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CHEMICAL STUDIES OF INFERTILE SOILS DERIVED FROM ROCKS HIGH IN MAGNESIUM

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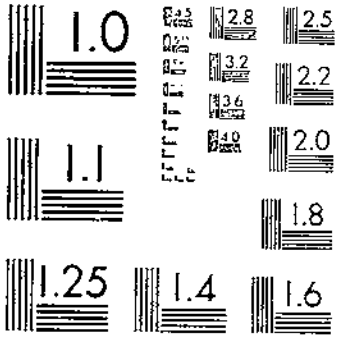

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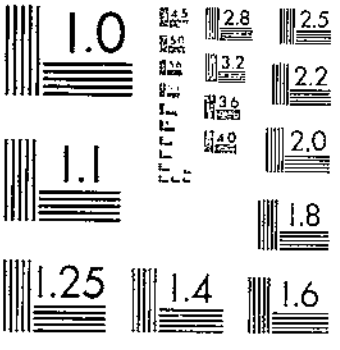

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UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D. C.

CHEMICAL STUDIES OF INFERTILE SOILS DERIVED FROM ROCKS HIGH IN MAGNESIUM AND GENERALLY HIGH IN CHROMIUM AND NICKEL

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INTRODUCTION

In many agricultural areas there are soils which are inferior to the soils in the immediate neighborhood in that they are relatively infertile. In most cases the cause of inferiority is apparent; such as rough stony land, shallow soil, poor drainage, and the lack of enough clay to retain moisture and plant-food elements.

In some cases, however, there are soils which from all ordinary appearances and climatic considerations should be more productive than they really are. This investigation was undertaken for the purpose of determining, if possible, the cause of such infertility. Notable examples of these soils are found in the Conowingo Barrens on the serpentine outcrops in Maryland and Pennsylvania. Other soils of like character have been described in soil literature. They are the soils on the Great Dyke in South Africa and the Nipe and related soils of Cuba and Puerto Rico.

The Conowingo, Nipe, and Great Dyke soils, although widely separated geographically and ranging in character from podzolitic to lateritic types, have one thing in common. They are formed from strata high in magnesia, generally diorites, which alter into serpentine and chlorite. These rocks differ from granites and gneisses in that they are extremely high in magnesia, generally low in lime, and always low in potash and soda. They may be low in alumina,

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through a growth of stunted oaks, scrub pines, and mountain laurel upon the heated soil, through which project boulders of the country rock. These areas are known throughout the country as the serpentine "barrens." Wild, uncultivated, almost unsettled, they stand in great contrast to the surrounding rich and prosperous country.

DESCRIPTION OF THE SAMPLES

The Conowingo soils, developed most extensively in Harford, Baltimore, and Montgomery Counties in Maryland, are perhaps the most infertile soils known which have good physical properties and favorable climatic environment. Less than 10 percent of these areas are cleared for agricultural purposes, and when so used are characterized by low yields. The virgin Conowingo soils support a very specialized and stunted tree growth. The low acre value and the very low percentage of cleared land on the Conowingo areas is taken as evidence that the Conowingo soils are infertile.

A good illustration of the infertility of the Conowingo series is presented by a long, narrow strip of Conowingo silt loam beginning just a few miles west of Rockville, Md., at Hunting Hill and running some 5 or 6 miles southwest from this point. Inside this area very little of the land is cleared, but just outside on the Chester loam the land is practically all cleared and is occupied by prosperous farms. The line of demarcation between the two series is unusually sharp and easily apparent to any observer. On the Conowingo side of the line the tree growth is stunted and the very few farms there present a picture of hopeless economic struggle.

In this connection it is interesting to note that as early as 1810 Isaac Tyson, Jr., was led to the discovery of chromium ores in Maryland and Pennsylvania "by his prompt recognition of the comparative barrenness of vegetation of the serpentine terrain" (Singewald (*33*)). It was presumably through this recognition that the Tyson Chrome Works monopolized the chromium industry in this country for over 40 years.

The description of the Conowingo series given below is quoted from Perkins and Winant (*25, pp. 20–21*).

> The surface soil of Conowingo silt loam to a depth of about 6 or 8 inches is grayish-yellow or very light brown silt loam, having a smooth floury feel. In a few places in the wooded areas there is either a very thin covering of leaf mold or the first 2 inches of soil contains enough organic matter to give it a gray color. The subsoil is yellow or yellowish-brown silty clay loam extending to a depth ranging from 14 to 18 inches, at which depth it grades into yellowish-brown or brownish-yellow heavy, stiff, plastic clay, having a green or greenish-brown cast. This heavy clay layer ranges in thickness from a few inches to as much as a foot in some places, and it is underlain by greenish-yellow partly weathered rock or by the hard rock. In many places the surface soil grades into the heavy clay at a depth of a few inches and the clay is underlain at a depth ranging from 15 to 30 inches by rock, and in other places the rock comes near the surface or outcrops. In places on the more level areas, and particularly where this soil adjoins Aldino silt loam, a mottled light-gray, yellow, and rust-brown compact layer occurs at a depth ranging from 14 to 20 inches. Conowingo silt loam is derived from a dark-green rock related to gabbro and diorite, from steatite, and from serpentine, or serpentinized rock. In places quartz veins cut through these formations.
>
> * * * * * * *
>
> This soil occurs in gently rolling or slightly hilly areas, and surface drainage is fairly good. On the more level areas the run-off of rain water is slow, and the internal drainage of all areas is poor, owing to the impervious character of the subsoil.
>
> Probably not more than 20 or 30 percent of the land is cultivated or in pasture, and the remainder is forested, mainly with scrub oak, blackjack oak, white oak,

post oak, cedar, and hickory. Small areas are used in the production of corn, wheat, hay, and tomatoes. The yields of these crops are usually low unless the soil has been heavily fertilized and manured, or cover crops turned under prior to planting the crop. In a few places the soil is very shallow and such areas are of low agricultural value and should be devoted to forest or pasture.

The Conowingo stony loam is derived from the same parent material as the Conowingo silt loam. As the name implies, it is more stony and shallow. It is unproductive soil and practically none is under cultivation. The forest growth now on this soil shows it to be unsuited to forestry or orcharding.

Four other series of high-magnesium soils were studied, namely laterites from Puerto Rico; the Millville loam from Greenville, Utah; and the Corning and Jerome series from Josephine County, Oreg.

The locations and brief descriptions of the samples of soil studied, with a short series description in some cases, are given below. For convenience of future reference the soils are given in the order of the laboratory numbers assigned to them.

Laboratory nos. 2522–4, Limones clay.—Description taken from Bennett and Allison (*1, p. 31*), of an infertile shallow clay overlying serpentine or diorite in Central Soledad, Cuba.

Typically this is a 3-horizon soil, with the following vertical section features: (1) About 3 to 5 inches of dark-red or purplish-red clay, which cracks on drying to hard clods of small or medium size; overlying (2) pinkish-red clay, which cracks into very hard clods of medium to large size, with some fragments of partly decomposed parent rock; passing at about 12 to 30 inches into (3) rotten (partly decomposed) soft and hard parent rock—mostly serpentine and diorite. Typically, lime carbonate is not present. The type is of a droughty nature but not so much so as the Holguin clay. In many places the soil is shallow. When such areas are plowed, fragments of the soft clay and hard rock are usually turned up abundantly or in sufficient quantity to produce a decidedly gravelly or even a stony soil. If plowed wet enough to be decidedly sticky, clods are formed which become tough on drying. When dry, plowing is difficult and large clods are formed; but these tend to crack on exposure to sun to form a coarse-fragmental tilth. Harrowing is necessary to develop the most favorable seed-bed conditions.

The topography is undulating to hilly, and the drainage is well established. Frequently the soil of lower slopes and depressions is more brownish in color, often chocolate brownish, and is deeper, more retentive of moisture, and more productive.

Laboratory no. 2548, Holguin clay.—Central Miranda, 5 km west of Ingenio, Cuba. Bennett and Allison (*1, p. 30*) state:

This series includes purplish-red soils derived from the underlying igneous rocks, chiefly serpentine. Sharp horizonal differences are not usually distinguished through the profile. Frequently, however, such changes are noted in the deeper sections. Often there are only two indistinctly separated horizons above the hard rock, these being the upper purplish-red section and a lower section of mixed greenish partly decomposed rock material and reddish clay. Black and purplish-black concretions of irregular shape are typically abundant in the red horizons. Manganese ore is taken from the soil in some localities, indicating a series characteristic of high manganese content. Only the clay and stony clay types were seen, with some very shallow phases over serpentine.

A characteristic of this soil is its proneness to lose quickly its moisture in the dry season, with concomitant development of an extremely hardened condition accompanied by cracking and formation of hard clods. Crops suffer so intensely in the dry season that the soil is never favored for cultivation. A typical deep dry section in the foothills of the Nipe Mountains shows the following characteristics: (1) A 36-inch horizon of (dry) hard small clods with 20 per cent or more of purplish-black and black perdigón of irregular shape; this overlying (2) a layer 8 to 12 inches thick consisting of yellowish-brown and reddish cloddy clay, together with soft, partly decomposed rock with black and purplish-black facings; over (3) greenish and reddish soft and brittle partly decomposed rock with purplish-black facings along the seams and cracks, the interior of the partly

decomposed rocks being greenish in color; passing at depths of about 4 feet into (4) greenish rock (serpentine). In point of origin the material is related to the Nipe soil, but it is not nearly so friable. It is also related to the material of the Limones clay, but it is more purplish red, and harder when dry. There is some gradational soil between the true Holguin and the true Limones, such as the less purplish red shallow clay of the Holguin region. There is no free lime carbonate in the material at any depth, insofar as could be detected by the acid test.

Laboratory nos. 4722–6, Conowingo silt loam.—This sample was collected three-fourths of a mile north of Dublin, Md., in a forest, 100 feet on the southwest side of the road. Blackjack oak, smilax vines, and blueberry bushes were the predominating growth. Nos. 4725 and 4726 are from a profile about 50 feet north of no. 4722. The B and C horizons in this second profile are taken together. This particular phase contains a large quantity of a micaceous-appearing mineral which has been identified as vermiculite.

Laboratory nos. 5829–30–31 and 6175, Conowingo silt loam —This soil was taken 1 mile northeast of Belmont, Baltimore County, Md., 200 feet southeast of the road. It was in stumpage but had not been cultivated for some time. The tree growth was better than the Dublin Conowingo and no blackjack oak was noted on this location. The soil material in the lowest part of the profile shows a very large calcium content. The sand in this horizon was largely hornblende. This sample was taken near the middle of an area surveyed as Conowingo silt loam, and though not a fertile soil, it would appear to be more fertile than many soils of this series. It probably represents a high calcium phase of the Conowingo due to the presence of a large quantity of hornblende and pyroxene in the original diorite.

Laboratory no. 5891, Nipe clay.—Nipe Bay, Oriente, Cuba. Bennett and Allison (*1, p. 29*) describe this series as follows:

> The Nipe soils occur extensively over the northwestern part of the Nipe Mountains, in the Province of Oriente. Topographically, they are undulating to gently rolling. The basal rock seen is a greenish, crystalline serpentine. The soil is derived from this rock. In some exposures the green stone passes down into a dark tough crystalline of basic-igneous character, resembling diorite, or peridotite, the serpentine representing an alteration product of the darker rock. The only type found consists of deep-red, friable material of a highly ferruginous nature. Roundish, flattish and irregularly shaped concretionlike pebbles of black and reddish-brown color are abundantly present. In many places these can be scooped up by the handful from the surface of the ground. A fresh exposure showed the following characteristics:
>
> (1) 0 to 26 inches—deep-red friable clay, containing round, flattish and rough-surfaced ferruginous pebbles (perdigón) of shiny-black (like desert polish), black, and reddish-brown color;
>
> (2) 26 to 40 inches—reddish-brown, friable clay, with but few perdigón;
>
> (3) 40 inches to 13 feet—yellow, very friable ochreous material;
>
> (4) 13 to 16 feet—reddish, yellowish and almost black, very friable material, the black predominating as a spongelike mass lying immediately over the green serpentine. In places the depth to unaltered rock is 40 to 50 feet. The top foot or two is often more compact than the material beneath. This is in the *plancha* layer.
>
> The vegetation consists of pine and wire grass. Palm trees, tree-fern, and other tropical plants were found in a limited belt which appeared to have a heavier rainfall than the average for the region. About 85 per cent of the ground surface is covered with short wire grass. None of this soil was seen in cultivation. The material is mined for the manufacture of iron. No lime carbonate was detected in any of the sections.

Laboratory nos. 6178–80, Conowingo silt loam.—This sample was taken one-half mile east of Cherry Hill, Harford County, Md., on rough stony land on a sidehill. The rock samples, nos. 6181a and

6181b represent the weathered surface soil and fresh rock from beneath this sample.

Laboratory nos. 6236–8, Conowingo silt loam.—This soil was located 5 miles south of Oxford, Pa. This is typical barren Conowingo silt loam. Rock sample no. 6239 was taken from the clay layer 20 inches deep in this profile.

Laboratory nos. 6241–43, Conowingo silt loam.—This sample was found one-half mile north of Jermantown, Fairfax County, Va., in a pine grove, 100 feet west of the road. It is rated as poor farm land, but cultivated flowers produce good blooms on this soil in this locality.

Laboratory no. 7574, soil material.—This sample was located on Mount Tamalpais, Marion County, Calif. It was collected and sent to the Department through the kindness of C. B. Lipman. It was taken from the same place as the soil sample described by Gordon and Lipman (*11*) as follows: "From the west peak of Mount Tamalpais, Marion County. Disintegrating serpentine rock. No vegetation on it except an occasional tuft of moss on rock masses. Free from contamination with any other rock or soil." It is recognized that this is not a soil. It is rather soil material. But since it has a standing in soil literature as an infertile soil material formed from serpentine rock, it became of interest to examine this soil material for nickel and chromium, and to ascertain its chemical and mechanical composition.

Laboratory nos. 7819–22, Millville loam.—Located near Logan, Utah, Greenville Experiment Farm. This is a classical example of a fertile soil high in magnesia. It has been studied by Stewart (*34*). The soil is formed from a lacustrine deposit of detritus from limestone, dolomite, and quartzite in the old Lake Bonneville basin. This soil is remarkably fertile and produces excellent crops even without the addition of fertilizers.

Laboratory nos. 8755–57, Corning gravelly silt loam.—This sample was taken from the northeast quarter of sec. 31, T. 39 S., R. 8 W., near Woodcock Creek, Josephine County, Oreg. Kocher and Torgerson (*16, p. 367*) give the following general description of the Corning series.

> The surface soils of types of the Corning series are red and dull red to brownish red or slightly yellowish red. Water-worn gravel of mixed origin and small iron concretions are common on the surface and in the surface material of most of the types, and some contain angular fragments of igneous rocks. The subsoil is typically dull red to bright red in color, compact, usually heavy in texture, and fairly retentive of moisture, and contains rounded gravel or angular rock fragments. In some of the included materials the subsoil is very compact and partly cemented when dry. Typically the heavy subsoil passes at depths of 3 to 5 feet into friable gravelly material similar to the surface soil. In its typical development the Corning series occupies terraces lying from a few feet to 100 feet or more above the present courses of the streams. The parent material consists typically of old water-laid deposits. The surface drainage is good.

This particular sample of Corning gravelly silt loam was sent in by W. L. Powers, of the Oregon Agricultural Experiment Station. It was selected because it was an infertile soil derived partly from one of the "poison spots" which occur occasionally in this soil.

Laboratory nos. 9338, 4343, and 9346, Nipe clay.—These are surface soils taken in the vicinity of Mayaguez, P. R. The parent rock is predominantly chlorite. These soils are markedly infertile.

Laboratory nos. 9356–59, Conowingo silt loam.—Located at Hunting Hill, Montgomery County, Md., three-quarters of a mile southwest of Hunting Hill and 75 feet west of Piney Meeting House Road. It was covered with a stunted tree growth of blackjack oak, pine, greenbrier, and blueberry bushes, with an occasional white oak. In many places patches of several square feet were entirely covered with moss. This sample was taken in a very infertile area of Conowingo, which is surrounded by fertile Chester soils. The line of demarcation between these two series is very sharp. In the Conowingo area there are numerous serpentine outcrops.

Laboratory nos. 9460–62, Conowingo silt loam.—This sample was taken one-half mile east-northeast of the crossroads at Potomac, Montgomery County, Md., about 100 feet southwest of a small stone house foundation. The tree growth was almost entirely pine, with occasional dogwood, cherry, and white oak. The tree growth was fairly good. This area is mapped as Conowingo but appeared to be a better soil. However, the deepest horizon contained a few fragments of serpentine.

Laboratory nos. 9465–70, Nipe clay.—Located 1 mile east of Mayaguez, P. R. These samples are much like Nipe clay, nos. 9338, 9343, and 9346. The parent rock is chlorite and the soil is infertile. This profile sample shows much magnesium in the lowest horizon and traces or very small quantities in the upper horizons where severe leaching has removed nearly all the magnesium. No. 9469 of this profile is remarkable in that it contains the maximum quantity of chromium of any soil ever analyzed in this Bureau.

Laboratory nos. 9889–91, Conowingo silt loam.—This sample was taken one-eighth mile southwest of Alberene, Va., near an old alberene mine. According to an official of the company now mining alberene in the vicinity there are two distinct phases of soil forming from talc strata, differing mainly in that one is less infertile than the other. This profile is from the more fertile phase.

Laboratory no. 9929, Jerome sandy loam.—This soil is the dark-colored phase from near the west corner of sec. 26, T. 39 S., R. 8 W., at the intersection of Sucker Creek and Oregon Cave roads in Josephine County, Oreg. It is on an outcrop of serpentine rock. The vegetation is scanty, consisting of short grass and weeds. Kocher and Torgerson (*16*) state that Jerome sandy loam has an impervious, heavy clay subsoil and when thoroughly dry this subsoil bakes into a bricklike mass which is not easily penetrable by the roots of plants.

Laboratory nos. 9931–33, Corning gravelly loam.—This sample was taken near the southwest corner of sec. 10, T. 39 S., R. 8 W., Josephine County, Oreg., from a small clear spot, probably the site of an abandoned farm. Scant grass and large oaks were on the area where sample was taken. Conifers and oaks are plentiful on higher areas of the same type.

MECHANICAL COMPOSITION OF THE SOILS

The mechanical analyses of some of the high magnesium soils used in this study are given in table 1. The analyses were made by L. T. Alexander and H. W. Lakin, of this Bureau.

TABLE 1.—*Mechanical analyses of high-magnesium soils*

Soil type, location, and sample no.	Depth	Mechanical fraction							
		Fine gravel	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	Colloid
Limones clay, Limones Farm, Central Soledad, Cuba:	*Inches*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
2522	0–4	1.2	2.0	1.5	7.6	8.7	29.6	49.6	[1] 61.7
2523	4–16	7.6	6.9	3.2	12.5	11.2	22.7	36.2	-------
Conowingo silt loam, ¾ mile north of Dublin, Md.:									
4722	0–6	3.9	2.3	1.2	3.3	6.4	53.0	28.7	17.7
4723	6–10	3.4	9.3	5.4	12.4	11.6	30.7	26.8	21.5
4724	10–30	9.4	13.4	7.0	15.5	12.7	24.4	17.8	14.5
4725	0–6	2.1	1.8	1.0	2.6	4.0	56.9	30.0	18.6
4726	6–30	7.0	8.9	3.5	13.6	18.8	25.9	22.0	18.5
Conowingo silt loam, Belmont, Baltimore County, Md.:									
5829	-------	2.1	1.9	1.1	3.4	4.1	56.9	30.6	17.4
5830	-------	.7	1.3	1.3	5.7	7.9	39.7	43.4	32.7
5831	-------	.0	1.8	1.9	10.0	16.5	39.2	30.8	32.2
6175	-------	-------	-------	-------	-------	-------	-------	-------	-------
Nipe clay, Nipe Bay, Oriente, Cuba:									
5891	0–12	4.6	4.1	2.0	2.3	1.6	21.2	63.9	50.2
Conowingo silt loam, ½ mile from Cherry Hill, Harford County, Md.:									
6178	-------	.8	1.5	1.1	2.0	2.1	62.4	28.4	15.8
6179	-------	.7	.8	.6	1.1	1.8	60.2	34.6	22.4
6180	-------	.3	.3	.4	1.0	1.9	59.8	35.9	23.4
Conowingo silt loam, 5 miles south of Oxford, Pa.:									
6236	0–12	2.6	3.3	1.8	3.2	5.3	52.4	31.6	24.3
6237	12–20	8.5	11.4	5.4	11.8	16.3	32.1	14.2	10.9
6238	20–26	3.1	4.0	2.2	4.4	6.5	46.3	33.2	26.2
Conowingo fine sandy loam, ½ mile north of Jermantown, Fairfax Co., Va.:									
6241	0–4½	5.2	7.4	4.2	14.0	21.6	34.6	12.8	9.7
6242	4½–13	3.5	8.1	4.5	14.0	20.7	36.6	12.9	9.1
6243	13–22	7.5	5.2	2.7	8.8	15.0	43.0	15.7	8.2
Millville loam, Greenville, Utah:									
7819	-------	.1	.2	.4	4.1	17.7	57.0	16.6	14.1
7820	-------	0	.2	.2	2.8	15.3	59.6	20.2	12.7
7821	-------	0	.1	.1	1.0	13.7	59.2	25.0	16.2
7822	-------	0	.1	.1	1.9	14.9	62.5	19.9	10.6
Corning sandy clay loam:									
8755	-------	8.5	7.8	0.8	14.5	12.8	24.2	22.2	15.1
8756	-------	1.3	1.5	1.4	3.1	4.8	28.5	58.8	50.0
8757	-------	-------	-------	-------	-------	-------	-------	-------	-------
8758	-------	1.1	1.5	1.9	8.0	11.8	24.6	50.8	43.5

[1] By water-absorption method.

In general, there is nothing shown in the mechanical analyses of these soils to explain the observed infertility. In some soils, such as the Dublin, Cherry Hill, and Oxford Conowingo soils, there is not enough coarse material to give good internal drainage. The silt in these soils contains a large percentage of vermiculite which has a micalike form and consequently does not pack as closely as some silt particles.

Russell (*80, pp. 170, 546*) maintains that soils containing over 15 to 25 percent of fine silt (English standards) are often difficult to drain and to work, "and that this close packing, being the result of particle size and not of any special colloidal property, cannot be mitigated by the usual clay cultivation devices such as treatment with lime." While Russell's theory may be applicable in some cases, it does not generally apply to these high-magnesium soils because the Millville loam—the most fertile soil on the list—is also very high in silt. In

defense of Russell's theory, however, it should be said that the lower horizons of some of the Conowingo profiles show certain chemical characteristics which indicate poor drainage. Thus, samples 4724, 6180, 9458, and 9459 (table 2) show a slight negative value or gain in weight when treated with hydrogen peroxide in the determination of organic matter. This is probably due to the prescence of active ferrous iron, that is, ferrous iron in a more active condition than in the undecomposed ferrous-magnesium silicates.

The mechanical analyses show an adequate percentage of colloidal matter to hold soil moisture and to prevent the too rapid leaching of the plant food elements.

CHEMICAL COMPOSITION OF THE SOILS

The analyses of the soils were made by the methods outlined in circular 139 (*23*) with special determinations according to Hillebrand and Lundell (*14*). The presence of chromite in many of the samples made it necessary to fuse the unattacked residue from the sodium carbonate and niter fusion with potassium pyrosulphate to effect the solubility of the chromium. The results of the analyses are given in table 2.

The outstanding features shown by the chemical analyses of the soils are the generally very high percentages of magnesium and the comparatively very high percentages of chromium and nickel. Maximum percentages of these elements occurring in soils, so far as recorded, are shown in table 2. The Mount Tamalpais soil material with 36.42 percent of magnesium oxide is the highest. The subsoil of the Oxford Conowingo, no. 6237 (12 to 20 inches) with 25.01 percent of magnesium oxide, is the maximum percentage of this constituent yet recorded for a natural soil. Nipe clay, no. 9469, with 5.23 percent Cr_2O_3, contains the maximum quantity of chromium, and Limones clay, no. 2524, contains the maximum quantity of nickel, 0.453 percent NiO.

The quantities of nitrogen, potassium, and phosphorus are in the main low, but not lower than in many fertile soils. The Millville loam which is the only fertile soil studied, is very high in potash and fairly high in phosphorus. It is, however, not as high in potash as the Limones clay, no. 2522, or the Cherry Hill Conowingo, no. 6180. Both of these two last-named soils are markedly infertile. The nitrogen in the Millville profile is not very different from the other soil profiles. The most conspicuous difference between the fertile Millville and the other infertile soils is the absence of chromium and nickel in the Millville profile.

The Corning soils, nos. 8755–57, 9931–33, and the Jerome, no. 9929, are markedly infertile individual members of soil series which are productive under some conditions. The samples selected represented "poison spots" in the area. The quantities of plant-food elements are comparable with those of the Millville, but there is in these soils a high percentage of chromium and generally nickel, which is in strong contrast to the Millville soil. The more fertile areas of Corning soils, as represented by two samples examined, but of which the analyses are not shown in the table, contain no chromium or nickel.

The quantities of calcium vary widely. In the Conowingo soils it is generally low, but in some it is abnormally high. The lowest

TABLE 2.—*Chemical composition of soils derived from rocks high in magnesia*

Soil type and location	Laboratory no.	Depth	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	Cr_2O_3	NiO	MnO	CaO	MgO	K_2O	Na_2O	P_2O_5	SO_3	N	Ignition loss	Organic matter	Colloid content	CO_2 as carbonate	pH
		Inches	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	
Limones clay, Limones Farm, Central Soledad, Cuba	2522	0–4	51.25	0.96	17.40	10.69	3.19	0.325	0.17	3.56	3.35	2.06	1.29	0.22	------	0.17	9.14	1.96	61.7	(1)	------
	2523	4–16					.42	.032													
	2524	16–42	45.85	.63	13.62	7.84	3.49	.453	.10	13.19	4.20	1.74	1.12	.30	------	.01	11.34	------	------	7.24	------
Holguin clay, Central Miranda, 5 km west of Ingenio, Cuba	2548	0–36	18.22	.37	12.06	55.50	.051	.031	.48	(2)	3.69	.39	.22	.05	------	.11	8.72	2.04	------	(1)	6.70
Conowingo silt loam, ¼ mile north of Dublin, Md	4722	0–6	66.30	.83	7.17	6.44	.17	.003	.09	.20	12.96	.66	.53	.03	0.13	------	5.55	1.36	17.7	(1)	5.85
	4723	6–10	47.00	.46	13.60	11.09	.24	(2)	.11	.06	18.31	.27	.20	.06	.12	------	9.20	.99	21.5	(1)	5.62
	4724	10–30	37.23	.20	16.47	12.23	.31	(2)	.14	.04	22.70	(2)	.07	.05	.10	------	10.96	—.21	14.5	(1)	6.62
	4725	0–6	68.40	.84	7.36	5.58	.24	.021	.07	.20	11.66	.73	.50	.04	.13	------	5.02	1.38	18.6	(1)	4.88
	4726	6–30	54.99	.17	6.82	7.89	.37	.050	.07	.05	23.70	.11	.12	.02	.11	------	6.26	.50	18.5	(1)	5.32
Conowingo silt loam, Belmont, Md	5829	½–8	73.13	1.57	10.38	6.20	.42	.081	.17	1.14	1.66	1.08	.56	.04	.06	------	4.50	1.00	17.4	(1)	4.06
	5830	8–18½	56.45	1.53	18.66	11.00	.06	(2)	.11	1.54	2.11	.84	.41	.03	.05	------	7.65	.71	32.7	(1)	4.86
	5831	18½–26	46.75	1.48	22.45	12.29	.10	(2)	.15	4.05	4.40	.49	.22	(2)	.07	------	7.28	.55	32.2	(1)	5.16
	6175	36–56	46.60	1.05	20.26	11.63	.04	(2)	.29	7.50	6.69	.20	1.15	.02	.03	------	5.13	.02	------	(1)	5.78
Nipe clay, Nipe Bay, Oriente, Cuba	5891	0–12	11.05	1.03	14.58	55.23	3.60	.280	.59	.04	.60	.10	.17	.06	.29	.11	12.42	------	63.9	(1)	------
Conowingo silt loam, Cherry Hill, Harford County, Md	6178	0–4	77.94	1.43	8.90	3.52	.16	.034	.17	.49	1.45	1.52	.67	.02	.11	------	4.65	1.58	15.8	(1)	4.32
	6179	4–8	73.18	1.25	12.03	5.10	.10	.054	.08	.41	1.53	1.85	.81	.02	.13	------	3.86	.36	22.4	(1)	------
	6180	8–20	65.90	1.16	14.44	6.75	.09	.057	.11	.94	2.56	2.16	1.46	.06	.13	------	4.29	—.06	23.4	(1)	------
Conowingo silt loam, 5 miles south of Oxford, Pa	6236	0–12	68.77	------	8.86	7.81	.33	.002	.13	1.66	4.65	1.22	.71	.04	.11	------	4.62	1.08	24.3	(1)	6.12
	6237	12–20	51.49	.18	7.52	8.33	.36	.064	.08	(2)	25.01	.12	.03	.04	.08	------	7.32	.69	10.9	(1)	6.82
	6238	20–26	52.24	.65	10.95	18.81	.08	(2)	.29	1.61	8.44	.94	.45	.02	.09	------	6.07	.51	26.2	(1)	6.28
Conowingo silt loam, Jermantown, Va	6241	0–4½	62.35	.42	10.28	10.90	.34	.058	.15	6.26	19.37	.01	.03	.02	.12	------	6.22	.33	9.7	(1)	5.33
	6242	4½–13	47.75	.41	10.41	10.78	.09	(2)	.16	6.01	18.35	.05	.02	(2)	.09	------	6.46	.73	9.1	(1)	5.00
	6243	13–22	46.50	.80	7.18	7.00	.08	.021	.16	4.72	11.69	.35	.38	(2)	.11	------	5.73	.62	8.2	(1)	4.45
Soil material, Mount Tamalpais, Marion County, Calif	7574	------	40.28	.12	2.36	9.31	.29	.250	.13	(2)	36.42	(2)	.02	.02	.08	------	12.25	------	1.8	(1)	8.09
Millville loam, Logan, Utah	7819	0–10	34.16	.33	7.13	2.55	(1)	(1)	.08	16.30	10.58	1.82	.45	.17	.19	.11	26.02	1.80	15.1	22.00	8.11
	7820	15–38	33.77	.37	7.22	2.50	(1)	(1)	.07	17.00	10.76	1.80	.55	.16	.22	.09	25.85	1.48	12.7	22.62	8.23
	7821	42–64	24.12	.30	5.34	1.85	(1)	(1)	.06	23.68	11.59	1.31	.43	.12	.25	.05	31.01	.68	------	28.79	8.28
	7822	65–96	23.94	.28	5.14	1.82	(1)	(1)	.05	23.59	12.17	1.29	.37	.11	.20	.03	31.58	.48	10.6	30.58	8.30
Corning gravelly silt loam, Josephine County, Oreg	8755	0–1	65.31	.75	11.59	12.32	1.32	(2)	.36	.46	1.83	.41	.23	.13	.09	------	6.49	------	15.1	(1)	6.06
	8756	2–10	35.23	3.46	27.50	19.90	.48	.11	.31	.32	.45	.24	.04	.42	.08	------	12.05	------	50.0	(1)	6.01
	8757	10–20	59.23	.78	15.23	13.49	.67	(2)	.09	.44	2.21	.73	.39	.07	.12	------	7.00	------	43.5	(1)	6.22
Nipe clay, 1 mile northeast of Mayaguez, P. R	9338	0–8	8.07	.78	18.06	54.35	.61	------	.15	.33	.27	.05	(3)	.08	.27	.114	16.49	------	------	------	------
Nipe clay, 3½ miles northeast of Mayaguez, P. R	9343	0–8	14.54	1.40	24.84	39.66	.53	------	.09	.19	(1)	.11	(3)	.07	.27	.130	17.82	------	------	------	------

[1] None.

[1] Trace.

TABLE 2.—*Chemical composition of soils derived from rocks high in magnesia*—Continued

Soil type and location	Laboratory no.	Depth	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	Cr_2O_3	NiO	MnO	CaO	MgO	K_2O	Na_2O	P_2O_5	SO_3	N	Ignition loss	Organic matter	Colloid content	CO_3 as carbonate	pH
		Inches	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	
Nipe clay, 3 miles southeast of Mayaguez, P. R.	9346	0–6	12.10	0.97	22.52	46.49	0.64	------	0.11	0.22	(2)	0.07	(2)	0.06	0.23	0.152	16.96	------	------	------	------
Conowingo silt loam, Hunting Hill, Md.	9456	0–7	75.82	1.08	8.97	5.04	.18	0.020	.13	.42	1.96	1.35	0.58	.03	.12	.042	4.36	1.26	------	(1)	5.80
	9457	7–18	63.03	.88	12.82	16.20	.20	.030	.20	.68	3.81	1.53	.65	.03	.16	.038	6.11	.68	------	(1)	6.20
	9458	18–22	57.68	.71	10.57	10.25	.26	.041	.24	.79	11.00	1.07	.42	.04	.07	.030	7.45	−.01	------	(1)	6.82
	9459	22–30	54.62	.64	8.06	11.20	.28	.072	.23	.46	15.44	.78	.22	.04	.07	.013	7.69	−.47	------	(1)	7.00
Conowingo silt loam, Potomac, Md.	9460	0–9	76.78	1.45	8.87	4.81	.03	(1)	.08	1.69	.19	.78	.54	.05	.12	.048	4.27	1.91	------	(1)	4.42
	9461	10–22	69.53	1.39	13.67	7.57	.04	(1)	.05	1.03	.09	.99	.47	.06	.10	.014	4.94	.38	------	(1)	4.55
	9462	22–30	67.17	1.33	16.15	8.39	.05	(1)	.05	1.03	.53	1.11	.56	(2)	.08	(1)	5.45	------	------	(1)	4.82
Nipe clay, 1 mile east of Mayaguez, P. R.	9465	0–5	12.52	.72	15.34	48.54	3.86	------	.26	.12	.19	.09	.01	.14	.24	.266	17.48	------	------	(1)	5.39
	9466	5–15	8.78	.57	16.43	57.61	3.30	------	.22	.10	(2)	.02	(2)	.05	.22	.030	12.80	------	------	(1)	6.55
	9467	15–50	3.00	.42	18.69	57.79	3.54	------	.31	.06	.09	(2)	.02	.07	.62	.032	15.29	------	------	(1)	5.72
	9468	60	2.56	.43	15.21	64.90	3.18	------	.23	.16	.11	(2)	.06	.08	.72	(1)	12.82	------	------	(1)	5.59
	9469	144	2.29	.39	12.62	63.48	5.23	------	.22	.20	(2)	(2)	.03	.08	.55	(1)	12.40	------	------	(1)	5.59
	9470	156	16.89	.34	10.45	49.57	4.67	------	.22	.37	6.02	(3)	(1)	.04	.18	(1)	10.82	------	------	------	6.32
Conowingo silt loam, Alberene, Va.	9889	0–8	70.49	1.53	11.62	5.65	.32	.061	.07	.67	3.50	.90	.18	.09	.08	.074	5.21	------	------	(1)	5.06
	9890	8–24	50.01	.75	8.97	12.19	.26	.058	.25	5.86	15.27	.21	(2)	.04	.10	.038	5.98	------	------	(1)	6.08
	9891	24–36	57.52	1.06	10.85	8.79	.39	.074	.14	3.74	11.50	.47	.09	.06	.07	.050	5.45	------	------	(1)	5.62
Jerome sandy loam, Josephine County, Oreg.	9929	0–4	43.29	1.33	12.41	12.31	2.37	.051	.21	6.34	14.13	.11	1.18	.07	.07	.100	5.96	------	------	(1)	6.20
Corning gravelly clay loam, Josephine County, Oreg.	9931	0–2	53.96	2.04	18.06	11.62	.074	.039	.20	3.80	2.54	.58	1.24	.13	.04	.060	6.30	------	------	(1)	6.01
	9932	2–10	33.03	.68	12.96	28.71	.056	(2)	.71	1.15	10.36	.30	.30	.21	.07	.150	11.47	------	------	(1)	6.70
	9933	12–18	51.74	2.06	15.66	10.04	.200	.025	.22	4.88	2.57	.86	1.40	.44	.10	.230	10.39	------	------	(1)	6.13

[1] None. [2] Trace.

horizon of the Belmont Conowingo, no. 6175, shows nearly, if not quite, the maximum calcium content of any carbonate-free soil. There is some indication that the high-lime Conowingo soils are less infertile than the low-lime Conowingo soils. The difference in lime content is due to the difference in the parent rock. The presence of hornblende and pyroxenes accounts for the high calcium content. Hornblende pockets evidently occur frequently in the altered diorite. An example of such an occurrence is brought out in the Oxford and the Alberene Conowingo profiles, nos. 6236–38 and 9889–91.

The variation in ferric oxide from 3.52 percent in the Cherry Hill Conowingo to 55.5 percent in the Holguin clay shows a tremendous variation in the composition of soils formed from the same rock, serpentine, weathering under different climatic conditions.

There is a very large and significant variation in the sulphur content of the various soils which is due to the chemical characteristics of the colloidal clay. The Conowingo soils with a silica-sesquioxide ratio around 2 show quite ordinary quantities of sulphur. The Nipe, with a silica-sesquioxide ratio of less than unity, show much larger quantities, an indication of anion exchange, or, stated in another way, the high sulphur content is an indication of basic ferric sulphates.

The hydrogen-ion concentration of the soils varies considerably. In general, there is a decrease in acidity as the depth increases. Many of the surface soils are quite acid. It is quite evident that these serpentine soils do not owe their infertility to an alkaline reaction. The Mount Tamalpais soil material is alkaline as Gordon and Lipman (*11*) have stated. The only soil showing an alkaline reaction is the Millville loam, which is remarkably fertile.

Since the Mount Tamalpais sample is alkaline and is practically pure serpentine, and the lower profiles of many of the serpentine soils approach neutrality, it is probable that the disintegrating solution, after acting on the rock in the first stages of soil formation, is alkaline.

The organic matter in these soils is low. Mention has been made of soil samples of Conowingo silt loam (nos. 4724, 6180, 9458, and 9459) which show a small negative value for organic matter as determined by the hydrogen peroxide method. In these cases, since some organic matter is undoubtedly present, the gain in weight is to be attributed to increase in weight of inorganic constituents, in these cases probably to oxidation of ferrous iron. These four soils are the only ones of several hundred that have given an actual gain in weight when treated with hydrogen peroxide. This characteristic of gaining weight with hydrogen peroxide would seem in itself to indicate probable infertility, since both ferrous iron and the conditions producing ferrous iron tend to inhibit plant growth.

The Nipe clays show interesting examples of a residual clay from which nearly all the magnesium in the parent serpentine had been leached away. The parent rock of the Puerto Rico Nipe soils is a chlorite containing about 30 percent MgO. The profile samples of Nipe clay, nos. 9465–9470, show that the magnesium has been pretty largely removed from the upper 12 feet while the lowest horizon shows the presence of considerable magnesium. The fact that the magnesium has been largely removed from the surface of the Nipe clay and that the infertility still remains is additional evidence that the infertility is not due to an excess of magnesium. Since the chro-

mium remains in large quantities it would seem that this is the toxic factor.

There is a possibility that the presence or absence of some of the "trace elements" not determined in the analyses may be a factor in the infertility of soils formed from serpentine rocks. The original rock from which the serpentine is formed is of very different composition as compared with the granites, shales, etc., which form the great superficial outcrops. Further, the serpentine has undergone extensive alterations, carrying with it the opportunity for enrichment or impoverishment of the various trace elements.

In addition to the chromium and nickel noted in the above analyses, cobalt is present in the Dublin Conowingo and probably present in many of the other soils where nickel occurs. Bertrand and Mokragnatz (*2, 3*) found 13.6 and 17.4 parts per million of nickel in two European soils. These same soils contained 2.8 and 3.7 parts per million of cobalt. They also found that both nickel and cobalt are common constituents of plant ash in very small quantities, thus showing that both nickel and cobalt are of general occurrence in soils. It is to be expected that cobalt will accompany nickel and if the proportions of Bertrand and Mokragnatz hold true in general one would expect to find about one-fifth as much cobalt as nickel in the soil.

CHEMICAL COMPOSITION OF THE SOIL COLLOIDS

In table 3, which shows the chemical composition of the colloids separated from high-magnesium soils, the figures for chromium and nickel are not given except for the Nipe samples because of probable contamination during the process of separating the colloidal matter from the soil. Work to be reported on later will show that chromium exists in the soil in two different forms and also that chromium and nickel are in a condition to be dissolved from the soil by neutral ammonium acetate.

The Dublin Conowingo colloids, nos. 4722 and 2725, with 11.92 and 12.11 percent of magnesia, respectively, have the highest percentages of magnesia of any soil colloid yet recorded. These colloids have a silica-sesquioxide ratio approaching 3 and the sodium and calcium contents are almost negligible.

Formerly, the maximum magnesium content for soil colloids had been found in the pyrophyllitic type of colloids (*5*) such as those of the Fallon loam and Yolo clay. These colloids with 5.67 and 5.60 percent of magnesia, respectively, were developed in regions of scant rainfall. They have a silica-sesquioxide ratio approaching 4 and have, in addition to high magnesium, high percentages of calcium and the alkalies. The Conowingo colloids, being developed in a humid region show a sharp contrast in chemical composition, mainly in the magnesium content, to other soil colloids developed in humid regions and show probably the maximum influence of the composition of the parent material on the composition of the colloidal matter. Another phase of the influence of the composition of the parent material not brought out in the analyses is the accumulation of chromium in the residual soil and probably also in the colloidal matter.

The so-called plant-food elements are not high, but with the exception of calcium they are generally higher in the colloidal fraction than in the whole soils. In the Belmont and Jermantown profiles,

TABLE 3.—*Chemical composition of colloids from high magnesian soils*

Description and laboratory no.	Depth	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	CaO	MgO	K_2O	Na_2O	P_2O_5	SO_3	Ignition loss	Carbonates	$\frac{SiO_2}{R_2O_3}$ ratio
CONOWINGO SILT LOAM, ¾ MILE NORTH OF DUBLIN, MD.															
	Inches	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	
Colloid of 4722	0–6	41.35	0.37	16.38	12.81	0.18	0.06	11.92	0.43	0.11	0.18	0.21	16.09	(1)	2.86
Colloid of 4723	6–10	39.20	.32	21.81	16.00	.11	.04	7.29	.45	.07	.13	.18	14.86	(1)	2.08
Colloid of 4724	10–30	38.70	.33	20.89	14.58	.08	.31	8.93	.44	.17	.08	.13	15.50	(1)	2.18
Colloid of 4725	0–6	43.49	.37	16.33	12.65	.20	(2)	12.11	.42	.02	.20	.22	14.53	(1)	3.02
Colloid of 4726	6–30	41.20	.45	21.34	15.62	.10	.09	7.59	.34	(2)	.14	.16	13.47	(1)	2.24
Very fine micaceous (fraction of 4724)[3]	10–30	40.63	.13	15.36	11.49	-------	(2)	21.78	.11	(2)	-------	-------	10.59	(1)	3.05
Mica from sands, 4726	6–30	59.02	.15	2.53	5.42	.07	(2)	28.41	(2)	(2)	-------	-------	4.01	(1)	-------
NIPE CLAY, NIPE BAY, ORIENTE, CUBA															
Colloid of 5896	0–12	10.19	-------	15.84	62.51	-------	0.23	0.05	(2)	(2)	-------	-------	9.86	(1)	0.31
Colloid of 5897[4]	40–60	5.55	0.41	11.47	66.59	0.36	(2)	.07	0.07	0.02	0.03	0.14	13.51	(1)	.17
Colloid of 5898[5]	100–144	12.89	.57	17.93	53.52	.58	(2)	.21	.16	.03	.05	.14	12.70	(1)	.42
CONOWINGO SILT LOAM, ½ MILE EAST OF CHERRY HILL, HARFORD COUNTY, MD.															
Colloid of 6178	0–4	43.49	1.00	24.23	11.90	0.22	0.06	2.73	1.43	0.22	0.20	0.18	14.92	(1)	2.32
Colloid of 6179	4–8	42.38	.91	24.80	11.89	.10	.19	2.25	1.29	.21	.11	.11	12.50	(1)	2.09
Colloid of 6180	8–20	44.70	.85	22.13	15.58	.08	.19	3.21	1.82	.19	.15	.07	11.75	(1)	2.37
CONOWINGO SILT LOAM, 5 MILES SOUTH OF OXFORD, PA.															
Colloid of 6236	0–12	38.42	0.85	23.51	18.20	0.07	0.27	3.00	1.13	0.13	0.21	0.10	14.12	(1)	1.92
Colloid of 6237	12–20	35.39	.74	21.38	25.28	.14	.25	2.95	1.02	.12	.11	.08	13.00	(1)	1.60
Colloid of 6238	20–26	37.77	.66	18.22	26.07	.13	.28	4.00	1.14	.20	.07	.09	11.62	(1)	1.84

[1] None.
[2] Trace.
[3] Contains also 0.37 percent Cr_2O_3 and 0.240 percent NiO.
[4] Contains also 1.50 percent Cr_2O_3.
[5] Contains also 0.80 percent Cr_2O_3.

TABLE 3.—*Chemical composition of colloids from high magnesian soils*—Continued

CONOWINGO SILT LOAM, ½ MILE NORTH OF JERMANTOWN, FAIRFAX COUNTY, VA.

Description and laboratory no.	Depth	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	CaO	MgO	K_2O	Na_2O	P_2O_5	SO_3	Ignition loss	Carbonates	$\frac{SiO_2}{R_2O_3}$ ratio
	Inches	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	
Colloid of 6241	0 – 4½	43.51	0.73	21.86	11.08	0.13	0.45	7.59	0.78	0.13	0.11	0.18	13.69	(1)	2.66
Colloid of 6242	4½–13	41.26	.66	24.82	14.61	.05	.50	4.81	.45	.08	.03	.12	13.16	(1)	2.06
Colloid of 6243	13 –22	40.42	.53	24.61	14.98	.08	.59	4.56	.36	.06	.03	.23	13.87	(1)	2.01
CONOWINGO SILT LOAM, BELMONT, BALTIMORE COUNTY, MD.															
Colloid of 5829	½– 8	45.32	1.03	26.26	10.78	0.12	0.16	1.01	0.97	0.17	0.17	0.14	13.77	(1)	2.32
Colloid of 5830	8 –18½	42.63	.97	28.24	13.02	.05	.19	1.39	.75	.11	.09	.11	13.03	(1)	2.01
Colloid of 5831	18½–26	41.10	.94	29.69	13.16	.04	.21	.99	.42	.03	.06	.09	13.79	(1)	1.83
Colloid of 5832	36 –56	42.18	.97	29.93	12.22	.06	.32	1.02	.34	.09	.06	.06	13.29	(1)	1.89
MILLVILLE LOAM, GREENVILLE, UTAH															
Colloid of 7819	0–10	43.21	0.70	19.54	8.20	0.19	2.89	4.25	3.52	0.25	0.26	0.34	16.71	1.49	2.97

[1] None.

where large quantities of calcium are shown in the soil, very little if any appears in the colloids.

There is considerable variation in the magnesium, iron, and aluminum of different profiles and in different horizons of the same profile. In the Dublin Conowingo the magnesia decreases about 4.5 percent from the A to the B horizon. This decrease cannot be explained by removal of sesquioxides from the A to the B horizon. It is too great to be accounted for through dilution by sesquioxides. There is, of course, the possibility that the observed difference may be due to a difference in composition of the parent rock. It will be noted that while the magnesia and iron oxide and alumina vary considerably, the combined water remains sensibly constant. One explanation of this is that the magnesia and iron oxide and alumina replace each other. A more probable explanation, however, is that the colloids of these soils consist of two major constituents having different magnesia, iron oxide, and alumina contents, but the same water of hydration. The composition of the very fine micaceous fraction given in table 3 indicates this may be true. It was noticed in the separation of the colloidal matter from the soil that there was a very fine scalelike material that did not settle out by gravity but was thrown out on the centrifuge bowl. A sample of this material was separated by those properties and the analysis is given in table 3. In composition this fraction resembles the vermiculites. It is higher in alumina and water and lower in magnesia than the mica separated from the sands. It seems probable that a considerable quantity of this very fine scalelike material would enter the colloidal fraction, and being finer in the colloidal matter than the fraction analyzed, it would probably have a higher combined water content.

Viewed in this way the Conowingo colloids may be considered to be made up of two distinct main constituents, very fine vermiculite particles and the common type of halloysitic acid soil colloid, found in soils of this region. Direct evidence of this is wanting, however, for the X-ray patterns made by S. B. Hendricks and M. E. Jefferson of this Bureau show that the fine vermiculite fraction had a distinct pattern, but the corresponding soil colloids were singularly free from lines of any sort. Hendricks and Jefferson point out that as much as 20 percent of a very fine crystalline substance may be present in a colloidal substance without giving definite X-ray pattern to the mixture.

It is well known that biotite and muscovite alter into vermiculite in the presence of percolating waters containing magnesium and possibly this is the explanation of the large "insoluble" or nonexchangeable proportion of magnesium in the soil colloids. MacIntyre, Shaw, and Robinson (*23*) found that magnesium applied to the soil as carbonate or hydroxide soon reacted with the silica to form an absorption complex in which very little of the magnesium is exchangeable. In soil colloids, numerous studies have shown that much less of the magnesium is exchangeable than of calcium or generally of the alkalies. The micas are of wide-spread occurrence in soils and it is probable that the magnesium is retained by the soil colloids in a vermiculite form, resulting from the alteration of muscovite and biotite.

Comparing the chemical composition of the colloidal matter with the soil from which it is extracted, perhaps the most striking differ-

ence is in the retention of the magnesium and the rejection of the calcium by the colloid as it forms from the parent rock. In the lowest profile of the Belmont Conowingo with 7.50 percent of calcium oxide in the soil, only 0.32 percent of calcium oxide appears in the colloid. Of the 6.69 percent of magnesium oxide in the same soil, 1.02 percent of magnesium oxide appears in the separated colloidal matter. The Jermantown surface soil, with 6.26 percent of calcium oxide, yields a colloid with only 0.45 percent of calcium oxide, while the respective figures for magnesium are 19.37 and 7.59 percent. Petrographic determinations by W. H. Fry of this Bureau showed a large proportion of hornblende in these soils. Both soils are fairly acid and the colloids, being low in calcium, indicate that the hornblende is very resistant to weathering. Here is a case where the chemical composition of the soil with respect to calcium is quite misleading and it is necessary to have a colloid analysis to obtain the true picture.

In nearly all the work previously done by this Bureau it has been found that the colloidal matter separated from the soil is considerably higher in magnesia than the whole soil. The Conowingo series presents a notable exception to this generality in that the whole soil is considerably higher in magnesia than the colloidal matter. This, of course, is because of the high proportion of unchanged serpentine in the soil which is not present in the colloidal matter.

The silica-sesquioxide ratio shows considerable variation through the profile, being generally higher in the surface colloid. This ratio is considerably higher in the surface colloids of the Conowingo series than in other series developed in this region. The Nipe soil is a laterite developed under tropical conditions from the weathering of serpentine rock and the contrast between the Conowingo and Nipe colloids is an interesting case of the variation in chemical composition of two soil colloids developed in greatly differing climatic conditions from the same general parent material.

CHEMICAL COMPOSITION OF THE PARENT ROCK

The ultimate parent rock of the Conowingo series of soils is gabbro, but the immediate parent material is an impure serpentine rock mass into which the gabbro has altered. The minerals involved in the alteration are largely chrysolite and to a less extent pyroxene and amphibole. Chrysolite is a magnesium silicate which frequently contains nickel and chromium; pyroxene and amphibole contain considerable calcium in addition to magnesium and other constituents.

The composition of the serpentine rock mass is variable, depending upon the proportions of the different minerals in the original diorite. Serpentine contains little or no calcium, but in some places where the proportion of pyroxene and amphibole is high, pockets rich in calcium are found. Thus, verde antique is a mixture of serpentine and marble, and in some places in Cuba pockets of calcium carbonate are found in the Nipe soil, which is formed from serpentine (*1*). The high calcium content of the Belmont Conowingo probably is because this particular portion of the gabbro is high in pyroxene and amphibole. A layer of very different composition from the rest of the profile occurs in the B horizon of the Oxford Conowingo. This is undoubtedly due to a variation in the composition of the parent material. These examples serve to show that considerable variation may occur in the composition of the soil owing to differences in parent material, and

also that it is difficult, on account of these variations, to find a piece of parent rock similar in composition to the parent rock that formed any particular soil profile. Nevertheless, to be certain that the general parent material was really serpentine rock, an attempt was made to collect such samples in a few cases. Petrographic identifications made by W. H. Fry showed the rocks to be mainly serpentine. The chemical analyses are given in table 4.

TABLE 4.—*Chemical composition of high-magnesium rocks from which certain soils are derived*

Laboratory no.	Type and location	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	Cr_2O_3	NiO
		Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
6181a	Fresh serpentine, Cherry Hill, Md.	37.98	0.10	0.78	12.45	0.13	0.44	----
6181b	Decomposed serpentine, Cherry Hill, Md.	39.55	.10	.59	14.37	.12	.60	----
6182	Serpentine, Dublin, Md.	43.82	.06	2.41	10.92	.27	.34	0.111
9570	Soapstone, Alberene, Va.	33.30	.38	6.44	11.31	.27	.38	.200
9607	Serpentine, Hunting Hill, Md.	40.27	(1)	3.02	9.29	.19	.38	.090
9930	Serpentinelike rock, Josephine County, Oreg.	43.50	.19	7.02	7.62	.20	.38	.070

Laboratory no.	Type and location	CaO	MgO	K_2O	Na_2O	P_2O_5	SO_3	Ignition loss
		Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
6181a	Fresh serpentine, Cherry Hill, Md.	(1)	37.68	0.06	0.01	0.03	0.52	10.35
6181b	Decomposed serpentine, Cherry Hill, Md.	(1)	34.61	.04	.03	.02	.02	10.05
6182	Serpentine, Dublin, Md.	(1)	32.98	(1)	.07	(1)	.10	9.93
9570	Soapstone, Alberene, Va.	4.56	25.94	(1)	.01	.02	.35	12.02
9607	Serpentine, Hunting Hill, Md.	.03	35.53	.14	(1)	.02	.06	11.00
9930	Serpentinelike rock, Josephine County, Oreg.	8.92	23.21	.18	.11	.02	.12	5.43

[1] Trace.

In the analyses in table 4 no figures are given for ferrous iron. Although some iron is undoubtedly present in this state, it was all determined as ferric iron.

In general, the analyses are much the same as given by Dana (*6*) for serpentine.

The first two samples, 6181a and 6181b, represent the whitish, incoherent layer on the outside of an embedded serpentine boulder and the fresh, tough, green serpentine near the middle of the boulder. There is comparatively little change in composition, except for the sulphur which has been nearly all removed. Some magnesium has been lost, and iron, chromium, and silica have been gained, but the changes are small. It would seem as though the constituents were being carried away by the ground water in much the same proportions as they occur in the rock.

Chromium and nickel are present in considerable quantities in all the rocks. The alumina varies considerably and it would seem that the percentages of alumina in the rock would determine the quantity of colloidal matter formed in the weathering of the rock. None of the Conowingo colloids contains less than 16.33 percent Al_2O_3. It appears that serpentines containing very little alumina will not produce enough colloidal matter to form a very deep soil, but will

produce the rocky Conowingo barrens. In this case the magnesia and silica are carried away by the ground and river waters in much the same proportion as they occur in the serpentine, leaving but little insoluble product of hydrolysis to form a soil colloid. It is only when the serpentine contains enough alumina to form the kaolinitic acid complex or the vermiculite complex that enough colloidal matter will remain as a residual product to form a normal soil covering.

Chromium apparently occurs in two forms in the parent rocks and the soils formed from them. One form, chromite or ferrous chromite, is not attacked by fusion with sodium carbonate and potassium nitrate and is left as a brownish black insoluble residuum when the products of fusion are treated with hydrochloric acid. The insoluble chromite can be filtered and dissolved by fusion with potassium pyrosulphate. In this way a rough separation may be made of the chromium occurring as chromite and the chromium replacing alumina and ferric iron which is made soluble by fusion with sodium carbonate and niter. Using this proximate method of distinguishing between the two forms, it was found that the Hunting Hill serpentine, no. 9607, contained 0.19 percent Cr_2O_3 as chromite and 0.19 percent Cr_2O_3 in the soluble form. The Schuyler, Va., soapstone, no. 9570, contained 0.15 percent Cr_2O_3 as chromite and 0.23 percent Cr_2O_3 soluble. The rock from Josephine County, Oreg., no. 9930, contained 0.07 percent Cr_2O_3 as chromite and 0.31 percent Cr_2O_3, soluble. A poison spot in the Jerome sandy loam in this county contained 2.37 percent Cr_2O_3 as chromite and 0.37 percent Cr_2O_3, soluble. Several other poison spots contained from 1.80 to 2 percent Cr_2O_3. Some of the Conowingo soils contained but little chromite, as low as one-fifth of the total quantity of chromium being present in this form. The chromium in the Nipe soils is largely in the form of chromite. The perdigón, or iron concretions in the Nipe, are considerably higher in chromium than the surrounding soil. According to Bennett and Allison (*1*) perdigón have been formed from soil material after the formation of the soil. From this it would appear that chromium may be dissolved and precipitated in the soil in much the same manner as iron. This is an important point to bear in mind in considering the probable toxicity that chromium gives to soils. Chromium exists in several states of oxidization and is particularly toxic in the chromate condition (*17*).

Dolomite enters into the parent material of the Millville loam. Dana (*6*) states that cobalt and zinc rarely occur in dolomite but does not mention the occurrence of nickel and chromium.

AVAILABILITY OF CHROMIUM, NICKEL, AND OTHER CONSTITUENTS

It has been shown that chromium and nickel are ever present constituents of the infertile Conowingo, Jerome, Corning, and Nipe soils. These elements are toxic to plant growth as will be shown later. It remains to be proved that chromium and nickel are at least to some extent soluble and that they are taken up by plants in sufficient quantities to be toxic. To obtain evidence on the first point, the solubility of chromium and nickel or their exchangeability was tested by the ammonium acetate method of Schollenberger and Dreibelbis (*32*). Chromium was estimated colorimetrically as chromate in very small volume and nickel was determined by precipitation with dimethylglyoxime. The solutions were obtained

by percolating 200 to 500 g of soil with 2 to 5 l, respectively, of normal, neutral ammonium acetate. The results are given in table 5, together with the results for the common elements and also barium, as this element was present in all cases.

The data given in table 5 show the presence of appreciable quantities of available chromium in all of the soils and the presence of available nickel in all but one of the soils tested. When twentieth-normal hydrochloric acid was substituted for the neutral ammonium acetate in leaching soil no. 4722, the quantities of chromium and nickel in the leachate were considerably increased. This soil is fairly acid and it is probable that greater quantities of chromium and nickel are available to plants growing in this soil than the quantities which appear in the ammonium acetate leachate.

TABLE 5.—*Soil constituents made soluble by leaching 100g of soil with 1l of neutral, normal, ammonium acetate, according to method of Schollenberger and Dreibelbis (32)*

Laboratory no.	SiO_2	$Al_2O_3 + Fe_2O_3$	Cr_2O_3	NiO	MnO	CaO	BaO	MgO	K_2O	Na_2O
	Milli-equiva-lent	*Milli-equiva-lent*	*Milli-equiva-lent*	*Milli-equiva-lent*	*Milli-equiva-lent*	*Milli-equiva-lents*	*Milli-equiva-lent*	*Milli-equiva-lents*	*Milli-equiva-lent*	*Milli-equiva-lent*
2623	0.18	0.19	(1)	0.0041	0.04	4.28	0.02	1.41	0.04	0.11
4722	.10	.05	0.0060	.0120	.04	.16	.02	4.09	.06	.13
4725	.11	.02	.0010	.0110	.05	.17	.02	4.19	.05	.10
5820	.03	.14	.0020	.0030	.19	.75	.05	1.21	.06	.14
6178	.03	.03	.0030	.0054	.35	.55	.01	1.16	.08	.11
6236	.30	.01	.0020	.0038	.04	.60	.06	8.06	.03	.08
6241	.31	.15	.0011	.0076	.02	8.33	.02	14.28	.06	.09
7504	.33	.03	.0080	.0030	.07	.70	.01	1.27	.01	.10
9338	.07	.20	.0015	----------	.06	2.06	.05	3.17	.07	.27
9343	.24	.14	.0007	----------	.03	.02	.02	.62	.04	.08
9346	.12	.24	.0025	----------	.02	.81	.01	.20	.16	.34
9456	.30	.13	.0010	.0060	.11	.16	.03	5.88	.04	.06
9480	.21	.24	.0010	(2)	.03	.09	.04	.37	.02	.08
9859	.24	.14	.0010	.0021	.24	6.46	.03	9.66	.22	.28
9932	.47	.25	.0045	.0372	.13	3.75	.03	5.57	.37	.15

[1] Present, but quantitative reading lost.
[2] None.

NOTE.—Since this manuscript was prepared for publication, C. F. Marbut, Chief of the Division of Soil Survey, sent in an unusual soil from the Napa area, Calif. This soil, Maxwell clay adobe, is developed from serpentine and is reported to be infertile. The California State Soil Survey notes that the soil contains considerable excess of magnesia over lime. The surface soil contains 0.028 percent Cr_2O_3, 0.068 percent NiO, and is lower than many soils of the Conowingo series in chromium, but comparatively high in nickel. The pH of the A, B, and C horizons is 7.96, 5.43, and 8.40, respectively. The C horizon contains magnesite. When treated as outlined for the samples in table 5, the soils yielded the following figures:

Sample no.	Depth	SiO_2	R_2O_3	Cr_2O_3	NiO	CaO	MgO	BaO	K_2O	Na_2O
	Inches	*Milli-equivalent*	*Milli-equivalent*	*Milli-equivalent*	*Milli-equivalents*	*Milli-equivalents*	*Milli-equivalents*	*Milli-equivalent*	*Milli-equivalent*	*Milli-equivalents*
C114	0–10	0.04	0.32	None	Trace	3.13	37.7	0.18	0.70	0.70
C115	10–34	Lost	.46	do	do	2.27	39.0	Lost	.42	2.70

These figures are much the same as those reported in table 5 except that no soluble chromium is shown. If the toxicity in this soil is caused by the presence of toxic metallic elements it must be due to nickel and barium, as no soluble chromium is demonstrated. Sufficient lime and potash are shown. Loew's (*19*) theory would seem to explain the infertility of this soil.

The presence of barium in the leachate from all the soils is surprising. Barium in small quantities occurs quite generally in plants, (Failyer (*8*), and Robinson, Steinkoenig, and Miller (*29*)). The quantities of barium in the plant apparently vary according to the quantities of barium in the soil. It is possible that barium may be a

factor in the infertility of these soils but so little is known about the exchangeability of barium in soils no comments can be made on this phase.

Available potassium is generally low in these serpentine soils. This is in harmony with the findings of Gordon and Lipman (*11*).

Available magnesium is high in all but the Nipe clay soils, nos. 9343 and 9346 and the Potomac Conowingo silt loam, no. 9460. All of these soils except the Limones clay, no. 2523, and the soils just mentioned, show considerable excess of magnesia over lime. In many of the soils the lime and perhaps some other constituents are too low for optimum plant growth. In these cases the lime-magnesia theory of Loew cannot be properly applied.

If Loew's theory is applied and the effect of the paucity of both calcium and some other elements is neglected it will be seen that in 11 of the 15 soils examined, Loew's theory that an excess of magnesia over lime is responsible for the toxicity to plants may be taken as a satisfactory explanation of the observed toxicity. In 3 of the 4 exceptions, the quantities of both lime and magnesia are so low that they may be limiting factors of plant growth. Since, however, soluble chromium is present in all the 15 soils, the theory that the infertility is due to soluble chromium appears more attractive than Loew's theory. It is quite probable that both factors play a part. It also appears that in certain instances, low hydrogen-ion concentration values or a general lack of available plant food may contribute to the infertility of these soils.

It has been shown that chromium and nickel are present in the ammonium acetate extract of practically all the soils examined and it is probable these elements are taken up by plants growing on the soils. Direct evidence on this point is shown in table 6 which shows the partial ash composition of the leaves of blackjack oak and red oak grown on the Dublin Conowingo soil also the partial composition of red oak leaves grown on Chester loam at Falls Church, Va. Both of the two soils involved are low in calcium. The Chester soil does not contain enough nickel or chromium to be detected in 5 g. There is over 25 times as much magnesium in the Dublin Conowingo soil as in the Falls Church Chester soil.

TABLE 6.—*Partial composition of oak leaves grown on Conowingo soil compared with that of oak leaves grown on Chester soil*

Material, location, and soil	SiO_2	R_2O_3	Cr_2O_3	NiO	CaO	MgO	P_2O_5
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Blackjack oak leaves, Dublin, Md., Conowingo soil	0.59	0.45	0.0006	0.0005	2.33	1.68	0.28
Red oak leaves, Dublin, Md., Conowingo soil	.53	.24	.0004	.0006	2.07	1.56	.24
Red oak leaves, Falls Church, Va., Chester soil	.35	.48	(1)	(1)	2.07	.72	.51

[1] Trace.

It is regretted that no blackjack oak could be found growing on Chester loam to compare with the Conowingo specimen. This tree seems to thrive uncommonly well on the Conowingo soils and is not commonly found on adjoining soils. It would seem to be particularly tolerant to chromium, nickel, and an excess of magnesia.

The main deductions to be made from the data of table 6 are that the leaves grown on the Dublin Conowingo soil are very much higher in chromium, nickel, and magnesium than the leaves grown on the Chester soil. The calcium content is about the same in all cases. The phosphoric acid is very much higher in the leaves grown on the Chester soil. In most of the constituents the composition of the ash of the leaves follows the composition of the soil.

The lower figure for phosphoric acid in the leaves grown on the Conowingo soil gives a possible clew to the mechanism of chromium toxicity. Chromium phosphate would probably be nearly as insoluble as aluminum phosphate under soil conditions. Koenig (*17*) found chromium to be concentrated in the roots of plants suffering from chromium toxicity and it seems quite probable that chromium may prevent the utilization of phosphorus by the plant.

Bertrand and Mokragnatz (*3*) found small quantities of nickel and cobalt also in the ash of a large number of plants. They believe these elements to be common constituents of plants. Bertrand and Mokragnatz used large quantities of plant material, up to and over a kilogram, and obtained as much as 3.3 parts per million of nickel, though most plants contained less than 2 parts per million. The quantities reported as traces from the oak leaves from Falls Church, Va., are less than 1 part per million. Four and six parts of nickel per million were found in the leaves of the oak growing on the Conowingo soil.

Robinson, Steinkoenig, and Miller (*29*) found traces of chromium in 14 out of 48 plants tested. The soils on which the plants grew contained, at the most, 0.013 percent of chromic oxide.

TOXICITY OF CHROMIUM AND NICKEL SALTS

Both chromium and nickel were found to be toxic by the earlier agricultural chemists. Koenig (*17*) gives a summary of the literature up to 1912 on the effect of chromium on plant growth. He gives a comprehensive report of his own work on the growth of a number of different kinds of plants in water cultures, in sand cultures, and in humous soils to which various chromium compounds had been added. Koenig found that chromium was taken by plants from all the chromium compounds used. Chromium in all but the smaller concentrations proved to be very toxic. Small applications of chromous salts and very small applications of chromates were stimulating. The chromates were the most toxic followed by chrome alum and chromium salts. The very insoluble chromite was stimulating in higher concentrations and the heaviest applications were toxic to the more sensitive plants. Germination was prevented by a small concentration of chromium and the roots of the plants in the chromium cultures contained more chromium than other parts of the plant. In sand cultures 50 parts per million of chromium as dichromate were toxic. It took higher concentrations to produce toxicity in humous soils. Lime counteracted chromium toxicity. Lead and silver salts counteracted toxicity due to chromates. Chromium in small concentrations killed yeast cells.

Pfeiffer, Simmermacher, and Rippel (*26*) grew plots of oats and barley to which were added different chromium compounds. Favorable results were obtained in some cases; unfavorable results in others. They concluded that the practical value of chromium as a soil amendment was not established.

Voelcker (*36, p. 161*), using pot-culture methods, reported that 50 parts per million of chromium prevented the growth of corn and barley the first year but was stimulating the second year. With wheat, as much as 250 parts per million of chromium lost its injurious effects the third year and became stimulating.

Haselhoff, Haun, and Elbert (*12*) investigated the use of waste materials from chrome tanneries for composting. They found chromium in the form of hydrated oxide to be somewhat toxic and that chromates were very toxic. The toxicity of both forms was greater in sandy than in clay soils.

L. A. Hurst of this Bureau reported [1] a certain sample of triple superphosphate very toxic to young sugar beets. This superphosphate contained considerable chromium. When treated with an excess of lime the superphosphate was no longer toxic. If the toxicity was due to chromium, as appears reasonable, this result is in harmony with Koenig's conclusion that lime counteracts chromium toxicity. Millar, as reported by McCool (*21, p. 219*), at the Michigan Agricultural Experiment Station found that a sample of triple superphosphate from the same source as that reported above prevented the germination of beans. Hill, Marshall, and Jacob (*13*) have shown that chromium is an ever-present but very variable constituent of phosphate rock. Some deposits contain from 10 to 50 times as much chromuim as others. It is not improbable that the chromium content of phosphates is a factor in their fertilizer value.

It is evident that the toxicity due to chromium will depend not only on the quantity and the form of the chromium but on soil conditions such as pH value, oxidation, and reduction and presence of other metals. Chromium is present in all soils, but generally in small quantities. Robinson (*27*) found from 10 to 180 parts per million in 13 fertile surface soils of the United States, the average being 74 parts per million Cr_2O_3. This is an entirely different order of magnitude from the chromium content of the infertile high-magnesium soils which run from 510 to 38,360 parts per million, averaging 8,350 parts. The fertile soils have a chromium content which Koenig and Voelcker class as stimulating, while the infertile soils contain quantities which Koenig classes as toxic.

Koenig has shown that even chromite, probably the most insoluble of the chromium compounds occurring in soils, will dissolve in sufficient quantity to be taken up by plants. There is probably some natural equilibrium between the quantity of chromite in the soil and the more soluble forms of chromium. Chromite in the soil is therefore a potential source of soil toxicity. Koenig states that chrome alum in the soil may be changed to the very toxic chromates. Waksman (*37*), however, does not list chromium as one of the metals oxidized by bacteria. There are, however, may soil organisms which cause corresponding oxidization of sulphur, iron, manganese, arsenic, and other elements. Since lead and other chromates occur in nature as secondary minerals, it is not improbable that under some soil conditions chromium salts may be converted into the very toxic chromates. It has been stated that chromium in low concentrations kills yeast cells. It is quite possible that chromium in concentrations too low to be directly toxic to plant growth may have a profound effect on the microbiological flora of the soil.

[1] Private communication.

Scharrer and Schropp (*31*) review the literature on the effect of nickel and cobalt on plant growth and present their own data on the growth of corn, barley, rye, oats, beans, and peas in sand and water cultures containing small quantities of the metals. Their work on cobalt was more extensive than on nickel. Nickel in sand cultures in quantities of about 50 parts per million was somewhat stimulating, but was toxic at higher concentrations. Cobalt at concentrations less than 1 part per million was stimulating to corn and barley but toxic to other plants, and in higher concentrations was toxic to all plants. The earlier works reviewed by Scharrer and Schropp show, in general, that nickel and cobalt are toxic to plant growth, and particularly toxic to yeast.

The quantities of chromium, nickel, and probably cobalt found in the infertile soils derived from high-magnesium rocks are higher than the quantities which the above investigators have found to be toxic to plant growth. It would seem that enough work had been done with chromium to establish the theory that the smaller quantities which are found in fertile soils do not harm and perhaps may be beneficial. The larger quantities, however, of the order of 0.1 percent and more, would seem to be toxic. In applying the quantitative factor in chromium toxicity due consideration must be given to the pH value, texture, and composition of the soil. It is probable that there is also a quantitative aspect of the effect of nickel and cobalt on plant growth on natural soils. Bertrand and Mokragnatz (*2, 3*) and also McHargue (*22*) have found small quantities of these metals in fertile soils of the order of 1 to 10 parts per million. The former report nickel and cobalt widely distributed in plants.

SUMMARY AND CONCLUSIONS

A number of soils derived from high-magnesium rocks in Maryland, Pennsylvania, Virginia, Utah, Oregon, California, Cuba, and Puerto Rico have been studied to determine the cause of their infertility. Mechanical and chemical analyses of the soils have been made. The chemical composition of the colloidal matter separated from the soils has been determined and in a few cases the parent rocks from which the soils have been formed have been analyzed.

The availability of nickel, chromium, and some of the other constituents has been studied, using the neutral ammonium acetate leaching method. In a few cases nickel and chromium have been determined in plants growing on the infertile soils.

From this study the following conclusions are drawn in regard to these soils.

The mechanical analysis shows a sufficient quantity of colloidal matter to retain moisture and the plant-food elements and not too much to make the soil unworkable. In some cases there is not enough coarse material to give good internal drainage and there is a large quantity of silt which is deleterious in some soils. The high silt content is not a predominating factor causing infertility.

All the infertile soils show a comparatively high percentage of chromium and nickel; cobalt was shown to be present in one soil—the only one tested for this element. In most cases the magnesium was very high though it was low in others. The calcium, potassium, and phosphorus were generally low, but not lower than in many soils that are successfully farmed. In other cases these constituents are

quite high but, with the exception of the Millville loam, are accompanied by very high percentages of chromium and considerable nickel.

Chromium occurs in the soil in two forms, an acid-soluble form, presumably comparable to the acid-soluble iron and aluminum, and an acid-insoluble form, ferrous chromite, the chromite of mineralogy.

An alkaline pH is not a dominant factor in causing the infertility of these soils. The reactions of the infertile soils vary from very acid to slightly alkaline. The surface soil is generally quite acid and numerically the pH value increases generally with depth to the parent rock.

Many of the soil colloids in these series are extremely high in magnesium. They vary considerably in composition in the different soils also in the same profile. It is probable that these soil colloids contain a considerable proportion of vermiculite, though X-ray evidence on this point is negative.

Comparisons of the chemical compositions of the soils, colloids, and parent rock show that this group of soils is unique in showing a profound influence of the composition of the parent rock on the compositions of the soil and colloids. The influence of climate is also shown, for, in the temperate climate, magnesium largely remains with the soil but in the tropical laterites it is largely lost. Both in the temperate climate and in the tropics the high content of chromium from the parent rock is largely retained in the soils and nickel is largely lost.

Chromium and nickel in these soils are available in the sense that they are dissolved by leaching the soil with neutral ammonium acetate and both metals are taken up in comparatively large quantities by plants growing on some Conowingo soils.

The ammonium acetate leachate from all the soils examined contained a determinable quantity of barium.

It is believed by some investigators that an unfavorable calcium-magnesium ratio may cause infertility, but the theory cannot be properly applied in general since in many cases the lack of both calcium and magnesium is a limiting factor of plant growth apart from their mutual relation.

The literature shows that very small quantities of chromium and nickel are somewhat stimulating to plant growth and that larger quantities are very toxic. The evidence is that practically all soils contain some small quantity of chromium and nickel. The infertile soils under consideration, however, contain a comparatively great quantity of these elements. It is therefore important to find some quantitative expression for the amounts of these elements a cultivated soil may safely contain. This quantity will vary with the reaction, texture, and general composition of the soil.

Whereas poor mechanical composition, causing poor internal drainage, an excess of magnesium, and lack of plant-food elements may be frequent causes of infertility in the soils studied, the only general and dominant cause of infertility in soils derived from ferromagnesian rocks is the comparatively high percentages of chromium and nickel. In the past, two very different assumptions have been made to account for the infertility of soils derived from serpentine rock. (1) Loew's theory stated that the infertility was due to an excess of magnesia over lime; (2) Gordon and Lipman held the main causes for the infertility of such soils were lack of plant-food elements and an alkaline

hydrogen-ion concentration. From the present study of the chemical composition of the soils and soil extracts, the writers believe that the presence of comparatively large quantities of chromium and nickel, and perhaps cobalt, are the dominant causes of infertility in serpentine soils in which the physical conditions are favorable for plant growth.

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