THE GENESIS AND CHARACTERISTICS OF THE FRAGIPAN OF THE BELTSVILLE SOILS

by

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INTRODUCTION

Fragipans are common in soils of several physiographic provinces of this country. The term "fragipan" denotes a compacted layer of soil material (17), usually high in silt or sand or both, that appears to be cemented when dry, but loses its cemented nature when it is moistened. Such compacted layers are usually found immediately beneath the illuvial horizons of the soil. Those soils containing fragipans are generally found on gently sloping topography. Well developed fragipans interfere with water and root penetration through the soil. For this reason, fragipan soils are of practical importance in both agricultural and urban areas. Fragipans are also of interest to soil scientists in that they represent special problems in both soil formation and soil management.

The Beltsville soil contains a well developed fragipan. This soil, classified as an intergrade of a Gray-Brown Podzolic Planosol, is common in Coastal Plain of Virginia and Maryland, especially along the Piedmont-Coastal Plain contact zone. The fragipan is usually found about twenty inches below the surface of the ground and ranges from less than one foot to more than two feet in thickness. The Virginia Soil Survey recently called attention to profiles of Beltsville over granite and schist as well as Coastal Plain deposits.

A general interest and increasing demands for information have lead to additional research on this soil. At present, outside of field studies, the Beltsville soil has not been studied intensively in Virginia. The field observations will be more significant and capable of further interpretation when accompanied with laboratory data.

This study was undertaken to gain information of the properties of the Beltsville soil, particularly the fragipan. This information is fundamental in arriving at a means of increasing the permeability of the fragipan and also in deciding how this layer has formed. It is postulated that data on the Beltsville soil also may be important in the study of other fragipan soils. The investigation deals primarily with the mechanical composition, the mineralogical character, and some of the chemical and physical properties of three different soil profiles.

REVIEW OF LITERATURE

Fragipans occur in soils developed from both residual and transported materials (17). The special environmental conditions favoring their formation are still obscure. The fragipan in some soils appears to be a pedogenic horizon. In other soils, as the Beltsville, there is evidence suggesting that the fragipan formed as a result of conditions unrelated to the present course of soil formation.

In 1935 Marbut (11) described a fossil land surface in the Leonardtown soil [1] in areas around Washington, D. C. He proposed that the Leonardtown soil developed in this area under the influence of a ground water table, lying about thirty inches below the surface of the ground, at which level an indurated layer formed. Marbut's opinion as to whether or not the indurated layer coincided with the fossil land surface was not found. Marbut also reported that the A and B horizons of the Leonardtown soil were normal podzolic horizons for the Washington area, but the indurated layer had a very high silica content and the C horizon had a low silica to alumina ratio. He concluded that the C horizon was not the true parent material of the Leonardtown soil and that induration of the fragipan is accompanied by an accumulation of silica.

A report by Nikiforoff <u>et al</u>. in 1948 (13) revealed that the fragipan in the Leonardtown soil lacked appreciable cementation outside of aggregation due to clay. They also found that the

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[1] The Leonardtown soil is now classified as the Beltsville soil series.

high silica content of this layer was due to a high quartz content and not to free colloidal silica. Findings of gibbsite and a high kaolinite content, along with brighter iron oxide coloring in the soil horizons below the fragipan, indicated that this material had been slightly laterized. This evidence, and that showing a high gravel content in the fragipan and horizons lower than the solum, lead them to believe that the material developed into the solum had a different geologic origin from the material underlying the solum. Nikiforoff wrote the following conclusions: ... "it appears that the induration of the pan is an original rather than a secondary characteristic developed because of the close packing of particles during their deposition and before the accumulation of the silty material on the surface of the pan, that is, well before development of the Leonardtown soil began."

Krusekopf (10) reported that the hardpan in certain soils of the Ozark region appears to have formed by cementation with free colloidal silica derived in place during the weathering of cherty limestone. He also generalized that since the hardpan is low in sesquioxides and occurs below the zone of active illuviation it is unlikely that it formed by illuvial processes or represents advanced maturity of the soil.

Winters (20) made some generalizations on silica hardpan development in the Red-Yellow Podzolic soil region. The geologic origin of the soil parent material was considered of less consequence in hardpan development than the physical nature of the material. He also explained that fine sand and silty materials appear to be most favorable to hardpan formation. Winters reasoned that impeded drainage resulting from an impervious substratum may well cause hardpans to develop. He also reasoned that the well developed hardpans are generally found in soils with the most impeded drainage. The absence of hardpans in poorly drained young alluvium and colluvium was explained on the basis that a considerable period of time is required for hardpans to develop.

Physical compaction was reported by Smith and Browning (16) as the cause of the indurated nature of the fragipan or siltpan in West Virginia soils. They found that aggregates of siltpan material, that appeared to be cemented when dry, slaked easily when placed in water. They also reported that siltpans generally occur in soils on gently sloping or level topography.

Fitzpatrick (4) recently reported the results of an investigation of the genesis of the macrostructure of hardpans in soils of Scotland and Norway. He concluded that the macrostructure of these hardpans is related to permafrost conditions. The hardpans were always found in areas that were either known or suspected of having had a periglacial climate. He expressed a close similarity between the macrostructure of these hardpans and that of the fragipan in the Beltsville soil.

MATERIALS AND METHODS

A. Soil Sampling

Profile samples of the Beltsville soil were taken in Fairfax County, Virginia in September, 1955, five months prior to completion of the soil survey of this county.[1] The soil was sampled at three locations. These included one profile over Coastal Plain deposits, one over the Peters Creek schist of the Wissahickon, and one profile over granitic materials. In the discussion that follows these profiles will be designated CP, S, and G, respectively.

Profile CP was taken from an idle field at Pohick Station on Route 638, one and one-fourth miles north of the Shirley Highway. A pit was opened for sampling and making descriptions. Nine core samples were taken from the A_p, B_{21}, and B_{m1} horizons for determinations of bulk density, permeability, and porosity. The soil type is Beltsville loam. The slope two percent and erosion is slight. Internal drainage is medium, whereas external drainage is slow to medium. The underlying geologic material is Coastal Plain, Sunderland Terrace. Additional description follows.

A_p	0-8"	Brown (10YR 5/3) friable loam with weak fine granular structure. Small roots are numerous. Few, fine faint mottles of dark grayish-brown (10YR 4/2).
A_3	8-11"	Light yellowish-brown (10YR 6/4) friable heavy loam with weak fine subangular blocky structure. There are common, fine, faint mottles of yellowish-brown (10YR 5/4). Many small roots.

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[1] Sampling areas were located by H. C. Porter and E. F. Henry of the Virginia Agricultural Experiment Station. C. I. Rich, R. D. Krebs and J. F. Derting also of the Virginia Agricultural Experiment Station assisted the writer in obtaining samples.

B_{21}	11-16"	Yellowish-brown (10YR 5/6) friable silty clay loam with moderate, fine, subangular blocky structure. Few, faint mottles of light yellowish-brown. The ped faces have a strong brown coating. Many small roots.
B_{22}	16-19"	Mottled yellowish-brown (10YR 5/6) and pale brown (10YR 6/3) friable silty clay loam with weak, fine, subangular blocky structure. Mottles are common, medium and distinct.
B_{m1}	19-27"	Distinctly mottled strong brown (7.5YR 5/6) and light gray (10YR 7/2) extremely hard to indurated brittle loam with moderate, coarse, angular blocky structure. This soil crushes easily into a friable mass. Some evidence of platy structure. Strong brown hues are common on the faces of broken peds. There are a few partly rounded and angular quartzite pebbles in this horizon.
B_{m2}	27-56"	Strong brown (7.5YR 5/6) faintly mottled with yellowish-brown (10YR 5/6) extremely hard, brittle, light fine sandy clay loam with moderate, medium angular blocky structure. This material crushes easily to a fine granular mass. Few, small, semi-rounded quartzite fragments.
C_1	56-74"	Yellowish-brown (10YR 5/8) very friable light fine sandy clay loam with weak, fine, subangular blocky structure. Faint mottles of strong brown and brownish-yellow.
C_2	74-82"	Distinctly mottled strong brown, light brownish-gray, and very pale brown very friable fine sandy loam with very weak, fine, subangular blocky to massive structure. Mottles are common, medium and distinct.

Profile S is from a road cut one mile south of Fairfax Station on Highway 123. This area supports a forest of pines and hardwoods mostly of oak species. The soil type is Beltsville silt loam, erosion is slight, and the slope is two percent. The soil has medium internal drainage and slow to medium external drainage. The underlying geologic material is

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All symbols are described in the Soil Survey Manual (17).

the Peters Creek schist. The profile was described as follows:

A_2	0-6"	Very pale brown (10YR 8/4) friable light silt loam with fine to very fine granular structure with some evidences of fine platy structure.
B_1	6-9"	Yellowish-brown (10YR 5/6) friable silty clay loam with moderate, medium, subangular blocky structure.
B_2	9-20"	Strong brown (7.5YR 5/6) firm to friable silty clay loam with moderate, medium to coarse subangular blocky structure.
B_{m1}	20-33"	Predominately light yellowish-brown (10YR 6/4) loam mottled with white, pale brown and strong brown. Weak platy to massive structure. Reddish-brown and strong brown clay skins are prominent on the broken ped faces.
B_{m2}	33-46"	Light yellowish-brown loam mottled with white, pale brown and strong brown. Weak, coarse, platy structure. This layer contains numerous small angular quartz pebbles.
D	46-76"	Mottled yellowish-red, reddish-brown, pale brown, and very pale brown. Very friable, highly micaceous light silt loam with massive structure.

Profile G was taken in a corn field on the Lorton, D. C. penal institution farm. The soil type is Beltsville silt loam. Erosion is moderate and the slope is three percent. This soil has medium internal drainage and slow to medium external drainage. Field evidence indicated that the underlying geologic formation was granitic. This profile was described as follows:

A_p	0-10"	Light yellowish-brown (2.5YR 6/4) friable light silt loam with weak, fine, granular structure. Many roots. The lower part of this layer is slightly lighter in color and texture.
B_{21}	10-17"	Yellowish-brown (10YR 5/4) firm to friable silty clay loam with moderate, medium to fine, subangular blocky structure. Many small roots. The lower part of this layer is faintly mottled with brown and strong brown.

B_{22}	17-18"	Dominately yellowish-brown (10YR 5/4) firm silty clay loam with moderate, medium, subangular blocky structure. Mottled with brown and strong brown. This is a transitional horizon, being more like the B_{21} than the underlying B_m.
B_m	18-35"	Mottled brown (7.5YR 4/4) and light brownish-gray (10YR 6/2) extremely hard, indurated, heavy loam with weak, medium, platy to moderate, medium, angular blocky structure. Brown clay skins are prominent on the ped faces. Few, coarse, distinct mottles of brownish-yellow. Broken soil aggregates show definite vesicular pores.
C	35-50"	Strong brown (7.5YR 5/6) friable loam, with very weak, fine, subangular blocky structure. Distinctly mottled with yellowish-red and yellowish-brown.
D_1	50-60"	Mottled red (2.5YR 4/6) and reddish-yellow (7.5YR 7/8) friable fine sandy clay loam with very weak, fine, subangular blocky structure. A few, small, angular, white quartz particles are mixed with the soil material.
D_2	60-75"	Red (2.5Y 4/6) mottled with yellowish-red, and reddish-yellow, very friable fine sandy loam. Many small white angular quartz fragments.

B. Preparation of Samples.

The samples collected were allowed to air dry in the laboratory for two weeks. The soil was crushed by hand with a wooden rolling pin until all aggregates passed through a 2 millimeter sieve. Particles greater than 2 millimeters in diameter were weighed as well as those less than 2 millimeters in diameter.

C. Physical Properties.

1. Permeability: Permeability tests were run in the Agriculture Engineering laboratory with the assistance of Mr. W. L. Turner. The procedure and apparatus used is basically the same as that described by Uhland and O'Neal (18). The amount of water percolating through

the soil cores was determined as inches per hour.

2. Bulk Density: Bulk density determinations were made on soil cores dried at 110°C until a constant weight was obtained. The volume of the cores was obtained by calculating the internal volume of the cylinder in which the core was contained. The following formula was used:

$$\text{Bulk Density} = \frac{\text{soil weight in grams}}{\text{volume of cylinder in cubic centimeters}} = \text{grams/cc}$$

3. Porosity: The porosity of the core samples was calculated from the loss of weight when the saturated cores were dried at 110°C. Each gram of weight lost in drying was assumed to equal one cubic centimeter of water. The volume of water lost on drying divided by the volume of soil times 100 equals the porosity of the soil.

4. Mechanical Analysis: The procedure of mechanical analysis followed that of Jackson *et al.* (6) without prior removal of iron oxides. For heavy textured horizons 50 grams of air dry soil was separated; whereas, 100 grams of air dry soil was separated for the light textured horizons. The percentage of each size class was determined from the weight of the separate dried at 110°C. Sand was subdivided into the five size classes of the United States textural classification scheme (17). Particles greater than 2 millimeters in diameter were separated by sieving.

C. Chemical Analysis.

Duplicate determinations were made for pH, percentage organic matter and free iron oxides, exchangeable cations, and cation exchange capacity.

1. pH: The pH determinations were made according to the procedure

of Peech et al. (14) using a Beckman, glass electrode, Model G pH meter. A soil-water suspension was prepared with 20 grams of soil and 20 milliliters of distilled water. The samples were stirred frequently for one hour before measuring the pH.

2. Organic Matter: The percentage of organic matter was determined by the wet combustion method outlined by Peech et al. (14). A 2 gram sample was used because of the low organic matter content of the soil. Titrations were made on a Beckman, Model R, automatic titrator using platinum and calomel electrodes.

3. Exchangeable Cations: The methods of extraction and preparation of the exchangeable cations for analysis generally followed the procedures outlined by Peech et al. (14). Exchangeable calcium, magnesium, potassium and sodium were determined on the Beckman DU flamephotometer with photomultiplier, using an acetylene-oxygen flame.

4. Cation Exchange Capacity: Cation exchange capacities were determined flamephotometrically with sodium as the saturating cation. Determinations were made on both the whole soil and the clay fractions. The sample size for the whole soil was 1 gram; whereas, 50 milligrams of clay were used. The samples were first saturated with normal, neutral sodium acetate. After removal of the excess sodium acetate with methyl alcohol, the exchangeable sodium was replaced with ammonium by washing with normal, neutral ammonium acetate.

5. Free Iron Oxides: Free oxides of iron were extracted from the soil and clay according to the procedure of Aguilera and Jackson (1). The percentage free iron was determined by polarographic analysis.

Samples of 0.5 grams were used of the whole soil and 50 milligrams of the clay.

D. Mineral Analysis.

1. Preparation of Clay and Fine Silt For Analysis:

a. Magnesium Saturation: The clay and fine silt were magnesium saturated by washing, in a centrifuge procedure, two times with normal magnesium acetate followed by three washings with 0.5 normal magnesium chloride. Excess magnesium salts were removed by washing five times with methyl alcohol. At the last alcohol washing the clay sample was divided into two parts. One part was suspended in water for X-ray analysis and the other part was dried in an evacuated silica-gel dessicator, ground, and stored for differential thermal and other analyses. The clay remaining from the free iron oxide extractions was also magnesium saturated prior to X-ray analysis.

b. Ethylene Glycol Solvation: Specimens of the clay mounted on glass X-ray slides were solvated with ethylene glycol by placing the slides in a dessicator containing a free surface of ethylene glycol. The specimens were allowed to remain in the dessicator overnight or until the clay took on a moist appearance.

c. Potassium Saturation: Approximately 50 milligrams of the wet clay was potassium saturated by heating in normal KCl at 80-90°C for six hours in a water bath. Three additional KCl washings were used to complete the potassium saturation. Excess KCl was removed by washing with methyl alcohol.

2. Differential Thermal Analysis: Differential thermal analysis

of the 2-0.2 micron clay and 0.2-0.08 micron clay consisted of comparing the thermal reactions of the clay with that of a standard nonreacting oxide of aluminum (Al_2O_3). Specimens of clay were heated in stainless steel blocks in vertically mounted furnaces. The rate of heating was 12.5°C per minute in the range from 50 to 1000°C. The differential thermal patterns were recorded by a Leeds-Northrup, X-Y recorder.

3. X-ray Analysis: X-ray diffraction patterns were obtained with a General Electric proportional counter type instrument using Cu Kα radiation generated at 35 kilovolts and 25 milliamperes. Specimens of clay and fine silt were parallel oriented by transferring 50 milligrams of each sample, dispersed in 1 millileter of water, to a glass slide and allowing this to dry in a quiet atmosphere at room temperature. Diffraction patterns of magnesium and potassium saturated slides were obtained at room temperature, after heating at 300°C for four hours, and again after heating at 500°C for four hours. Magnesium saturated samples from which free iron oxides were removed were also X-rayed at room temperature.

RESULTS AND DISCUSSION

A. Physical Properties.

1. Bulk Density, Permeability, and Porosity: The bulk density, permeability, and porosity of the fragipan and solum of profile CP are reported in Table 1. An extremely high bulk density was found for this fragipan, 1.86 gm/cc compared to a bulk density of 1.44 gm/cc in the A_p horizon and 1.61 gm/cc in the B_{21} horizon. The porosity of this fragipan is 36.3 percent. Porosity values of the A_p and B_{21} horizons were 49.4 and 52.1 percent, respectively. Nikiforoff *et al.* (13) reported a porosity of 30 percent for the fragipan of the profiles they studied.

Water percolated through this fragipan at the rate of 0.47 inches per hour, compared to 11.97 inches per hour in the A_p horizon and 4.44 inches per hour in the B_{21} horizon. Although the fragipan has this low permeability, the soil is classified, nevertheless, as moderately well drained.

2. Mechanical Analysis: The results of the mechanical analysis are given in Tables 2-7. The percentage of total gravel, sand, silt, and clay are shown graphically in Figures 1-4, respectively. There are several significant points of interest in the distribution of the various soil fractions. The material in the horizons above the fragipan is much finer in texture than the material comprising the fragipan and lower horizons. A sharp increase in medium and coarse sand and gravel (greater than two millimeters in diameter) is found below the solum. This increase is especially obvious in the gravel fraction.

Table 1. - Bulk density, permeability, and porosity of a Beltsville loam developed over Coastal Plain deposits.

Horizon	Depth, inches	Bulk Density, Grams/cc	Permeability, inches per hour	Porosity, percent
A_p	0-8	1.45	11.97	49.4
B_{21}	11-16	1.61	4.44	52.1
B_{m1}	19-27	1.86	0.47	36.3

Table 2. - Distribution of gravel and sand in a Beltsville loam developed over Coastal Plain deposits.

Horizon	Depth, inches	Percentage of size classes (diameter in millimeters)						
		> 2mm	2-1	1-0.5	0.5-0.25	0.25-0.1	0.1-0.05	2-0.05
A_p	0-8	0.1	0.8	5.7	9.8	16.5	7.2	40.0
A_3	8-11	0.2	0.8	4.9	7.2	12.3	5.7	30.9
B_{21}	11-16	0.1	1.0	5.8	8.6	13.0	4.4	32.8
B_{22}	16-19	0.1	1.4	7.2	10.4	18.0	6.4	43.4
B_{m1}	19-27	0.2	1.5	8.0	11.9	19.9	4.4	45.7
B_{m2}	27-56	0.4	1.9	8.4	13.1	19.8	6.7	49.9
C_1	56-74	0.4	1.5	7.4	15.9	24.6	6.7	56.1
C_2	74-82	0.3	0.8	6.3	19.7	31.5	7.6	65.9

Table 3. - Distribution of sand, silt, and clay in a Beltsville loam developed over Coastal Plain deposits.

Horizon	Depth, inches	Percentage of size classes (diameter in microns)								
		Sand	Silt				Clay			
		2000-50	50-20	20-5	5-2	Total	2-0.2	0.2-0.08	<0.08	Total
A_p	0-8	40.0	15.0	28.8	5.3	49.1	5.6	2.1	2.6	10.3
A_3	8-11	30.9	13.4	30.7	6.3	50.4	9.9	4.8	3.5	18.2
B_{21}	11-16	32.8	11.6	26.5	6.6	44.7	11.2	8.0	3.9	23.1
B_{22}	16-19	43.4	12.5	26.3	3.7	42.5	7.6	4.2	2.5	14.3
B_{m1}	19-27	45.7	13.0	20.7	6.9	40.6	7.0	4.1	2.7	13.8
B_{m2}	27-56	49.9	6.0	14.2	4.7	24.9	9.0	11.4	3.3	23.7
C_1	56-74	57.1	7.0	10.9	0.9	18.8	7.6	13.7	3.8	25.1
C_2	74-82	65.9	5.3	11.2	1.5	18.0	5.5	8.6	2.1	16.2

Table 4. - Distribution of gravel and sand in a Beltsville silt loam developed over schist.

Horizon	Depth, inches	Percentage of size classes (diameter in millimeters)						
		> 2	2-1	1-0.5	0.5-0.25	0.25-0.1	0.1-0.05	2.0-0.05
A_2	0-6	0.3	0.4	1.6	1.2	10.4	18.6	32.2
B_1	6-9	0.2	0.4	1.1	1.2	8.7	16.7	28.1
B_2	9-20	0.2	0.6	1.2	1.2	8.0	15.2	26.2
B_{m1}	20-33	1.1	1.4	3.2	2.8	14.6	19.8	41.8
B_{m2}	33-46	5.1	1.9	4.0	3.4	18.1	20.5	47.9
D	46-76	0.5	0.6	2.2	2.2	16.2	22.3	43.5

Table 5. - Distribution of sand, silt, and clay, in a Beltsville silt loam developed over schist.

Horizon	Depth, inches	Percentage of size classes (diameter in microns)								
		Sand	Silt				Clay			
		2000-50	50-20	20-5	5-2	Total	2-0.2	0.2-0.08	<0.08	Total
A_2	0-6	32.2	18.1	25.2	7.2	50.5	9.6	3.1	2.8	15.5
B_1	6-9	28.1	15.4	25.2	7.5	48.1	12.9	5.2	4.2	22.3
B_2	9-20	26.2	13.8	22.0	6.9	43.3	15.7	7.8	6.7	30.2
B_{m1}	20-33	41.8	12.7	18.2	5.4	36.3	10.7	7.4	3.3	21.4
B_{m2}	33-46	47.9	10.1	11.6	4.5	26.2	11.1	9.3	4.5	24.9
D	46-76	43.5	8.2	13.7	6.0	27.9	11.5	9.9	5.8	27.2

Table 6. - Distribution of gravel and sand in a Beltsville silt loam developed over granite.

Horizon	Depth, inches	Percentage of size classes (diameter in millimeters)						
		>2mm	2-1mm	1-0.5mm	.5-.25mm	.25-.1mm	.1-.05mm	2-.05mm
A_p	0-10	1.0	1.5	8.4	7.3	6.4	3.5	27.1
B_{21}	10-17	0.2	0.8	5.2	4.4	2.6	3.2	16.2
B_{22}	17-18	0.2	1.0	6.6	4.8	4.4	3.6	20.4
B_m	18-35	5.0	1.7	8.0	7.1	5.9	3.2	25.9
C	35-50	6.1	3.5	11.9	10.0	7.5	3.4	36.3
D_1	50-60	4.7	3.4	9.6	8.2	6.7	2.9	30.8
D_2	60-75	10.5	19.9	22.0	6.2	4.4	1.7	54.3

Table 7. - Distribution of sand, silt, and clay in a Beltsville silt loam developed over granite.

Horizon	Depth, inches	Percentage of size classes (diameter in microns)								
		Sand	Silt				Clay			
		2000-50	50-20	20-5	5-2	Total	2-0.2	.2-.08	<.08	Total
A_p	0-10	27.1	20.1	29.6	7.6	57.3	7.5	3.4	2.8	13.7
B_{21}	10-17	16.2	21.3	26.2	4.7	52.2	14.2	10.9	4.7	29.8
B_{22}	17-18	20.4	16.7	25.5	7.4	49.6	14.0	10.0	3.9	27.9
B_m	18-35	25.9	13.4	25.9	6.8	46.1	11.9	9.0	5.3	26.2
C	35-50	36.3	7.8	17.8	4.7	30.3	11.1	14.6	6.0	31.7
D_1	50-60	30.8	6.5	12.0	2.7	21.2	14.7	24.0	7.9	46.6
D_2	60-75	53.2	3.5	4.7	1.4	9.6	11.0	19.2	4.0	34.2

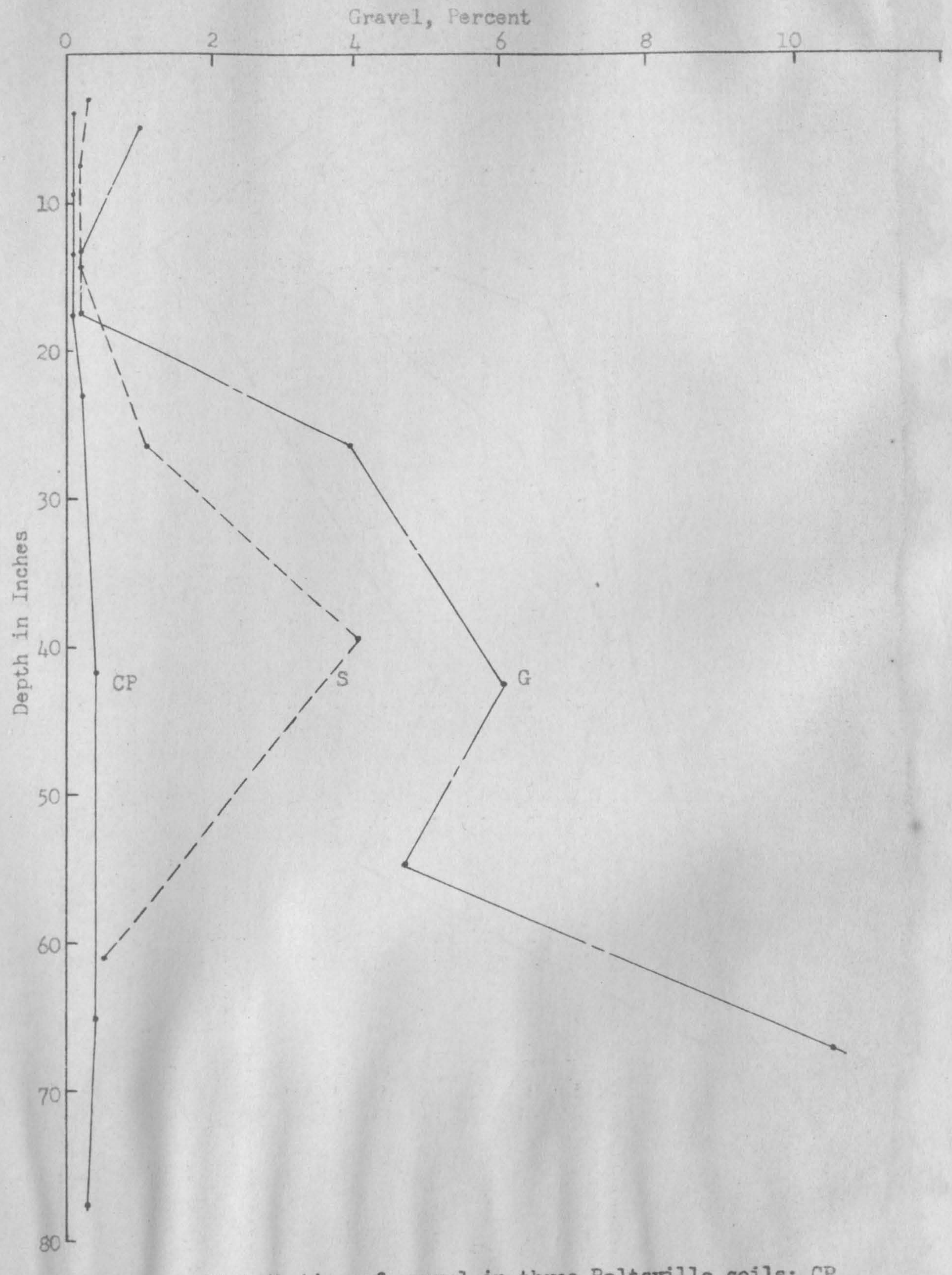

Figure 1. - Distribution of gravel in three Beltsville soils: CP, developed over Coastal Plain deposits; S, developed over schist; G, developed over granite.

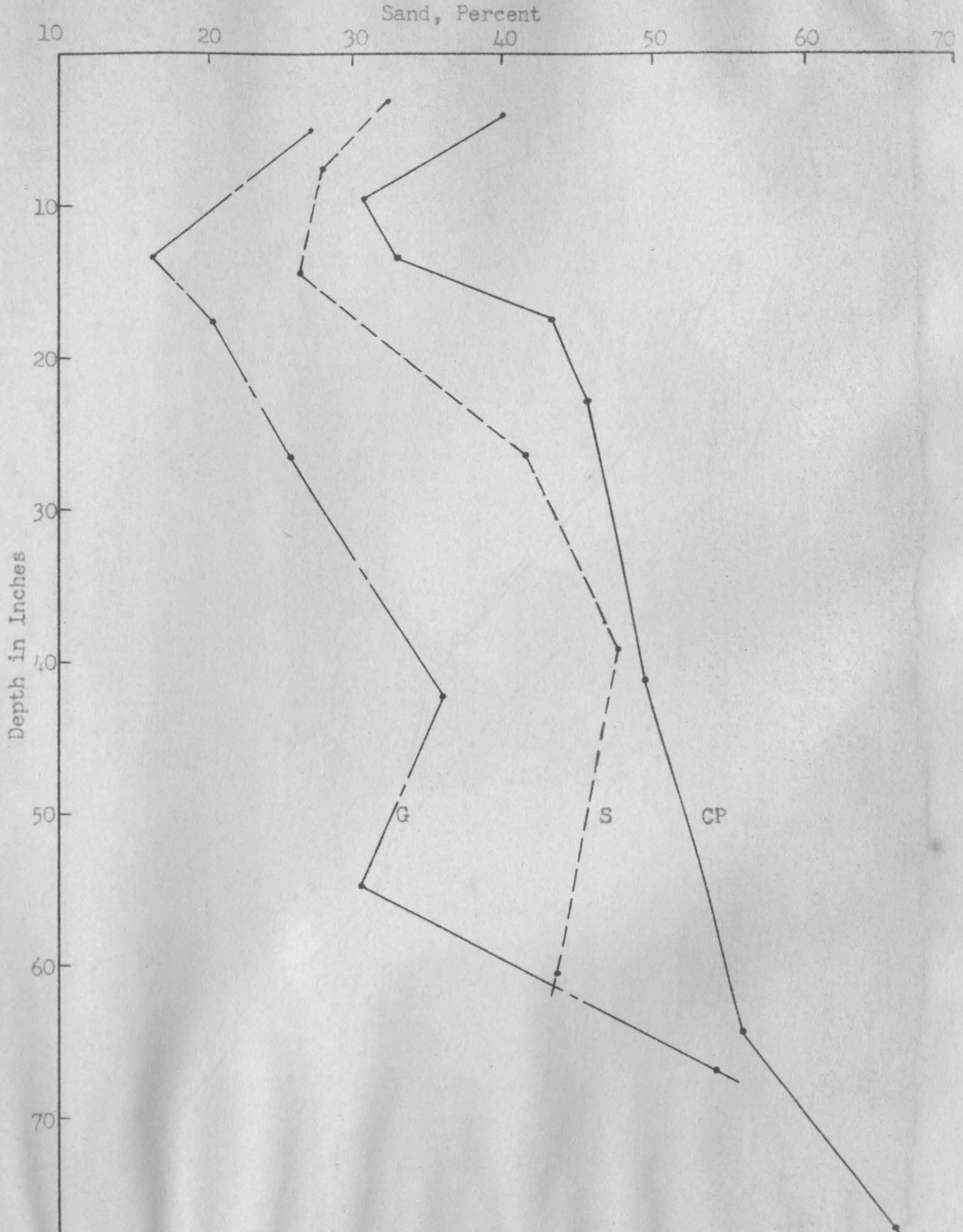

Figure 2. - Distribution of sand in three Beltsville soils: CP, developed over Coastal Plain deposits; S, developed over schist; G, developed over granite.

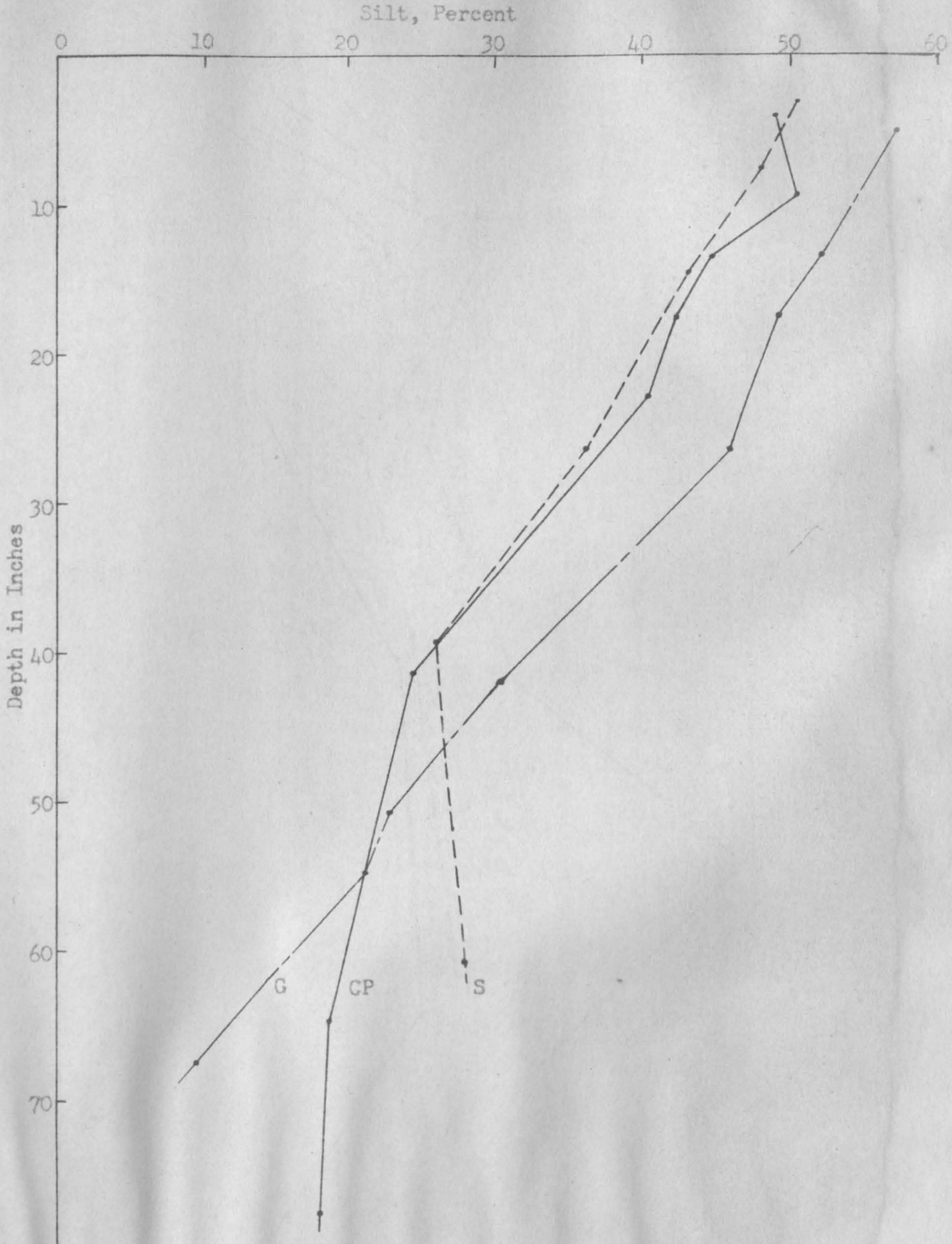

Figure 3. - Distribution of silt in three Beltsville soils: CP, developed over Coastal Plain deposits; S, developed over schist; G, developed over granite.

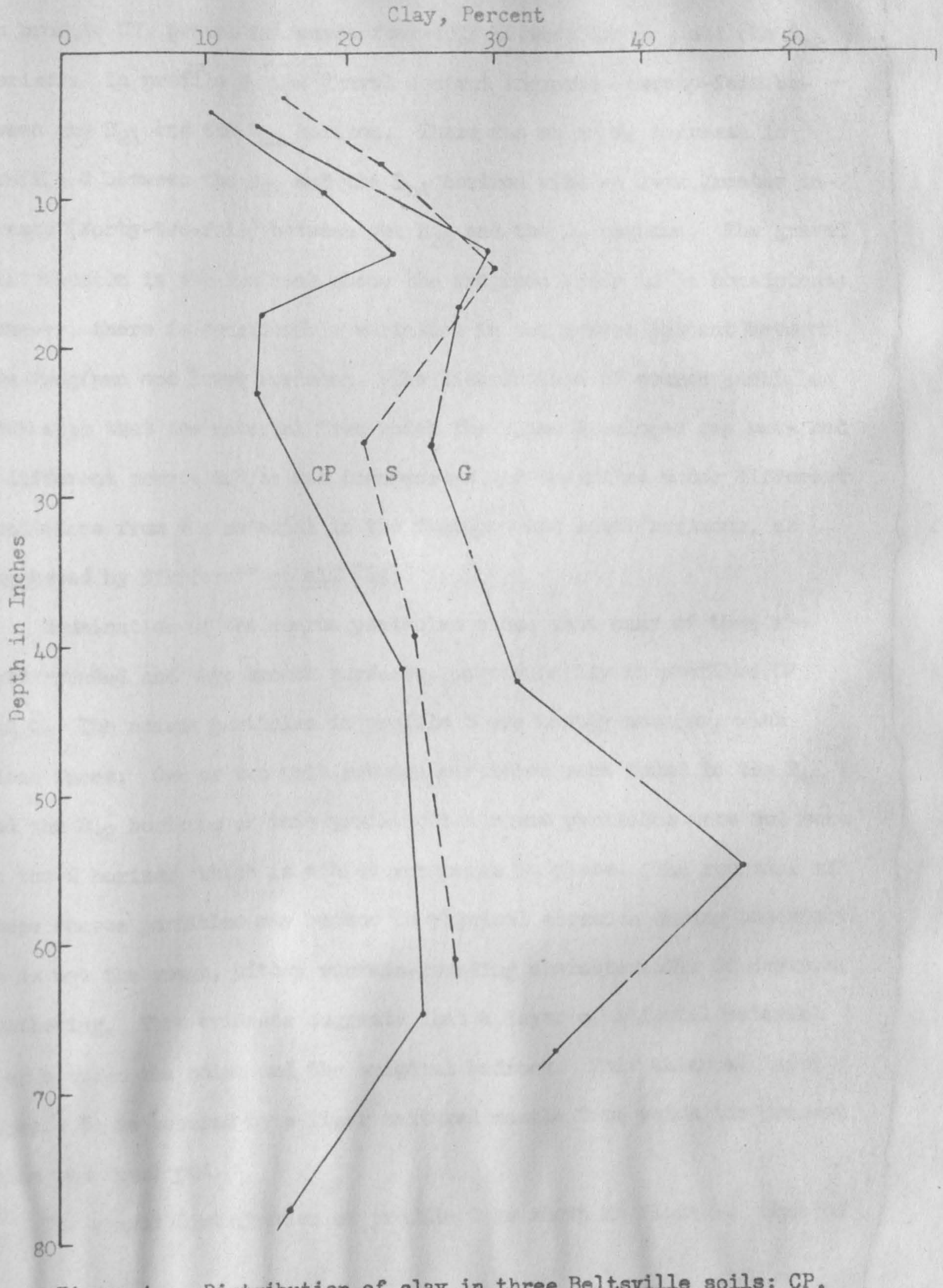

Figure 4. - Distribution of clay in three Beltsville soils: CP, developed over Coastal Plain deposits; S, developed over schist; G, developed over granite.

In profile CP, gravel increases four-fold between the B_{22} and the B_{m2} horizon. In profile S, the gravel content increases twenty-fold between the B_{21} and the B_{m2} horizon. There was an equal increase in profile G between the B_{22} and the B_{m1} horizon with an even greater increase (forty-two-fold) between the B_{22} and the D_2 horizon. The gravel distribution in the horizons above the fragipan tends to be consistent; however, there is considerable variation in the gravel content between the fragipan and lower horizons. The distribution of coarse particles indicates that the material from which the solum developed may have had a different source and/or was transported and deposited under different conditions from the material in the fragipan and lower horizons, as suggested by Nikiforoff _et_ _al_. (13).

Examination of the coarse particles shows that many of them are well rounded and have smooth surfaces, particularily in profiles CP and G. The coarse particles in profile S are mostly angular, with clean faces. One or two well rounded particles were found in the B_{m1} and the B_{m2} horizons of this profile; but round particles were not seen in the D horizon, which is schist weathered in place. The rounding of these coarse particles may be due to physical abrasion during transport. It is not the rough, pitted surface-rounding characteristic of chemical weathering. This evidence suggests that a layer of alluvial material lies between the solum and the original bedrock. This alluvial layer appears to be covered by a finer textured mantle from which the present solum was developed.

The gravel distribution of profile G is shown in Plate 1. Some of

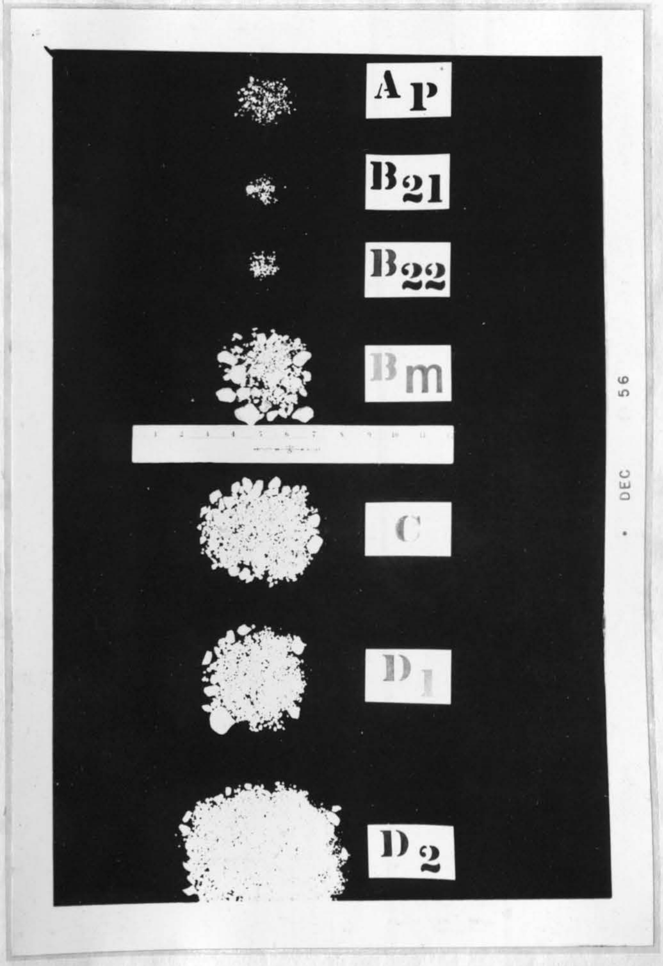

Plate 1. - Distribution of gravel in a Beltsville silt loam developed over granite. Note size and shape of gravel in the fragipan and lower horizons. The quanity of gravel shown for each horizon was removed from a 1000 gram sample of soil.

the particles in the fragipan are one inch or more in diameter. Particles as much as two inches in diameter were seen in other profiles of this soil. The few gravels found in the solum are smaller than those in and below the fragipan. The gravels in the fragipan are larger in size than those in the deeper horizons. In the fragipan of profile G, 60 percent of the gravel has a diameter greater than one centimeter as compared to 30 percent in the C and D_1 horizons and 10 percent in the D_2 horizon. This evidence not only indicates stratification of the material, but also suggests that the material in the fragipan may have been reworked with concomitant removal of finer particles, that is, this layer may have been an exposed surface.

The report of Nikiforoff _et_ _al_. (13) contains the following statement: "The clay content of the B horizon is significantly higher than any other horizon in the profile." This generalization does not hold for the soils reported here. The clay content of the B horizon is significantly higher than that of the A horizon and fragipan. However, these data show that the B horizon may not be the horizon of maximum clay content. A second clay maximum occurs below the fragipan and tends to be higher in clay than the B horizon of the solum. In profile G, the clay content of the D_1 is one and one-half times higher than that of the B_{21} horizon. This heavy texture of the horizon below the fragipan was also noted in the field description. The second clay maximum may be responsible for the low silica to alumina molar ratio in the C horizon referred to by Marbut. (11)

The silt content of the A horizon of these profiles ranges from 49 to 57 percent. There is a gradual decrease in silt down to the fragipan. Silt decreases rapidly with increasing depth below the fragipan. The content of total sand increases with soil depth with the exception of the high clay layer below the fragipan. Sand increases sharply in the fragipan and below it.

The mechanical analysis shows that the A horizon of one of these soils has a loam texture, and that the texture of the A horizon of the other two soils is silt loam. The texture of the fragipan in all cases is loam. The clay content of the fragipan varies from 14 percent to 26 percent. Visual inspection of the fragipan material under magnification indicates that the average texture of the fragipan was at one time coarser. The broken ped faces contain coatings of eluviated clay. Cracks, which were possibly old structural lines, are now filled with fine material. It is possible that the low permeability of the fragipan has resulted because of the plugging of most of the cracks and pores with fine particles. Further evidence of plugging is the filling of larger polygonal cracks such as those described by Nikiforoff. (13) These cracks were found to be filled with material composed of 60 percent or more clay.

B. Chemical Analysis.

1. Base Saturation and pH: Results of pH determinations show that the soils are strongly acid. The fragipan generally is not the most acid horizon of the profile. The highest acidity generally occurs in the B_1 and B_2 horizons. Exchangeable hydrogen also tends to be highest in the B_1 and B_2 horizons.

Base saturation and pH are shown graphically in Figure 5. The percentage base saturation in profile S shows the increase with depth common in virgin, humid-region soils. In profiles CP and G there is a decreasing base saturation with depth, probably because the samples came from cultivated fields where lime may have been applied. Profile CP shows a sharp decrease in base saturation at the fragipan horizon.

2. Organic Matter: The organic matter content of the A horizon of the three Beltsville soils is low, ranging from 1.27 percent to 1.85 percent. Organic matter decreases rapidly below the A horizon. Little or no organic matter was found in and below the fragipan of these profiles.

3. Exchangeable Cations: The results of chemical analyses are shown in Tables 8-10. Exchangeable bases are low in comparison to exchangeable hydrogen, especially in profile S, which came from a forested area. Exchangeable calcium is concentrated mainly in the B horizons; whereas, magnesium is highest in or below the fragipan. A sharp decrease in calcium is found beginning at the fragipan in all profiles, although the decrease is not as noticeable in profile S since all horizons are low in this element. Magnesium tended to increase sharply at the fragipan in profiles S and G. The increase was not as pronounced in profile CP. Exchangeable sodium showed a gradual increase with increasing depth. Potassium, which is low in all horizons of these soils, tends to be extremely low in the fragipan horizons.

4. Cation Exchange Capacity of the Whole Soil: The cation exchange capacity of the whole soil (Tables 8-10) is low in all horizons

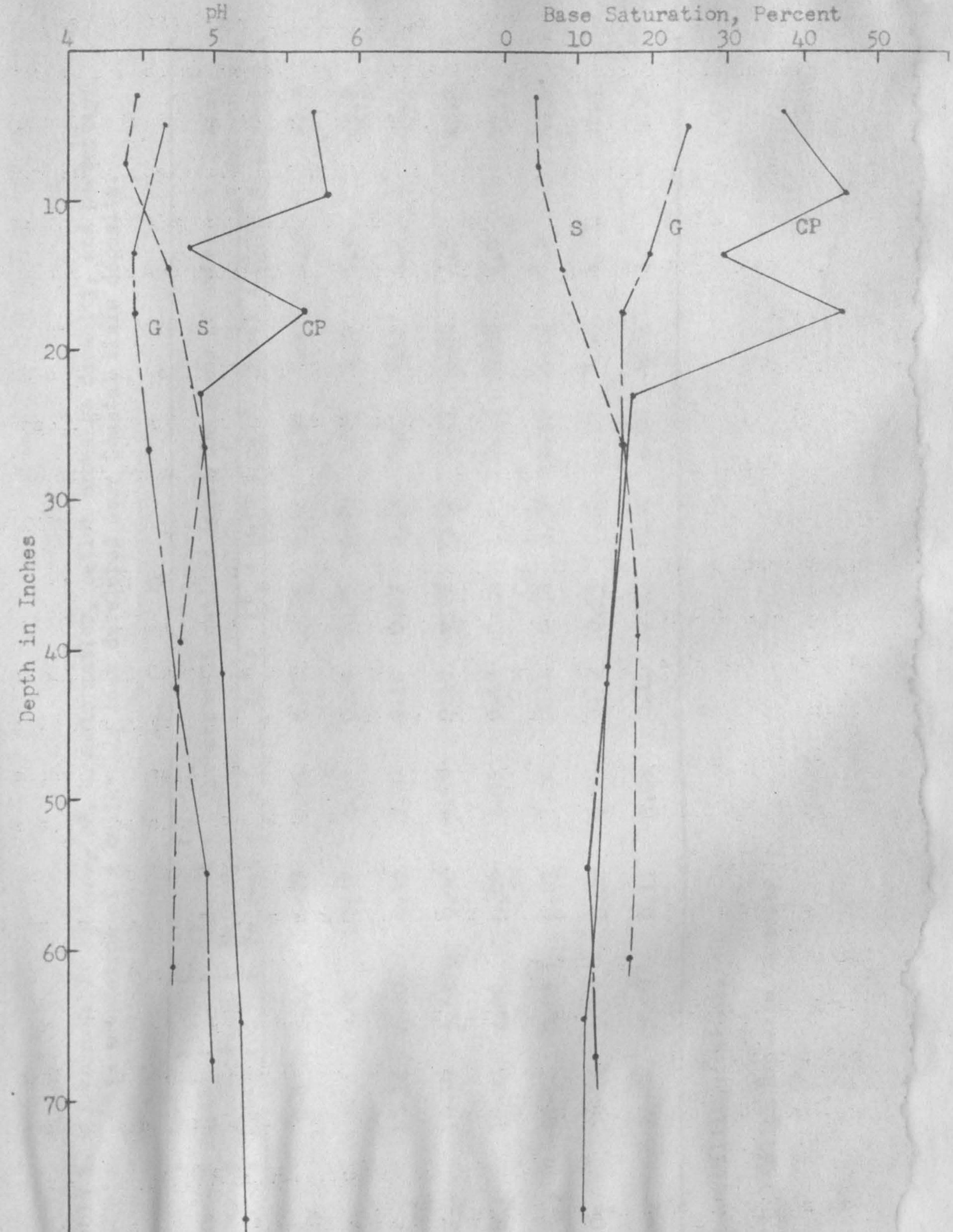

Figure 5. - Base saturation and pH of three Beltsville soils: CP, developed over Coastal Plain deposits; S, developed over schist; G, developed over granite.

Table 8. - Exchangeable cations, pH, organic matter, cation exchange capacity, and percentage base saturation of a Beltsville loam developed over Coastal Plain deposits.

Horizon	Depth, inches	pH	Organic Matter, Percent	Exchangeable cations (me.*/100 grams of soil)							Base Saturation, Percent
				H^+	Na^+	K^+	Mg^{++}	Ca^{++}	Total	CEC**	
A_p	0-8	5.68	1.27	4.50	0.08	0.05	0.34	2.23	7.20	4.2	37.5
A_3	8-11	5.77	0.42	4.50	0.09	0.05	0.72	2.93	8.29	5.3	45.7
B_{21}	11-16	4.80	0.25	5.70	0.10	0.07	0.62	1.62	8.11	6.8	29.7
B_{22}	16-19	5.61	0.38	3.65	0.10	0.05	0.64	2.22	6.66	4.5	45.2
B_{m1}	19-27	4.89	0.09	4.95	0.07	0.04	0.62	0.32	6.00	4.7	17.5
B_{m2}	27-56	5.05	0.03	7.20	0.11	0.03	0.98	0.10	8.42	7.0	14.5
C_1	56-74	5.19	0.08	6.95	0.12	0.03	0.62	0.06	7.78	6.45	10.7
C_2	74-82	5.20	0.11	5.05	0.11	0.02	0.37	0.06	5.61	4.7	10.0

* Milliequivalents

** Cation Exchange Capacity

Table 9. - Exchangeable cations, pH, organic matter, cation exchange capacity, and percentage base saturation of a Beltsville silt loam developed over schist.

Horizon	Depth, inches	pH	Organic Matter, Percent	Exchangeable cations (me.*/100 grams of soil)							Base Saturation, Percent
				H^+	Na^+	K^+	Mg^{++}	Ca^{++}	Total	CEC**	
A_2	0-6	4.45	1.29	5.20	0.07	0.04	0.06	0.05	5.42	4.35	4.2
B_1	6-9	4.38	0.70	7.40	0.08	0.06	0.10	0.13	7.77	5.95	4.8
B_2	9-20	4.68	0.49	10.10	0.09	0.10	0.58	0.09	10.96	9.10	7.9
B_{m1}	20-33	4.93	0.09	6.70	0.10	0.01	1.13	0.05	7.99	6.55	16.1
B_{m2}	33-46	4.75	0.00	8.45	0.10	0.07	1.64	0.04	10.30	8.80	18.0
D	46-76	4.70	0.00	11.25	0.12	0.07	1.95	0.02	13.41	11.35	16.1

* Milliequivalents

** Cation Exchange Capacity

Table 10. - Exchangeable cations, pH, organic matter, cation exchange capacity, and percentage base saturation of a Beltsville silt loam developed over granite.

Horizon	Depth, inches	pH	Organic Matter, Percent	Exchangeable cations (me.*/100 grams of soil)							Base Saturation, Percent
				H^+	Na^+	K^+	Mg^{++}	Ca^{++}	Total	CEC**	
A_p	0-10	4.65	1.85	6.70	0.11	0.10	0.32	1.67	8.90	6.75	24.7
B_{21}	10-17	4.38	0.41	12.35	0.13	0.11	0.97	1.77	15.33	10.25	19.5
B_{22}	17-18	4.40	0.34	11.20	0.17	0.05	0.83	1.13	13.38	10.95	16.3
B_m	18-35	4.54	0.16	10.95	0.17	0.02	1.43	0.46	13.03	9.60	16.0
C	35-50	4.71	0.11	10.45	0.20	0.01	1.34	0.16	12.16	10.50	14.0
D_1	50-60	4.95	0.14	12.55	0.25	0.04	1.22	0.08	14.14	13.30	11.3
D_2	60-70	4.98	0.15	9.45	0.25	0.04	0.85	0.12	10.71	10.35	11.8

* Milliequivalents

** Cation Exchange Capacity

of these profiles and indicates a lack of minerals with high cation exchange capacities. A very low cation exchange capacity is characteristic of the fragipan and the A horizon. The cation exchange capacity increases or decreases in the profile in the same manner as the clay content. If the cation exchange capacity of pure kaolinite is assumed to be 10 milliquivalents per 100 grams, it can be calculated that this soil contains very little material with an exchange capacity higher than kaolinite.

5. Free Iron Oxide Content of the Whole Soil and Clay Fractions: The results of the free iron oxide analyses for the whole soil and the three clay fractions are given in Table 11. The distribution of free iron oxide in the whole soil is shown graphically in Figure 6.

There is considerable variation in the amounts of free iron within the individual profiles and between the different profiles. The variation is most apparent in the amounts of free iron in the whole soil and in the 2-0.2 micron clay fraction. The free iron content of the fine clay (less than 0.2 microns) is high compared to that of the whole soil and coarse clay (2-0.2 microns).

Free iron in the whole soil of the A horizon averages about 0.83 percent, with a slightly higher value in the Beltsville silt loam soils (profiles S and G) and a slightly lower value in the Beltsville loam (profile CP). Free iron increases significantly in the B horizon, as is common in podzolic soils. The free iron content of the fragipan is only slightly higher than that of the A horizon. Free iron in the whole soil increases in the horizons below the fragipan. In profiles CP and G

Table 11. - Distribution of free iron oxides in the whole soil and clay fractions of three Beltsville soils.

Horizon	Depth, inches	Percentage free iron (Fe)			
		2-0.2	0.2-0.08	< 0.08	Whole Soil
		Beltsville loam developed over Coastal Plain deposits			
A_p	0-8	1.65	7.76	8.64	0.66
A_3	8-11	2.06	8.34	9.69	1.22
B_{21}	11-16	2.76	8.11	8.36	1.46
B_{22}	16-19	3.12	8.23	7.37	1.03
B_{m1}	19-27	1.65	6.82	8.68	0.70
B_{m2}	27-56	2.23	7.90	9.30	1.53
C_1	56-74	3.39	7.49	8.81	1.83
C_2	74-82	2.77	6.74	8.59	1.06
		Beltsville silt loam developed over schist			
A_2	0-6	1.54	7.52	10.64	0.92
B_1	6-9	1.98	8.37	11.28	1.37
B_2	9-20	3.18	9.70	9.67	2.30
B_{m1}	20-33	1.93	9.55	6.55	1.27
B_{m2}	33-46	1.95	9.44	5.25	1.12
D	46-76	2.05	5.89	6.45	1.46

Table 11(Continued)

Horizon	Depth, inches	Percentage free iron (Fe)			
		2-0.2	0.2-0.08	< 0.08	Whole Soil
		Beltsville silt loam developed over granite			
A_p	0-10	2.22	7.87	9.75	0.91
B_{21}	10-17	3.41	6.36	9.27	2.05
B_{22}	17-18	3.61	6.77	9.37	1.97
B_m	18-35	2.74	6.27	9.15	1.61
C	35-50	2.17	6.80	11.35	2.12
D_1	50-60	2.57	7.64	11.28	3.18
D_2	60-75	6.60	7.89	9.93	3.22

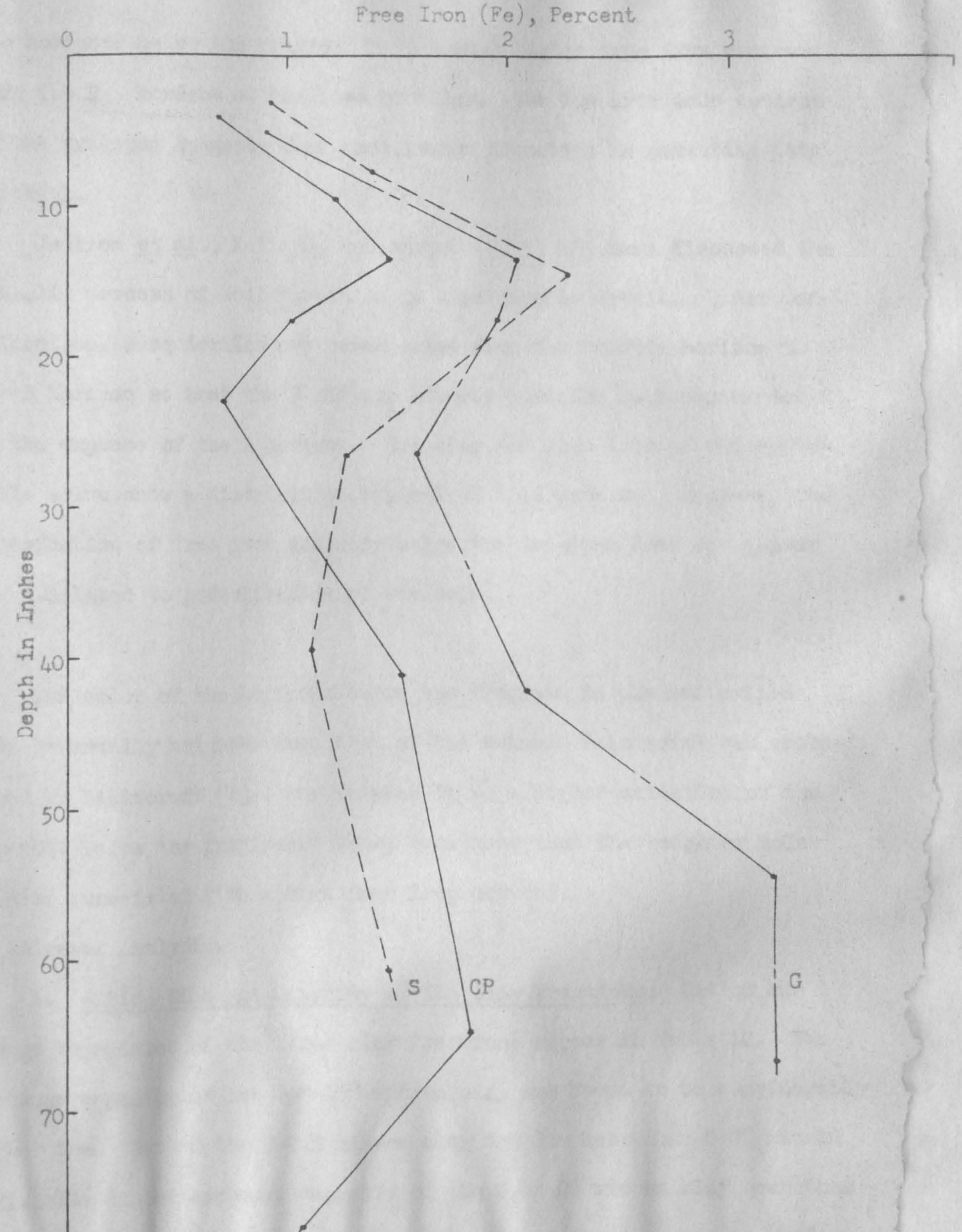

Figure 6. - Distribution of free iron oxides in three Beltsville soils: CP, developed over Coastal Plain deposits; S, developed over schist; G, developed over granite.

the horizons below the fragipan have a much higher free iron content than the B_{21} horizon of the same profiles. The low free iron content of the fragipan suggests that iron is not important in cementing this material.

Jackson et al., Kellogg, and Marbut (7, 9, 12) have discussed the podzolic process of soil formation in considerable detail. Under podzolization, sesquioxides are transported from the surface horizon to the B horizon so that the B horizon becomes enriched in sesquioxides at the expense of the A horizon. The clay and free iron of the Beltsville solum show a distribution typical of this process. However, the distribution of free iron and clay below the fragipan does not appear to be related to podzolization of the solum.

The color of the horizons below the fragipan in the Beltsville soil is usually brighter than that of the solum. This point was emphasized by Nikiforoff (13), who related it to a higher oxidation of the material below the fragipan. These data show that the brighter color is also associated with a high free iron content.

C. Mineral Analysis.

1. Cation Exchange Capacity of the Clay Fractions: Cation exchange capacities of the three clay fractions appear in Table 12. The exchange capacity of the 0.2-.08 micron clay was found to be considerably higher than that of the 2-0.2 micron clay and the less than 0.08 micron clay. The higher exchange capacity of the 0.2-.08 micron clay over that of the 2-0.2 micron clay may be due primarily to the increase in surface

Table 12. - Cation exchange capacity of the clay fractions of three Beltsville soils.

Horizon	Depth, inches	Cation exchange capacity me./100 grams		
		Clay fraction (diameter in microns)		
		2-0.2	0.2-0.08	< 0.08
Beltsville loam developed over Coastal Plain deposits				
A_p	0-8	15.9	33.3	23.5
A_3	8-11	15.9	30.5	22.1
B_{21}	11-16	14.7	27.0	21.2
B_{22}	16-19	16.8	32.1	23.8
B_{m1}	19-27	24.6	35.8	23.4
B_{m2}	27-56	18.3	29.2	19.8
C_1	56-74	18.7	25.7	20.9
C_2	74-82	14.2	31.9	24.8
Beltsville silt loam developed over schist				
A_2	0-6	12.4	32.2	23.0
B_1	6-9	19.7	28.7	25.3
B_2	9-20	20.2	35.9	24.9
B_{m1}	20-33	21.9	24.5	30.2
B_{m2}	33-46	22.9	44.4	30.8
D	46-76	24.7	37.5	33.6

Table 12 (Continued)

Horizon	Depth, inches	Cation exchange capacity me./100 grams		
		Clay fraction (diameter in microns)		
		2-0.2	0.2-0.08	< 0.08
		Beltsville silt loam developed over granite		
A_p	0-10	12.4	34.2	26.4
B_{21}	10-17	19.1	34.3	32.4
B_{22}	17-18	21.1	37.0	29.0
B_m	18-35	26.1	39.4	29.7
C	35-50	23.1	36.8	24.3
D_1	50-60	21.1	25.9	22.6
D_2	60-75	17.8	24.4	23.4

area and to a lack of quartz in this finer fraction. The low exchange capacity of the less than 0.08 micron clay relative to that of the 0.2-.08 micron clay may be due in part to a higher free iron oxide content in the less than 0.08 micron clay and in part to the fact that highly weathered amorphous minerals with low exchange capacity may comprise a large part of the finer material. Jackson et al. (7, 9) point out that the minerals of advanced stages of weathering tend to concentrate in the fine clay fractions. It was also found that the cation exchange capacity of the clay in the fragipan tended to be slightly higher than that of the other soil horizons. In profile S, a high exchange capacity occurs also in the clay of the horizons below the fragipan. The high exchange capacity of clay from these horizons is associated with the degree of collapse of the vermiculite type minerals when potassium saturated. (See X-ray analysis.)

2. Differential Thermal Analysis: The relative distribution of the clay minerals giving a characteristic endothermic peak in the temperature range from 550-580°C is shown in Table 13. Both kaolinite and halloysite give similar endothermic reactions in this temperature range (5). However, the symmetry of the thermal curves and the sharp 7.2 Angstrom peak in the X-ray analysis indicates that the mineral is primarily kaolinite. The distribution of the mineral is based on the area subtended by the thermal peak, assuming that the area is proportional to the concentration of the reacting mineral.

The kaolinite content of the 2-0.2 micron clay and the 0.2-0.08 micron clay, as determined by differential thermal analysis, is highest

Table 13. - Relative distribution of kaolinite and/or halloysite in the 2-0.2 and 0.2-0.08 micron clay fractions of three Beltsville soils as determined by differential thermal analysis.

Horizon	Depth, inches	Area of the 550-580°C endothermic reaction in square centimeters	
		2-0.2	0.2-0.08
Beltsville loam developed over Coastal Plain deposits			
A_p	0-8	5.8	4.7
A_3	8-11	7.4	9.3
B_{21}	11-16	5.4	8.3
B_{22}	16-19	7.0	8.0
B_{m1}	19-24	4.8	10.3
B_{m2}	27-56	9.6	12.1
C_1	56-74	9.1	13.1
C_2	74-82	9.0	13.2
Beltsville silt loam developed over schist			
A_2	0-6	7.2	9.1
B_1	6-9	9.1	12.6
B_2	9-20	10.0	10.3
B_{m1}	20-33	7.7	4.3
B_{m2}	33-46	16.9	12.5
D	46-76	16.4	16.5

Table 13(Continued)

Horizon	Depth, inches	Area of the 550-580°C endothermic reaction in square centimeters	
		2-0.2	0.2-0.08
Beltsville silt loam developed over granite			
A_p	0-10	5.6	9.6
B_{21}	10-17	10.6	12.6
B_{22}	17-18	8.8	12.7
B_m	18-35	8.3	11.6
C	35-50	13.2	13.5
D_1	50-60	8.0	16.6
D_2	60-75	15.1	17.9

in the horizons below the fragipan. Kaolinite tends to be low in the clay fractions of the fragipans and A horizons of these profiles.

A sharp endothermic reaction between 285°C and 300°C indicates that some gibbsite is present in the clay of the sub-fragipan horizons of profiles CP and G. The gibbsite reaction was absent in profile S and in the solum of profiles CP and G. The gibbsite reaction occurs in the differential thermogram tracings of profile CP in Figure 7. The size of the gibbsite reaction is small in the fragipan, but increases into the C_1 horizon. The reaction decreases in intensity in the C_2 horizon.

A small endothermic reaction at 845°C was found in the 0.2-0.08 micron clay fraction of the fragipan in profile S, and may be due to a trace of montmorillonite. (5, 19) This reaction was not observed elsewhere in this or the other profiles studied. The general lack of montmorillinite is indicated also by the low base content and cation exchange capacity of this soil.

A prominent exothermic heat reaction occurred between 340°C and 370°C. The reaction tended to be larger in the deeper soil horizons. The release of heat is probably due to molecular rearrangement and crystallization to hematite of amorphous iron. (5)

3. X-ray Analyses:

a. Relative Distribution of Minerals: X-ray analyses indicate that the principal crystalline minerals in the three Beltsville profiles are vermiculite (14.2 A)*, illite (10.1 A), kaolinite (7.2 A), and

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* Most indicative reflections

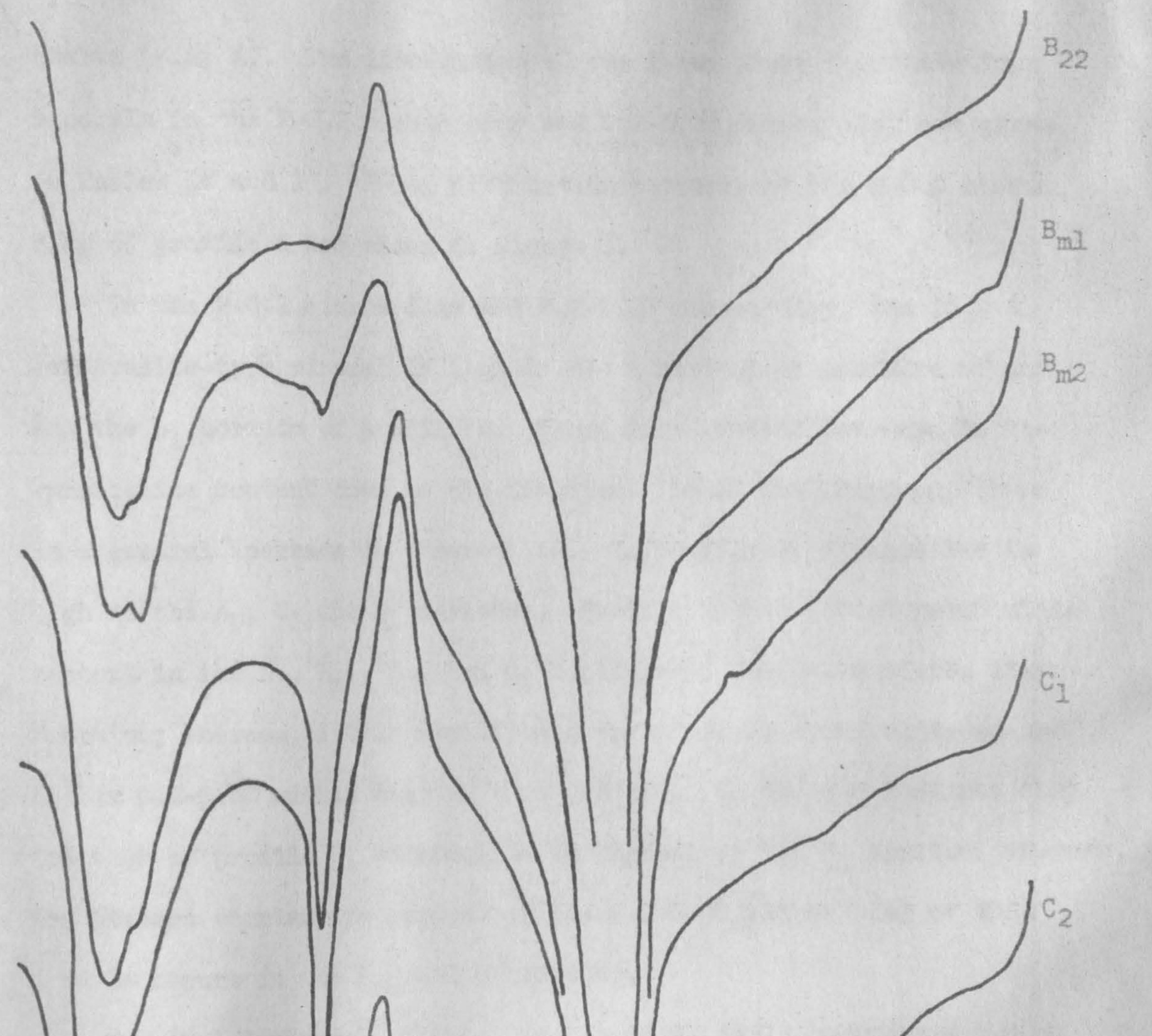

Figure 7. - Differential thermal analysis tracings of magnesium saturated 0.2-0.08 micron clay in the Beltsville loam, profile CP (Developed over Coastal Plain terrace deposits.)

quartz (4.26 A). The intensities of the X-ray peaks for these four minerals in the 2-0.2 micron clay and 0.2-0.08 micron clay are given in Tables 14 and 15. X-ray diffraction patterns of the 2-0.2 micron clay of profile G are shown in Figure 8.

In the 2-0.2 micron clay and 0.2-0.08 micron clay, the 14.2 A, vermiculite-type mineral is high in the A horizon of profiles CP and G, and the B_1 horizon of profile S. There is a general decrease in the vermiculite content down to the fragipan. Below the fragipan, there is a general increase in vermiculite. In profile G, vermiculite is high in the A_p, C_1 and D_1 horizons. Profile CP has a high vermiculite content in the A_3, B_{m1}, C_1, and C_2 horizons of the 2-0.2 micron clay fraction; whereas, little significant variation in vermiculite occurs in the 0.2-0.08 micron clay of this profile. In the 2-0.2 micron clay fraction of profile S, vermiculite is highest in the B_1 horizon; whereas, the highest vermiculite content of the 0.2-0.08 micron clay of this profile occurs in the B_{m2} and D horizons.

The 10.1 A mineral, illite, was found in small amounts or not at all in the 0.2-0.08 micron clay. The illite content in the 2-0.2 micron clay of the sub-fragipan horizons is considerably less than the illite content in the horizons including the fragipan and above. An exception was found in 2-0.2 micron clay of the D_2 horizon in profile G where illite was high. Illite shows a general decrease in abundance with increasing profile depth in the clay fraction of these profiles.

The distribution of kaolinite (7.2 A), as determined by X-ray analysis, is in fair agreement with the distribution observed in the

Table 14. - Intensity of X-ray diffraction peaks of the 2-0.2 micron clay fraction (free iron removed) of three Beltsville soils.

Horizon	Depth, inches	Counts per second for minerals*			
		Vermiculite	Illite	Kaolinite	Quartz
		d values in angstrom units			
		14.2	10.1	7.2	4.26
Beltsville loam developed over Coastal Plain deposits					
A_p	0-8	1760	110	630	330
A_3	8-11	2350	190	900	270
B_{21}	11-16	1130	200	590	360
B_{22}	16-19	1920	200	780	300
B_{m1}	19-27	2520	180	740	390
B_{m2}	27-56	1800	100	580	190
C_1	56-74	2800	110	1250	140
C_2	74-82	2600	130	970	220
Beltsville silt loam developed over schist					
A_2	0-6	1550	550	1160	250
B_1	6-9	1900	400	1960	210
B_{21}	9-20	1100	530	1630	220
B_{m1}	20-33	1000	380	1260	250
B_{m2}	33-46	700	100	4350	150
D	46-76	1200	80	4970	90

Table 14(Continued)

Horizon	Depth, inches	Counts per second for minerals*			
		Vermiculite	Illite	Kaolinite	Quartz
		d values in angstrom units			
		14.2	10.1	7.2	4.26
Beltsville silt loam developed over granite					
A_p	0-10	3000	230	900	320
B_{21}	10-17	1650	350	900	240
B_{22}	17-18	1100	260	730	250
B_m	18-35	1600	300	910	260
C	35-50	3200	170	1040	210
D_1	50-60	3790	160	1260	220
D_2	60-75	2080	250	2150	70

* Cu Kα radiation generated at 35 kilovolts and 23 milliamperes

Table 15. - Intensity of X-ray diffraction peaks of the 0.2-0.08 micron clay fraction (free iron removed) of three Beltsville soils.

Horizon	Depth, inches	Counts per second for minerals*			
		Vermiculite	Illite	Kaolinite	Quartz
		d values in angstrom units			
		14.2	10.1	7.2	4.26
Beltsville loam developed over Coastal Plain deposits					
A_p	0-8	2000	0	810	50
A_3	8-11	2050	30	990	0
B_{21}	11-16	1600	0	800	0
B_{22}	16-19	2000	0	930	0
B_{m1}	19-27	2500	0	1080	0
B_{m2}	27-56	2500	0	1080	0
D_1	56-74	2600	0	1300	0
D_2	74-82	2400	0	1050	0
Beltsville silt loam developed over schist					
A_2	0-6	1900	60	1600	20
B_1	6-9	1950	70	1950	0
B_2	9-20	1400	70	1730	60
B_{m1}	20-33	1700	60	1530	0
B_{m2}	33-46	2900	0	2950	20
D	46-76	2960	0	3120	0

Table 15(Continued)

Horizon	Depth, inches	Counts per second for minerals*			
		Vermiculite	Illite	Kaolinite	Quartz
		d values in angstrom units			
		14.2	10.1	7.2	4.26
		Beltsville silt loam developed over granite			
A_p	0-10	2800	0	1100	0
B_{21}	10-17	2100	60	1000	0
B_{22}	17-18	1420	60	950	0
B_m	18-35	1500	60	900	0
C	35-50	2600	0	1490	0
D_1	50-60	2450	0	1480	0
D_2	60-75	1600	0	3050	0

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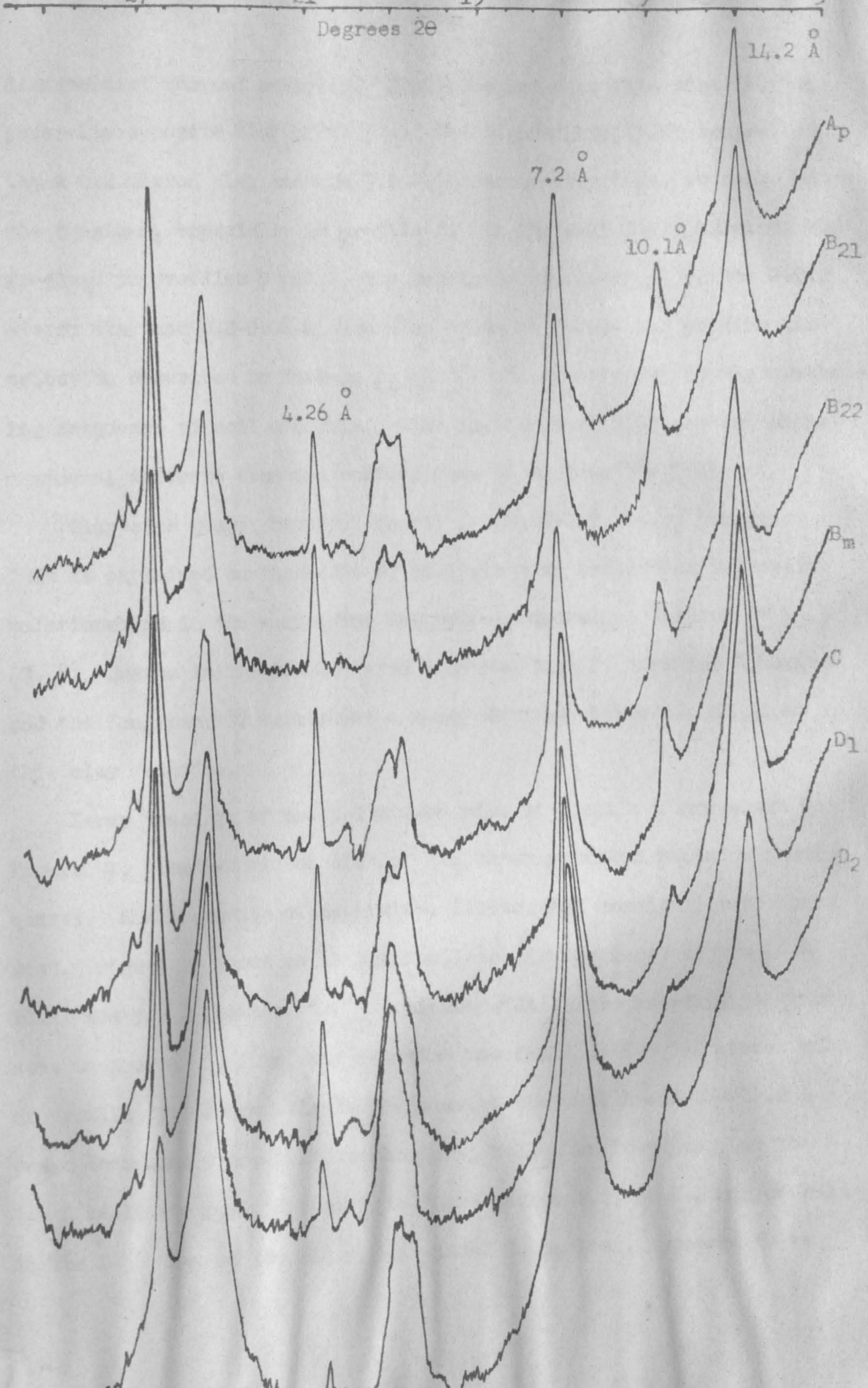
* Cu Kα radiation generated at 35 kilovolts and 23 milliamperes

Figure 8. - X-ray diffraction tracings of the 2-0.2 micron clay fraction of a Beltsville silt loam developed over granite. Iron removed.


27
21
15
9
3
Degrees 2θ
14.2 Å
7.2 Å
10.1Å
4.26 Å
A_p
B_{21}
B_{22}
B_m
C
D_1
D_2

differential thermal analysis. Kaolinite has a profile distribution generally opposite that of illite. The highest kaolinite content of the 2-0.2 micron clay and the 0.2-0.08 micron clay tends to occur below the fragipan, especially in profile S. In the soil horizons above the fragipan in profiles G and S, the kaolinite distribution in the 2-0.2 micron clay and 0.2-0.08 micron clay tends to follow the profile distribution described by Jackson et al. (7, 8) in relation to the weathering sesquence of soil minerals. That is, the kaolinite content shows a general decrease from the surface down to or into the fragipan.

Clay-size quartz occurred mostly in the 2-0.2 micron fraction. This is explained on the basis of particle size weathering intensity relationships in the weathering sesquence proposed by Jackson et al. (7, 8). Quartz in the 2-0.2 micron clay was high in both the A horizon and the fragipan. Quartz shows a sharp decrease below the fragipan in this clay fraction.

X-ray tracings of the 5-2 micron silt of profile G are shown in Figure 9. The 5-2 micron silt of the three profiles contains mostly quartz. Small amounts of kaolinite, illite, and vermiculite are present. Figure 9 shows an almost complete disappearance of the 14.2, 10.1, and 7.2 A peaks of the 5-2 micron silt in the sub-fragipan horizons in profile G. The same relation was found in the 5-2 micron silt of profile CP. In profile S, the size of the 10.1 A and the 14.2 A peaks decreased sharply in the horizons below the fragipan, but the 7.2 A kaolinite peak increased in these horizons. The 5-2 micron silt in the D horizon of profile S, on visual inspection, appeared to be

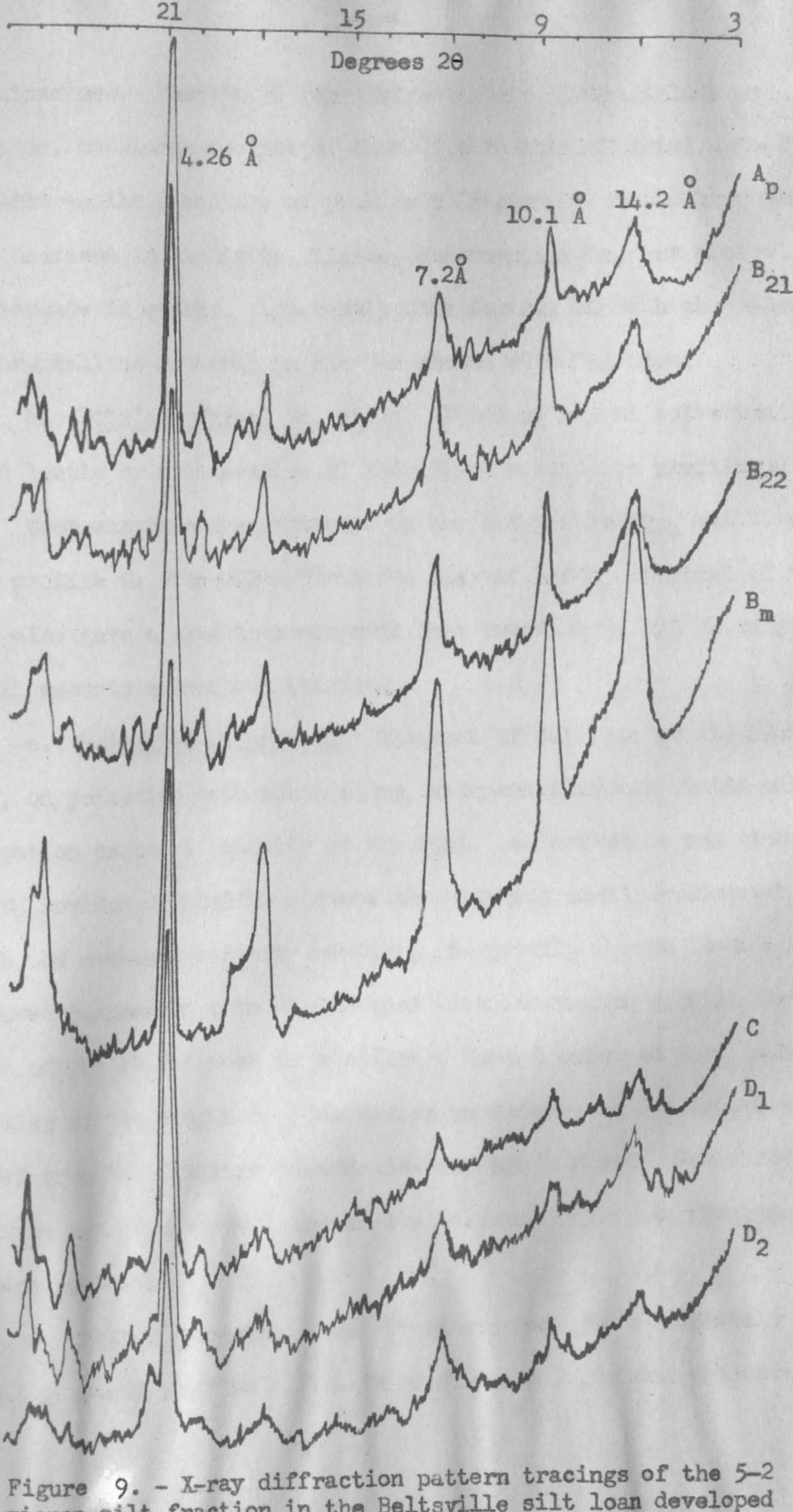


Figure 9. - X-ray diffraction pattern tracings of the 5-2 micron silt fraction in the Beltsville silt loam developed over granite.

highly micaceous. However, X-ray analysis shows little illite or vermiculite, but large amounts of kaolinite in this material. The 5-2 micron silt in the D horizon of profile G (Figure 9) not only showed a sharp decrease in kaolinite, illite, and vermiculite, but also a sharp decrease in quartz. Apparently this horizon has a high content of non-crystalline material in the 5-2 micron silt fraction.

b. Ethylene Glycol Solvation: Ethylene glycol solvation produced little or no expansion of the 14.2 A mineral in profiles G and CP. Some expansion was obtained in the clay of the B_{m1} and D horizons of profile S. The 0.2-0.08 micron clay of the B_{m1} horizon of this profile also gave a slight endothermic heat reaction at 845°C, indicating small amounts of montmorillinite.

c. Potassium Saturation: The ease of collapse of the 14.2 A mineral, on potassium saturation along, was generally associated with a high cation exchange capacity of the clay. An exception was observed in the D_2 horizon of profile G where the clay was easily collapsed, although the exchange capacity was low. In profile S, the 14.2 A X-ray peak showed increasing ease of collapse with increasing profile depth. Collapse of the 14.2 A peak in profiles CP and G occurred most readily in the clay of the fragipan. Increasing resistance to collapse was encountered from the fragipan towards the surface horizon. Resistance to collapse was also encountered in the horizons below the fragipan containing gibbsite.

d. Heat Treatments: Heat treatments at 500°C completely shifted the 14.2 A peak to 10.1 A in profile S. A partial collapse of the 14.2 A peak to 10.1 A was obtained in the A_p, C, and D_1 horizons of profile G; whereas, a complete collapse was obtained in the other horizons. In profile CP, the fragipan was the only horizon showing a complete collapse of the 14.2 A peak to 10.1 A at 500°C. The attempts to collapse the 14.2 A mineral of profile G are shown in Figure 10.

4. Discussion of Mineral Analysis:

The intensity of weathering of the soil minerals throughout the three profiles is evident in the distribution of the less resistant minerals relative to their particle diameter. Jackson et al. (7, 8) point out that in the clay size fraction, weathering proceeds rapidly as the particle size diminishes, and the stage of weathering becomes more advanced with increasing proximity to the surface. Quartz tends to have a low resistance to weathering in the clay size range, but becomes highly resistant in the coarser than clay fractions. The less than 0.2 micron clay of these profiles consists primarily of vermiculite, kaolinite, and amorphous materials, with some gibbsite in the horizons below the fragipan of profile CP and G. Little quartz and illite were found in the fraction less than 0.2 micron in size in all three profiles. Both quartz and illite are plentiful in the 2-0.2 micron clay, but show a sharp decrease in abundance in the 2-0.2 micron clay from the horizons below the fragipan. Quartz is the major crystalline mineral in the 5-2 micron silt fraction throughout the profiles. However, illite, common in the 5-2 micron silt in the horizons above the fragipan, is conspicuously less abundant in the 5-2 micron silt in the horizons below the fragipan. In profile G illite (Figure 10) in

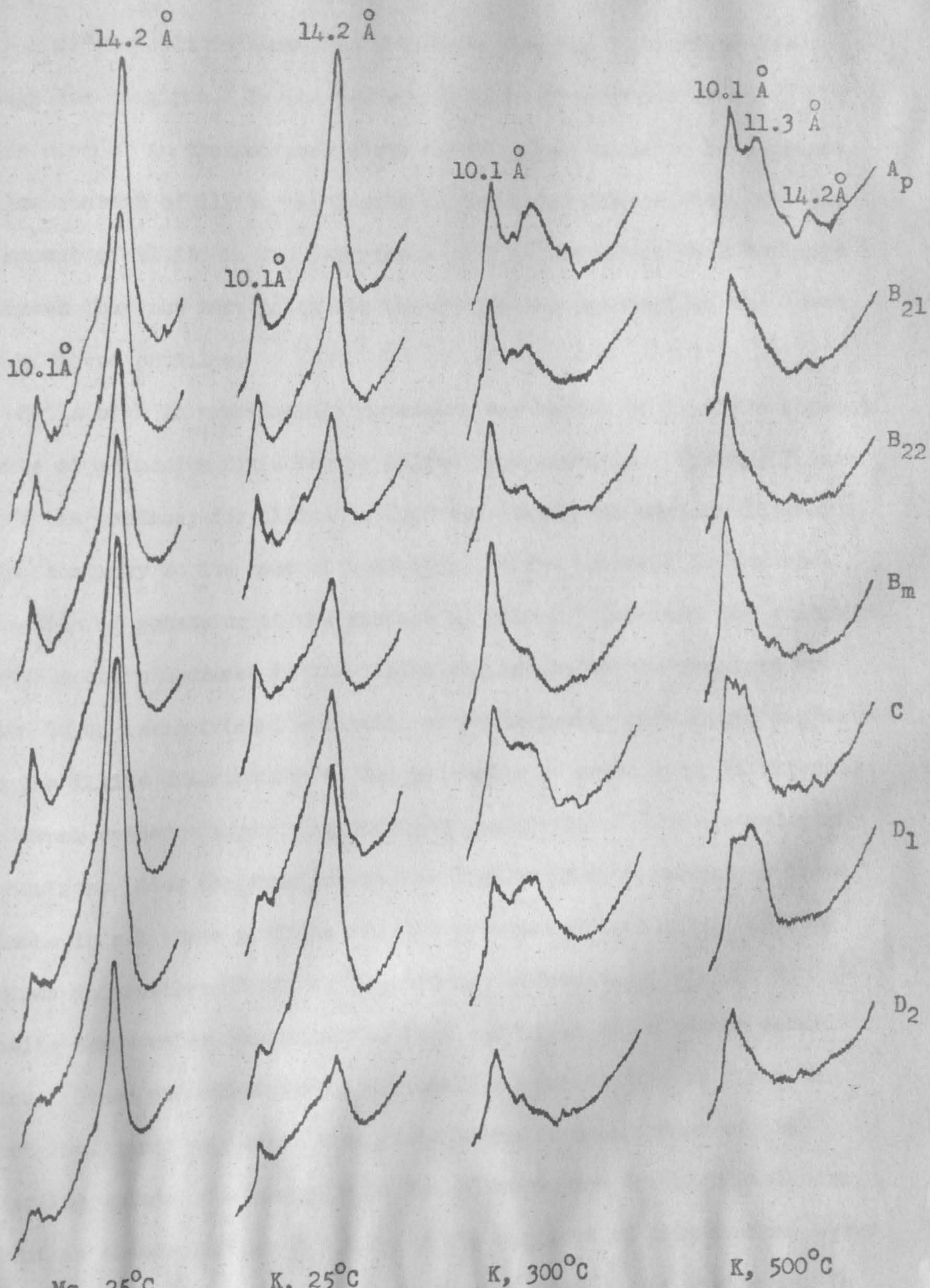


Figure 10.- Differential effect of potassium saturation and heat treatments on the basal spacing of the 14.2 A mineral in the 2-0.2 micron clay fraction in the Beltsville silt loan developed over granite as indicated by x-ray diffraction pattern tracings.

the 5-2 micron silt increases in abundance from the A_p horizon down through the fragipan. In the 5-2 micron silt of profiles CP and S the illite content in the horizons above the fragipan tends to be constant. The low content of illite and quartz in the 2-0.2 micron clay, and the low amount of illite in the 5-2 micron silt in the lower soil horizons indicates that the most intensive weathering has occurred in the lower part of these profiles.

Soils high in exchangeable potassium may have a high illite content because of potassium fixation by illite type minerals. Fieldes(3) explains the tendency for illite to increase toward the surface in many soils, contrary to its ease of weathering as due possibly to the concentration of potassium at the surface by plants. However, the evidence showing a sharp decrease in the illite content below the fragipan relative to an insignificant variation of exchangeable potassium, suggests that the illite distribution is due primarily to weathering differences.

Other evidence supporting stronger weathering of the minerals in the horizons below the fragipan is the high kaolinite content of these horizons in all three profiles and the presence of gibbsite below the fragipan in profiles CP and G. According to Jackson et al. (7, 8) gibbsite forms under conditions of high oxidation and ultimate desilication. Since podzolization is a reduction process (7) the gibbsite is not considered as formed during the podzolic development of the Beltsville solum. The position of the gibbsite and the high kaolinite content in these profiles relative to the horizons of illuviation, shows that these minerals are not the translocated products of weathering in the material above. Both gibbsite and kaolinite supposedly represent advanced stages of weathering of soil minerals. (7, 8) The distribution of these minerals in the soil profiles, then, is contrary to the assumption that weathering is most intensive at the soil surface.

The 14.2 A mineral in profiles CP and G collapsed easiest in the horizons that appear to be least weathered. In both these profiles the ease of collapse increased with depth down through the fragipan. In profile S the ease of collapse increased with depth throughout the profile. The 14.2 A mineral in the horizons containing gibbsite in profiles CP and G showed little collapse when potassium saturated. A high resistance of the 14.2 A mineral to collapse on potassium saturation was characteristic of the A horizon of the three profiles.

The resistance to collapse in the horizons that tend to be strongly weathered may be due to aluminum, released during weathering, contained in the interlayer positions of the 14.2 A mineral. Rich and Obenshain (15) were unable to collapse, by potassium saturation alone, the 14.7 A mineral in two Nason soils containing gibbsite and reported a general resistance to sollapse of the 14.7 A mineral in the A_2 horizon of other Nason and Tatum soils. Another variation of the 14.7 A mineral, previously easily collapsed by potassium saturation, was changed to the difficultly-collapsed type when it was aluminum saturated prior to potassium saturation. The effects of aluminum on the collapse of the 14.2 A mineral in the Beltsville soil was not investigated. However, the evidence that the strongly weathered horizons are the most resistant to collapse indicates possible interference by aluminum.

CONCLUSIONS

The results of the mechanical analysis shows that the Beltsville solum is derived from a fine textured parent material; whereas, the fragipan and lower horizons developed in material containing considerable amounts of gravel. In this respect the fragipan appears to be related to the lower horizons. In clay and free iron oxide content the fragipan is similar to the present A horizon. In mineralogical character the fragipan shows some properties found in either the horizons above or below. For example, the differential thermal analysis tracings of clay from profile CP (Figure 7) shows considerable gibbsite in the horizons below the fragipan, and some gibbsite in the fragipan, but none above. The illite and quartz content of the 2-0.2 micron clay and the illite content of the 5-2 micron silt in the fragipan is not greatly different from that of the horizons above, but is considerably different from the horizons below. The kaolinite content of the fragipan tends to be either lower or intermediate with respect to the horizons above and below. Therefore, it appears that the fragipan, while developed in the coarse textured material, has been influenced by the finer textured material above.

The evidence showing a higher content of more advanced weathered minerals and a low content of the less resistant minerals in the horizons below the fragipan strongly indicates a different type of weathering for this material than that operating in the Gray-Brown Podzolic development of the Beltsville solum. The distribution of clay and free iron oxides also is not normal for Gray-Brown Podzolic soil development and probably is due to more than one cycle of soil formation.

Nikiforoff (13) expressed belief that the filling of cracks in the fragipan occurred prior to the deposition of the fine textured mantle over the fragipan. This study shows no apparent reason why filling of these cracks could not have occurred during or subsequent to deposition of the fine textured mantle. In either case it is postulated that filling of cracks and pores with fine sediments has contributed to the high bulk density and low permeability of the fragipan.

This investigation is not considered complete enough to support any particular hypothesis as to how the fragipan of the Beltsville soil formed. The most tenable hypothesis based on these data is that the heavy texture found in the horizons below the fragipan probably was very important in initiating fragipan development. Water, rich in sediment, percolating from fresh deposited material, through a coarse textured horizon, would slow down on encountering the lower heavier textured horizons and deposition of the material in suspension would occur. Successive deposition would eventually completely fill the pores and cracks of the coarse textured horizon with fine materials translocated from above. This method of fragipan development is in agreement with the impervious substratum hypothesis proposed by Winters. (20)

SUMMARY

Three profiles of the Beltsville soil from Fairfax County, Virginia were studied in relation to the mechanical composition, the mineralogical composition, and some of the chemical and physical properites. Soil samples were selected to represent a profile developed over Coastal Plain deposits, schist, and granite, respectively.

A high kaolinite content, a low quartz and illite content, and the presence of gibbsite in the horizons below the fragipan indicate that this material has undergone more intensive or a different type of weathering than the material in the solum.

Two horizons high in clay were found in each of the profiles studied: one above the fragipan, which is the present illuvial horizon, and the other below the fragipan, which may be a buried illuvial horizon. In two of the profiles the heavy textured horizon below the fragipan had a higher clay content than the present illuvial horizon.

Fragipan formation possibly resulted from the deposition of material eluviated from a fine textured mantle above. The heavy texture of the material below the fragipan was probably effective in initiating the development of the fragipan.

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