed in a trough containing two or four revolving logs, each about 30 feet long and 18 inches in diameter, arranged in pairs, and each log fitted with blades that pass between the blades on the opposite log. The logs rotate in opposite directions, and the blades are so adjusted as to give the pebbles and broken fragments of bowlders a movement in one direction, the logs being so inclined that a stream of water flowing in the opposite direction removes the fine material and conveys it through troughs to the waste heap.

From the logs the phosphate passes through two cylindrical screens, 12 to 14 feet long, placed one inside the other and containing openings large enough to permit clay and fine sand to escape. The inner screen is perforated by openings measuring 1½ inches by three-eighths of an inch; the outer by openings measuring one-eighth by one-sixteenth of an inch.

In its passage through the screens the phosphate is washed by jets of water ejected from a perforated pipe situated inside of the screen and by water from similar pipes on the outside of the outer screens. This removes the sand and clay that still adheres to the phosphate.

Sorting.—The coarser phosphate, held on the inner screen, falls upon a circular wooden table, while the finer material from the outer screen passes directly to the "wet" bin below this table. The table carrying the coarse material revolves slowly and a number of men and boys who stand about it remove the fragments of limestone, clay, and flint that are mixed with the phosphate. At the end of a complete revolution the phosphate is automatically scraped from the table ("picking belt") and falls into the "wet" bin with the finer material.

Drying.—From the "wet" bin the phosphate is conveyed in a small car running on a narrow track to the upper part of the dry shed. This shed consists of a floor, upright wooden posts, and a roof that usually projects several feet beyond the edge of the shed. Boards are nailed about the lower part of the bin to prevent the phosphate from being lost, and in bad weather some of the sheds are boarded up several feet from the bottom to exclude rain.

In these sheds the rock is thoroughly dried by placing a layer of phosphate about 2 feet thick on the floor and stacking wood upon it to a depth of about 2 feet. This wood is so arranged that one layer lies across the other and considerable space is left between the sticks. Phosphate rock is dumped upon the wood to a depth of 10 to 15 feet and the wood is then fired and allowed to burn until it is consumed. The rock is ready for shipment as soon as it is cool enough to be loaded on cars. At some mines the rock is dried in rotary metal cylinders similar to those used at the pebble-phosphate mines, but this method is seldom used in the rock-phosphate region.

Waste products.—In the process of mining and washing rock phosphate a great deal of material not suited to the requirements of the market is rejected. Possibly much of this will be utilized at some future time, though the present demand is too small to make marketing profitable. Phosphate of lower grade than the market specifications is, as far as possible, left in the pit. In dredging it is necessary to excavate both low and high grade material, because it is impossible to tell in advance what sort of material will be obtained. After being washed much of the low-grade rock is rejected unless it is rich enough to be brought to market requirements by admixture with higher-grade rock.

In addition to the loss of low-grade rock, a large amount of soft phosphate is washed into the waste heap and some phosphate is removed from the picking table through mistake or because it is intimately associated with such substances as limestone or flint. It is impossible to determine exactly how much phosphate goes to the waste heap, but it has been estimated at two or three times the amount saved.

PEBBLE PHOSPHATE.

Stripping.—Before land-pebble phosphate can be mined it is necessary to remove the overburden, consisting of a varying thickness of sand or of friable sand rock. This overlying material is removed by hydraulic giants or by steam shovels. In hydraulicking, the sand is loosened by a jet of water and washed into a hole, from which it is removed by centrifugal pumps and conveyed through pipes to the waste heap.

The steam shovel is used in removing the overburden at a number of mines and is especially applicable to deposits in which the sand is partly indurated or contains hard lumps, such as concretions of iron oxide, that are too large to be handled by centrifugal pumps. The overburden is lifted by the steam shovels and dumped into small cars run on a temporary track. These cars are hauled to the waste heap, unloaded, and returned to the excavation to be refilled.

Excavating.—Nearly all the land-pebble phosphate is excavated by hydraulic methods, the rock being loosened and washed into a depression (sump hole) by a hydraulic giant. From the sump hole the phosphate and matrix are removed by one or more centrifugal pumps and conveyed through pipes to the washer. At some plants it is necessary to use a second pump to raise the phosphate to the top of the washer. At one mine the phosphate is excavated by a steam shovel, which is placed on a temporary track and operated by lowering a scoop attached to cables, by which the phosphate is hoisted from the pit and dumped on small cars to be hauled by cable to the sheds.

Washing.—The washers in the land-pebble phosphate region are of the same general type as those used in the rock-phosphate region, though they vary considerably in details of construction. From the hoisting pumps the phosphate is forced through the pipes to the washer and dumped on a cylindrical screen containing openings an inch in diameter. The screen is about 12 feet long and 4 feet in diameter, and is inclined, the upper end being about 2 feet higher than the lower. The phosphate passes through the openings and the lumps of clay and other débris retained on the screen are discharged into a trough that conveys them to the waste heap.

After passing through the openings in the separating screen the phosphate pebbles fall upon a second screen, about 18 feet long and 6 feet wide. This screen is inclined, one end being about 18 inches higher than the other, and the phosphate is washed across it by a stream of water. About half the area of the screen is occupied by perforations half an inch long by one-sixteenth of an inch wide. In passing over this screen the material is freed from much of its fine sand and clay, which pass through the perforations in the screen and enter the waste trough along with the clay balls and other débris.

The rock next passes through logs similar in arrangement and adjustment to those used in washing rock phosphate. The logs of the pebble-phosphate washers are, however, shorter, generally only about 18 feet long. There are four of them, arranged in pairs. The logs are inclined in the direction opposite to the way the phosphate is moving, at a slope, according to Mendenhall,[1] of about 1 to 24; in other words, one end of the pair of logs is about 9 inches higher than the other. A stream of water flowing through the trough containing

[1] Mendenhall, H. D., Modern land-pebble phosphate mining plants in Florida: Eng. News, vol. 60, No. 16, p. 413, Oct. 15, 1908.

the logs carries the fine sand and clay out of the trough in one direction as the phosphate is carried in the other direction by the flanges or blades on the logs.

From the first pair of logs the phosphate passes into a 12-foot screen composed of two revolving cylinders, one inside the other, the outer one having a diameter of about 4 feet and the inner one of about 3 feet. The rock in the screen is washed by jets of water thrown from perforated pipes inside and outside the screen. The cylinders contain perforations measuring one-half by one-sixteenth inch, and are inclined in the direction in which the rock is moving, the difference in the height of the two ends being about a foot. On the inside of the screen there are ridges which, as the screen rotates, agitate the rock and cause it to be more thoroughly washed.

From this screen the rock passes through another pair of logs, which are duplicates of the first pair, and from these it goes to a screen like the one just described. From the last screen the rock falls into a hopper and is conveyed by cars to the dry shed, where it is dumped into a "wet" bin.

Sorting.—The picking table is not so important a part of the equipment of the washer in the pebble-phosphate region as in the rock-phosphate region, for the pebble phosphate is nearly all fine, and sorting by hand would be a very slow process. However, hand sorting is done at some mines, chiefly to remove clay balls and like débris.

Drying.—From the wet bin the rock is carried in buckets, attached to a belt, to the driers. These driers are revolving cylinders, resembling those used in the manufacture of Portland cement, though somewhat smaller. They are so inclined that the material passes slowly through them by gravity. Longitudinal ridges on the inside of the cylinder cause the rock to fall through the heated air as the cylinder is rotated. The heat is applied at the upper end, and in passing the length of the cylinder (about 30 feet) the rock is thoroughly dried. Mines that handle 3,000 tons of rock in 24 hours operate about 10 cylindrical driers.

From the driers the rock is conveyed to a car placed on scales, and after being weighed is dumped in the dry bins. From the dry bins it is carried by gravity to cars to be shipped to market.

Waste products.—The amount of phosphate lost in mining the pebble phosphate is probably less than in mining the rock phosphate, because the matrix of the pebble phosphate is predominantly sandy, whereas that of the rock phosphate is usually clayey and contains much soft phosphate. However, there is considerable clay and soft phosphate in the finer-grained portions of the pebble phosphate, and practically all this material goes to the waste heap either as finely comminuted sediment or as clay balls.

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