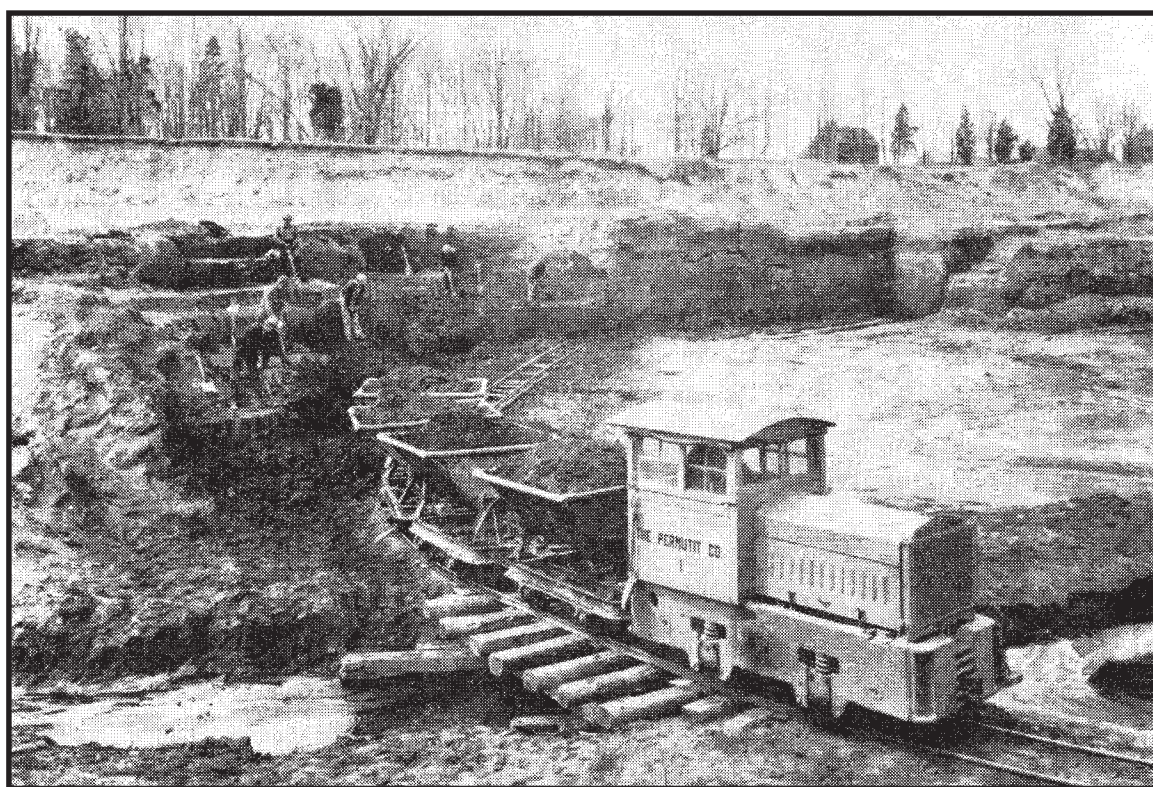


# Greensand and Greensand Soils of New Jersey: A Review



Greensand pit Birmingham, New Jersey

Courtesy Permutit Company

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# Foreword

New Jersey has some 325,000 acres of greensand (glaucanite-bearing) soils that extend from Monmouth County southwestward through Salem County. This belt of land has been recognized as one having prized agricultural soils since colonial days. Following is a review of earlier research concerning the function of glauconite in the soil, and then the report goes into some detail describing New Jersey conditions.

Numerous publications suggest that the potassium in glauconite is the main reason as to why glauconite-bearing soils are so favorable for crop growth. Such a viewpoint, however, has never been convincingly demonstrated to be factual. The beneficial effects of glauconite in the soil appear to be closely related to a combination of factors such as effecting a high sorptive capacity for soil nutrients and a relatively high moisture retention capacity. Glauconite also produces general ameliorative effects within the soil. Further, some glauconite-bearing deposits (greensands) are rich in available calcium and phosphorus.

Apart from agriculture, in more recent years there has been public concern for the high levels of certain heavy metals present in some of the greensand soils of the State. This report makes some preliminary statements concerning the quantity and function of select heavy metals present in soils and suggests methodologies for recognizing and evaluating problem sites.

Geologist J.H. Dooley kindly made a critical review of the entire manuscript and offered many constructive comments. Accordingly, I owe him many thanks for his untiring contribution. Dr. Stephanie L. Murphy was also most helpful in bringing this report to fruition. Ms. Zehdra Allen-Lafayette produced the geologic map (Fig. 7). Mr. J. A. Bognar constructed the map showing locations of the former greensand pits of New Jersey (Fig. 11). Ms. Helena Brody served as an untiring and patient typist of the report. Credit is also extended to Mr. Brian Parish of Desktop Publishing for bringing the report to the stage of publication.

J.C.F.T.

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## Historical Developments

The desirable properties of glauconite-bearing soils and the addition of greensand to land for the enhancement of agricultural productivity have long been recognized in New Jersey and elsewhere. During the 1760's, greensand was already being applied to farm fields in Monmouth County with beneficial results. J.B. Crawford, who applied greensand to his fields in the Nut Swamp area near Holmdel, stated that 44 years later, the fields continued to show improvement from the additions (Cook, 1868). Pierce (1823) also reported that a considerable portion of the land in Monmouth County had been rendered very productive by the addition of greensand. Cook (1868) stated that the addition of [greensand] marl was of incalculable value and raised the land from the lowest state of exhaustion to a high state of improvement. Gordon's History and Gazetteer of New Jersey of 1830 stated that the addition of greensand to farm fields had saved some districts from depopulation, and may one day contribute to the conversion of the sandy pine deserts [Pine Barrens] into regions of agricultural wealth. Cook (1868) came to similar conclusions and, accordingly, stated:

1. The most valuable [greensand] marls are those which contain the largest percentages of phosphoric acid.
2. The most durable marls are those containing carbonate of lime.
3. Greensands containing phosphoric acid or carbonate of lime become active fertilizers when composted with quick lime.
4. Marls that are acid and burning from containing sulfate of iron can be rendered useful as fertilizers by composting with lime.
5. Crops particularly improved by marl are forage crops, grass, clover, etc.; for these the green marl may be spread upon the surface at a rate of 100 to 400 bushels [5-20 tons] per acre. The crop yield is generally doubled,

and in some cases quadrupled by this application.

Cook (1868) reported that during the early stages in the use of marl, it was thought that the beneficial effects were due to their potash content, but it was later discovered that some of the marls containing sufficient potash were "totally worthless as fertilizer".

During early agricultural development in New Jersey, 25 to 50 tons of greensand were generally applied per acre, but rates as high as 100 tons per acre were not uncommon. There were even instances of as much as 250 cartloads (tons?) per acre being added to the land. During the mid 1880s, nearly 1,000,000 tons of greensand were applied annually to New Jersey farms, but by the end of the century, production had declined greatly. During World War I, when German potash supplies to the United States were cut off, there was renewal of the greensand industry in New Jersey. But by the mid 1950s, greensand use had again greatly dwindled with most of it being marketed as a "soil conditioner".

In Virginia, Ruffin (1842) described the beneficial effects from greensand application to the land. Most of his experiments were with shell-bearing greensands, therefore it is uncertain as to whether the increased yields of crops were mainly due to glauconite or from the carbonate-bearing shells in the greensands.

Greensands were also recognized as a valuable ingredient in other parts of the globe, particularly England, France, Germany, Hungary, Belgium, Russia, Australia, New Zealand, and Japan. Morton (1842) stated that in England, the greensand soils were under the highest degree of cultivation and formed "the best garden land in the kingdom". Paine and Way (1848), in discussing the desirable agricultural properties of soils developed from greensand marl in England, stated that the yield of hops was ten times the average of the otherwise best soils. They stated further that the best greensand soils were those rich in phosphoric acid.



## Formation and Properties of Glaucinite

Introduction of the term glauconite is generally credited to Brongniart (1823) in France and Keferstein (1828) in Germany, but even before this time frame, the terms greensand and green earth had already been used by a number of investigators. The term glauconite is probably from the Greek glaukos meaning bluish green (McRae, 1972). Cloud (1955), however, stated that possibly the term could have been derived from the mythical fisherman Glaucus.

Glaucinite is a finely divided, dioctahedral micaceous mineral of marine origin. While globally it is present in deposits dating from the pre-Cambrian to the present, in New Jersey it is concentrated in the Cretaceous and lower Tertiary-age deposits. The origin, properties, and distribution of glauconite have been detailed by many investigators such as Murray and Renard (1891), Ross (1926), Hadding (1932), Galliher (1935), Hendricks and Ross (1941), Smulikowski (1954), Cloud (1955), Warshaw (1957), Burst (1958), Hower (1961), Grim (1968), Tapper and Fanning (1968), McRae (1972), Fanning et al. (1989), among others. Grim (l.c.) states "Glaucinite forms during marine diagenesis at times of slow or negative sedimentation, and in relatively shallow [marine] water. It is generally believed the presence of montmorillonite is required for glauconite formation. In addition, peculiar reducing conditions and concentrations of magnesium and alkalies seems to be essential for its formation."

Takhashi (1939) stated that glauconite may also originate from organic opaline silica, feldspars, and pyroxenes. Reports on the New Jersey glauconite deposits have been detailed by Cook (1868, 1887), Clark (1894), Mansfield (1923), Bader and Wolfe (1948), Light (1950), Owens and Minard (1960), Markewicz and Lodding (1983), Dooley (1998, 2001), and others.

Use of the terms glauconite, greensand, greensand marl and lime marl as used in this report follows:

Glaucinite - A term used to describe predominantly sand-size, generally greenish aggregates found in unconsolidated deposits and sedimentary rocks and also as an iron-rich, mica-like mineral analogous of an illite. The mineral is rich in iron and consists of various colors: green, yellow, blueish, red, or black. Some glauconite may be nearly colorless.

Greensand - A predominantly sand-sized deposit, generally unconsolidated, that is usually green owing to a considerable proportion of glauconite.

Greensand marl - A loosely used term to describe unconsolidated deposits rich in glauconite.

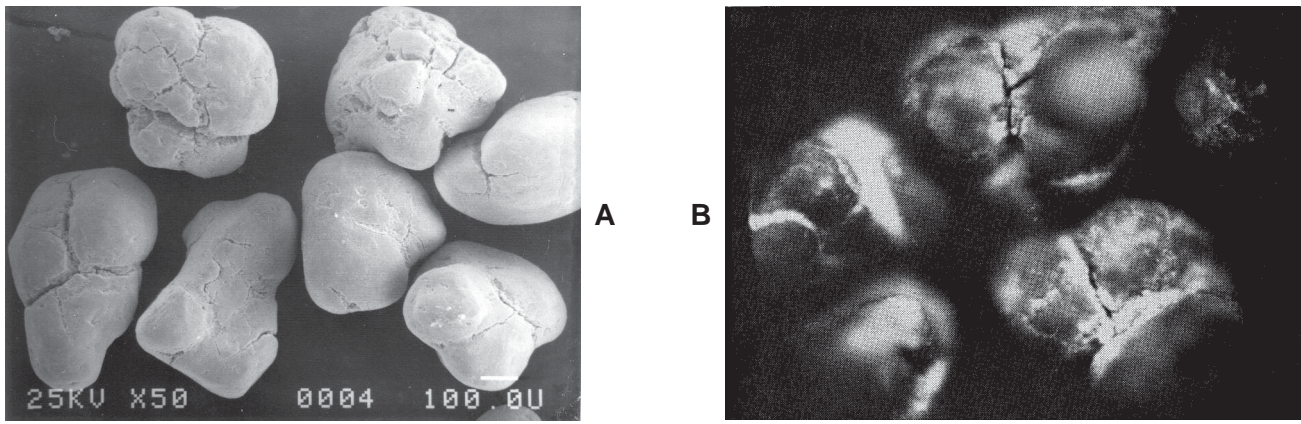
Lime marl - A generalized term applied to loose, earthy deposits containing a relatively high proportion of calcium carbonate or dolomite (Bader and Wolfe, l.c.). Within the Coastal Plain of New Jersey, the lime marls are rich in fossil shells as well as glauconite.

Other terms such as clay marl, sand marl, and lime sand marl have also been used to describe certain glauconite-bearing deposits. Further, terms such as black marl, poison marl, ash marl, and acid marl have been used to describe greensands having strongly acidic properties.

Glaucinite deposits, as exemplified by New Jersey conditions, are generally unconsolidated but, in many parts of the globe the glauconite is a constituent of consolidated rock types such as sandstone, shale, limestone and dolomite.

## Physical Features of Glaucinite

Unlike the sand-size fractions of most soils in which particles consist of discrete minerals such as quartz, orthoclase, calcite, etc., with glauconite the sand-size particles are made up of relatively stable pellets of clay-size mica. The pellets generally range from about 0.5 to 0.05 mm in diameter (Fig. 1A) with some being as much as 4 mm. Figure 1B shows the botryoidal appearance of the sand-size glauconite pellets. Individual spheres within the aggregates consist of glauco-



**Fig. 1. A,** Electronmicrograph of glauconite pellets from the Hornerstown formation (Photograph by R. Holzer). **B,** Micrograph of glauconite from the Hornerstown formation. The pellets consist of dark green sand-size aggregates of glauconite with a grayish clay substance cement. 55x.

nite cemented with clay-size siderite. It is generally believed that some glauconite pellets form primarily as clay fillings in marine shells (Fig. 2).

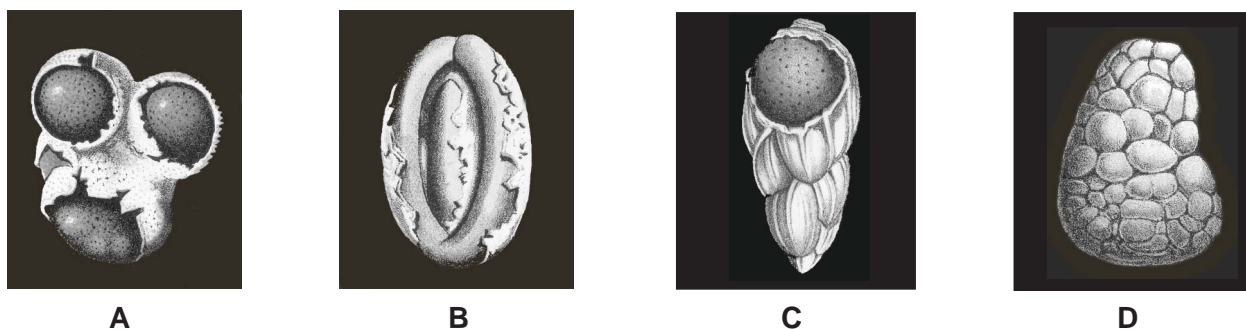
Hadding (l.c.) showed that whereas glauconite occurs primarily as large, rounded pellets and clusters of sand-size aggregates, the glauconite also occurs as clay-size flakes of micaceous material. Owens and Minard (l.c.), divided New Jersey glauconites into primary and reworked varieties, with the latter subdivided into marine detrital and fluvial detrital. Galliher (l.c.) has shown that some glauconite has formed in shallow seas as an alteration product of biotite.

Illite and muscovite generally have hardnesses of 2.0 to 2.5 whereas that of glauconite approximates 2.0 to 2.3 (Hutton and Seelye, 1941). With the physical makeup of greensand, the question arises as to whether hardness of the aggregate or that of the mica flakes is being measured. Further, some of the pellets appear soft and un-

altered and can be crushed with the fingernail, but others may be cemented with iron, calcium, or phosphate minerals which affect the hardness of the pellets.

The specific gravity of glauconite ranges from 2.3 to 2.9 depending upon composition and the degree of drying. McRae (l.c.) detailed the internal morphology of glauconite pellets such as the presence of homogenous aggregates, lamellar aggregates, grain coatings, inclusions and others.

Glauconite imparts special moisture relationships in soils. For example, Fig. 3 shows the amount of water retained in various materials at different tensions. It will be noticed that Sassafras silt loam, a soil formed predominantly on a quartz-feldspar mixture, retains only about 8% moisture at a tension of 15 atm. On the other hand, the Marlton "sandy loam" soil, consisting primarily of glauconite, retains about 14% moisture at 15 atm tension. Further, the Hornerstown



**Fig. 2.** Glauconite casts in various marine shells. Reproduced from reports of the Challenger Expedition. A, B, and C, glauconite casts; D, glauconite-like particles.

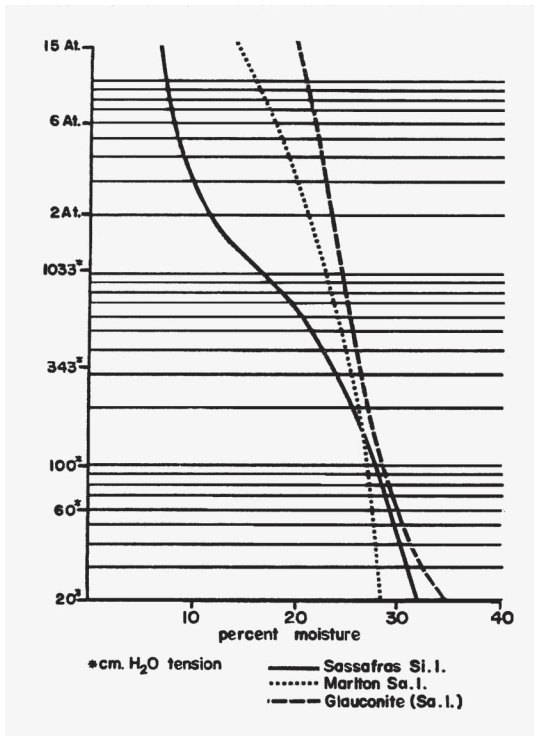


Fig. 3. Moisture release curves of glauconite and selected soils at various tensions. The Sassafras soil is glauconite free. The Marlton soil is high in glauconite. (Tedrow, 1986.)

greensand retains some 20% moisture at 15 atm tension. Table 1 shows additional information concerning the influence of glauconite on the moisture retention properties of soils. As the glauconite content of the various soils increases, the moisture content at a given tension also increases.

In virtually all situations, glauconite in soils is present in sizes ranging from several millimeters to less than 1 micron. Mansfield (1923) showed the sizes of the glauconite fractions (and probably a little quartz etc.) in a greensand sample from New Jersey (Tab. 2). It will be noted that the glauconite is concentrated in the 20 - 60 mesh (0.84 - 0.25mm) size range. Figure 4 shows the particle-size range together with the amount of glauconite in Marlton soil. The five coarser fractions (a,b,c,d,and e) were determined microscopically. The two finer fractions were estimated by x-ray diffraction.

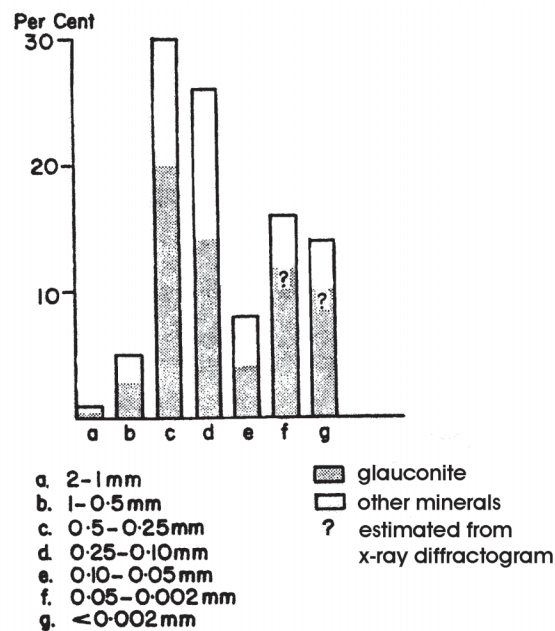
McRae (l.c.) and Tapper and Fanning (l.c.) detailed the internal morphology of glauconite pel-

Table 1. Quantity of Moisture Retained in Various Soils and Greensand Deposits at Two Tension Levels (unpublished data of Prof. N. A. Willits).

	6 Atm. Tension (%)	15 Atm. Tension (%)
Sassafras medium sand fraction (A <sub>2</sub> ) (no glauconite)	2.3	1.3
Colts Neck medium sand fraction (A <sub>2</sub> ) (<5% glauconite)	2.4	1.6
Freehold loam (A) (low glauconite)	-	10.0
Marlton loam (A <sub>2</sub> ) (high glauconite)	-	15.0
Hornerstown glauconite (bankrun)	-	15.0
Hornerstown glauconite (bankrun-medium sand)	13.9	13.5
Hornerstown glauconite (bankrun-fine sand)	20.0	16.4

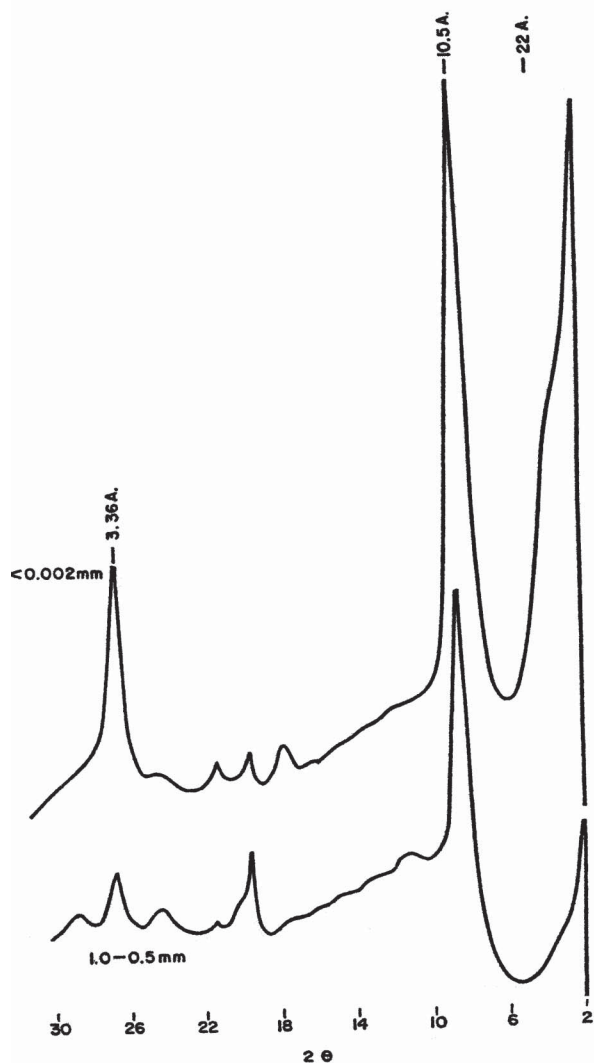
**Table 2. Sizes of Grains of Glauconite, Quartz, etc. in Washed Greensand From New Jersey (Mansfield, 1923).**

	Glauconite			Quartz and others		
	Quantity in sample (gms)	Quantity held on sieves	gms.	Quantity in sample (gms)	Quantity held on sieves	gms.
		mesh			mesh	
Salem area (G-1A)	8.87	200	0.30	1.29	20	0.16
		40	4.80		40	0.47
		60	2.85		60	0.45
		80	0.59		80	0.17
		100	0.29		100	0.09
		100+	0.03		100+	0.02
Pemberton area (G-15A)	5.27	20	0.09	4.79	20	0.18
		40	1.22		40	0.74
		60	1.69		60	0.66
		80	0.87		80	0.72
		100	0.80		100	0.95
		100+	0.62		100+	1.55

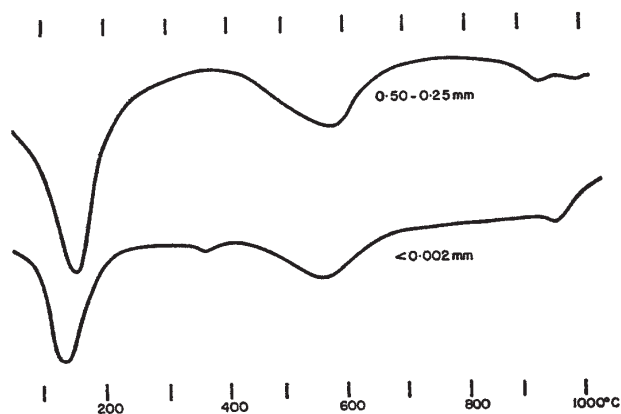


**Fig. 4.** Histogram of Marlton topsoil showing the quantity of glauconite present in various size fractions. (Tedrow, 1986).





**Fig. 5.** X-ray diffractograms of sand-size glauconite and of clay-size glauconite from the Hornerstown Formation. (Tedrow, 1986).



**Fig. 6.** Differential thermal analyses of glauconite from the Hornerstown Formation. (Tedrow, 1986).

lets. Since the pellets consist of aggregated flakes of mica rather than single crystals, there are micropores present within the matrices of the pellets. These same authors point out that some similar-appearing glauconite pellets will float in heavy liquids, but other pellets will sink. If one air dries sand-size glauconite and then immerses it in water, there generally is a bubbling effect as air is expelled from the pellets, indicating that the glauconite pellets have an internal microcosm of micropores. This structure is believed to be partially responsible for the unusually large moisture retention capacity of the glauconite pellets.

### Mineralogical Properties of Glauconite

Glauconite is a hydrous potassium aluminium silicate mineral with a crystalline structure similar to that of illite and/or muscovite. The mineral composition of sand-sized glauconite is virtually identical to that of clay-sized glauconite. In order to show that the mineral composition of sand-size glauconite is very similar to that of clay-size glauconite, Fig. 5 is given. It will be noticed that x-ray diffraction patterns of the sand-size glauconite and that of the clay-size glauconite are very similar.

In order to further substantiate the similar mineral composition of sand-sized glauconite to that of clay-sized glauconite, differential thermal analyses were made of the two different sized materials (Fig. 6). The two fractions yielded results indicating that they are mineralogically similar. These findings are in line with those in the report by McRae (l.c.).

### Chemical Properties of Glauconite

Glauconite in general terms is a hydrous silicate of ferric and ferrous iron, potassium, magnesium and alumina. Since there are considerable desirable soil properties associated with glauconite, it is pertinent to state that the mineral contains up to about 7-8% potash ( $\text{K}_2\text{O}$ ) and, in some instances, a little more (Hower, l.c.). Greensand, on the other hand, is a deposit consisting of glauconite and other constituents. How much glauconite needs to be present before the material can be referred to as greensand? Apparently limits have never been stated, but ped-

**Table 3. Analyses of New Jersey Marls (abstracted from Clark, 1892). (%).**

	Lower Marl		Middle Marl		Upper Marl	
Sample number	6	7	10	11	12	13
Phosphoric acid	0.84	0.38	0.19	0.50	6.87	3.73
Sulfuric acid	0.12	0.20	0.41	0.34	3.12	2.44
Silicic acid and sands	52.07	53.10	51.15	47.50	44.68	49.68
Potash	6.46	3.78	7.08	5.29	3.97	4.98
Lime	1.01	–	0.49	0.56	4.97	4.14
Magnesia	1.53	0.70	2.02	2.70	2.97	0.47
Alumina	6.96	6.30	8.23	8.60	6.04	28.71
Oxide of iron	21.55	15.39	23.13	20.52	18.97	
Water	9.31	8.64	6.67	13.57	8.63	5.54
Carbonic acid	–	–	–	–	–	–
Carbonate of lime	–	–	–	–	–	–
<b>Total</b>	<b>99.85</b>	<b>100.59</b>	<b>99.37</b>	<b>99.50</b>	<b>99.32</b>	<b>99.69</b>

6 Mount Pleasant Hills  
 7 Freehold  
 10 Eatontown  
 11 Freehold  
 12 Poplar  
 13 Shark River

ologists generally consider 3-5% glauconite as the lower limit of “glauconite-bearing” soils. In situations where the non-glauconite material is coarse-grained quartz, feldspar etc., the native soil (in the humid regions) may be somewhat depauperate. But where the greensand contains carbonate-bearing materials including fossil shells and phosphates, the soil has a high level of trophism. On the other hand, there are situations in which sulphide-bearing minerals such as pyrite and marcasite may be present in the

greensand matrix giving rise to the “poison marls” (a.k.a. black marls and in some places ash marls).

Table 3 gives the chemical composition of a number of greensand deposits from Monmouth and Middlesex Counties. These data are from locations high in glauconite.

Just as certain physical properties of the soil tend to change in composition with change in

particle size the mineral and chemical composition of soils also tend to change. Brown and Jackson (1958) for example reported coarse sands may generally consist of quartz, feldspars, heavy minerals and so on but the clay fractions will be comprised of minerals such as illite, kaolinite, vermiculite and others. Normally the sand fractions in soils exhibit very little chemical reactivity, but sand-size glauconite has a relatively high cation exchange capacity and therefore plays an important role in soil chemistry. Glauconites from Belgium were found to have cation exchange capacities ranging from 29 to 35 me per 100 g (Closs, Fripiat and Vielyoye, 1961). Owens and

Minard (l.c.) reported that the Hornerstown glauconite had cation exchange capacity values of 21 and 22 me per 100 g, and samples from the Navesink Formation had values of 23 and 25. McRae (l.c.) reviewed reports by various investigators concerning the cation exchange capacities of glauconites and, accordingly, cited values ranging from 5 to 39 me per 100 g. Tedrow (1966) fractionated the Marlton soil, one with over 90% glauconite, and found that the cation exchange capacities of the sand-size fractions ranged from 19 to 31 me per 100 g (Tab. 4). These high values are believed to represent one of the main reasons why glauconite-bearing soils usually

**Table 4. Cation Exchange Capacities of Sand-size Fractions From Marlton Soil. The Soil Contains Over 90% Glauconite. (Tedrow, 1986).**

Particle size (mm)	Cation exchange capacity (me/100 g)
2-1	ND*
1-0.5	19
0.5-0.25	21
0.25-0.20	20
0.10-0.05	31

\*Not determined

**Table 5. Sorption of Selected Heavy Metals by Glauconite From the Hornerstown Formation (analyses by Prof. N.F. Shimp)\*.**

	Cu (ppm)	Mn (ppm)
Initial content	40	200
Content at saturation	5000	3200
Content after 3 washings	4400	2840
Content after 9 washings	3920	2840
Content after 20 washings	3360	2320

\*Washed coarse sand (1.0-0.5 mm) contained more than 99% glauconite. After washing, 100 gm samples were soaked in 0.5 N CuSO<sub>4</sub> or 0.5 N MnSO<sub>4</sub> for a 2-week period and excess Cu and Mn removed with ethanol. Samples were washed with 150 ml 0.01N HC1 with a pH of 3.2.

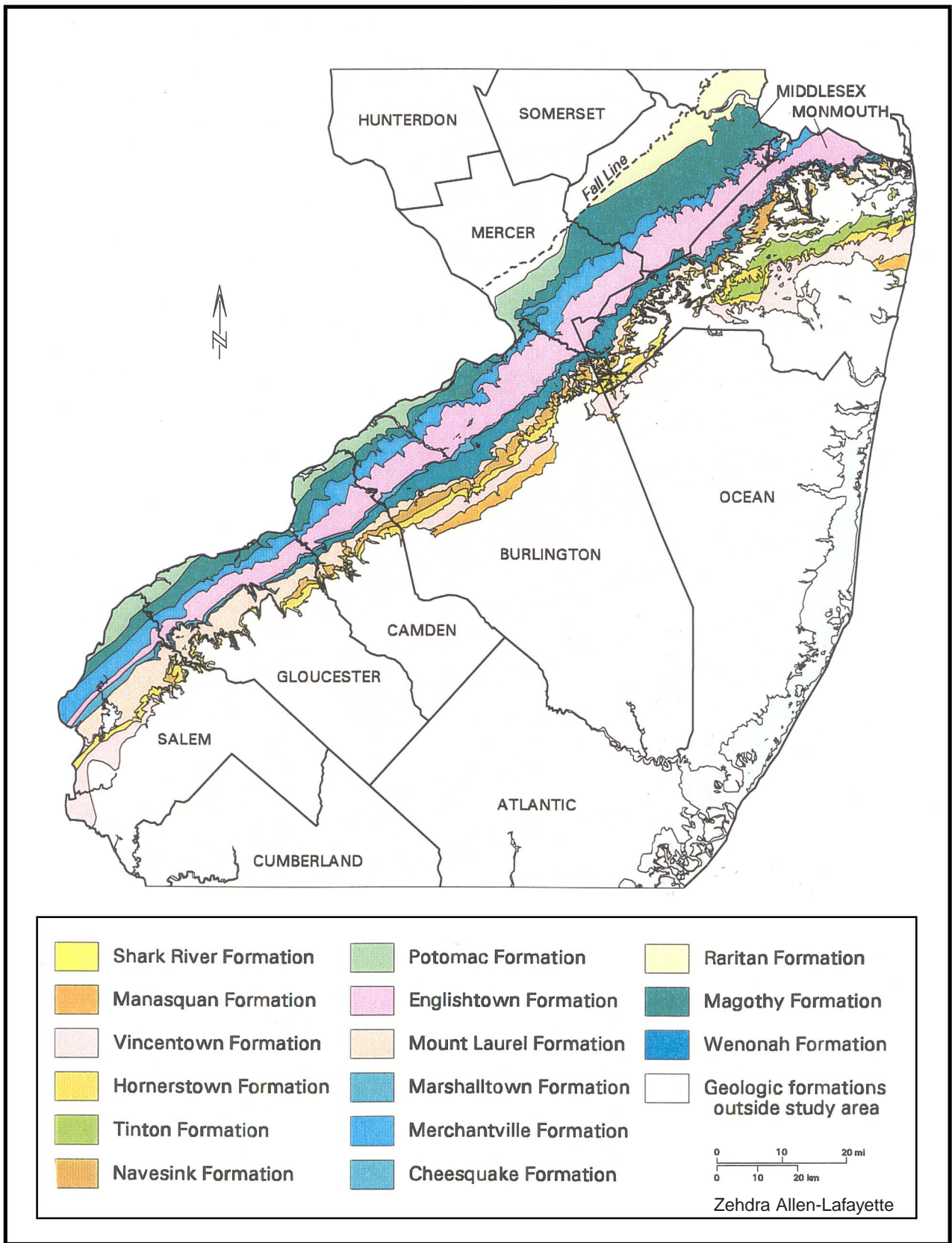
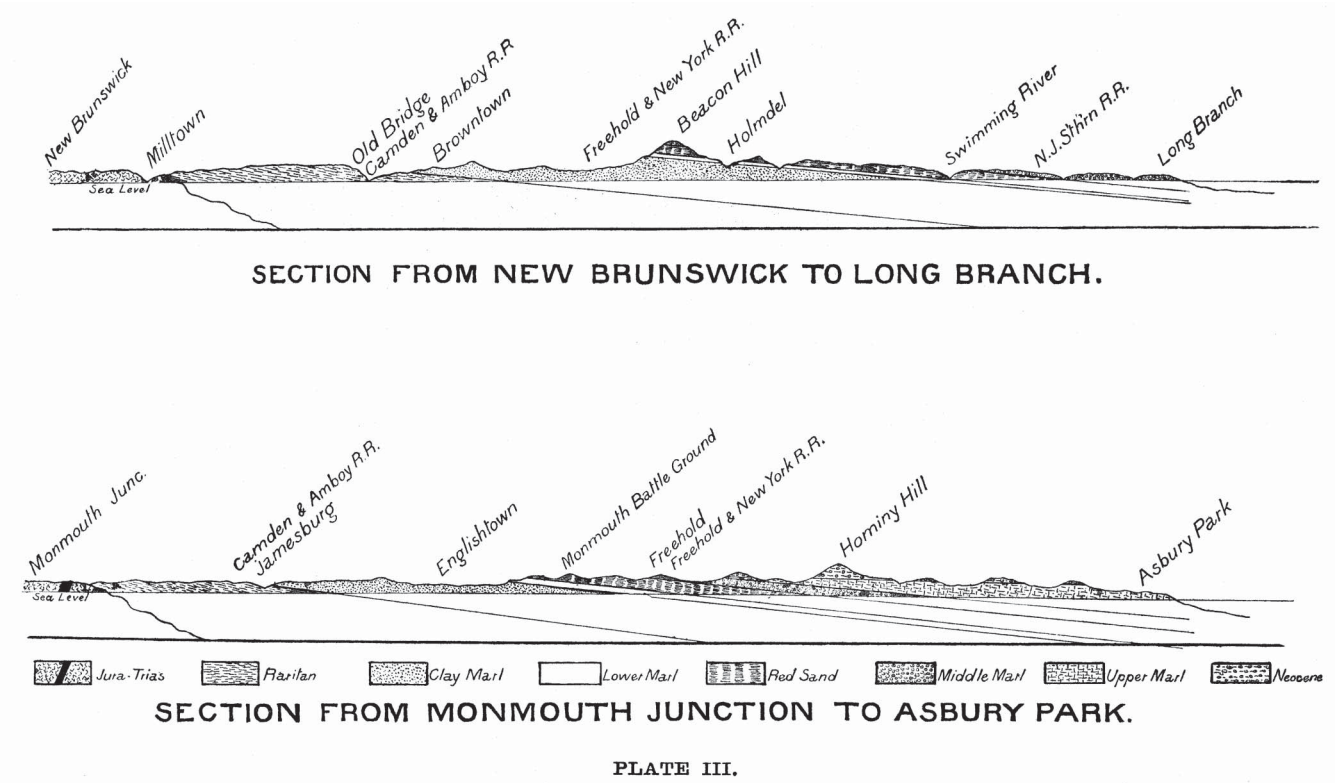


Fig. 7. Geologic map of certain formations in the New Jersey Coastal Plain.

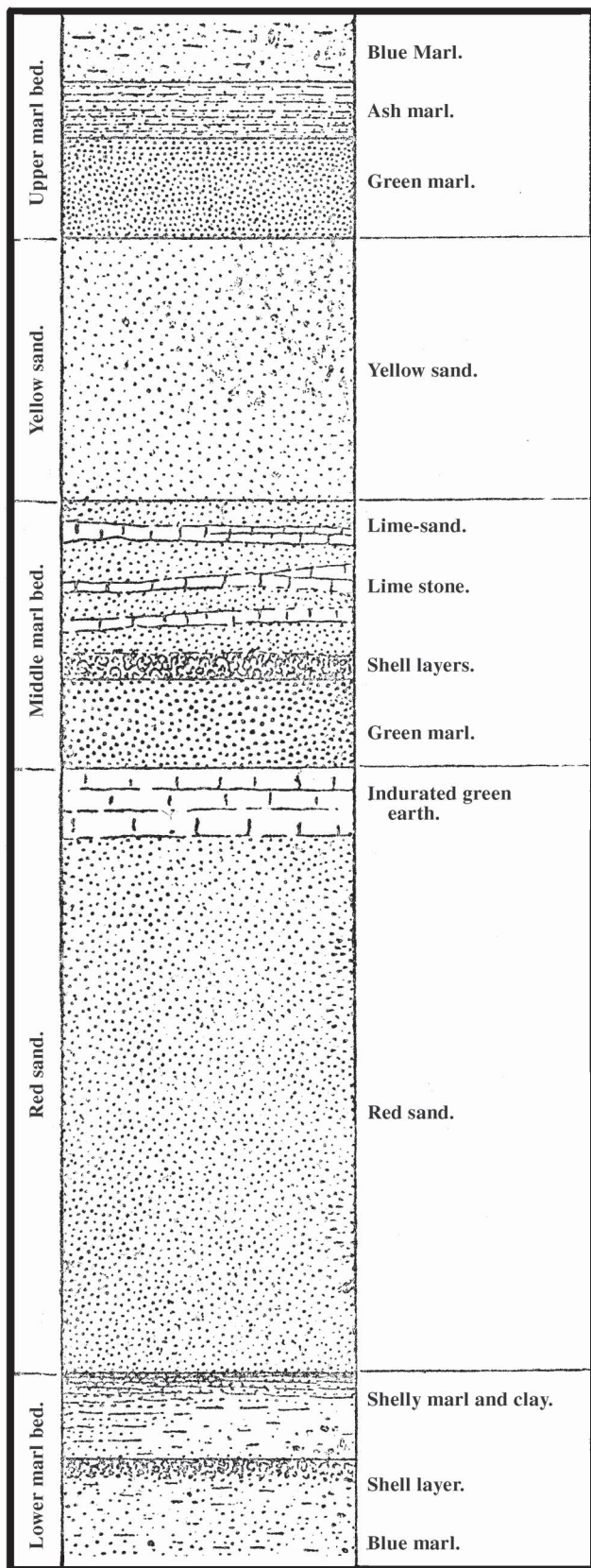




**Fig. 8.** Cross sections of the geologic formations in the northern part of the Coastal Plain (Clark, 1893).



**Fig. 9.** The major greensand beds of New Jersey (Cook 1874). The Lower marl bed approximates the Navesink and Marshalltown Formations, the Middle marl bed approximates the Hornerstown Formation and the Upper marl bed approximates the Manasquan and Shark River Formations.



**Fig. 10.** Columnar section showing the greensand formations of New Jersey. The diagram shows their comparative thickness (Cook, 1887.)

have desirable agricultural potential. Glauconites, with their high cation exchange capacities will naturally also have high sorption capacities for various heavy metals. In order to show the high potential for heavy metal sorption on glauconite, Prof. N.F. Shimp saturated Hornerstown glauconite with copper and a second sample with manganese. Repeated washings of the saturated samples with dilute hydrochloric acid showed that the glauconite had high sorption/retention capacities (Tab. 5).

In some situations, particularly with the Red Bank sand, much of the glauconite is impregnated with iron and exists as a heavy mineral. Ahenkorah (1963) reported that most of the heavy mineral suites in the Colts Neck soil were actually iron-enriched glauconite. Fanning et al. (l.c) also reported the presence of excess oxidized iron in glauconites from New Jersey and Maryland.

## Greensands of New Jersey

The nature, properties and distribution of New Jersey greensands has been thoroughly stated by Cook (1868, 1874, 1887), Clark (1892), Mansfield (1923), Kummel (1940), Dooley (2001), and others. The greensands occur in a belt extending some 100 miles long from the Navesink Highlands along the southern shore of Raritan Bay to the Salem area along Delaware Bay (Fig. 7). The belt is generally 10 to 20 miles wide with the strata dipping to the southeast about 25 to 60 ft per mile (Fig.8). The greensands are mantled in many places with Quaternary sediments (Bridgeton, Pensauken, and Cape May Formations). Further to the east the greensands dip beneath the Kirkwood Formation, Cohansey Formation, and Cape May Formation. At Atlantic City the Shark River, uppermost of the main greensand formations was found to be over 1300 ft below sea level (Miller et al., 1994). Extensive areas throughout southern New Jersey also appear to be covered with aeolian - derived sediments.

Cook (1874) originally divided the greensand (marl) beds into Lower, Middle, and Upper (Fig. 9). More details concerning properties including generalized thickness of the deposits is depicted in Fig. 10. Table 6 shows the glauconite-bearing formations by Kummel (1940) of the Coastal Plain

**Table 6. Major Glauconite-bearing Deposits of New Jersey (Kummel, 1940 et seq.).**

**Cenozoic (Tertiary)**

Shark River Formation	11 ft.	Rich in glauconite.
Manasquan Formation.	25 ft.	Rich in glauconite. "Ash marl" near top.
Vincentown Formation	25-100 ft.	Glauconite and limesand.
Hornerstown Formation	30 ft.	Glauconite and limesand.

**Mesozoic (Cretaceous)**

Tinton Formation	10-20 ft.	Glauconite present.
Red Bank sand	0-130 ft.	Usually nonglauconitic.
Navesink Formation	25-40 ft.	Glauconite present.
Mt. Laurel Formation	5-60 ft.	Glauconite present.
Wenonah Formation	20-35 ft.	Non glauconitic.
Marshalltown Formation	30-40 ft.	Argillaceous greensand.
Englishtown Formation	20-140 ft.	Sparingly glauconitic.
Woodbury Formation	50 ft.	Non glauconitic.
Merchantville Formation	50-60 ft.	Rich in glauconite.
Magothy Formation	25-175 ft.	Sparingly glauconitic.

Note: Quaternary deposits containing small quantities of glauconite mantle some of the formations.

For more detail see Owens et al. (1998).

beginning with the Magothy and extending upward through the Shark River.

The greensands of New Jersey have a range of properties, some of which are highly beneficial to agriculture. Those rich in carbonates are naturally conducive to plant growth as are those high in phosphorus. On the other hand the ash marls, because of their acidity, impart undesirable properties to the soil. Further, glauconite in the greensands generally appears to have undergone very little alteration, but in some situations, as exemplified the Red Bank and Tinton Sands, ferruginous glauconite is present (Ahenkorah, 1963). As to how ferruginous glauconite reacts within the soil remains largely unknown.

Nearly all of the greensands of the State are loose and friable, but in some situations where the deposits are rich in clay-size glauconite, the internal drainage of the soil tends to be very slow. This situation coupled with low relief will generally give rise to poorly drained soil.

At a few locations along the Manasquan River and elsewhere the greensand beds are consolidated into sandstone up to 20 or more feet in thickness. In the Atlantic Highlands area some of the glauconite-bearing beds are also consolidated.

### **Morphology and Classification of Glauconite-bearing Soils in New Jersey**

The first report concerning morphology and classification of glauconite-bearing soils at the series level in New Jersey was by Bonsteel and Taylor (1902) in the Salem area. At that time the name Collington was used for virtually all of the glauconitic soils except those in the poorly drained sites which were designated as Meadow. But even before that time there were preliminary discussions concerning glauconite soils in the State (Cook, 1874).

Marbut (1935) reported the chemical and mechanical composition of a Collington soil in the Auburn area of Salem County (Tab. 7). Joffe (1937) also reported on the chemical composition of the Collington soil. Joffe (l.c.) stated that the cation exchange capacity of the Collington soil approximated 16 me per 100 g in the uppermost mineral horizon and decreased to 7 me per 100 g at depth. This soil had approximately 50% base saturation and a pH approximating 4.5 to 5.0.

Classification of soils rich in glauconite at the series level has always been enigmatic, the main reason being the unique set of properties associated with the sand and the silt fractions. Marbut (1928) addressed the problem of soil development in the greensand sectors of New Jersey as follows:

“Associated with the Sassafras soils are the Collington soils differentiated from the Sassafras on the basis of the character of the Parent Material. Sassafras soils are derived from sands and clays, while the Collington soils derived from beds of glauconite or beds of sands and clays which contain a high percentage of glauconite. If the percentage of glauconite is small the soils developed from the material will develop into Sassafras soils. In fact it is possible and probable that in time the soils from all of the material will develop into what are essentially Sassafras soils. The Collington soils as mapped however, are soils in which the glauconite material still continues to influence the color at least, as well as the texture of both the A and B horizons. The A horizon is somewhat richer brown in color than the A horizon of the Sassafras, and also in usual cases less light in texture. The glauconite decomposes into clay more readily than the minerals in the parent material of the Sassafras so that other things being equal, the Collington soils will be heavier and being heavier they will require a longer time to leach out the minerals which give them their color, such as the iron, than would be the case in the more sandy Sassafras soils. The B horizon as well as the A horizon in

the Collington soils is heavier than in the corresponding horizons in the Sassafras. The B horizon is also deeper and richer in color. The C horizon consists of the glauconite and sands and clays with glauconite constituting a considerable part of the material. The Collington soils are therefore younger in point of development than are the Sassafras soils. They are not younger in years, since they have undoubtedly been developing through the same period of time as the Sassafras, but because of the more resistant character of the glauconite than of the simple sands and clays of the Sassafras, they require a longer time to reach that stage of moderately advanced podsol development characteristic of the Sassafras than is required by the Sassafras soils themselves. This is a relationship of soils that we shall encounter repeatedly on the various parts of the United States. While the Collington soils must be regarded as mature in that they have a well defined podsol profile, yet I desire to emphasize the fact that maturity does not mean exactly the same stage of development in all soils. Maturity does not mean the complete annihilation or elimination of all of the characteristics rather than parent material characteristics. True soil characteristics are dominant in the Collington soils as well as in the Sassafras. The true characteristics are expressed in the soil profile. I mean by that in the more presence of the relatively light textured A horizon and the heavier textured B horizon. The A horizon therefore is podsolized and the B horizon in this case is as much a podsol B horizon as is the B horizon in the Sassafras soils.

There are however, in the region where the Sassafras soils and Collington soils are developing, soils that are young and are still being mapped as members of the Collington series. We realize that this is not exactly correct from the soil mapping point of view, since very young soils should be differentiated from mature soils. The young Collington soils consist really of little else than the parent material.”



**Table 7. Composition of Collington Loamy Fine Sand, Auburn, N.J. (Marbut, 1935). (%)**

Horizon	Depth (in.)	Mechanical								Chemical										
		2-1mm	1-0.5mm	0.5-0.25mm	0.25-0.10mm	0.10-0.05mm	0.05-0.005mm	<0.005 mm	SiO <sub>2</sub>	TiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	Al <sub>2</sub> O <sub>3</sub>	M <sub>n</sub> O	CaO	MgO	K <sub>2</sub> O	Na <sub>2</sub> O	P <sub>2</sub> O <sub>5</sub>	SO	Ig.l.*
A <sub>1</sub>	0-3	1.5	7.6	17.2	52.9	5.8	8.9	5.8	90.58	0.56	1.44	1.56	0.01	0.26	0.22	0.31	0.38	0.09	0.22	4.96
A <sub>2</sub>	3-24	0.4	9.0	22.6	54.6	3.4	7.0	3.4	95.19	0.62	2.11	0.50	0.01	0.31	0.18	0.22	0.52	0.09	0.15	0.95
B	24-36	0.2	7.4	18.6	47.7	7.1	9.3	7.1	87.24	0.05	1.28	7.10	0.01	0.19	0.33	0.36	0.56	0.36	0.21	1.51
C	36-60	0.6	9.3	13.8	30.4	7.1	9.9	7.1	64.76	0.67	13.54	9.30	0.04	0.04	2.06	4.37	0.97	0.11	0.07	4.37

\* Loss on ignition

There have been many changes in soil classification at the series level over the years. Tables 8A,B,C, D and E show how glauconite-bearing soil series names have evolved and are currently being used. The name Collington fine sandy loam, low greensand-content phase was introduced by Lee and Tine (1927) and they stated that this soil type does not differ in essential characteristics from the typical except in the small percentage of glauconite present. The name Collington fine sandy loam, low greensand-content phase ap-

proximates the current use of the soil series name Freehold. Further, subvarieties of the Collington such as Collington clay loam and Collington loam as depicted by Dickey and Lee (1916) are now recognized as the Marlton series.

In order to provide a basis for describing the more prominent well-drained (Normal or Mature in the sense of Marbut), glauconite-bearing soils of New Jersey the following information is taken from the work of Jablonski and Baumley (1989).

**Table 8A. Early Surveys of Glauconite-bearing Soils in New Jersey.**

Soil Survey	Parent Material	Well Drained Soil	Imperfectly Drained Soil	Poorly Drained Soil
Salem Area (1902)	Glauconite-bearing sands	Collington	—————	Meadow
Trenton Area (1902)	Glauconite-bearing sands	Collington	—————	Meadow
Camden Area (1915)	Glauconite-bearing sands	Collington	Shrewsbury	Keansburg Freneau on floodplains
Freehold Area (1916)	Glauconite-bearing sands	Collington Colts Neck on reddish sands	Shrewsbury	Keansburg Freneau on floodplains
Chatsworth Area (1923)	Glauconite-bearing sands	Collington	Shrewsbury	Keansburg Freneau on floodplains
Trenton Area (1926)	Glauconite-bearing sands	Collington	Shrewsbury	Keansburg Freneau on floodplains
Camden Area (1926)	Glauconite-bearing sands	Collington	Shrewsbury	Keansburg Freneau on floodplains
Freehold Area (1927)	Glauconite-bearing sands	Collington Collington (low greensand)	Shrewsbury	Keansburg Freneau on floodplains
Salem Area (1929)	Glauconite-bearing sands	Collington Collington (low greensand)	Shrewsbury	Keansburg Freneau on floodplains

**Table 8B. Soil Series Names Introduced at the Pennsauken Creek Project (U.S. Soil Conservation Service, 1936).\***

Series Name	Description
Marlton	Deep, well-drained soil, high in glauconite. Equivalent to Collington clay loam and Collington loam of earlier surveys.
Freehold	Deep, well-drained soil, small quantities of glauconite. Approximates Collington sand, low greensand - content phase of earlier surveys.
Adelphia	Deep, moderately well drained to somewhat poorly drained soil formed on glauconite.

\* Proceeding were not published.

**Table 8C. U.S. Soil Conservation Service Soil Survey of Monmouth County (1947) and Cox (1948).**

Parent Material	Well-Drained Soil	Moderately Well to Somewhat Poorly Drained Soil	Poorly Drained Soil	Very Poorly Drained Soil
High glauconite content	Marlton	Kresson	_____	_____
Intermediate glauconite content	Collington	<u>Adelphia</u> Donlonton	<u>Shrewsbury</u> Colemantown	<u>Keansburg</u> Matlock
Low in glauconite content	Freehold	Holmdel	_____	_____

**Table 8 D. Classification of New Jersey Glauconite Bearing Soils by Quakenbush (1955).**

The main greensand [glauconite] belt with sandy or gravelly substrate				
Composition	Well Drained Soil	Moderately Well and Somewhat Poorly Drained Soil	Poorly Drained Soil	Very Poorly Drained Soil
High glauconite content	Marlton	Kresson	Colemantown	Matlock
Intermediate glauconite content	Collington	<u>Adelphia</u>	<u>Shrewsbury</u>	<u>Keansburg</u>
	Monmouth (brown)	Donlonton (dark brown)	Colemantown	
Low glauconite content	Freehold Colts Neck (red sand) Howell (clayey)	Holmdel	Shrewsbury	Keansburg

**Table 8 E. Soil Surveys 1962 to 1989.**

<b>Soil Survey</b>	<b>Parent Material</b>	<b>Well Drained Soil</b>	<b>Moderately Well Drained Soil</b>	<b>Somewhat Poorly Drained Soil</b>	<b>Poorly Drained Soil</b>	<b>Very Poorly Drained Soil</b>
Gloucester County (1962)	High glauconite content Med. glauconite content Low glauconite content	Marlton Collington Freehold	Marlton Collington Freehold	Kresson Kresson Kresson	Colemantown Colemantown Colemantown	Matlock Matlock Matlock
Camden County (1966)	High glauconite content Med. glauconite content Low glauconite content	Marlton Collington Freehold	Marlton Holmdel	Kresson Holmdel	Colemantown Shrewsbury Shrewsbury	_____
Salem County (1969)	High glauconite content Low glauconite content	Marlton Howell	Marlton Howell	_____	_____	_____
Burlington County (1971)	High glauconite content Med. glauconite content Low glauconite content Sand over glauconite	Marlton Collington Freehold Tinton	Marlton Adelphia Holmdel Pemberton	Kresson Adelphia Holmdel Pemberton	Colemantown Shrewsbury Shrewsbury	_____
Mercer County (1972)	Glauconite sands	Tinton	_____	_____	_____	_____
Ocean County(1980)	Sand over glauconite Sand over glauconite Glauconite with clayey subsoil	Collington Tinton	Adelphia Pemberton	Adelphia Pemberton Kresson	Shrewsbury	_____
Monmouth County (1989)	High glauconite content Med. glauconite content Low glauconite content Red sand Sand over glauconite	Marlton Collington Freehold Colts Neck Tinton	Marlton Adelphia Holmdel	Kresson Adelphia Holmdel	Colemantown Shrewsbury	_____



**Marlton:**

- Ap (0-8 in.) Very dark grayish brown (10YR 3/2) loam, granular structure, 30% glauconite.
- Bt<sub>1</sub> (8-18 in.) Very dark grayish brown (2/5YR 3/2) sandy clay loam, subangular blocky structure, 40% glauconite.
- Bt<sub>2</sub> (18-34 in.) Dark olive gray (5YR 3/2) clay loam, subangular blocky structure, distinct clay films, 60% glauconite.
- Bt<sub>3</sub> (34-46 in.) Dark olive gray (5YR 3/2) clay with strong brown (7.5YR 4/6) mottles, subangular blocky structure, distinct clay films, 80% glauconite.
- C (46-60 in.) Dark olive gray (5YR 3/2) sandy loam with strong brown (7.5YR 4/6) mottles, granular structure, 80% glauconite.

**Collington:**

- Ap (0-11 in.) Dark reddish brown (7.5YR3/2) sandy loam, granular structure, friable.
- BA (11-13 in.) Dark brown (7.5YR 4/4) sandy loam, subangular blocky structure, many worm holes, small amount of glauconite.
- Bt (13-29 in.) Dark brown (7.5YR 3/4) sandy clay loam, subangular blocky structure, worm holes common, glauconite common.
- BC (29-32 in.) Dark brown (7.5YR 3/4) sandy loam, massive structure, 25% glauconite.
- C1 (32-44 in.) Dark brown (7.5YR 3/4) sandy loam, friable, green-colored aggregates, 25% glauconite.
- C2 (44-80 in.) Dark brown (7.5YR 3/4) coarse sandy loam, variegated with reddish and green grains, 30% glauconite.

**Freehold:**

- Ap (0-9 in.) Dark yellowish brown (10YR 4/4) sandy loam, subangular blocky structure friable.
- BA (9-12 in.) Dark brown (7.5YR 4/4) sandy loam, subangular blocky structure, friable.
- Bt1 (12-18 in.) Dark brown (7.5YR 4/4) sandy loam, friable, a few clay films.
- Bt2 (18-25 in.) Dark brown (7.5YR4/4) sandy clay loam, subangular blocky structure, friable.
- BC (25-35 in.) Brown (7.5YR5.4) sandy loam massive, friable sandy loam, granular structure.

- C (35-70 in.) Yellowish brown (7.5 YR 5/8) loamy sand.

**Sassafras:**

This soil is generally glauconite free.

- Ap (0-11in.) Dark brown (10 YR 3/3) sandy loam, granular structure.
- BA (11-17 in.) Yellowish brown (10 YR 5/6) sandy loam, subangular blocky structure.
- Bt (17-23 in.) Yellowish brown (10 YR 5/6) sandy clay loam, subangular blocky structure, some clay films present.
- BC (30-36 in.) Reddish yellow (7.5 YR 6/6) sandy loam, subangular blocky structure.
- C (36-60 in.) Reddish yellow (7.5 YR 6/6) loamy sand, loose.

**Colts Neck:**

This soil contains up to 10% glauconite.

- Ap (0-10 in.) Dark reddish brown (5 YR 3/2) sandy loam, granular structure.
- BA (10-15 in.) Dark reddish brown (5 YR 3/4) sandy loam, granular structure.
- Bt<sub>1</sub> (15-24 in.) Reddish brown (5 YR 4/4) sandy clay loam, subangular blocky structure.
- Bt<sub>2</sub> (24-35 in.) Reddish brown (5 YR 4/4) sandy loam, subangular blocky, structure, a few clay films.
- BC (35-42 in.) Reddish brown (5 YR 4/4) loamy sand, weak granular structure.
- C (42-60 in.) Reddish brown (5 YR 4/4) loamy sand, iron-cemented fragments throughout.

During the developmental years there was very little attention given to classification of glauconite-bearing soils of New Jersey beyond the series level. Within the 1930-1960 period the well drained soils were generally referred to as Gray Brown Podzolic with the poorly drained associates designated as Low-Humic Gley or Humic Gley.

With advent of the new system introduced by the U.S. Department of Agriculture the latter half of the 20<sup>th</sup> century classification/taxonomy has drastically changed. The current classification of the glauconite-bearing soils of the State is given in Table 9.

The problem of classifying the Collington and Freehold soils at the higher categories is not as troublesome as it is with the Marlton. The Collington and Freehold series have developed well-oxidized B and C horizons. The well-developed colors, dark brown and/or yellowish brown result more from the oxidation of the iron in the glauconite rather than authigenic clay formation in the traditional sense.

Another problem classification of soils in the greensand belt is that of the effects of aeolian activity (Salisbury and Knapp, 1917 and Newell et al., 2000). An examination of soil profiles within this belt will almost invariably show that the glauconite tends to increase with depth. Therefore, with the glauconite content increasing at depth, the non-glauconite material such as quartz and feldspar decreases. Normally pedologists tend

**Table 9. Soil Series Names Used in the Greensand Sectors of New Jersey.**

Series	Year Established	Glauconite Content*	Internal Drainage	Classification According to Soil Taxonomy (1972 et seq.)
Adelphia	1936	M	Moderately well to somewhat poorly drained	Aquic Hapludult
Collington	1901	M	Well drained	Typic Hapludult
Colemantown	1947	H	Poorly drained	Typic Ochraquult
Colts Neck	1913	L	Well drained	Typic Rhodudult
Delanco	—	M	Moderately well to somewhat poorly drained	Aquic Hapludult
Donlonton	1943	M	Moderately well to somewhat poorly drained	Aquic Hapludult
Freehold	1936	L	Well drained	Typic Hapludult
Freneau	1916	M	Poorly drained	—
Holmdel	1947	L	Moderately well to somewhat poorly drained	Aquic Hapludult
Howell	1947	L	Well drained	Typic Hapludult
Keansberg	1916	H	Very poorly drained	Typic Umbraquult
Kresson	1947	H	Somewhat poorly drained	Aquic Hapludult
Lincroft	1947	L	Well drained	Typic Udipsamment
Marlton**	1936	H	Well to moderately well drained	Typic Hapludult
Matlock	1947	H	Very poorly drained	Typic Umbraquult
[Meadow]	1901	M	Very poorly drained	—
Manalapan	1947	M	Poorly drained	—
Monmouth	1947	L	Well drained	Typic Hapludult
Pemberton	1967	M	Moderately well to somewhat poorly drained	Arenic Hapludult
Shrewsbury	1916	M	Poorly drained	Typic Ochraquult
Tinton	1947	L	Well drained	Arenic Hapludult

\*H-high, M-medium, L-low

\*\*Name proposed at the Pennsauken Conference (1936).

to build their case on the presence of an original uniform matrix with depth but within the greensand belt such a condition is rarely present.

The Colts Neck soil has always presented a classification problem at the higher categories. With its prominent reddish colors some investigators have allied this soil with an earlier lateritic process. For example, Joffe and Kunin (1942) concluded that the Colts Neck soil represents a podzolic process replacing early laterization. This statement has not received widespread acceptance. For example, Prof. J.H.C. Martens stated to me that feldspars in Colts Neck soil were strikingly unweathered. It appears that the reddish colors are of a geologic nature rather than resulting from pedogenic processes. The soil contains up to some 40% glauconite in the sand-size fraction. The clay-size minerals consist of hydrous mica, vermiculite, chlorite and an expanding 14A mineral. Kaolinite, quartz, and plagioclase are also present in small quantities (Ahenkorah and Tedrow, 1964). The pH values of virgin sites of the Colts Neck soil are generally within the 3.6 to 3.9 range. Of special interest is the preservation of plagioclase in the clay-size fraction. Further, preservation of fresh-appearing plagioclase in the sand-size particles together with the absence of a "clay bulge" of kaolinite/gibbsite should largely rule out an earlier lateritic process. It will be noted that current classification of this soil by the U.S. Department of Agriculture is Typic Rhodudult [typical, dark red, humid, ultimate] but the soil does not correspond very well to the definition. Ahenkorah and Tedrow (l.c.) suggested the term Pseudo red yellow podzolic be used for the Colts Neck soil.

There is no detailed record available as to where greensand applications were made to the land in New Jersey. Cook (1868) mentioned the names of a number of specific farms where greensand was applied but locating the farms including boundaries is beyond the scope of this report. Figure 11 shows locations of the former greensand pits in New Jersey. Of the million tons or so dug each year during the mid 1860s it has been estimated that about one half was used locally and distribution was generally within a distance of 15-20 miles or so from the pits. The other half

was shipped by rail to more distant points. A partial list of rail shipments as stated by Cook (1868) is given in Table. 10. Of special interest to pedologists and agronomists is the specific locations as to where the greensand was applied. The literature mentions application to sections such as the "sandy soils in the vicinity of the Monmouth-Ocean County border" and "further to the south". On the other hand application of greensand to those areas having an appreciable amount of native glauconite such as the Marlboro, Pemberton, and the Medford Lakes areas was also common practice.

The question of how the application of glauconite to soil potentially affects the classification of soils apparently has never been addressed. In extreme cases where upwards of 250 tons of greensand were applied per acre the result should be considered in soil classification. Much of the area where greensand applications were made has succumbed to housing and industrial development, which adds the complexity of reconstructing past events.

## **Early Studies Concerning the Availability of Potassium in Greensands**

The question of availability of potassium from the glauconite in greensand deposits has been a problem for over two centuries. Glauconite, whether existing as a natural soil component or added as a soil amendment to enhance crop growth, has been recognized throughout the globe. The literature, however, does not always present a unified picture as to the underlying causes for the increased crop growth from greensand additions to soils.

Patterson (1906) concluded that greensand marls of Maryland had very little value for the commercial extraction of potassium. Blair (1916) reported that the New Jersey greensands gradually release potash and that crops can "use potash of marl to a considerable extent". Blair's work was not convincing that there was a direct release of appreciable potash from the glauconite. Lipman and Blair (1917) grew barley, buckwheat and soybeans using greensand. Their work did not show that the increased yields were due to

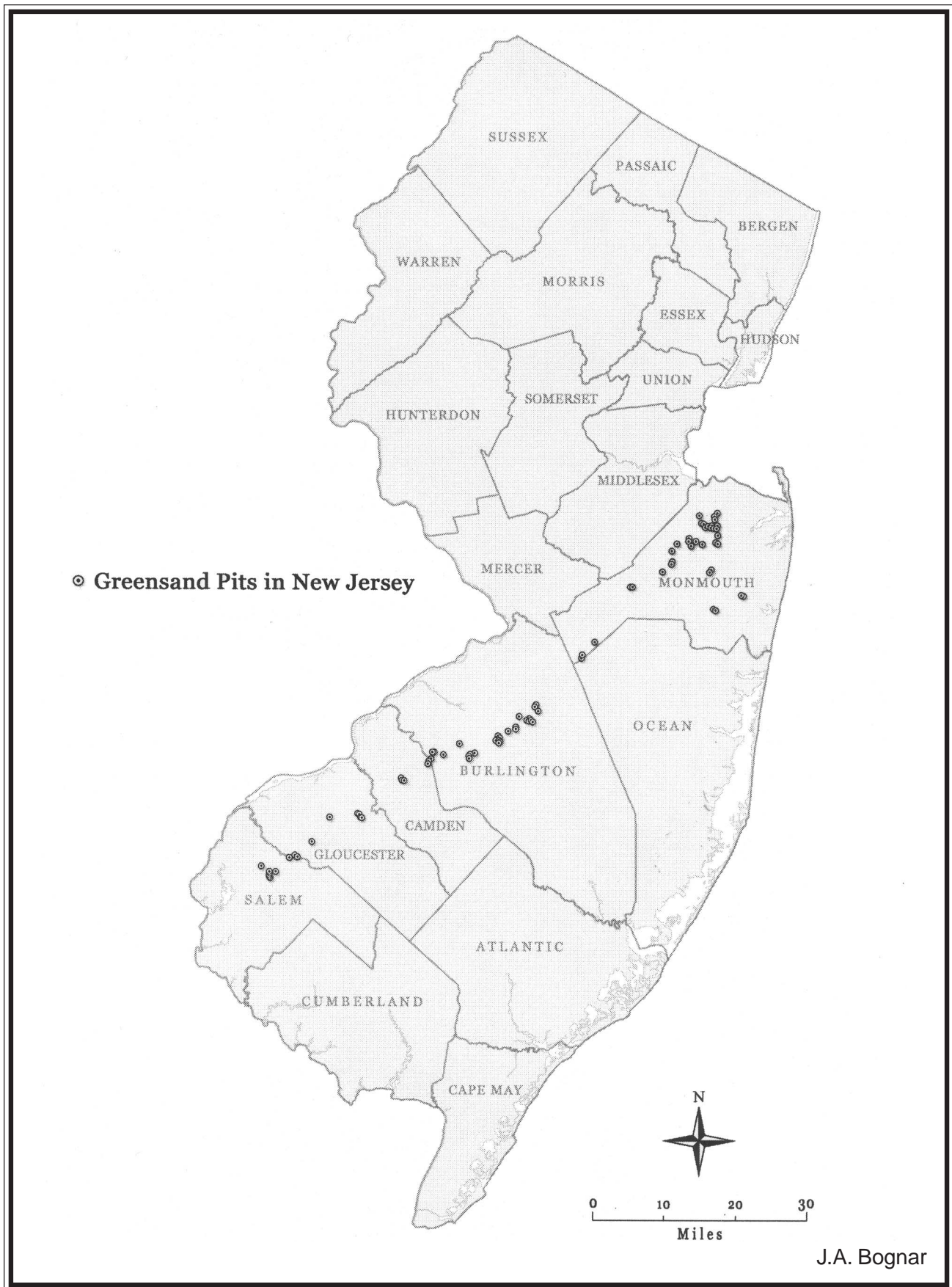


Fig. 11. Greensand pits in New Jersey (Redrawn from Mansfield (1923)).



**Table 10. Some Shipments of Greensand by Rail During the 1860s (Cook, 1868).**

<u>Year(s)</u>	<u>Carrier</u>	<u>Tons</u>	<u>Destination</u>
1864-65	Squankum Marl Co.	2,500	South towards Toms River
1867	Squankum Marl Co.	20,000	Eatontown, Manchester
1867	Freehold-Jamesburg Agr.R.R.	18,340	Bordentown, Trenton, Millstone
1867	Pemberton R.R.	25,000	Mt. Holly, Burlington, Camden, South Amboy, Flemington, Belvidere, Trenton, New Brunswick
1867	Camden and Atlantic R.R.	11,000	"along the [R.R.] line"
1867	West Jersey Marl Co.	52,000	South Amboy, New Brunswick

Note: Shipments were also made to Rocky Hill, Salem, and points toward Cape May

the release of potassium from the greensand. True and Geise (1918) concluded that greensand and greensand marls were able to supply sufficient potassium to satisfy the demands of wheat and red clover during the first two months of their growth.

Various investigators (Cook, 1868; Ames and Boltz, 1919; McCall and Smith, 1920 and Lipman et al., 1921; among others) studied the effect of greensand composted with manures and/or inoculated sulfur on plant growth with positive results. Whether the increased yields in these studies were due to potassium release from the greensand or from other causes had not been established.

Rudolfs (1922) stated that "it is necessary that a certain degree of acidity be produced before the potassium [in greensand] becomes water soluble. The amount of sulfates formed does not necessarily have to reach a certain quantity, but the acidity produced has to be of a certain intensity. The point at which the potassium of the greensand becomes more rapidly water-soluble lies between the pH values 2.7 and 2.13, as is shown by determination made from extracts treated with sulfuric acid". Further, Rudolfs stated that dry greensand substituted for the potassium in the cultural solution was apparently not able to replace the potassium fully for the needs of plants but composted greensand

seemed to render sufficient potassium available for their needs. Using the *Aspergillus niger* method for determining availability of potassium in selected potassium-bearing minerals, Eno and Reuzer (1955) found that potassium released was greater in muscovite and biotite than in glauconite, but that microcline was inferior to glauconite.

Prof. N.F. Shimp and this author conducted a series of acid leachings of potassium from New Jersey glauconite-bearing soils (Tab.11). After 3 to 6 extractions with normal acetic acid, quantities of potassium released from the samples were quite small.

### **Trace Element\* Content of Greensands in New Jersey**

Trace elements in soils and sediments have, for many years, been receiving attention of investigators in plant and animal nutrition. But, with increasing concerns for environmental quality, there is also now major attention given to trace elements from the standpoint of toxicity as well as deficiency. The former is especially true with the greensand deposits in New Jersey. Dooley (1998) made analyses of New Jersey greensands and, of 7 sites, he reported 7 to 31 ppm arsenic, 5 to 18 ppm beryllium, <0.2 to 1.2 ppm cadmium, and 130 to 1000 ppm chromium

\* In this report the term "trace elements" is commonly used. Other terms such as heavy metals, trace metals or metallic ions are also used. In a *sensu stricto* arsenic is not a heavy metal. For more details see Alloway (1993).



**Table 11. Potassium (ppm) Leached from the A Horizons of Various Glauconite-bearing Soils (data of N.F. Shimp and this author).**

<u>Leaching number</u>	<u>Marlton sandy loam</u>	<u>Collington sandy loam</u>	<u>Freehold sandy loam</u>
1	4.5	4.5	4.5
2	2.8	2.8	2.5
3	1.8	1.5	1.5
4	1.5	1.0	1.2
5	1.3	0.5	0.5
6	1.2	0.5	0.5
7	1.0	0.5	<0.5
8	1.0	0.5	<0.5
9	0.5	<0.5	<0.5
10	0.5	<0.5	<0.5
11	0.5	<0.5	<0.5
12	0.5	<0.5	<0.5
13	0.5	<0.5	<0.5
14	0.5	<0.5	<0.5
15	0.5	<0.5	<0.5
16	0.5	<0.5	<0.5
17	0.5	<0.5	<0.5
18	0.5	<0.5	<0.5
19	0.5	<0.5	<0.5
20	0.5	<0.5	<0.5

\*A 50 gm sample was leached with 100 ml of N acetic acid.

among other elements present. In a subsequent publication, Dooley (2001) made an exhaustive report of trace element content of New Jersey greensands and soils. His report is the most definitive work to date concerning greensands throughout the State. Some of the high values of elements in New Jersey such as arsenic may be in part from past agricultural practices. Schnepfe, May and Naeser (1964) reported that glauconite serves as a scavenger matrix for nuclear waste products such as cesium and strontium.

In his discussion of the sorption of metallic ions by soils, Alloway (1993) signaled out individual reactions taking place, such as co-precipitation, organic complexation, cation exchange,

specific adsorption, selectivity of absorbents for different metals, surface complexation, and others. Based on the microstructure of the sand and silt-size glauconite, it is believed that another category, herein termed the "sponge effect", can be added to the above list. Glauconite is sometimes referred to as a scavenger mineral. That is, it acts as an acceptor or a sorbing matrix for certain elements within the immediate environment. Markowitz and Lodding (l.c.) reported various quantities of beryllium, cobalt, chromium, nickel, molybdenum, vanadium, titanium, and uranium present in glauconite. The quantity of trace metals in the greensands appears to be at least partially and perhaps primarily controlled by the nature of the depositional environments. Further, Hendricks and Ross (1941) describe overlapping

**Table 12. Total Concentration of Selected Trace Elements in Various Greensand Formations From New Jersey. (Dooley, 1998).**

Element	Marshalltown Formation	Navesink Formation			Hornerstown Formation		
	Bass River (ppm)	Marlboro (ppm)	Sewell (ppm)	Bass River (ppm)	Sewell (ppm)	Delta Lee (ppm)	Bass River (ppm)
Arsenic	22	25	31	12	12	27	7.1
Beryllium	5	6	5	5	7	8	8
Cadmium	<0.2	1.2	<0.2	<0.2	<0.2	<0.2	<0.2
Chromium	150	130	130	130	380	1000	400
Copper	3.8	<0.5	1.7	2.6	6.7	8.3	1
Nickel	32	17	19	30	21	48	46
Lead	19	<2	<2	13	3	31	8
Zinc	56	70	84	86	370	370	96

**Table 13. Total Concentration of Selected Heavy Metals in Various Greensand Formations From New Jersey Using Nitric Acid Extractions. (unpublished data of W.T. Bell, Jr. and J.C.F. Tedrow).**

Element	Navesink Formation	Hornerstown Formation			Shark River Formation	
	Porcey Park (ppm)	Hornerstown (ppm)	West Freehold (1) (ppm)	West Freehold (3) (ppm)	Lefetras Brook (ppm)	Neptune (ppm)
Arsenic	7.3	10	33	70	10	11
Beryllium	1.0	1.0	2.3	1.7	1.7	1.0
Cadmium	1.9	1.0	7.9	2.7	3.5	2.2
Chromium	29	ND*	270	380	92	31

\*not determined

Procedure used was digestion with nitric acid followed by atomic absorption spectroscopy. Depths of the samples range from 5 to 20 feet.

plates of minerals having monoclinic symmetry in glauconite pellets. Tapper and Fanning (l.c.) also showed that the individual glauconite pellets have a grainy internal structure, and Markowitz, Lodding and Hower (l.c.) reported on the porosity of the glauconite grains. These properties also contribute to the sponge effect of glauconite.

Dooley (1998) made a detailed study of the trace element content of New Jersey greensands (Tab. 12). These data serve as a reliable baseline

for New Jersey and beyond. Also, Bell and Tedrow (unpublished) determined arsenic, beryllium, cadmium, and chromium contents of greensands at a number of locations in New Jersey (Tab. 13). The main reason for limiting this investigation to these four elements was that they are the ones under particular scrutiny in connection with environmental concerns.

There is very little information available concerning possible changes in trace element content of greensands according to depth. Such

studies were made, however, on a farm in West Freehold (Tab. 14). The uppermost samples (0-7 in., 0-6 in., and 0-8 in.) can be considered as being from the Ap horizons. The lower layers (7-15 in., 6-12 in. and 8-17 in.) approximate the subsoils. Changes in the remaining deeper layers represent variations in the character of the matrices. These data should serve as baseline information pertaining to the variations one may encounter in sampling various depths of greensand deposits.

## Evaluating Glauconite-bearing Soils for their Heavy Metal Availability

During earlier years trace element research in soils was primarily allied with agriculture and usually concerned deficiencies such as molybdenum, zinc, copper, and cobalt (Bear, 1954). But during the past half century, research has been restated to also include toxicities of heavy metals in soils, geologic materials, industrial sites, waste-material sites, waterways, and ground water, among others. In order to provide for proper environmental conditions, Federal and State agencies have issued guidelines concerning the upper acceptable levels of heavy metals in New Jersey. Arsenic (As), beryllium (Be), and cadmium (Cd) have been receiving prime attention from the standpoint of the toxic levels they have induced in some situations. But in general, concerns have focused on the total quantity present in the soil rather than the amount that is potentially available to enter the soil-plant-animal food chain.

Since particular attention has been directed toward arsenic, beryllium, and cadmium, some comments on these elements follow:

Arsenic: According to O'Neil (1993) the quantity of total arsenic in soils generally ranges from 1 to 40 ppm, but the levels may be elevated due to mineralization, additions of arsenic-based pesticides and other sources. Kabota-Pendias and Pendias (1984) state that the critical quantity of arsenic in soils is in the 20 to 50 ppm range. Dooley (1998) reported 7.1 to 31 ppm arsenic in the greensands of New Jersey.

Beryllium: Very little reliable information is available as to the normal content and function of beryllium in soils. The element is extremely rare in nature. Dooley (1998) reported values of 5 to 8 ppm of beryllium in the greensands of New Jersey.

Cadmium: Values for soils in uncontaminated sites in the United States range from 0.005 to 2.4 ppm (Alloway, 1993). In the greensands of New Jersey, Dooley (1998) reported values of 0.2 to 1.2 ppm of cadmium present.

Current state regulations primarily concern the upper permissible limits of certain trace elements in soils, but they do not always take into account solubility or the form of the element. While some materials may be readily soluble, others may be only slightly soluble or nearly insoluble. Geochemists have attached this problem of solubility of elements and minerals by establishing solubility series, weathering series, etc.

Apart from the contribution of organic matter, trace elements in soils can be considered at some three or more levels of solubility as follows:

1. Materials readily soluble in water: Variations in solubility will occur, however, depending on temperature, composition, pH, CO<sub>2</sub>, etc. of the ground water.
2. Materials relatively soluble to somewhat insoluble: These are generally considered to approximate the exchangeable cations (and/or exchangeable anions). It is generally considered to be the quantity of materials extracted by ammonium acetate (1 N, pH 7.0). Other extractants used are solutions of ammonium chloride, barium chloride, calcium chloride, and dilute acids. Another method of extraction is by electro dialysis (Mattson, 1926).
3. Nearly insoluble materials: These are represented by quartz, feldspar, and other minerals. Further, some of the trace elements may exist as inclusions in sand and silt grains rendering the elements virtually insoluble. Therefore, simply reporting a total

**Table 14. Trace Element Content of Glauconite-bearing Soils at Three Sites. The soils, classified as the Freehold\* Series, are developed on the Hornerstown Formation (unpublished data of W.T. Bell, Jr. and J.C.F. Tedrow).**

Depth (in.)	pH	Arsenic (ppm)	Beryllium (ppm)	Cadmium (ppm)	Chromium (ppm)	Copper (ppm)	Lead (ppm)	Mercury (ppm)	Nickel (ppm)	Zinc (ppm)
West Freehold (1)										
0-7	5.3	16	3.5	3.5	260	6.17	18	0.13	18	150
7-15	4.9	11	2.8	3.3	320	<0.4	19	<0.04	16	130
15-24	4.8	21	5.0	4.9	420	27	21	<0.04	21	200
24-48	4.7	12	11	10	250	51	20	<0.04	73	62
West Freehold (2)										
0-6	4.8	55	1.5	3.4	200	1.3	15	0.05	7.9	62
6-12	4.8	52	1.2	2.5	220	<0.4	8	0.05	6.6	51
12-20	4.5	77	0.9	2.2	290	<0.4	6.8	<0.04	5.6	51
20-42	4.1	22	1.0	1.6	340	17	16	<0.04	6.3	170
42-48	4.0	11	0.9	2.0	340	11	13	<0.04	6.5	68
West Freehold (3)										
0-8	4.7	17	0.7	1.4	68	3.2	13	0.15	4.8	35
8-17	5.1	17	1.3	2.4	130	1.1	<2.9	0.07	7.0	43
17-30	4.8	14	1.0	1.5	110	1.4	7.5	<0.04	4.8	33
30-60	4.6	15	0.9	1.6	110	<0.4	5.3	<0.04	4.5	35

\*The mapping units shown on the Monmouth County soil survey list the soils as the Marlton series. Taxonomically it is believed that the Freehold series would be more proper.

elemental content in the soil has some serious limitations.

Shuman (1991) states that metals in soils can be considered into several categories relative to their availability of materials as follows:

- a) those dissolved in the soil solution
- b) those occupying exchange sites on inorganic soil constituents
- c) those absorbed on inorganic soil constituents
- d) those associated with soil organic matter
- e) those precipitated as solids
- f) those present in secondary minerals
- g) those present in primary minerals

The problem of solubility of trace elements in soils has been reviewed in exemplary form by McLean and Bledsoe (1992). These authors state that reporting the total concentration of metals in soils is useful for determining any net change in element content available to enter the food chain over time, however, such methods do not give an indication as to the chemical form of the metal in the soil. Calvert, Bourgeois and Msaky (1990) also provided a basic review of the various methodologies used for extracting heavy metals in soils and sediments.

4. Determining the constituents soluble by making two leachings using 0.1N hydrochloric acid. These values should approximate the constituents available to enter the food chain over tens of years or perhaps as much as a century. This statement is one of empiricism based on many years of research dealing the assessment of soils for their availability of nutrients. The method does not involve geochemistry including kinetics of individual elements or ions. Without question, the procedure should be considered preliminary and requires further evaluation.
5. Dissolution of all solid components in the soil. Various methods such as heated mixtures of nitric acid, sulfuric acid, hydrofluoric acid and perchloric acid are used. The methods will usually account for about 80% or more of the

heavy metals. Page, Miller, and Keeney (1982), McLean and Bledsoe (l.c.) and many others have reviewed the various methodologies used. For a total analysis, however, the soil should be fused with sodium carbonate followed by solution in acid. Another method for total analysis of the soil is by spectrographic techniques.

To show the quantities of arsenic, beryllium, and cadmium released in a greensand soil using various extractants, a pit was excavated near Iron Bridge in Monmouth County and soil samples taken. The soil, approximating the Freehold series, had the following characteristics:

Depth	Description
0-6 in (Ap)	Dark brown (10 YR3/3m) sandy loam, weaksubangular structure, firm, estimated 5% glauconite.
6-16 in (B <sub>1</sub> )	Dark yellowish brown (10YR 4/4m) clay loam with a few strong brown (7.5YR 5/6) concretions, subangular, blocky structure, firm, estimated 15% glauconite.
16-24 in (B <sub>2</sub> )	Dark yellowish brown (10YR 4/4m) sandy clay loam with brown and black spots, subangular blocky structure, firm, estimated 15% glauconite.
14-96 in (C)	Yellowish red (5YR 5/6m) sandy clay loam, firm, with many concretions, estimated 20% glauconite. 96+in – Dense, multicolored, weakly cemented glauconitic sandstone slabs.

Figures 12, 13, and 14 show the quantity of arsenic, beryllium, and cadmium released from the Freehold sandy loam soil through the use of various chemical reagents. It will be noted that there is no definitive pattern of distribution with depth. Further, indications are that the geologic nature of the matrices is the prime controlling factor in determining the quantity of the elements under discussion.

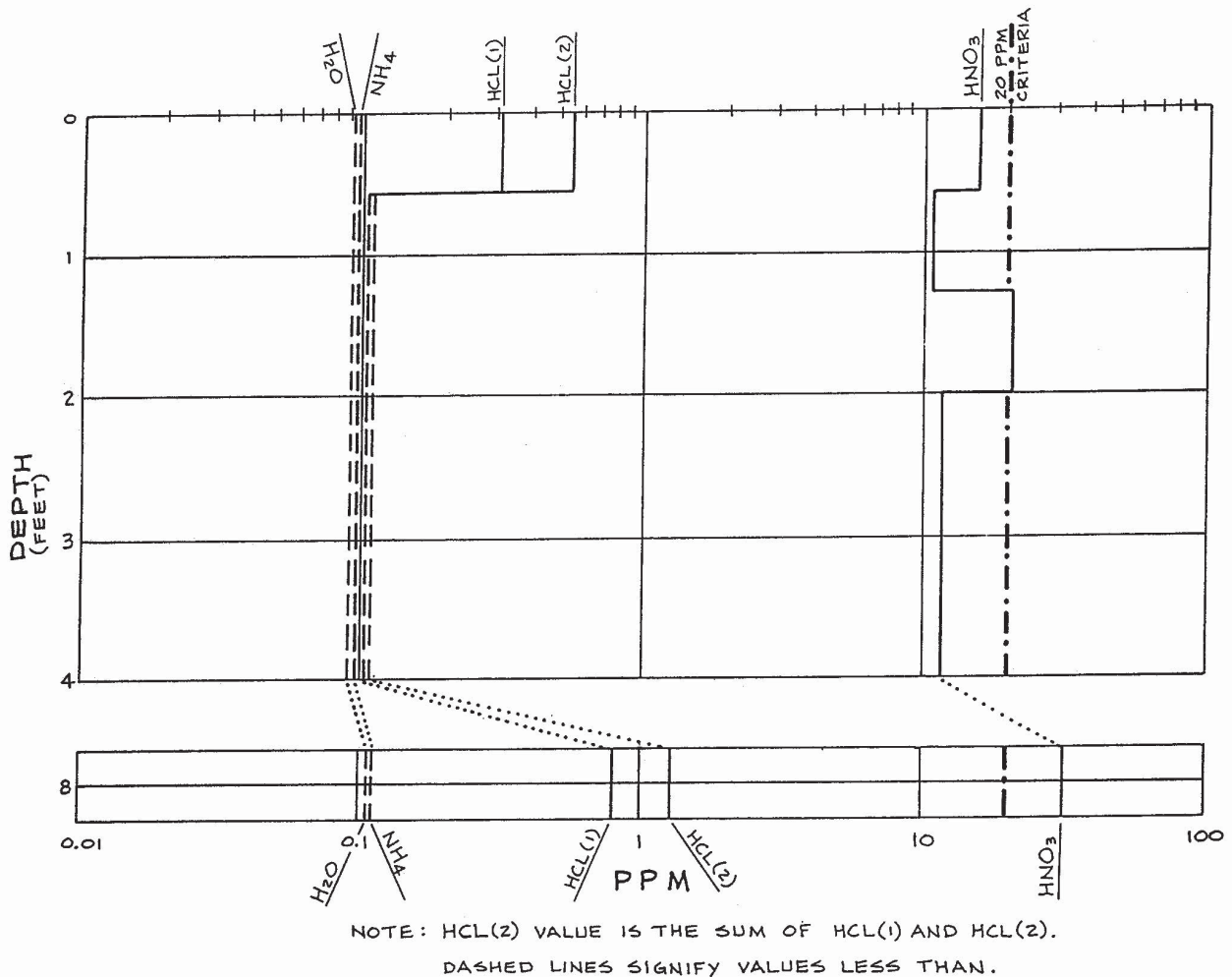


It is believed that, in most situations, the double hydrochloric acid extraction could be used as a guideline for approximating the quantity of heavy metals entering the soil-plant system over a period of at least several tens of years. In very sensitive areas such as playgrounds and yards the number of extractions with acid could be increased accordingly.

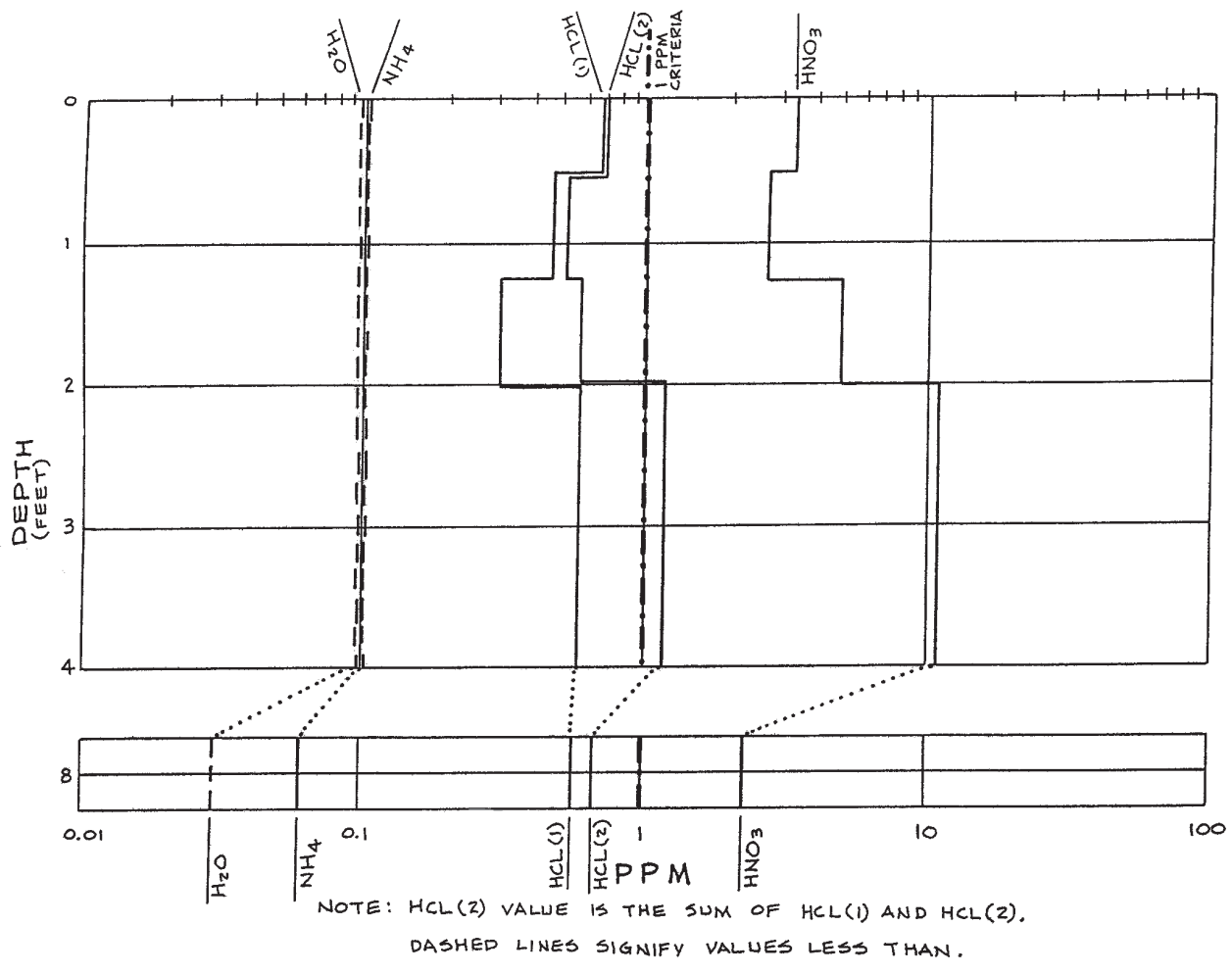
Apparently there are few, if any, regulations specifically concerning the acceptable limits of

arsenic in New Jersey greensand soils other than those codes applicable to all soils in general. The problem of arsenic in potable water, however, has been receiving increased public attention (Amendment to N.J. Administrative Code 7:10 - 5.2. N.J. Register, January 22, 2002).

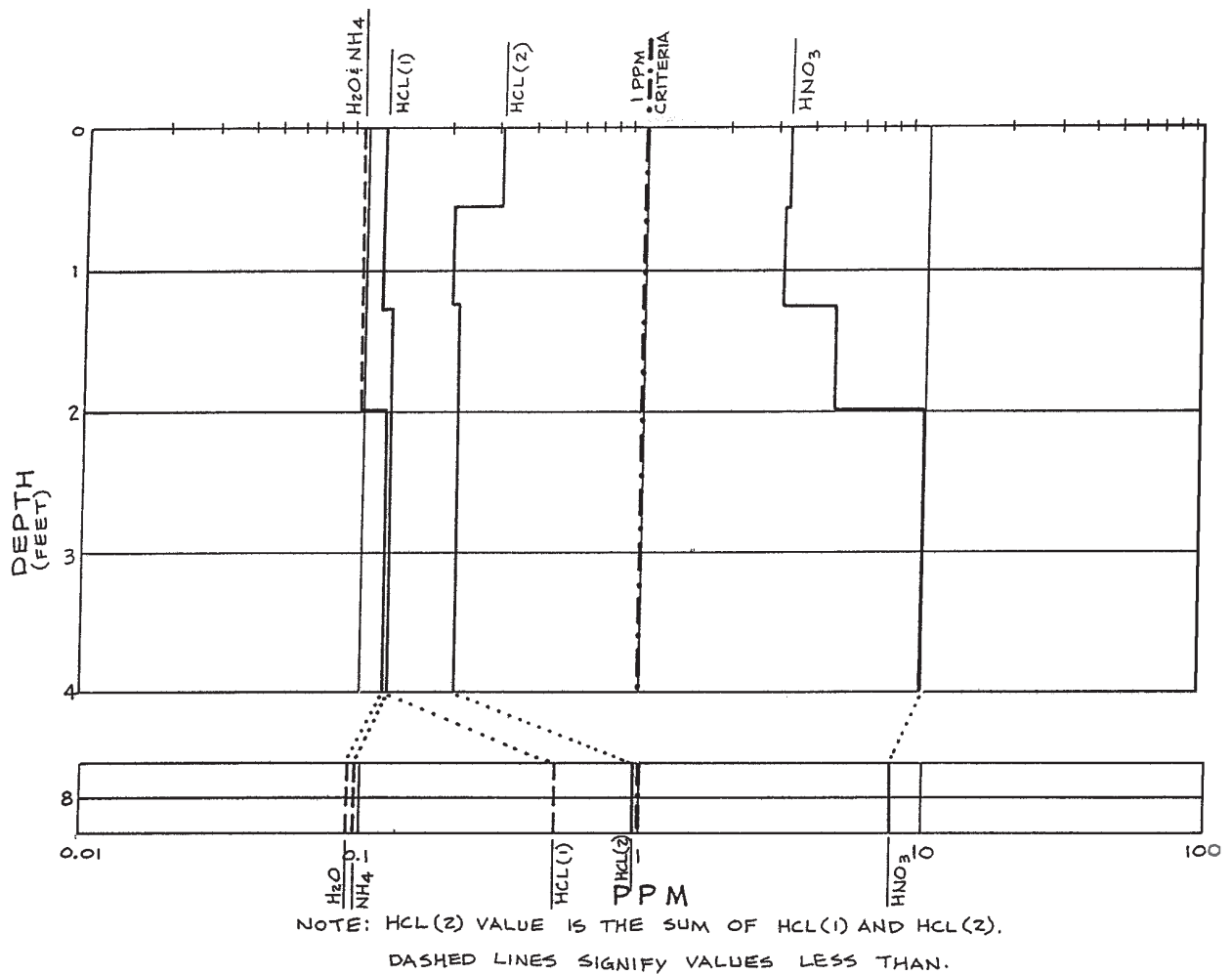
While this report primarily concerns greensand soils, the principle of trace element extraction should also be applicable to non-greensand soils.



**Fig. 12.** Diagram showing the quantity of arsenic solubilized in the Freehold sandy loam soil using different extracting agents. The heavy vertical dot-dash line indicates the upper permissible limit established by regulatory agencies. The HCL (2) values indicate the summation of the two leachings. NH<sub>4</sub> denotes NH<sub>4</sub>Ac (unpublished data of W.T. Bell, Jr. and J.C.F. Tedrow).



**Fig. 13.** Diagram showing the quantity of beryllium solubilized in the Freehold sandy loam soil using different extracting agents. The heavy vertical dot-dash line indicates the upper permissible limit established by regulatory agencies. The HCL(2) values indicate the summation of the two leachings. NH<sub>4</sub> denotes NH<sub>4</sub>Ac (unpublished data of W.T. Bell, Jr. and J.C.F. Tedrow).



**Fig. 14.** Diagram showing the quantity of cadmium solubilized in the Freehold sandy loam soil using different extracting agents. The heavy vertical dot-dash line indicates the upper permissible limit established by regulatory agencies. The HCL (2) values indicate the summation of the two leachings. NH<sub>4</sub> denotes NH<sub>4</sub>Ac (unpublished data of W.T. Bell, Jr. and J.C.F. Tedrow).

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# Appendix

## Earlier surveys describing glauconite-bearing soils in New Jersey.

### Camden Area

Patrick, A.L., C.C. Engle and L.L. Lee. 1915. Soil Survey of the Camden Area, New Jersey. U.S.D.A., Bu. Soils. U.S. Govt. Prtg. Off. pp. 155-195.

Burke, R.T.A. and L.L. Lee. 1926. Soil Survey of the Camden Area, New Jersey. U.S.D.A., Bu. Chem. and Soils. U.S. Govt. Prtg. Off. 35 pp.

### Chatsworth Area

Lee, L.L. et al. 1923. Soil Survey of the Chatsworth Area, New Jersey. Field operations of 1919. U.S.D.A., Bu. Soils. U.S. Govt. Prtg. Off. pp. 469-515.

### Freehold Area

Dickey, J.B.R. and L.L. Lee. 1916. Soil Survey of the Freehold Area, New Jersey. Field operations of 1913. U.S.D.A., Bu. Soils. U.S. Govt. Prtg. Off. 51 pp.

Lee, L.L. and J.E. Tine. 1927. Soil Survey of the Freehold Area, New Jersey. U.S.D.A., Bu. Chem. and Soils. U.S. Govt. Prtg. Off. 53 pp.

### Salem Area

Bonsteel, J.A. and F.W. Taylor. 1902. Soil Survey of the Salem Area, New Jersey. U.S.D.A., Div. of Soils. U.S. Govt. Prtg. Off. pp. 125-148.

Burke, R.T.A., J. Thorp and W.G. Seltzer. 1929. Series of 1923. Soil Survey of the Salem Area, New Jersey. U.S.D.A., Bu. Chem. and Soils. U.S. Govt. Prtg. Off. pp. 1649-1696.

### Trenton Area

Burke, R.T.A. and H.J. Wilder. 1902. Soil Survey of the Trenton Area. New Jersey. U.S.D.A., Bu. Soils. U.S. Govt. Prtg. Off. pp. 163-186.

L.L. Lee. 1926. Soil Survey of the Camden Area, New Jersey. U.S.D.A., Bu. Chem. and Soils. U.S. Govt. Prtg. Off. pp. 1575-1632.

## Later surveys describing glauconite-bearing soils in New Jersey.

### Burlington County

Markley, M.L. 1971. Soil Survey of Burlington County, New Jersey. U.S.D.A. 120 pp.

### Camden County

Markley, M.L. 1966. Soil Survey of Camden County, New Jersey. U.S.D.A. 94 pp.

### Gloucester County

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