

NOTES ON THE GREENSAND DEPOSITS OF THE EASTERN UNITED STATES.

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INTRODUCTION.

The United States has recently experienced a serious shortage of potash as a result of the shutting off of foreign supplies, and this has led to a vigorous search for new sources of supply in this country and for possible methods of utilizing mineral deposits containing potash. Prominent among these efforts have been the search for deposits of potash salts or potash-containing waters; attempts to utilize the potash of certain plants, such as the kelp of the Pacific coast and the sagebrush of the arid plains; experiments in obtaining potash from the feldspar and other minerals contained in rocks; and the search for material having a sufficiently high content of potash to warrant its commercial exploitation.

Potash is exceedingly abundant in the earth's crust, but usually forms only a small percentage of the rock containing it. Most granites, for example,¹ contain 4 to 8 per cent of potash, and a few of the nephelite and leucite rocks contain over 9 per cent of potash. Many of the rhyolites, porphyries, trachytes, syenites, monzonites, and basalts contain more than 5 per cent of potash. Some minerals, such as sylvite (52.4 potassium) and niter (46.5 potash), contain more than 20 per cent, theoretically, of potash or of potassium, but these minerals are relatively rare in this country and have not yet been found in quantities large enough to be of commercial interest. A few other minerals, such as leucite, alunite, orthoclase, muscovite, biotite, and lepidolite, contain 4 to 16 per cent of potash, averaging about 8 per cent. These are the minerals for which special search has been made. At least one large deposit of leucite-bearing rock averaging about 10 per cent of potash is known in Wyoming, and a claim has been filed on it. Small but workable deposits of alunite, carrying 7 to 11 per cent of potash, have been found in Utah and adjoining States. Small deposits of sericite (muscovite) schist, carrying 5 to 8 per cent of potash, are known in Georgia and the

¹ Clarke, F. W., The data of geochemistry, 3d ed.: U. S. Geol. Survey Bull. 616, pp. 433 et seq., 1916.

Carolinas. The other minerals mentioned are abundant but are commonly scattered through the rocks as isolated crystals or occur as thin veins or stringers, so that though selected specimens may yield 10 per cent or more of potash, the quantity of such minerals in any body so far known that will maintain an average that high is relatively insignificant.

In their extent and availability these resources of potash-bearing minerals or rocks present a strong contrast to the greensands of the Eastern States, which underlie the surface of hundreds if not thousands of square miles within reach of the steam shovel, and which range in thickness from a few feet to 30 feet and carry 5 to 7 per cent of potash. As a cubic foot of greensand weighs about 90 pounds and (if 7 per cent material) contains 6.3 pounds of potash, a square mile of sand 1 foot thick will yield 78,000 tons of potash. A 20-foot bed that covers a square mile should yield 1,500,000 tons of potash; a 20-foot bed of 5 per cent greensand should yield 1,000,000 tons to the square mile and should also carry about 2,000,000 tons of iron, and possibly 500,000 tons of phosphoric acid. The figures given apply to the best sands only, but if the samples taken indicate the character of the sand throughout the full thickness of the bed there are many square miles of greensand containing 7 per cent of potash and perhaps hundreds of square miles containing 4 or 5 per cent. In view of the possible ease of mining these sands they would seem to offer an adequate source of potash for perhaps several hundred years, provided a cheap method of extracting the potash can be found.

The object of this paper is to place before chemical engineers and others succinct information as to the location and extent of easily accessible greensand deposits in the Eastern States and their content of potash, and thus to provide an answer for many inquiries made of the United States Geological Survey. The paper brings together the results of analyses of samples of greensand that were collected by W. C. Phalen and the writer and analyzed in the chemical laboratory of the United States Geological Survey by W. B. Hicks and R. K. Bailey and gives notes on the occurrence and extent of the beds sampled. It will be noted that the analyses do not substantiate many older analyses of glauconite, the potash-bearing mineral in greensand, which gave 11 and 12 or even 14.5 per cent of potash. All modern analyses indicate that glauconite contains only 7 to 8 per cent of potash.

The samples were taken from deposits that lie near transportation lines, either rail or water, and that could be handled cheaply, in large quantities, either by the steam shovel or dredge or other mechanical means. These limitations to the study were set in the belief that the demand for potash is urgent and possibly only tem-

porary, and that what is immediately desired is rather information as to the best and most available deposits for possible utilization than a comprehensive report that would be of value in the development of the industry.

After a brief review of the available information concerning the greensand deposits of the eastern United States, either published or unpublished, a number of the most promising deposits were selected for study. When the selection had been made Mr. Phalen visited areas in New Jersey, and the writer visited areas in Delaware, Maryland, Virginia, North Carolina, Tennessee, and Arkansas.

In general, the results show that the best and most available deposits are in New Jersey and Delaware, samples from which yielded from 3.50 to 7.15 per cent of potash, the highest percentages coming from deposits in New Jersey. The samples from Maryland yielded 4.45 per cent or less; the samples from Virginia, which contained much lime, yielded 2 to 2.50 per cent; those from North Carolina 2.96 or less, and those from Arkansas 4.90 per cent or less. No glauconite sand was found in Tennessee in the area from which it had been reported by Troost.¹ Since the above was written it has been learned that a little greensand containing not over 3 per cent of potash has been found by Mr. Bruce Wade in McNairy County, Tenn., at the foot of a hill west of Adamsville.

The deposits at these localities are ample to supply any immediate need. Most of those in New Jersey and Delaware are 20 feet or more thick and in many places the thickness of the overburden is less than that of the bed. The practical question therefore is whether these greensands can be used commercially.

COMPOSITION OF GREENSAND.

The term greensand as here used is applied to an unconsolidated sandy deposit containing glauconite. Under the magnifying glass the best greensand appears to be composed entirely of grains of glauconite, less than 1 per cent being grains of quartz sand. More commonly it includes a larger proportion of quartz sand, amounting to one-half or more of the whole. Sand that is composed mainly of grains of glauconite is dark green to light green and becomes darker or almost black when wet. If the proportion of quartz sand is large the sand has a characteristic "pepper and salt" appearance, with only a greenish tinge, and may grade into ordinary yellow or white sand as the proportion of glauconite decreases. In fresh glauconite the grains are light green but a little weathering generally produces a dark coating on them, making them almost black. Such

¹ Troost, Gerard, Seventh report of the geological survey of Tennessee, p. 30, 1844.

grains, however, appear green when broken. The grains of glauconite are fairly soft and can readily be broken by the finger nail. The size of the grains differs in different deposits. In some deposits more than 85 per cent of the glauconite will go through a 100-mesh sieve; in others one-half or more is caught on a 60 or 80 mesh sieve. In general the grains range from one-fortieth to one one-hundredth of an inch in diameter or less. In some samples the grains of sand are about as large as the grains of glauconite; in others the two differ greatly in size. The following table shows these differences:

Results of sifting two samples of greensand from Maryland.

[Grains counted on cross-section paper.]

Mesh of screen.	1		2	
	Quartz.	Glauconite.	Quartz.	Glauconite.
On 10.....	0	0	0	0
On 30.....	0	0	22	10
On 60.....	400	346	979	437
On 80.....	369	402	224	325
On 100.....	381	527	44	358
Through 100.....	262	677	8	235

1. Sample 36, Marlboro, Md.

2. Sample 29, Severn River, Md.

Other deposits show an even more striking difference, which is illustrated by a comparison of greensand from Aquia Creek, Va., with that from Birmingham, N. J.

Results of sifting two samples of greensand from Virginia and New Jersey.

[Percentages.]

Mesh of screen.	Aquia Creek, Va.	Birmingham, N. J.	Mesh of screen.	Aquia Creek, Va.	Birmingham, N. J.
On 30.....	0	5	On 100.....	10	2
On 60.....	2	90	Through 100.....	85	0
On 80.....	3	3			

Many deposits of greensand contain, in addition to the glauconite and quartz, more or less calcite, commonly in the form of shells or fragments of shells or as cement derived from shells, and a little clay or other fine material, and some deposits contain a little iron phosphate. Microscopic study would probably reveal particles of undecayed feldspar and other minerals, for a good hand lens shows that a few samples contain a small amount of very fine feldspathic material. The greensand in many southern deposits contains an appreciable amount of mica. Glauconite is a silicate of iron and potassium. The following analyses of glauconite, given by Dana,¹ show its general composition:

¹ System of mineralogy, 6th ed., p. 463, 1892.

Analyses of glauconite.

	1	2	3	4	5	6	7	8	9	10	11
Silica.....	49.42	51.24	49.76	50.62	50.42	46.91	49.09	46.90	52.86	50.70	46.58
Alumina.....	10.23	12.22	8.18	3.80	4.79	7.04	15.21	4.06	7.08	8.03	11.45
Ferric oxide.....	16.01	13.44	16.00	21.03	19.90	23.06	10.56	27.09	7.20	22.50	20.61
Ferrous oxide.....	3.00	3.06	3.77	6.02	5.96	2.64	3.06	3.60	19.48		
Magnesia.....	3.78	3.93	3.97	a. 57	2.28	4.40	2.65	.70	2.90	2.16	1.27
Lime.....	.31	.10	.41	a. 54	3.21	2.95	.55	.20	Trace.	1.11	2.49
Potash.....	7.91	7.50	7.57	7.14	7.87	7.31	6.05	6.16	2.23	5.80	6.96
Soda.....	.26	.31	.52		.21	.91	1.21	1.28	Trace.	.75	.98
Water.....	8.08	8.20	9.82	9.14	5.28	4.71	11.64	9.25	8.43	8.95	9.66
Insoluble material	.80										
	99.80	100.00	100.00	99.86	99.92	99.93	100.02	99.24	100.18	100.00	100.00

a Carbonates.

1. Swir River, Russia. Kupffer, A., Jahresb. Chemie, 1870, p. 1307.
2. Ontika, Russia. Kupffer, A., idem.
3. Grodno Valley, Russia. Kupffer, A., idem.
4. Havre, France. Haushofer, K., Jour. prakt. Chemie, vol. 102, p. 38, 1866.
5. Antwerp, Belgium. Dewalque, F., Soc. géol. Belgique Annales, vol. 2, p. 3, 1875.
6. Gozzo Island, Mediterranean Sea. Bamberger, E., Min. pet. Mitt., p. 271, 1877.
7. Ashgrove, near Elgin, Scotland. Heddle, M. F., Roy. Soc. Edinburgh Trans., vol. 29, p. 79, 1879.
8. Agulhas Bank, Indian Ocean. Gumbel, C. W., K.-bayer. Akad. Wiss. Sitzungs., vol. 16, p. 417, 1886.
9. French Creek, Pa. Knerr, E. B., and Schoenfeld, J., Am. Chem. Jour., vol. 6, p. 412, 1884.
10. New Jersey. Hunt, T. S., Canada Geol. Survey [Fifteenth] Rept. Progress, pp. 486-488, 1863.
11. Red Bird, Miss. Hunt, T. S., idem.

At a few places the sand is so fine grained as to have the appearance of a green or black clay. One such deposit, from Silver Run, Del., appeared on analysis to contain almost as much potash as pure glauconite.

The following table gives the results of a number of tests made by G. H. Cook.¹ In these tests the clay was removed by stirring in water and decanting. Afterward the washed sand was dried, the quartz sifted out or picked out by hand, and the two parts weighed.

Results of sifting and washing New Jersey greensands.

Locality.	Glauconite.	Clay, etc.	Quartz.
Lower marl bed.			
Marlboro, Monmouth County.....	58.4	33.6	6.6
Manalapan, Monmouth County.....	75	25	
Do.....	65	32.5	2.5
Perrineville, Monmouth County.....	52.5	28.8	18.7
Marshallville, Salem County.....	40.8	32.0	27.2
Sculltown, Salem County.....	25.6	36.0	38.4
Middle marl bed.			
Tinton Falls, Monmouth County.....	82.0	17.2	.8
Blue Ball, Monmouth County.....	81.2	17.2	1.6
Do.....	84.2	15.8	
Pemberton, Burlington County.....	90.3	9.8	1.9
Medford, Burlington County.....	88.5	11.5	
Inskips Bridge, Burlington County.....	71.4	28.5	
White House, Camden County.....	77.3	21.1	
Barnsboro, Gloucester County.....	91.3	7.8	.9
Hurffville, Gloucester County.....	89.0	11.0	
Blackwood, Camden County.....	71.1	28.9	
Mullica Hill, Gloucester County.....	86.6	12.5	.9
Woodstown, Salem County.....	74.3	21.8	3.9
Upper marl bed.			
Vincentown, Burlington County.....	67.6	28.8	3.6
Clementon, Camden County.....	16.6	33.6	49.8

¹ Cook, G. H., *Geology of New Jersey*, pp. 277 et seq., 1868.

In connection with a study of the greensands of New Jersey, Mr. Cook made a chemical study of the green grains from a number of beds, the glauconite having been carefully picked out by hand:

Analyses of glauconite grains in New Jersey greensands.^a

	1	2	3	4	5	6	7
Silica.....	38.50	42.80	45.85	47.10	45.51	50.01	41.72
Ferrous oxide.....	4.26	3.72	2.98	3.71	3.84	3.84	3.02
Ferric oxide.....	20.96	17.42	17.11	16.80	19.02	19.00	14.96
Alumina.....	6.40	6.02	7.88	5.72	7.96	7.36	5.92
Lime.....	1.06	2.01	1.21	1.97	3.84	.31	8.02
Magnesia.....	2.13	2.04	2.51	2.88	2.46	2.86	2.93
Potash.....	8.19	7.99	8.08	7.01	6.74	7.37	6.06
Sulphuric acid.....	.38	.34	.27	.72	1.12	.43	1.00
Phosphoric acid.....	1.15	1.40	1.72	1.02	.99	.62	7.35
Water at 100° C.....	6.02	4.07	3.26	64.76	.56	.00	1.38
Water above 100° C.....	3.80	3.91	4.85	64.15	7.38	7.74	6.30
Quartz.....	7.70	6.99	4.30	4.10	.85	.40	.90
	100.55	98.68	100.11	99.97	100.29	98.98	99.63

^a Cook, G. H., *Geology of New Jersey*, pp. 280-281, 1868: Analyses 1-4 by J. C. Smock; analyses 5-7 by Julius Koch.

^b Includes carbon dioxide.

1. "Clay marl," Matawan, Monmouth County.
2. "Lower marl bed," Marlboro, Monmouth County.
3. "Middle marl bed," Blackwood, Camden County.
4. "Upper marl bed," Squankum, Monmouth County.
5. "Lower marl bed," Cream Ridge, Monmouth County.
6. "Middle marl bed," White Horse, Camden County.
7. "Upper marl bed," Squankum, Monmouth County.

As the analyses showed some quartz, lime, and phosphoric and sulphuric acids, which Mr. Cook believed formed no part of the glauconite, the analyses were recomputed so as to exclude those substances, as follows:

Recalculated analyses of glauconite grains in New Jersey greensands.^a

[Numbers assigned to columns correspond to those in preceding table.]

	1	2	3	4	5	6	7
Silica.....	42.64	48.63	49.15	51.11	48.97	50.93	51.53
Ferrous oxide.....	4.71	4.23	3.21	4.03	4.13	3.90	3.73
Ferric oxide.....	23.22	19.80	18.48	18.23	20.46	19.35	18.47
Alumina.....	7.09	6.84	8.51	6.21	8.56	7.50	7.32
Magnesia.....	2.36	2.32	2.79	3.14	2.64	2.91	3.62
Potash.....	9.07	9.08	8.73	7.60	7.26	7.50	7.49
Water at 100° C.....	6.66	4.62	3.52	5.16	7.94	7.88	7.81
Water above 100° C.....	4.21	4.43	5.22	4.50			
	100.00	100.00	100.00	100.00	100.00	100.00	100.00

^a Cook, G. H., *Geology of New Jersey*, p. 281, 1868. Analyses 1-4 by J. C. Smock; analyses 5-7 by Julius Koch.

From all these analyses the author has derived the following table showing approximately the composition of glauconite:

Approximate composition of glauconite.

Silica-----	50
Ferrous oxide-----	4
Ferric oxide-----	19
Alumina-----	7.5
Magnesia-----	3
Potash-----	7.5
Water-----	8.5
Soda and lime-----	.5
	<hr/>
	100.0

Roughly, glauconite consists of one-half silica, one-fourth iron oxides, one-tenth aluminum and magnesium oxides, one-sixth potash, water, and other substances, the potash forming about 1 part in 13.

If this analysis shows the maximum percentage of potash in glauconite, it is obvious that greensand, even if it is entirely glauconite, can hardly run over 7 or 8 per cent potash. As already mentioned, the best greensands of New Jersey appear to be almost entirely glauconite and on analysis yield 6.40 to 7.15 per cent of potash. In order to test the matter further the writer made an electromagnetic separation of the glauconite grains from sample 36, repeating the process twelve times in order to procure glauconite grains that should be as nearly pure as possible. This material, on analysis, gave 7.05 per cent of potash. If, therefore, a greensand, on examination under a hand lens, appears to be one-half quartz it probably contains no more than 3.5 to 4 per cent of potash. In the particular sample used in the experiment just cited, however, though the sample appeared to be fully one-half quartz, the analysis of the sample as a whole gave 4.48 per cent of potash. The unexpectedly large percentage of potash in this sample indicates that too much reliance must not be placed on a sight test, even though it is based on relations so obvious as those described.

ORIGIN AND NATURE OF GREENSAND.

The origin of greensand is still somewhat in doubt, but there is good reason for believing that it is a product of the alteration of clay or feldspar, particularly clay. The steps assumed by Murray and Irvine¹ are, first, the formation of iron sulphide in sea water in the presence of decomposing vegetable matter and, second, the replacement of the aluminum of the clay by this iron, resulting in a compound that combines with the potash in sea water to form glauconite,

¹ Collet, L. W., *Les dépôts marins*, p. 169, Paris, 1908. See also Murray, John, and Irvine, Robert, On the chemical changes which take place in the composition of the sea water associated with blue muds on the floor of the ocean. *Roy. Soc. Edinburgh Trans.*, vol. 27, pt. 3, 1893.

the potash in the sea water having been derived from potash feldspars, mica, and other potash-bearing minerals that are brought into the sea. Some water also enters into the glauconite molecule. According to Murray and Renard,¹ the sulphates in sea water act on the iron in mud or clay in the presence of organic matter, producing iron sulphide, which later oxidizes to the hydroxide. At the same time the alumina is removed from the clay by solution, and colloidal silica is liberated, which reacts upon the ferric hydroxide in the presence of potassium salts extracted from the adjacent minerals, the reaction forming glauconite.

As a consequence of variations in the conditions under which glauconite is formed the process of formation does not appear to be very uniform or to produce a single definite compound, for the alumina may not be completely removed and the potassium may be in part replaced by other bases. If the glauconite were pure and had the formula suggested by Dana, $\text{Fe}'''\text{KSi}_2\text{O}_6 + 3\text{H}_2\text{O}$, it should contain 13 per cent of potash. As a matter of fact, the analyses quoted indicate that some of the potassium is always replaced by other bases.

The most common type of glauconite consists of minute botryoidal pellets whose forms are due, apparently, to the fact that the clay from which they were derived occupied cavities in minute shells. The pellets in another type are round and smooth, as if they had been derived by erosion and redeposition from a deposit of the first type. A third type, which includes glauconite stains and the grains that fill crevices and cavities, may be due in part to the alteration of grains of feldspar.

Glauconite is found in deposits on the sea bottom at depths ranging from about 300 feet to 2 miles.

Recently formed glauconite is well described and illustrated in the report of the *Challenger* expedition.² Some of the deposits found by that expedition were almost pure glauconite. Most of the deposits found, however, contained from 40 to 50 per cent of foraminiferous and other calcitic shells. The grains of recent glauconite rarely if ever exceed 1 millimeter in diameter, and are typically rounded or mammillated, hard, and black or dark green. The surface of some of the grains is dull, that of others is shiny. Many of the grains have vaguely the form and appearance of Foraminifera and other organisms. Mixed with these typical grains are many pale-green particles that have the distinct impress of calcareous shells, many being obviously internal casts.

¹ Murray, J., and Renard, A. F., *Challenger* Rept., Deep-sea deposits, p. 389, 1891.

² Idem, pp. 378 et seq.

To those who are interested in the origin and nature of the glauconite in greensand a recent paper by M. I. Goldman¹ will be of interest. Reference should also be made to Clarke's "Data of geochemistry,"² which cites other works, and to the earlier papers of Collet³ and Thoulet.⁴

METHOD OF SAMPLING.

In obtaining the samples of greensand the endeavor was made to see that they represented the average material at the places where they were taken. The samples from New Jersey, obtained by Mr. Phalen, were taken with a soil auger that reached a depth of 12 feet. Most of the samples were taken in old pits. The auger was started at the top of the deposit and driven at an angle so as to cut downward through the deposit and, at the same time, to reach as far as possible from the exposed face. The material brought out by the auger formed the sample.

The samples taken by the writer were cut from the deposits with an army adz such as is used in digging trenches. In the steepest and freshest face of a deposit (mostly in stream or road cuttings) a vertical trench 6 to 10 inches wide was dug to a depth of 3 feet or less and to a length that depended on the thickness of the deposit or on the thickness of the part of the deposit that appeared to be of uniform quality. Where different parts of the deposit appeared to be of different grades, two or more cuttings were made, so as to procure separate samples for analyses. Then a cut was made 3 inches wide and 1 to 2 inches deep for the whole length of the trench, and the material cut off was caught on oilcloth, mixed, and quartered down to make about a 1-pound sample, in about the same way that a sample of coal is taken. By making a series of cuts it was hoped to detect any enrichment that might have occurred and to obtain general information that might be of value in a study of these deposits. David White has suggested that the leaching of a deposit at the surface might enrich parts of it that lay at a lower level. At one or two places the top of a deposit seemed to be slightly richer than the lower part. At other places the proportion of glauconite manifestly increased from above downward. On the whole, the evidence and the

¹ Goldman, M. I., The petrography and genesis of the sediments of the Upper Cretaceous of Maryland: Maryland Geol. Survey, Upper Cretaceous, pp. 111-182, 1916.

² Clarke, F. W., The data of geochemistry, 3d ed.: U. S. Geol. Survey Bull. 616, pp. 516 et seq., 1916.

³ Collet, L. W., Les dépôts marins, pp. 132-194, 303-306, Paris, 1908.

⁴ Thoulet, M. J., Étude bathylithologique des côtes du golfe du Lion: Inst. océanographique Annales, vol. 4, No. 6, pp. 62 et seq., Paris, 1912.

analyses do not indicate such enrichment. A few samples were taken to study the effect of weathering, either by comparing the analyses of samples cut at the face of the trench, where the deposit was weathered to red or brown, and at the back of the trench, where the material was still green and apparently unweathered; or by comparing the analyses of samples cut at the top of a bank, where the greensand made the surface soil, and lower in the bank, where the greensand appeared unweathered. (See analyses of samples 31, 32, 51, 52, and 53.)

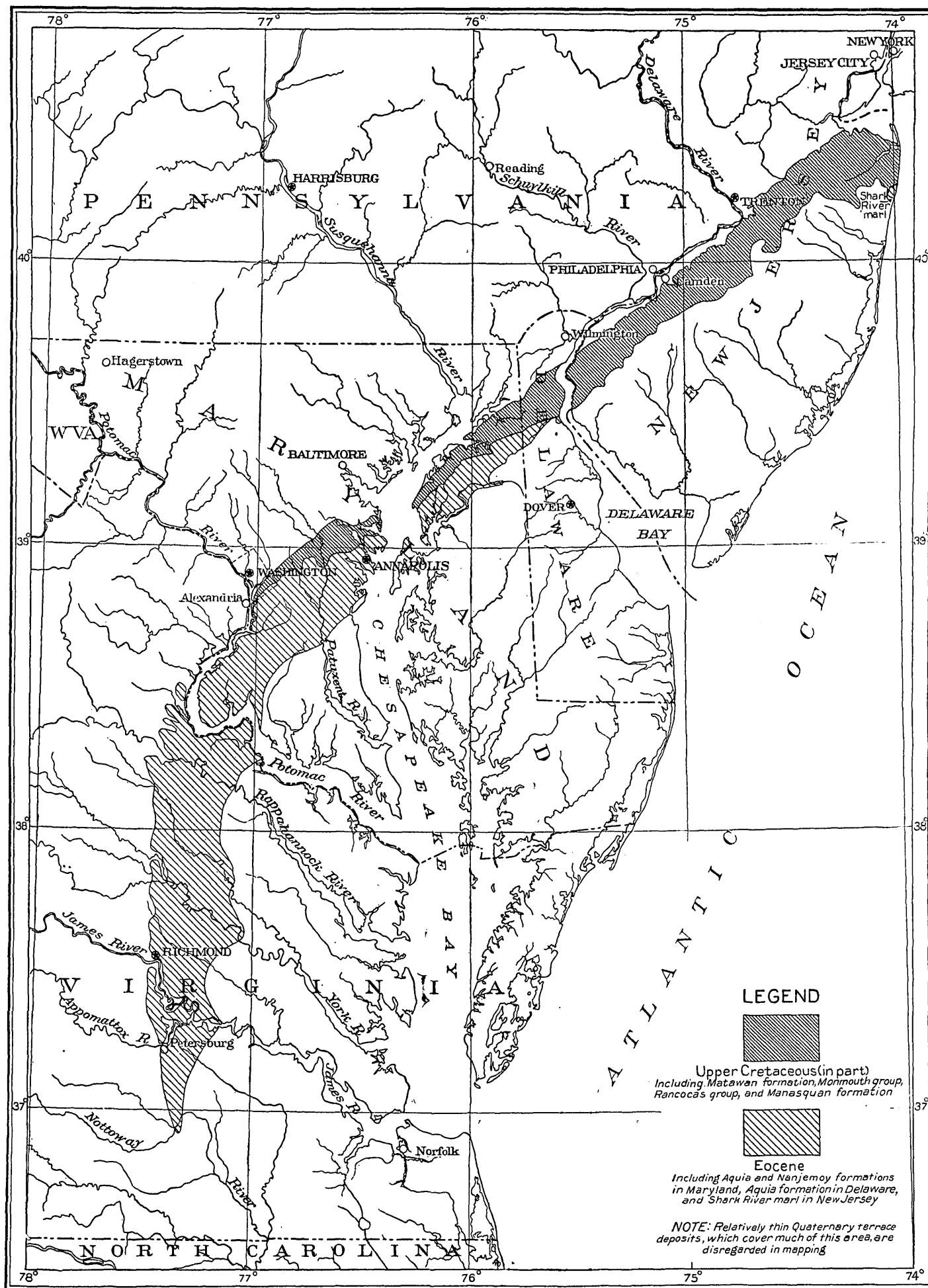
GEOLOGIC OCCURRENCE OF THE GREENSANDS.

The unconsolidated greensands of the northern Atlantic States are found in the Aquia and Shark River formations of the Eocene and in the Manasquan, Rancocas, and Monmouth formations of the Cretaceous. The following table shows the geologic age and thickness of these formations in New Jersey, Delaware, and Maryland:

Principal greensand-bearing formations of New Jersey, Delaware, and Maryland.

Age.	New Jersey.	Delaware.	Maryland.
Eocene.	Shark River marl, from a thin film to 11 feet thick.	Aquia formation, 35 feet thick.	Nanjemoy formation: Woodstock greensand marl member, 70 feet thick. Potapaco clay member, 71 feet thick. Aquia formation: Paspotansa greensand marl member, 47 feet thick. Piscataway indurated marl member, 69+ feet thick.
Upper Cretaceous.	Manasquan formation, 25 feet thick. Rancocas group: Vincentown sand, 25-70 feet thick. Hornerstown marl, 30 feet thick. Monmouth group: Redbank sand, from a thin film to 100 feet thick, including Tinton sand member, 10-20 feet thick. Navesink marl, 25-40 feet thick. Mount Laurel sand, 5-60 feet thick. Matawan formation.....	Rancocas formation, 20 feet thick. Monmouth formation, 80 feet thick. Matawan formation, 30 feet thick.	Rancocas formation, a few feet thick (?) Monmouth formation; a thin film at the south; increases to 100 feet at the north. Matawan formation; 10 feet thick at the south; 50 feet thick at the north.

The formations listed differ greatly in thickness from north to south. In general the Eocene strata are lacking at the north and thicken to the south, whereas the Cretaceous strata are well represented in New Jersey but become thin or disappear in Maryland or before reaching that State. Of the New Jersey formations the Shark



SKETCH MAP OF NEW JERSEY AND PARTS OF MARYLAND AND VIRGINIA, SHOWING GENERAL DISTRIBUTION OF GREENSAND-BEARING FORMATIONS.

River and Manasquan formations were called by the older New Jersey geologists the "Upper marl bed," the Hornerstown marl was called the "Middle marl bed," the Navesink marl was called the "Lower marl bed," and the Matawan formation was called the "Clay marl bed."

In the writer's opinion the term "marl" should be restricted to earthy deposits containing an appreciable amount of lime. Under this definition most of the greensand deposits of New Jersey and neighboring States should not be called marls, but they have been so generally thus designated in geologic reports and popular speech that it will be difficult to change the usage.

The sketch map (Pl. II) shows on a small scale the distribution of these formations in the three States mentioned and the location of places where samples were taken for analysis.

THE GREENSAND BEDS.

NEW JERSEY.

EXPOSURES OF THE BEDS.

The greensand beds of New Jersey have been described in some detail by previous writers.¹ Only brief notes on the thickness and other features of the sands will be quoted here. These notes will be followed by a list of the localities visited by Mr. Phalen, a statement of the thickness of the greensands sampled by him, and the names of the owners of the land from which the samples were taken. The following data are abstracted from the report by G. H. Cook:²

At Highlands, Monmouth County, on the shore of Sandy Hook Bay, the greensand is 25 feet thick and is overlain by 14 feet of clay. On Hop Brook, Atlantic Township, the greensand is 16 feet or more thick and is overlain by 21 feet of clay and low-grade greensand. At a locality about $1\frac{1}{4}$ miles north of Freehold there is a deposit of greensand $21\frac{1}{2}$ feet thick underlying 7 feet of clay. On McCleas Creek 20 feet of greensand has been dug on the P. J. McCleas place.³ W. V. Conover dug 21 feet of greensand on the north shore of Navesink River, opposite Redbank. William Smith dug 20 feet of greensand in Nut Swamp, and Azariah Conover dug 25 feet of greensand at Middletown. Pits had been opened along the north

¹ Rogers, H. D., *Description of the geology of the State of New Jersey*, 1840. Cook, G. H., *Geology of New Jersey*, 1868. Clark, W. B., *A preliminary report on the Cretaceous and Tertiary formations of New Jersey*: New Jersey Geol. Survey Ann. Rept. for 1892, pp. 169-239, 1893. See also *Atlas of New Jersey*, New Jersey Geol. Survey; and *New Jersey Agr. Exper. Sta. Bull.* 61, 1916.

² *Op. cit.*, pp. 263-276.

³ The names here given are those of the owners of the land in 1868, when Cook's report was published.

slope of the Mount Pleasant Hills from a point above Middletown nearly to Marlboro. Near Holmdel P. R. Smock dug 16 feet of greensand, and on the Schank place, on the north side of Hop Brook, the greensand is 21 feet thick, including, as is common in this area, a 14-inch layer of shells near the middle. At Marlboro Uriah Smock dug 17 feet of greensand. Between Freehold and Englishtown J. C. Thompson dug 15 feet of greensand, and on Manalapan Creek at Black Mills the sand is 20 feet thick. At Cream Ridge 12 feet of greensand has been exposed.

In Burlington County, on Rancocas Creek, three-fourths of a mile northwest of Jacobstown, Mr. Rogers is said to have found 27 feet of greensand, and on the D. G. Lippincott place, half a mile below Mount Holly, 7 to 20 feet of greensand has been found. In Camden County, on Cooper Creek, on the Bridge Kay place, 2 miles from Haddonfield, the greensand is 10 to 15 feet thick. These localities are all on the "lower marl bed" or Navesink marl.

In Monmouth County the "middle marl bed" or Hornerstown marl (or greensand) is 8 to 10 feet thick between Long Branch and Eatontown; 18 feet thick on the Peter Casler place on Town Neck; and 11 feet thick near Eatontown, on the G. A. Corlies place. At Tinton Falls P. Hendrickson dug 10 feet into greensand, and half a mile south of Colts Neck the greensand is 12 to 13 feet thick. About a mile southwest of Blue Ball the greensand is 10 to 14 feet thick, and at Hornerstown it is 11 feet thick.

In Ocean County the greensand is 10 feet thick on Lahway Creek, near Prospertown, and 14 feet thick at New Egypt.

In Burlington County the greensand is 14 to 15 feet thick at Springfield and 22 feet thick at Pemberton. The whole bed is exposed between Vincentown and Eayrstown. It is 15 to 16 feet thick along Sharps Run, west of Medford, and 13 feet thick at Marlton.

In Camden County the greensand is 6 to 13 feet thick at White Horse; 30 feet thick at Laurel Mills, on Big Timber Creek; and 18 to 20 feet thick at Blackwood.

In Gloucester County the greensand is 13 feet thick on Mantua Creek, at Hurffville; 12 feet thick southeast of Barnsboro; and 12 to 20 feet thick on Raccoon Creek.

In Salem County the greensand is 15 feet thick on Nihomus Run; 18 feet thick along Mannington Creek; and 25 feet or more thick on the William Barber place, on Mannington Creek.

The upper bed of greensand is described in Cook's report as consisting of two beds—"green marl" below, 17 feet thick, and a "blue marl" above, 11 feet thick, separated by 9 feet of "ash marl."

In Monmouth County the greensand is 16 feet thick, along Poplar Brook; 18 feet thick on the H. Hurley place on Shark River; 10 to

12 feet thick at Farmingdale, along the Mingumhorne; 13 to 15 feet thick at many places along the Manasquan; and 15 feet thick on the Timber Swamp, where dug by the Squankum Marl Co.

In Burlington County the greensand is 12 feet thick at Poke Hill.

In addition to these localities Cook mentions many pits and localities where the greensand has been dug, without giving the thickness found.

SOURCES OF THE SAMPLES.

The locations from which Mr. Phalen obtained samples, the present owners of the land, the observable sections of the beds, and the character of the samples are as follows:

Sample 1 was obtained from the land of Daniel Mahoney, half a mile northeast of Farmingdale, Monmouth County. The section shows 2 to 3 feet of greensand, reported to be 10 feet thick, overlain by 7 feet of black clay, and the clay overlain by 8 to 10 feet of gravel and clay.

Sample 2 was taken on the Mark Kilmartin place, 5 miles northeast of Freehold, Monmouth County, the sample including 15 feet of greensand. The greensand bed in this locality is overlain by 5 feet of clay and gravel.

Sample 3 was taken from the John Van Kirk place, Marlboro, Monmouth County. The 10 feet of greensand sampled is overlain by 3 to 5 feet of gravel. This greensand contains shells.

Sample 4 was taken on the Henry Butterworth place, between Pemberton and Vincentown, Burlington County, 5 feet of greensand being sampled. The bed at this place is overlain by 10 to 15 feet of clay and gravel.

Sample 5 was taken from a heap of greensand previously dug on the Ben Brown place, near Vincentown, Burlington County.

Sample 6 was taken at the same place as No. 5, but the greensand, 5 or 6 feet thick, was sampled in the bed.

Sample 7 was taken from a recently dug pile on the Ivens Horner place, $1\frac{1}{2}$ miles northeast of Pemberton, Burlington County.

Sample 8 was cut in the bed at the place from which sample 7 was obtained, where the greensand is 12 to 14 feet thick and the overburden 8 to 10 feet thick.

Sample 9 is an average sample from 10 feet of greensand, overlain by 2 feet of clay and gravel, on the William Hoffman place, north of Birmingham, Burlington County.

Sample 10 was cut on the Henry Edwards place, 2 miles southwest of Mullica Hill, Gloucester County. The greensand at this locality is 5 feet or more thick and is overlain by 15 to 20 feet of clay and gravel.

Sample 11 was cut from 10 feet of greensand, overlain by 8 to 10 feet of clay and gravel, on the William Wenzell place, just west of Sewell Village, Gloucester County.

Sample 12 was cut from an old marl pit southwest of Laurel Springs, Camden County, where the greensand showed a thickness of 10 to 12 feet, overlain by 20 feet of overburden.

DELAWARE.

As the samples taken in Delaware came from a relatively small area in New Castle County, a sketch map (fig. 1) is presented to

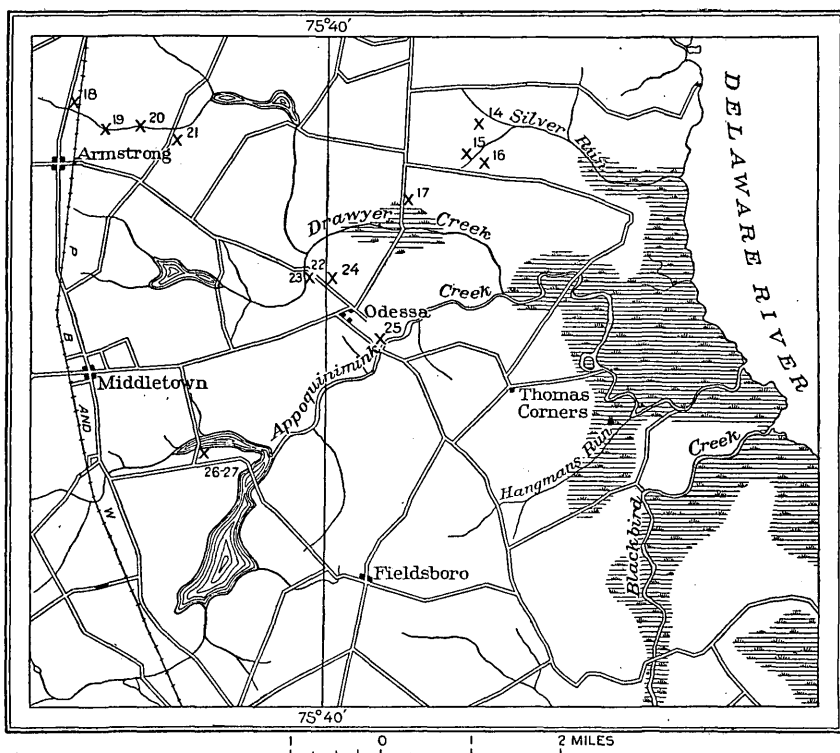


FIGURE 1.—Sketch map of area adjacent to Middletown, Del. X, Locality from which greensand samples were obtained.

show more in detail the locations of the several deposits from which samples were taken.

Sample 13 was taken by Mr. Phalen from an old greensand stock heap on the Howard Crossland place, on the Chesapeake & Delaware Canal, west of Delaware City.

Sample 14 was taken near the head of Silver Run from a 5-foot cut in the side of an old pit on the C. E. Pool place, formerly the Karsner place. This pit is about 20 feet deep to the water now standing

in it. The greensand at this point was reported by Booth¹ to have a thickness of 25 feet. The pit is said to have been last worked about 35 years ago. Its banks have fallen in and are overgrown with trees. The cut was made near the top of the greensand, where the bank was steepest and the talus thinnest. The upper 10 or 12 inches of the section sampled (sample 14B) is light green and resembles clay in grain and physical properties. The analysis shows it to contain 6.85 per cent of potash. The remainder of the sample represents dark-green sand with which are mixed many hard green and dark-red indurated slabs, averaging about one-half inch thick. This sample comes from the Rancocas formation. Booth² reports 8.50 per cent potash as the average of this pit.

Booth³ reports greensand on the S. Townsend place 23 feet thick, on the J. Vandegrift place, and on the Glazier place. These pits could not be located, but in searching for them greensand was noted at location 15, possibly not in place, for it appeared only as an irregular film over the bottoms of a branch of Silver Run. Sample 15 was taken at this place.

Sample 16 was taken not far from the place where sample 15 was obtained. Greensand at this place had been brought to the surface from a woodchuck burrow. The thickness and character of the sand is not known at either location 15 or 16.

There are a number of pits on both sides of the old State road north and south of the crossing of Drawyer Creek, and greensand is well exposed in a cut on the road north of the bridge. It appears to form the surface of the ground south of the bridge as far as the Drawyer Cemetery. Booth² reports the greensand as mined north of the creek on Mrs. L. Sims's farm east of the road and on the J. Rogers place west of the road. The freshest exposure seen was in the cut on the road at location 17, about 30 feet above sea level at the bridge. The greensand at this point appears to be confined to a narrow strip, for exposures in the cut on the west side of the road and in the hill above the point mentioned on the east side of the road show no greensand, but only yellow and red sand and the gravel of the Talbot formation of Quaternary age. Sample 17, taken at this place, represents a 6-foot cut.

The south prong of the north fork of Drawyer Creek is cut in the Monmouth formation, from a point west of the railroad, for a mile or more downstream. The greensand is exposed only at the creek

¹ Booth, J. C., *Memoir of the geological survey of the State of Delaware*, p. 55, Dover, 1841.

² *Idem*, p. 56.

³ *Idem*, pp. 54, 55.

level or for 1 or 2 feet above it. Samples 18 to 21 were taken at points along that branch.

Sample 18 was taken just east of the State road, between the road and the railroad track. It consisted of material from a 2-foot cut, 1 foot being taken above the water level of the stream and 1 foot taken below the water level.

Sample 19 was obtained from a woodchuck mound a few feet above the level of the stream bottom, a short distance east of the railroad.

Sample 20 was cut in the shallow bank of the stream, at and below water level.

Sample 21 was taken about 100 yards south of the bridge at this point, where about 10 feet of coarse yellow sand is exposed. This sand contains layers and patches of black sand, suggestive of oxidized glauconite. The sample analyzed consisted of portions of these black bands. Similar dark micaceous sand shows in the drains for some distance south of the bridge. Where sampled, the black material made up from 10 to 20 per cent of the whole.

Sample 22 was taken from a small exposure of high-grade greensand south of Drawyer Creek, at the point where the road from Odessa turns southeast. Only 2 feet of the greensand is exposed. It is overlain by a small thickness of yellow sand and gravel. This sample represents a 2-foot cut made at the side of the road.

Sample 23 was taken at the same point as sample 22, but it represents water-laid material taken from the bed of a little drain that was cut in the greensand at this point. The sample was taken in order to see what effect, if any, was produced on the material by erosion and transportation downstream, which possibly involved separation of the greensand from any associated clay and other matter that might have been carried away by the flowing water in which the sands were deposited. It was thought that this sample might show a concentration of the greensand and a somewhat higher percentage of potash. The analyses, however, show that the original deposit was so nearly pure glauconite that little or no concentration could take place, for they differ only by 0.02 per cent of potash and both show the highest percentage of any of the samples obtained, with the exception of the green clay that forms sample 14B.

About one-fourth of a mile south of the bridge on the east side of the road on which sample 22 was obtained a greater thickness of greensand is exposed, and the material that is revealed appears to belong stratigraphically above that sampled at location 22. Sample 24, which was taken at this place, represents a 6-foot cut. The greensand here appears to be less uniform than that at locality 22 and to be much harder; in part it is indurated with iron.

The Rancocas formation, from which samples 22 to 24 were taken, crops out along both forks of Appoquinimink Creek.

Sample 25 was cut in the bluff behind the wharf house at Odessa, just east of the old State road. The bank contains 15 to 18 feet of a red sand that is streaked with gray and locally hardened by iron. This sand has a faint greenish tinge, due to the presence of a small amount of glauconite.

Samples 26 and 27 represent two cuts on the north fork of Appoquinimink Creek, opposite the Reese mill, on the south side of the fork and beneath the floor of the old sand and gravel pit.

Sample 26 was taken from a 3-foot cut at the top of the bluff at this locality, and sample 27 from a 2-foot cut immediately below the 3-foot cut but made somewhat deeper into the face of the bluff. The upper cut contains many hard slabs, indurated with iron, which were absent in the lower cut and which presumably represent the results of incipient weathering.

MARYLAND.

In Maryland the greensand was sampled at only two points, which were selected after inquiry of the geologists who had worked over the area. The greensand at these points and that at Fort Washington, which was not sampled, was thought to be the most promising and to best fulfill the conditions of nearness to routes of transportation.

Two samples, 28 and 29, were cut in the cliffs on the north side of Severn River, in Anne Arundel County, about half a mile and 1 mile above the Annapolis Short Line bridge. The section shows from 30 to 70 feet of sand, most of which is a deep yellow brown at the surface. Many streaks of indurated sand are present. Toward the bottom the effects of weathering are less marked, and even at the exposed surface the sand has a greenish tinge. When examined with a hand lens, it has the appearance of pepper and salt. Two cuts, each 5 feet long, were made a fraction of a mile apart. The thickness of the greensand here is great, but it is uncertain to what extent it may be weathered, as the grain appears to be rather open. The sand at the bottom of the cliff runs low in potash, but the greensand could be readily separated from the coarse sand.

Samples 30 to 34 were taken in a long cut on the Chesapeake Beach Railway, in Prince Georges County, about halfway between Upper Marlboro station and Pennsylvania Junction. The face of the cut has a depth of about 30 feet, of which the upper 15 feet consists of sand and thin layers of gravel, deep reddish yellow at the top and reddish green at the bottom. This material is underlain by 15 feet or more of greensand. Sample 30 represents a 5-foot cut at the top of the greensand bed in the west end of the cut. This material is very fine grained and cuts like clay. Samples 31 and 32 are from a 2-foot cut made just below the last. Sample 31 was

taken directly in the surface of the railroad cut, where the material was obviously weathered; then a trench was dug 2 feet or more in depth to a point where the greensand had lost all appearance of weathering, and at the back of this trench sample 32 was taken. Samples 33 and 34 were cut at the east end of the cliff, sample 33 representing a 6-foot cut whose base was 4 feet above the track, and sample 34 a 3-foot cut just under the 6-foot cut. In both these samples the material cut like wet clay but broke like a sand. Sample 33 carried some streaks of ocher-yellow material, from which sample 34 was free, and sample 34 carried a considerable quantity of shell fragments, which doubtless gives it a high percentage of lime.

Traces of greensand occur in the long cut on the Pennsylvania Railroad south of Marlboro station. At one point, where sample 35 was taken, the cut exposes 10 feet or more of dark-drab and light-drab clay and brown sand, containing spots of bright greensand and locally flecks of cobalt-blue material, which was not studied but is supposed to be vivianite, or hydrous iron phosphate.

Two cuts were made on the bank beside the road, just north of the bridge at Marlboro. The section shows 10 feet of reddish-brown sand (Nanjemoy formation), 32 feet of coarse-grained olive-green sand, 2 feet of indurated greensand with shells, and 5 feet of unconsolidated greensand with shells. Sample 36 represents a 10-foot cut starting at the top of the 32-foot bed of greensand. Sample 37 represents a 5-foot cut starting 15 feet below the other. All of the section except the upper 10 feet are in the Paspotansa member of the Aquia formation.

Just west of this road cut are old openings that appear to have been extensive greensand pits.

Samples 38 and 39 represent the material from two 3-foot cuts, one above the other, made in the perpendicular bank of a small gully about a quarter of a mile west of the road cuts just described. This sand appeared to be less weathered at the surface than that at the road. The upper cut (sample 38) differed from the lower in showing traces of weathered pyrite, whereas the lower section showed much limonite.

VIRGINIA.

Three samples were taken in Virginia, all at the same locality in Henderson Bluff on Potomac River, 1 mile below the mouth of Aquia Creek, and about 6 miles east of Brooke station, on the Richmond, Fredericksburg & Potomac Railroad. A plant for drying and shipping the greensand has been put up at this point by B. L. Henderson, of Baltimore. This is the type locality of the Aquia formation. The section given by the Maryland Geological Survey is as follows:¹

¹ Maryland Geol. Survey, Eocene, p. 69, 1901.

Section on Potomac River below the mouth of Aquia Creek.

Pleistocene:	Feet.
Fine sand, light yellow, with white clay at base-----	26
Eocene:	
Aquia formation:	
Paspotansa member:	
Fine sand, light green; contains a few glauconite grains (zone 10)-----	10
Thick-bedded sandy and glauconite limestone (zone 9)-----	30
Fine sand, green or gray (zone 8)-----	30
Piscataway member:	
Dark greensand, containing broken shells (zone 7)	7
Dark greensand, containing whole shells (zone 6)	1
Light greensand, indurated (zone 5)-----	2
Greensand marl (zone 4)-----	8
Dark greensand, indurated (zone 3)-----	2
Greensand marl (zone 2)-----	16
	<hr/>
	132

Where the samples were cut, zone 2 has a greater thickness than that given in the section—at least 20 feet where samples 41 and 42 were cut and 22 feet where sample 40 was cut.

Sample 40 was taken from a 5-foot cut in the top of the 8-foot layer of greensand (zone 4) immediately back of the drying plant. Samples 41 and 42 were cut a short distance west of the plant. Sample 41 represents a 5-foot cut at the top of zone 2; sample 42 a 3-foot cut in the same bed, just above the shore. All the cuts include sands containing large quantities of shell fragments, so that the percentage of lime is probably from 50 to 75 per cent, necessarily greatly reducing the percentage of potash in the samples. The upper part of the section includes sands that show small percentages of glauconite. When crushed in the hand these sands suggest salt that has been slightly sprinkled with pepper.

NORTH CAROLINA.

The greensand of North Carolina was sampled at only one locality—a bluff 1 mile above Edwards Bridge, on the north side of Contentnea Creek, about 6 miles above Grifton, a station on the Atlantic Coast Line Railroad a few miles northeast of Kingston. The greensand at this point was said by L. W. Stephenson to appear to be much greener than any other that he had seen in the State. It is overlain by 6 to 8 feet of clay and yellow sand and gravel. The richer portion of the sand is 4 feet thick. Sample 43, taken at this locality, is a light-greenish sand, containing considerable quartz. Below the

layer sampled lies 8 feet of dark-gray sand, which here and there contains small stringers of greensand a few inches long and less than an inch thick. Sample 44 represents a 7-foot cut in this bed.

The greensand is reported to have been struck in ditches some distance north and east of this bluff. About a quarter of a mile above Edwards Bridge, nearly 5 feet of the lower bed is exposed in a bluff on the north bank. The greensand is overlain directly by the surface sand and gravel. The lower bed at this point is represented in sample 45.

TENNESSEE.

Troost,¹ the first State geologist of Tennessee, gave in his seventh annual report analyses of greensands from McNairy County, Tenn., showing from 10.10 to 11.30 per cent of potash. A preliminary study of this subject by the writer led to the belief that these analyses represented results not from samples of the bed as a whole but of selected grains of greensand, as appears to have been the custom at that period. Further, the analytical method then in use for the determination of the content of potash appears to have been faulty, and to have yielded too high a percentage of potash, even for the glauconite grains.

In Nashville the writer examined the samples of greensand (?) collected by Mr. Wade, of the State Geological Survey, in McNairy and adjacent counties, in a detailed study recently made of that area. None of the material so collected revealed any greensand under the hand lens. The writer then spent two days in examining railroad and road cuts in southeastern McNairy County without finding any trace of greensand. Most of the "sand" of the region seen in wells and the deeper railroad cuts is a dark, sandy shale, very dark when wet. Sample 46 came from a well nearly 5 miles northeast of Selmer.

Sample 47 represents the weathered surface material exposed in a road cut. All the soil of the region has a faint greenish-yellow tinge. Neither of the samples reveals any glauconite under the lens, though each contains considerable mica and possibly other potash-bearing material. The samples collected by Mr. Wade have been examined by Mr. Bowers, of the State Survey, who reports less than 3 per cent of potash.

ARKANSAS.

The only greensands in Arkansas that promised to be of value were represented by small specimens collected at Washington, Hempstead County, by L. W. Stephenson, which on analysis yielded 4.90

¹ Troost, Gerard, Seventh report of the geological survey of Tennessee, p. 30, 1844.

per cent potash. A suite of samples was therefore collected in that area, with the aid of Mr. William Taylor, of the Bureau of Soils, who was at that time making a survey of the soils of the county. The best exposure of sand was found in a road cut one-quarter of a mile or less east of the station at Washington. The section shows, from the top downward, 10 feet of greenish-gray sand, with bands of iron-stained sand; 7 feet of greenish-gray sand, of which sample 48 represents the upper 3 feet and sample 49 the lower 4 feet, which is much greener and richer than the top of the bed; 6 inches to 1 foot of calcareous hard greenish-gray sand; 4 feet of dark sand that has a pepper-and-salt appearance, from which sample 50 was obtained; 3 feet of dark sand containing much dark calcareous matter. Just east of Holz's store, on the J. R. Jones road, three sections were cut. Sample 51 represents 1 foot at the top of the section, including the oxidized red sand at the top of the road cut. Sample 52 represents a 2-foot cut immediately below the 1-foot cut, showing the same materials, only slightly weathered. Sample 53 is from a 3-foot cut, starting 1 foot below the bottom of the cut made for sample 52.

Samples 54 to 56 were taken in a road cut on the J. K. Jones road, about 3 miles from Washington. Sample 54 represents a 4-foot cut in the upper part of the section, sample 55 a 2-foot cut a few feet lower, and sample 56 a 3-foot cut at a horizon still lower.

The work of Mr. Taylor has shown an area of several square miles of greensand around Washington. The results of the sampling show that much of the greensand is low in potash, though sample 50 shows that some of the bed is, at least locally, fairly good.

ANALYSES OF GREENSANDS.

Results of analyses of the samples collected are given in the following table:

Analyses of greensands.

[W. B. Hicks and R. K. Bailey, analysts.]

No.	Locality.	Potas- sium.	Potash.	Analyst.
1	Farmingdale, N. J.	2.94	3.54	Hicks.
2	Freehold, N. J.	3.69	4.45	Do.
3	Marlboro, N. J.	3.69	4.45	Do.
4	do .....do	3.56	4.28	Do.
5	Vincentown, N. J.	3.10	3.74	Do.
6	do .....do	3.50	4.22	Do.
7	Pemberton, N. J.	3.50	4.22	Do.
8	do .....do	3.94	4.74	Do.
9	Birmingham, N. J.	5.85	7.07	Do.
10	Mullica Hill, N. J.	5.94	7.15	Do.
11	Sewell, N. J.	5.89	7.09	Do.
12	Laurel Springs, N. J.	5.31	6.40	Do.
13	2 miles west of Delaware City, Del.	2.80	3.36	Do.
14	Silver Run, Del.	5.10	6.15	Bailey.
14B	do .....do	5.69	6.85	Do.
15	do .....do	2.55	3.07	Do.

Analyses of greensands—Continued.

No.	Locality.	Potas- sium.	Potash.	Analyst.
16	Silver Run, Del.....	3.58	4.32	Bailey.
17	Drawyer Creek, Del.....	5.18	6.25	Do.
18	South prong of north fork of Drawyer Creek, Del.....	2.10	2.53	Do.
19	.....do.....	3.17	3.82	Do.
20	.....do.....	1.62	1.95	Do.
21	.....do.....	2.02	2.42	Do.
22	Drawyer Creek north of Odessa, Del.....	5.53	6.67	Do.
23	.....do.....	5.52	6.65	Do.
24	.....do.....	4.43	5.34	Do.
25	Odessa, Del.....	1.32	1.59	Do.
26	Appoquinimink Creek, Del.....	4.72	5.68	Do.
27	.....do.....	4.43	5.33	Do.
28	Severn River, Md.....	2.52	3.04	Hicks.
29	.....do.....	2.42	2.92	Do.
30	East of Upper Marlboro, Md.....	2.17	2.62	Do.
31	.....do.....	2.02	2.43	Do.
32	.....do.....	1.34	1.62	Do.
33	.....do.....	2.05	2.48	Do.
34	.....do.....	2.42	2.92	Do.
35	Marlboro, Md.....	3.69	4.45	Do.
36	.....do.....	3.15	3.79	Do.
37	.....do.....	2.76	3.32	Do.
38	.....do.....	3.21	3.86	Do.
39	.....do.....	1.73	2.08	Do.
40	Aquia Creek, Va.....	1.95	2.34	Do.
41	.....do.....	1.20	1.44	Do.
42	.....do.....	2.46	2.96	Bailey.
43	Contentnea Creek, N. C.....	1.14	1.37	Do.
44	.....do.....	1.12	1.35	Do.
45	.....do.....	1.95	2.35	Do.
46	East of Selmer, Tenn.....	1.69	2.18	Do.
47	.....do.....	2.67	3.22	Hicks.
48	Washington, Ark.....	3.68	4.43	Hicks and Bailey.
49	.....do.....	3.16	3.80	Hicks.
50	.....do.....	2.42	2.92	Do.
51	East of Washington, Ark.....	3.63	4.37	Hicks and Bailey.
52	.....do.....	3.57	4.30	Hicks.
53	.....do.....	3.76	4.53	Hicks and Bailey.
54	.....do.....	3.09	3.72	Bailey.
55	.....do.....	2.32	2.80	Do.
56	.....do.....			

Samples 1-13, inclusive, were collected by W. C. Phalen. Samples 14-56, inclusive, were collected by G. H. Ashley.

CONCLUSIONS.

From the above descriptions and analyses it is evident that, so far as present information goes, the best greensands are in New Jersey and Delaware; that the deposits in places have a maximum thickness of 20 or 30 feet, though as a rule it is less; that these deposits have a horizontal extent of many miles; that the quantity varies both in different parts of the section of the bed at the same place and from place to place; that in the main these beds outcrop at the surface and have a cover as a rule not more than their own thickness; that locally these deposits carry more than 7 per cent of potash, and that over large areas they carry from 5 to 7 per cent of potash; and that many of the deposits are close to transportation and so situated that they could be mined by dredge or steam shovel readily and cheaply.

The deposits examined south of Delaware are of lower grade. It is probable, however, that all of those examined have a sufficient extent for commercial use, if a cheap method of obtaining the potash can be found.

In view of the relative rapidity with which the potash becomes "available" or "soluble" when the greensand is used as a fertilizer in the ground, the question naturally arises as to whether the action of carbon dioxide, humic acid, or some of the other acids of the earth might not prove a possible solvent of the potash, for carbon dioxide could be readily obtained from limekilns in adjoining areas at little or no cost, and the product, if the process succeeded, would be in the form of potassium carbonate.

Experiments were made in dissolving the potash of the greensand in a solution of carbon dioxide. An automatic agitator was used and the tests lasted several hours. The solution contained such a small amount of potash, however, as to indicate that the process was not commercially feasible. Similar experiments, with like results, were carried on with sulphur dioxide, which could be obtained as a by-product from the smelters, and dilute hydrochloric acid also failed to give results of value.

As the subject of the processes of possible utilization of the greensands in the production of commercial potash is not within the province of this paper, no detailed study of the subject was made, and the experiments referred to were merely incidental to the analytical work, so that they may not be conclusive. The results obtained, however, do not lend hope to the successful use of such methods.

The concentration of the glauconite of the greensand by electric magnets should be entirely feasible, by employing possibly such methods as are to-day in use in concentrating low-grade ferruginous zinc ores. The chapters on potash salts in *Mineral Resources of the United States for 1913 to 1915* contain descriptions of methods proposed for the commercial extraction of potash from many of the minerals and rocks that contain it. The advantage of greensand over feldspars lies in its abundance and possible low first cost, exclusive of freight.



METHODS OF ANALYSIS OF GREENSAND.

By W. B. HICKS and R. K. BAILEY.

INTRODUCTION.

Owing to the fact that wide variation in the potash content of greensand marls is shown by several reports on the subject, it seems desirable to bring together here a brief summary of the methods of analysis that have previously been used, together with the method used in the present investigation. This comparison will explain the lack of concordance and will bring out more or less clearly the results which are not to be trusted on account of defective methods. Furthermore, the procedure which we have used is a departure from the usual methods of determining potash in silicate rocks and therefore requires description.

EARLIER METHODS.

ROGERS'S METHOD.

In his report on the greensand marls of New Jersey, Rogers¹ presented the results of a great many analyses of purified glauconite grains. By his method the sample was digested in a flask with rather strong hydrochloric acid for three days, or was boiled vigorously for five or six hours. The solution was filtered, and the undissolved portion was weighed and reported as silica. The iron and alumina were precipitated from the filtrate by ammonia and were separated from each other by caustic soda. The ammonium salts were removed by evaporating the solution to dryness and igniting the residue. The residue after ignition, which was assumed to consist of chlorides of calcium, magnesium, and potassium, was weighed, dissolved in water, diluted to definite volume, and divided in half. In one portion the calcium was precipitated as oxalate and determined as oxide, and the magnesium was determined as pyrophos-

¹ Rogers, H. D., Description of the geology of the State of New Jersey, pp. 186-216, 1840.

phate. Their equivalents as chlorides were subtracted from the weight of the combined chlorides and the remainder reported as potassium chloride. As a check determination of the potassium, the second portion of the solution was evaporated to dryness, the dry chlorides were extracted with alcohol to remove the calcium and magnesium, and the residue was weighed and reported as potassium chloride. It is stated that when necessary the salt was converted into potassium chloroplatinate and weighed, but no information is given as to which, if any, of the determinations were actually made according to the chloroplatinate method.

A great many analyses of carefully picked and purified greensand grains gave on an average 11.5 per cent of potash (K_2O), 0.5 per cent of lime (CaO), and a trace of magnesia (MgO). Soda is not reported. The high value for potash is evidently due to the defective methods of analysis. It seems certain that the soda is reported as potash and probably also a large portion of the magnesia and some of the silica, except in those results obtained by the chloroplatinate method. As there is no way of differentiating between the good and bad, all the results for potash in this report should be considered unreliable.

KOCH AND SMOCK'S METHOD.

In Cook's report¹ the analyses represent the material as it came from the pit and were made by Julius Koch and John C. Smock. Although the methods are very vaguely described, it appears that Koch decomposed the marl by digestion with hydrochloric acid, precipitated the iron and alumina by ammonia, removed the calcium by precipitation as calcium oxalate, separated the magnesium as oxide by means of a solution of barium hydrate and acetate, removed the excess of barium by sulphuric acid, evaporated the filtrate to dryness, and finally ignited and weighed the residual potassium sulphate. Smock decomposed the marl by digestion with hydrochloric acid, precipitated the iron and alumina by ammonia, and determined the potash as chloroplatinate after removing the ammonium salts and probably also the calcium and magnesium.

The digestion with hydrochloric acid would probably decompose the glauconite completely and take into solution the potash contained in it, but would not attack materially the feldspar and other potash minerals likely to be present. This method would tend to give low results for total potash when potash minerals other than glauconite were present. Unless a double precipitation was made, the iron precipitate would hold back some of the potash, causing low results in both methods. Koch weighed sodium sulphate and probably

¹ Cook, G. H., *Geology of New Jersey*, pp. 414-470, 1868.

some magnesium sulphate and silica with the potassium sulphate, which no doubt caused high results. On the whole, however, the errors tend to balance each other. Smock, who used the chloroplatinate method, should have obtained more trustworthy results.

METHODS USED BY THE UNITED STATES GEOLOGICAL SURVEY.

PROCEDURE.

For several years a modified chloroplatinate method for the determination of potash has been used by the Geological Survey, more especially in those determinations relating to the search for potash.¹ This procedure is applicable in the presence of sulphates, the alkali-earth metals, and small quantities of aluminum, iron, silica, and other substances. A further modification of this method here described is applicable in the presence of large quantities of iron and aluminum and has been adapted especially for the determination of potash in glauconite. It is much shorter than any other known method, and the results obtained by its use are in close agreement with those obtained by the J. Lawrence Smith method.² It was adopted after many preliminary experiments.

The mineral is decomposed by hydrofluoric and sulphuric acids, the excess of acids expelled by gentle ignition, and the residue dissolved in dilute hydrochloric acid. The solution thus obtained is evaporated to dryness in the presence of a slight excess of chloroplatinic acid. The residue is washed with 95 per cent alcohol containing 20 cubic centimeters of concentrated hydrochloric acid in a liter in order to remove the excess of chloroplatinic acid and soluble chloroplatinates. It is then washed through the filter with hot water, the potassium chloroplatinate reduced to metallic platinum by means of magnesium, and the platinum weighed. From the weight of the platinum the weight of potash is calculated.

Weigh out a half-gram sample of the mineral which has been ground to pass a 200-mesh sieve, place in a small platinum dish or a large platinum crucible, moisten with a few drops of water, and add about 10 cubic centimeters of hydrofluoric acid and the equivalent of about half a cubic centimeter of concentrated sulphuric acid. Hold the dish with the tongs and heat it and its contents cautiously over the free flame until the mineral is broken up and apparently completely decomposed, which requires only a very few minutes.

¹ Hicks, W. B., *Jour. Ind. Eng. Chemistry*, vol. 5, p. 650, 1913.

² *Am. Jour. Sci.*, 3d ser., vol. 1, p. 269, 1871; *Am. Chemist*, vol. 1, 1871; *Annalen der Chemie und Pharmacie*, vol. 159, p. 82, 1872. Hillebrand, W. F., *U. S. Geol. Survey Bull.* 422, p. 171, 1910 (reprinted, 1916).

The dark color due to organic matter should be disregarded. Evaporate the solution on the steam bath to complete dryness, and during this operation agitate the solution occasionally by giving the dish a gyratory motion with the tongs. This treatment is nearly always sufficient to decompose the mineral, but if decomposition seems incomplete add more hydrofluoric acid and evaporate a second time, agitating the mixture frequently. Heat the dish and its contents on a radiator¹ to expel the excess of hydrofluoric and sulphuric acids. Finally ignite gently to make sure of the complete removal of ammonium salts and to destroy organic matter. This operation will also expel much of the sulphuric acid combined with the iron and aluminum, but care should be taken not to heat high enough to render the iron and aluminum insoluble in hydrochloric acid. Cover the residue with dilute hydrochloric acid, which must be free from ammonium salts, and digest on the steam bath until solution is complete, adding more water and acid if necessary. Flakes of organic matter and a few grains of sand which remain undissolved may be neglected, but large amounts of undissolved calcium sulphate should be brought into solution.

The solution of the completely decomposed mineral is now filtered into a small Jena glass or porcelain evaporating dish, chloroplatinic acid slightly in excess of that necessary to combine with all the potassium present is added, and the solution evaporated on the steam bath until nearly all the hydrochloric acid is removed and the mass solidifies on cooling. Cover the residue with an alcohol-acid solution prepared by adding 20 cubic centimeters of concentrated hydrochloric acid to 1 liter of 95 per cent alcohol. Chloroplatinic acid and its soluble salts are likely to be occluded in the ferric sulphate and basic salts formed on evaporation, making their complete removal troublesome. The acid in the alcohol wash liquid tends to correct this difficulty by destroying the basic salts and changing a portion of the ferric sulphate into chloride, which is readily soluble in alcohol. If the residue is amorphous stir up the mixture gently with a glass rod made into a pestle and allow it to stand until it becomes crystalline, then grind up the residue thoroughly with the pestle and allow it to stand a half hour, or until it becomes quite crystalline. Decant the solution through a filter paper. Grind the residue thoroughly with the pestle, add 10 cubic centimeters of the alcohol-acid wash solution, stir thoroughly, allow the suspension to settle, and decant the solution through the paper. Continue the washing by decantation, using small portions of the alcohol-acid solution and thoroughly stirring up

¹ Hillebrand, W. F., U. S. Geol. Survey Bull. 422, p. 31, 1910 (reprinted, 1916). A large porcelain crucible serves well as a radiator for this purpose.

the residue after each treatment, until the excess of chloroplatinic acid has been completely removed, but be careful to keep the quantity of wash liquid around 75 cubic centimeters.

Dissolve the residue, which consists of potassium chloroplatinate mixed with salts of iron, aluminum, calcium, sodium, and other metals, in hot water, and wash the solution through the filter into a convenient-sized beaker. Acidify with hydrochloric acid, heat almost to boiling, and reduce the chloroplatinate to platinum by stirring the solution with a wad of magnesium ribbon held on the end of a glass rod, taking care to keep the solution slightly acid. About 1 cubic centimeter of concentrated hydrochloric acid and 0.5 gram magnesium should be added for each 0.2 gram of potassium present. After the complete reduction of the platinum and the complete solution of the magnesium allow the mixture to stand on the hot plate for an hour or so. The platinum will coagulate on the bottom of the beaker, and the solution will become colorless and limpid like water. To make sure of complete reduction add more magnesium, when, if reduction is incomplete, the solution will darken. Finally add strong hydrochloric acid, boil the solution, filter through paper, and wash thoroughly with hot water. The platinum is then ignited in a small porcelain crucible, cooled in a desiccator, and weighed. The weight of platinum multiplied by 0.4826 gives the weight of potassium as the oxide, K_2O .

PRECAUTIONS TO BE OBSERVED.

Pure glauconite is readily brought into solution by hydrofluoric acid, and the associated minerals are usually decomposed with little difficulty. If care is taken, after the expulsion of the excess of hydrofluoric and sulphuric acids, to insure complete solution in hydrochloric acid, no error should result from this part of the operation. The resulting solution, which contains all the iron and aluminum of the mineral, usually leaves a gummy residue on evaporation with chloroplatinic acid. On treatment with the alcohol-acid wash liquid, the residue often assumes the amorphous or noncrystalline condition. In this event the mixture should be set aside and the mass allowed to become crystalline; otherwise the washing can not be done successfully. The crystalline residue should be ground finely to enable the wash liquid to get at any inclosed soluble chloroplatinates, and special care must be taken to insure complete washing of the residue with a minimum amount of the alcohol-acid wash liquid. Therein lies one of the chief sources of error in the method. If all the soluble chloroplatinates are not removed the results, of course, will be too high and this error may be considerable unless special pains are taken to grind up all the lumps and to wash thoroughly. On the

other hand, if too much wash liquid is used the results are likely to be too low, because of the solubility of potassium chloroplatinate in alcohol acidified with hydrochloric acid. This error is not likely to be large, but the wash liquid should be kept around 75 cubic centimeters.

The solution containing the potassium chloroplatinate mixed with iron and other salts, which was obtained by washing the residue through the filter with hot water, should be kept sufficiently acid to prevent the formation of basic iron salts during the subsequent reduction of the platinum; otherwise the precipitate may be contaminated with iron. As a further precaution the solution containing the precipitated platinum should be acidified with strong hydrochloric acid and boiled just before filtering. Of course, the platinum must be completely reduced.

SOLUBILITY OF POTASSIUM CHLOROPLATINATE IN ALCOHOL ACIDIFIED WITH HYDROCHLORIC ACID.

An approximate determination of the solubility of potassium chloroplatinate in alcohol acidified with hydrochloric acid was made in order to determine whether or not such a solution could be used as a wash liquid in potash determinations. The potassium chloroplatinate was prepared by adding a slight excess of chloroplatinic acid to a strong solution of pure potassium chloride. The solution was filtered and the residue was washed with alcohol. After drying the potassium chloroplatinate so obtained was recrystallized from water, dried at 130° C., and preserved for use.

The solubility determinations were made by taking 550 cubic centimeters of the alcohol-acid mixture in a 1-liter glass-stoppered bottle, to which about 4 grams of potassium chloroplatinate were added. The stopper was inserted and sealed with paraffin. The bottle was then placed in a shaking machine and shaken violently end over end for 7 to 14 hours. The undissolved portion was allowed to settle, the solution was filtered, and 500 cubic centimeters of the filtrate were evaporated to dryness on the water bath. The residue was dissolved in hot water, and the platinum reduced to metal with magnesium and finally weighed. The acidity was determined by titrating 10 cubic centimeters of the filtrate with tenth-normal sodium hydroxide solution, using phenolphthalein as indicator. The approximate strength of alcohol was calculated from the quantity of 95 per cent alcohol and concentrated hydrochloric acid used in each mixture. The temperature at which the determinations were made was approximately 25° C. By this procedure the following results for the solubility of potassium chloroplatinate in alcohol acidified with hydrochloric acid were obtained:

Solubility of potassium chloroplatinate in alcohol acidified with hydrochloric acid.

No.	Time of shaking (hours).	Solution (cubic centimeters).	Platinum (gram).	K ₂ PtCl ₆ (gram).	Solubility.		HCl per liter (grams).	Approximate strength of alcohol (per cent by volume).
					Gram per liter.	Solution dissolving 1 gram of K ₂ PtCl ₆ (cubic centimeters).		
1	7	500	0.0078	0.0194	0.0388	25,800	6.82	93
2	14	500	.0081	.0201	.0402	24,880	6.82	93
3	14	500	.0152	.0379	.0758	13,190	13.40	91.5

The first two determinations recorded in the table are duplicates except for the time of shaking. The alcohol-acid mixture was prepared by adding 20 cubic centimeters of concentrated hydrochloric acid to 1 liter of 95 per cent alcohol. The acidity of the solution, which was determined by titration, was 6.82 grams of hydrochloric acid per liter, and the strength of the alcohol was calculated to be approximately 93 per cent. The mean of the two determinations gave for the solubility of potassium chloroplatinate in the solution 0.0395 gram per liter—that is, 1 gram of potassium chloroplatinate was dissolved by 25,340 cubic centimeters of the alcohol-acid mixture. The solubility of potassium chloroplatinate in 80 per cent alcohol, which is usually recommended for washing, is about 1 gram in 26,400 cubic centimeters of alcohol.¹ The solubilities are of the same order and the difference is of no significance in the determination of potash.

The third determination shows that the solubility increases rapidly with the acidity. Therefore care should be taken not to use a wash liquid containing more than 20 cubic centimeters of hydrochloric acid in a liter of 95 per cent alcohol.

COMPARISON OF RESULTS BY DIFFERENT METHODS.

Potash was determined in a number of glauconite samples by the hydrofluoric acid method described by Treadwell,² as the procedure is very short. The method was abandoned, however, as the results were soon found to be too low. The values actually obtained are given in the table below for the purpose of comparison. In order to check results and to give experimental proof of the reliability of the new method which has been developed the potash in a number of glauconite samples was determined by the J. Lawrence Smith method and by the new method described on page 53. The results are presented in the table on page 58.

¹Precht, H., Zeitschr. anal. Chemie, Jahrg. 18, p. 513, 1879.

²Treadwell, F. P., Analytical chemistry, vol. 2, p. 397, New York, John Wiley & Sons, 1909.

Percentage of potash in glauconite determined by different methods.

No.	J. Lawrence Smith method. ^a	New method.	Hydrofluoric acid method. ^b	No.	J. Lawrence Smith method. ^a	New method.	Hydrofluoric acid method. ^b
1.....	3.62	3.54 3.53	.....	11.....	7.13	7.08 7.06	6.22
2.....	4.46 4.48	4.30 4.54	.....	12.....	6.45	6.36 6.38	5.66
3.....	4.48	4.46 4.40	.....	40.....	2.10	2.07	.....
8.....	4.70	4.78 4.74	.....	41.....	2.50 c 2.56	2.41 2.27 c 2.35	.....
9.....	7.08	6.98	6.26	42.....	1.45 c 1.50	1.52 1.35 c 1.35	.....
10.....	7.18 7.20	7.00 7.10 7.24 7.16	6.01	44.....	c 1.31	c 1.29	.....
				X ^d	7.12 6.99	7.04 7.06	6.64

^a Hillebrand, W. F., The analysis of silicate and carbonate rocks: U. S. Geol. Survey Bull. 422, p. 171, 1910 (reprinted, 1916).

^b Treadwell, F. P., Analytical chemistry, vol. 2, p. 397, 1909.

^c Determinations by R. K. Bailey.

^d Practically pure glauconite grains separated from sample 36 by an electromagnet.

By reference to the table it will be observed that the results by the hydrofluoric acid method are considerably lower than those by the other two methods. In the hydrofluoric acid method the sulphate, iron, aluminum, calcium, and other substances were precipitated and removed in one operation. The precipitate, no doubt, retains considerable potash, which is exceedingly difficult to remove by washing. This explains the low results. The data show that this method is not satisfactory when the precipitate is large, especially if considerable potash is present.

It will be observed also that nearly all the results by the other two methods agree very closely. No. 41 shows the widest variation. In general the results by the new method are a little lower than those by the J. Lawrence Smith method, and the variations among themselves are more pronounced. Although the new method requires care and experience in manipulation and gives little lower and slightly more discordant results than the J. Lawrence Smith method, it is believed to be accurate enough for commercial work, and probably for all purposes except where extreme accuracy is desired. The procedure is much shorter than any other known method for determining potash in silicate rocks, and admits of carrying out several analyses simultaneously.

Practically all the determinations presented in this report have been carried out in duplicate by the new method, and it is believed that the results are very nearly correct, the maximum deviation being about 0.2 per cent.