A CHEMICAL INVESTIGATION OF THE CAUSE OF HARDPAN FORMATION IN SOUTHERN MARYLAND SOILS

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INTRODUCTION

Although Leonardtown soils have been mapped in eight counties of Maryland, they are found mainly in the southern part of the State. These soils are characterized by the presence of a hard, compact, relatively impervious layer in the lower part of the B horizon. This condition does not exist in the Sassafras soils, which exhibit the normal profile characteristics of this section. Both of these soils are generally considered to be formed from similar parent material, and they have been subjected to the same climatic forces. Their occurrence seems to depend upon topographic and drainage conditions.

The purpose of the present study was to subject the profiles of the two soil types to a chemical study, based on their morphological features, and to establish, if possible, some chemical criteria for the cause of hardpan formation in the Leonardtown soils.

REVIEW OF LITERATURE

The Russian scientists of the latter part of the nineteenth and first part of the twentieth century deserve much credit for their establishment of a basis for scientific and comprehensive classification of soils. Since 1879, when Dokuchaev (8)[*] first conceived the idea of the soil as a natural, dynamic body, many soil problems have been simplified by a study of the soil profile. This work was first introduced into the United States by Marbut (19) following the publication of Glinka's book in 1914.

The development of a classification scheme in this country was fairly rapid, although there were more complex environmental conditions to be considered here than in Russia. When Marbut, in 1935, published his Atlas of American Agriculture (17) his views on soil genesis stamped him as one of the outstanding pedologists of the world. It is only natural, therefore, that in any study of development of a soil profile in the United States frequent reference is made to the literature of Marbut and his co-workers. This is especially true in the present investigation, in that practically all of the research that has been done on Leonardtown soils has been carried out by workers of the United States Department of Agriculture, or those of the Maryland Agricultural Experiment Station.

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[*] Numbers in parentheses refer to literature cited.

The soils of southern Maryland lie in the Coastal Plain region of the Gray-Brown Podzolic soils. They are derived from materials that were deposited in the sea in relatively recent geological time. After this region was uplifted, the land surface was dissected, but areas of important size, still undissected, lie along the watershed between the drainage lines. Along the tops of these watershed ridges, soils have developed which have a compact layer in the lower part of the subsoil. Where this layer is well developed drainage is very poor (18). This condition did not always exist, and before the development of the indurated layer, percolation took place more easily, and the drainage was better than at the present time. As a result, the subsoils of the Leonardtown soils show little evidence of having been water-logged (24).

In comparing the Leonardtown soil with the Sassafras, which exhibits the normal profile characteristics of the Coastal Plain, Marbut (18) has advanced the following ideas:

> "The significant feature differentiating this soil from the Sassafras consists of the lower part of B horizon which is indurated into a hardpan. It is so hard and compact that it is difficult to penetrate with an augar and in digging requires a pick. Its character varies somewhat from place to place but the induration is always marked. In some places the indurated horizon seems to have no structure. Chemical analysis shows a higher percentage of silica in this layer than in any other part of the profile above it. It is apparent that there is cementation through the accumulation of silica. In other places the induration is less marked and the structure is well defined. The structure is very much like that of the

normal B horizon. These soils are in general finer in grain in all horizons than the Sassafras soils so that the normal B horizon breaks up into angular particles ranging from an eighth of an inch to a half inch in diameter. In the normal optimum moisture condition the material falls readily into a mass of these loose soil particles. This characteristic structure in some places extends downward into the indurated horizon. In such cases the particles become flattened, the longer axis of each particle lying horizontal. They indicate that their shape is due to pressure from the surface downward causing them to spread out horizontally into roughly disc-like shapes. This indicates that the B horizon originally extended to greater depts than at present, and when that was the case it had the normal structure of the B horizon. The lower part has become indurated, and in the induration these particles have become distorted as just described.

"Soils of this character are known in a number of places in the eastern part of the United States extending from somewhat west of the Mississippi river eastward. In all cases without exception they are found on flat surfaces which represent remnants of ancient plateaus. They are soils therefore which are made of material, or developed from material which has been lying in place for a long time. The pale leached appearance of the A horizon is partly due doubtless to the long time to which the material has been subjected to the action of the podzolic process. It is also partly due to the lack of perfect drainage, and this in turn is due in part to the flat or smooth topography on which the soils developed, and in part to the interruption of the downward percolation of water caused by the induration in the lower part of the B horizon .... . The induration in all of these soils wherever they occur in the eastern part of the United States seems to be related to the water table. An indurated layer is apparently developed at the average level or depth of the top of the water table. Through the action of podzolization on the surface soil, ..., silica is dissolved along with iron and alumina. The iron and alumina are deposited in the B horizon. The silica however, as in all podzolic soils, is not precipitated in the B horizon, but where the drainage is good passes out into the drainage waters. In this region where on account of the presence of the high water table the downward percolation of water is stopped and held by the water table it is apparent

> that for some reason some of the silica has been precipitated and through its precipitation has cemented this horizon. In the Sassafras soils where the water table lies far below the surface there is nothing to arrest the downward percolating water carrying silica in solution so that there is no deposition of the silica. In places the induration has become so pronounced that the water is held up on top of it for some time after heavy rains. This has caused a certain amount of podzolization of the material lying immediately above the indurated layer. There is therefore a second grayish or podzolized horizon lying immediately over the indurated layer."

It is obvious, from the preceding quotation, that Marbut assumed that hardpan formation in the Leonardtown soils was caused by cementation brought about through an accumulation of silica. He reasoned that the presence of a high water table had stopped and held the downward percolation of water and, as this water contained silica in solution (not quartz), the silica in some manner had been precipitated. If his assumptions are correct, the composition of the colloidal material from the upper horizons of the B should differ from that of the indurated layer, and the content of colloidal material should be larger in the indurated layer.

Holmes (12), however, did not find this to be true. In a study of the colloidal material of the Leonardtown silt loam soil, he found that the composition of the colloidal material from the A, B_1, and B_2 horizons was very similar. Results also showed that this indurated layer, the B_2 horizon, contained considerable less colloidal material than the B_1 horizon. From this data, he concluded that the hardness of this layer was due neither to the kind nor quantity of colloidal material present. He thought it might be due to a peculiar structure of the non-colloidal material.

Recent work by Anderson and Byers (6) also indicates that the colloidal material removed by eluviation in the Gray-Brown Podzolic soil region has the same composition as that found in the horizon above it. They found that in the Podzols a breaking up of the silicates by soil-developing processes had taken place, but no such decomposition of silicates had taken place in the Gray-Brown Podzolic soils.

Marbut found, when interpreting the chemical data of a Leonardtown silt loam analyzed by Hough (17), that the A and B_1 horizons showed the usual characteristics of the Podzolic soils. The silica-alumina ratio for the indurated B_2 horizon was extremely high, due to the high percentage of silica as well as the low percentage of alumina in this horizon. All of the other constituents were low. The C horizon had a very low silica-alumina ratio, caused by a high alumina content. It was not the true parent material of the solum developed above it.

Norton and Smith (23), in a study of soil profiles in southern Illinois, found in all of the flatter areas the presence of a plastic, compact, weathered drift. This material, termed gumbotil by glacial geologists, occurs at a depth from 72 to 103 inches. It is supposed to have developed under conditions of very poor drainage. The gumbotil profile is not found on the rolling areas of this region. Here the soils have formed under conditions of good drainage. Attention has been called to this work, because it brings out practically the same relationship that exists between the Sassafras and Leonardtown silt loam soils of southern Maryland. The Leonardtown soil, with its compact, indurated layer and poor drainage, occupies the flat areas, and the Sassafras soil, with its good drainage, occupies the rolling areas. Profile development, however, has not been similar in these two sections. In the gumbotil profile, the upper portion of the profile, above 40 inches, has developed since a change in the original drainage occurred, and might be termed a superimposed profile. The profile of gumbotil is very similar to that of the upper soil profile. In the Leonardtown profile, the horizons were well developed before any induration took place.

Bray (3,4) made a chemical study of Illinois soils, basing his work on the field research of Norton and Smith (23). His object was to establish, if possible, chemical criteria of soil development in addition to the physical criteria already in use. In the investigation, both the whole soil and the colloid were analyzed; the colloid analysis including the whole, coarse, fine, and superfine colloidal material. From the data obtained, Bray found that the breakdown of some of the coarse-sized colloid particles gave a finer colloid lower in potassium and higher in magnesium and iron than the residual coarser fraction. The downward movement of these finer particles produced a corresponding change in composition of the whole colloid. He attributed these effects to the greater ease of breakdown of the silicate particles which are higher in iron and magnesium in contrast to the higher aluminum-potassium colloid. Analysis of the non-colloidal fractions of the three horizons showed that accumulation did not take place in the non-colloidal fraction. He concluded that the downward movement of the beidellite-nontronite type of clay mineral as a superfine colloid is responsible for claypan formation in Illinois soils.

Smith (28) applied a laboratory study of claypan formation to natural claypan formation. His interpretation as to the possible causes of claypan formation is based very largely on flocculation effects due either to carbonates, ground water electrolytes, or positive iron oxide colloids. His explanation infers easy movement of the colloid which is stopped by some special set of conditions, whereas Bray considers that initial accumulation occurs due to the lack of active factors favoring movement rather than the presence at a special depth of flocculating agencies inhibiting movement.

Skeen (27), working on soils in the vicinity of the University of Pennsylvania, correlated hardpan formation with the hydrogen-ion concentration of the medium. His data indicated that with this heavy clay soil, there is a certain pH (about 4.8 ± 0.1) at which a hardpan layer will be formed.

He devised experiments to show that $Fe(OH)_3$ may be precipitated on Kaolin, resulting in a hardpan analogous in many physical respects to that found in the field.

Many workers, among them Frosterus (9); Brown, Rice, and Byers (5); McGeorge, Breazeale, and Burgess (20); Aarnio (1); and Morison and Sothers (22), studied some type of pan formation in soils, and in each case there was no doubt as to the cementing material present, or the condition causing pan formation. In the case of the Leonardtown soil, however, the indurated layer does not show by its color or effervescence in acid the kind of cementing material present.

EXPERIMENTAL

The ten soil samples used in this investigation were taken from wooded, virgin areas, and all were humid forest-soil types. They embraced only two soil type groups, the Leonardtown silt loam, and the Sassafras silt loam. Six samples were taken of the former, and four of the latter group. Sampling was done during October of 1935. In the three counties visited, the southern part of Prince Georges, Charles, and St. Marys, random samples were collected. The only precaution observed in selecting a spot for sampling was to see that the profile had well developed Leonardtown or Sassafras characteristics.

Data regarding the soil samples collected are to be found in Tables 1 and 2.

Method of Sampling

Whenever possible the samples were taken from a roadcut. Care was taken that all of the weathered material on the side of the cut was removed so that the samples would represent the normal characteristics of each horizon. When a roadcut was not available, a trench, five feet or more deep and wide enough to allow the removal of material from each horizon, was dug.

Plate I shows a typical profile of the Leonardtown silt loam, and Plate II shows that of the Sassafras silt

Table 1.—Location, horizon, sampling depth, and profile description of Leonardtown silt loam soils.

Sample No.	Locality	Horizon	Depth	Description of profile
			Inches	
1	0.5 mile south of T. B., Prince Georges County, Md.	A	½-6	Mellow, grayish-yellow silt loam.
	Do.	B_1	6-10	Friable, yellowish-brown silty clay loam.
	Do.	B_2	10-19	Friable, yellowish-brown mottled with gray, silty clay loam.
	Do.	B_3	19-36	Very compact, gray mottled with brown, fine sand, small rounded gravel, silt and clay.
	Do.	B_4	36-42	Compact, yellowish-brown mottled with gray and red, fine sandy clay with some gravel.
	Do.	C	42	Compact, yellowish-brown lightly mottled with grayish-red sandy clay.
2	State highway to Waldorf, 2.1 miles south of County line, Charles County, Md.	A	½-8	Mellow, yellowish-gray silt loam.
	Do.	B_1	8-28	Friable, brownish-yellow silty clay loam.
	Do.	B_2	28-29	Friable, yellowish-brown mottled with gray, silty clay loam.
	Do.	B_3	29-46	Very compact, gray mottled with brown, fine sand, small rounded gravel, silt and clay.
	Do.	B_4	46-50	Stiff, gray mottled with brown and red, sandy clay containing some gravel.
	Do.	C	50	Stiff, gray mottled with brown and occasionally streaked with red, clay.

Table 1. (Continued)

Sample No.	Locality	Horizon	Depth	Description of profile
			Inches	
3	1.10 miles southwest of Cheltenham, Prince Georges County, Md.	A	½-5½	Mellow, grayish-brown silt loam.
	Do.	B_1	5½-17½	Friable, yellowish-brown silty clay loam.
	Do.	B_2	17½-18½	Friable, yellowish-brown slightly mottled with gray, silty clay loam.
	Do.	B_3	18½-27	Very compact, brown mottled with gray, fine sand, small rounded gravel, silt and clay.
	Do.	B_4	27-29	Stiff, brown mottled with gray sandy clay.
	Do.	C	29+	Stiff, bluish-gray mottled with reddish-brown clay.
4	Near Brandywine, 500 feet east of Brandywine-Mechanicsville railroad, Prince Georges County, Md.	A	½-11	Mellow, grayish-brown silt loam.
	Do.	B_1	11-17	Friable, yellowish-brown silty clay loam.
	Do.	B_2	17-24	Friable, yellowish-brown mottled with gray, silty clay loam.
	Do.	B_3	24-36	Very compact, mottled gray and yellowish-brown, fine sand, small rounded gravel, silt and clay.
	Do.	B_4	36-50	Stiff, yellowish-brown slightly mottled with gray, sandy clay.
	Do.	C	50+	Stiff, yellowish-brown, mottled with gray and red, sandy clay.

Table 1. (Continued)

Sample No.	Locality	Horizon	Depth	Description of profile
			Inches	
5	1.5 miles northwest of Waldorf, Charles County, Md.	A	½-7	Mellow, brownish-gray silt loam.
	Do.	B_1	7-19	Friable, yellowish-brown silty clay loam.
	Do.	B_2	19-23	Friable, yellowish-brown mottled with gray, silty clay loam.
	Do.	B_3	23-46	Very compact, mottled about equally with yellowish-brown and gray, fine sand, small rounded gravel, silt and clay.
	Do.	B_4	46-51½	Stiff, reddish-brown mottled with gray, sandy clay.
	Do.	C	51½+	Stiff, streaked with gray and red, sandy clay. Colors deeper and mottled streaks and splotches larger than layer above.
6	2.6 miles southwest of New Market, St.Marys County, Md.	A	½-8	Mellow, grayish-brown silt loam.
	Do.	B_1	8-12½	Friable, yellowish-brown silty clay loam.
	Do.	B_2	12½-16	Friable, yellowish-brown mottled with gray, silty clay loam.
	Do.	B_3	16-32	Very compact, gray mottled with brown, fine sand, small rounded gravel, silt and clay.
	Do.	B_4	32-40	Stiff, brown mottled with gray and some reddish-brown, silty clay loam.
	Do.	C	40+	Stiff, gray streaked with reddish-brown, silty clay containing some gravel.

Table 2.—Location, horizon, sampling depth, and profile description of Sassafras silt loam soils.

Sample No.	Locality	Horizon	Depth	Description of profile
			Inches	
7	0.5 mile southeast of Morganza, St. Marys County, Maryland	A	½-8	Mellow, yellowish-gray silt loam.
	Do.	B_1	8-11	Friable, yellowish-brown sandy clay.
	Do.	B_2	11-20½	Friable, brown to reddish-brown sandy clay.
	Do.	B_3	20½-31½	Friable, rust-brown faintly streaked with gray, white, and red, sandy clay. Very high sand content and contains some gravel.
	Do.	C	31½+	Varies from white, gray, and yellow, to chocolate-brown and red in color. Friable, sand to sandy clay.
8	1.45 miles northeast of Rosaryville, Prince Georges County, Maryland	A	½-9½	Mellow, grayish-brown silt loam.
	Do.	B_1	9½-30	Friable, reddish-brown fine sandy clay.
	Do.	B_2	30-36	Slightly plastic, rust-brown and gray fine sandy clay.
	Do.	C	36+	Loose, pale yellowish-gray streaked with rust-brown, fine sandy loam. Gray predominating more than in layer above.

Table 2. (Continued)

Sample No.	Locality	Horizon	Depth	Description of profile
			Inches	
9	3.35 miles southwest of Marbury, Charles County, Maryland.	A	½-14	Mellow, grayish-brown silt loam.
	Do.	B_1	14-19	Friable, yellowish-brown silt loam.
	Do.	B_2	19-28	Friable, brown sandy clay loam.
	Do.	C	28+	Friable, yellowish-brown streaked with gray, sandy clay.
10	2 miles west of Pisgah, Charles County, Maryland	A_1	½-8	Mellow, grayish-brown silt loam.
	Do.	A_2	8-14	Friable, yellowish-brown clay loam.
	Do.	B_1	14-25	Laminated, reddish-brown silty clay.
	Do.	B_2	25-40½	Laminated, reddish-brown silty clay, more compact than layer above.
	Do.	C	40½+	Reddish-brown silty clay, slightly sandier and more friable at upper limits than B_2, but becoming heavier again at greater depths.

loam. In Plate I, horizons B_2 and B_4 were taken to be the horizons just above and below the indurated layer B_3; that is, they may be called transition layers. The compact, laminated structure of the B_3 horizon of the Leonardtown soil may be observed in the material removed from this layer. (Plate III)

About twenty-five pounds of a composite sample of soil was removed from each horizon and stored in heavy paper bags. The thin layer of organic matter covering the surface of these soils, the A_0 horizon, was removed and not considered in the sampling. In the case of the Leonardtown soils, therefore, each soil sample consisted of six horizon samples. For the Sassafras soils, the number of horizon samples varied from four to five.

Laboratory Procedure

After allowing the samples to air dry at room temperature, they were gently rolled with a wooden roller and passed through a 10-mesh screen. All particles of stone or gravel larger than fine gravel were removed. Each sample was then thoroughly mixed.

Mechanical analysis and pH value were determined on the samples thus prepared. For all other determinations, a portion of the sample was ground in a Braun pulverizer to pass a 100-mesh screen. Precaution was taken that all of the material subjected to grinding was recovered and thoroughly mixed.

The mechanical analysis of the samples was determined by means of the Bouyoucos hydrometer method (2). Hygroscopic moisture determinations were made by drying a 5-gram sample at 110° C. for 24 hours. These values were not recorded in the data, but were useful in calculating the weight of oven-dried material. The loss on ignition was carried out by weighing accurately about 1 gram of air-dried soil into a tared porcelain crucible. This was heated over a Bunsen burner to about 700° C. and kept at this temperature for one-half hour. After cooling and weighing, the crucible and contents were ignited again to bring them to constant weight. The ignition loss represents the organic matter and water of combination, and therefore must be expressed on the basis of oven-dried soil. To estimate the percent of combined water, the percent of organic matter was subtracted from the percent loss on ignition, and this figure divided by the dry weight of the soil expressed on an inorganic basis.

For determining the pH value of the samples, the Beckman Glass Electrode pH Meter was used. The electrodes were occasionally checked with a standard buffer solution. The values were obtained in the following manner: 10 grams of soil was shaken at intervals for 1 hour with 10 ml. of CO_2 free distilled water, and then a portion of this mixture transferred to a 5 ml. beaker. The electrodes were then immersed in the mixture, and the pH value read directly from the dial.

Total carbon was determined by the wet-combustion method, as proposed by Heck (10), the carbon dioxide resulting being estimated by absorption in standard alkali and titration of the excess alkali with standard acid. The carbon content of the soil, multiplied by the factor 1.724, was taken as a measure of the total organic matter in the soil (29).

The methods used for the determination of the major elements, that is, silicon, aluminum, iron, calcium, and magnesium, closely follow those developed by Hillebrand (11) for the analysis of rocks. They follow almost in detail, however, the methods described by Robinson (25). It is therefore considered unnecessary to repeat the steps in the procedures for determining these elements. Briefly the total analysis was carried out in the following manner: Duplicate 1 gram samples of each soil horizon were fused with 5 grams of C. P. sodium carbonate. The flux was treated with hydrochloric acid which left the insoluble silica as a residue. This was ignited, weighed, and treated with hydrofluoric acid. The loss in weight represented the silica. To the filtrate, ammonia was added to precipitate the sesquioxides at a pH of about 6.60. The precipitate was ignited, weighed, and then fused with potassium pyrosulphate. This melt was dissolved, reduced, and iron determined by titration against a standard permanganate solution. Titanium was determined by oxidizing the liquid from the iron titration with hydrogen peroxide and comparing the color with a standard titanium solution. Alumina was determined by subtracting the combined weights of ferric oxide and titanium oxide from the weight of the sesquioxide group. To the filtrate from the sesquioxide precipitation, ammonia and hydrogen sulphide were added to precipitate the ammonium sulphide group. The precipitate was discarded; ammonium sulphide driven from the filtrate by boiling, and calcium precipitated as the oxalate. Calcium was determined by titration against a standard permanganate solution. Magnesium was determined on the filtrate from the calcium separation by precipitating as magnesium ammonium phosphate, igniting, and weighing as the pyrophosphate.

It was necessary in each determination, except that for silica, to make a double precipitation. In the case of silica, a second evaporation was carried out; any silica present being combined with that obtained in the first evaporation.

DISCUSSION OF RESULTS

In any chemical investigation of the development of a soil profile, one should realize the importance of the profile divisions made in the field. These divisions are based on the morphological features of the soil. While the observable features of the profiles of the two soil types used in this study do not accurately express the degree of translocation or movement of the soil constituents, they do afford a foundation for a chemical study of the processes taking place in soil genesis, and the relation of chemical composition to the physical properties of the soil. Thus, it is evident that unless extreme care is taken to correctly differentiate and sample the various horizons of the soil profile, chemical results will not be conclusive. An attempt is made in the present study, by means of the following data obtained in the field and laboratory, to show some cause for the hardpan formation in the Leonardtown silt loam soils.

Field Observations

Considerable difficulty was experienced in selecting profiles which were typical of good Sassafras silt loam soils, as very little typical Sassafras soil exists in this section. A great deal of the soil mapped as Sassafras silt loam seemed to be a transition stage between the Leonardtown and Sassafras soils. For purposes of comparison with the

Leonardtown profiles, the four profiles selected strongly exhibited the normal characteristics of the Sassafras profile, and definitely showed no evidence of hardpan formation. In Tables 1 and 2 the field notes on the profile of these two soils are given.

It is evident from a study of Table 1 that the solum depth, the thickness of the soil horizons, and the depth at which hardpan formation occurs, may vary rather widely in separated areas of Leonardtown silt loam soils. This may be clearly shown by comparing sample number 3 with sample number 2. The former had a solum depth of only 29 inches, none of its horizons were over 12 inches in thickness, and hardpan formation started at 18.50 inches; the latter had a solum depth of 50 inches, one of its horizons, the B_1, had a thickness of 20 inches, and hardpan formation started at 29 inches. The solum depth of the six Leonardtown profiles ranged from 29 inches to 51.5 inches with a mean depth of 43.8 inches. Only one profile showed a solum depth of less than 40 inches, and here the hardpan layer was much shallower than in the other profiles. It indicated that this profile was not as fully developed as the others.

The thin layer of organic material covering these soils, which was discarded in this study, was found to be 0.50 inch in thickness. The horizon immediately below this layer was designated as the A horizon. It ranged in depth from 5.50 inches to 11.50 inches, with a mean depth of

7.58 inches, and was taken to be the horizon of eluviation. The B (B_1, B_2, B_3, B_4) horizon, or horizon of illuviation, varied in thickness from 23.50 to 44.50 inches, with a mean of 36.16 inches; the B_1 varied from 4 to 20 inches, with a mean of 9.75 inches; the B_2 varied from 1 to 9 inches, with a mean of 4.25 inches; the B_3 varied from 8.5 to 23 inches, with a mean of 15.58 inches; and the B_4 varied from 2 to 14 inches, with a mean of 6.58 inches. In all of the areas sampled, the indurated layer, or B_3 horizon, did not appear at a depth of less than 16 inches below the surface, and, as mentioned above, it ranged in thickness from 8.50 to 23 inches. The unconsolidated material below the B horizon was designated as the C horizon. It may be considered as the unweathered or incompletely weathered geologic formation.

The colors within the profiles of these soils were a great aid in differentiating the profiles into their successive horizons. The color of the A horizon was fairly uniform. It ranged from a yellowish-gray to a grayish-brown; the grayish-brown color occurring in three of the six samples. The intensity of color increased in the B_1 and B_2 horizons, with some mottling occurring in the B_2. Below the B_2 horizon, the material again became lighter in color; light gray generally being the basic color. This horizon, the B_3, was highly mottled, usually with brown. In the B_4 and C horizons the intensity of color again increased, especially the color of the mottling. Here, in addition to the gray or brown color or mottling, red streaks and mottles also appeared.

It was apparent from the light color of the A horizon of these soils and the relatively light colors within their profiles that they have been subjected to weathering for a long period of time. Coloring, which was in general more intense in the B_1 horizon, indicated that the substances which were washed out of the overlying A horizon by mechanical and chemical forces, had accumulated to a large degree in this horizon. The relatively thin transition layer, the B_2 horizon, lying between the B_1 and B_3 horizons was usually a little lighter in color than the B_1, but not as light as the B_3 horizon. Its lighter color and mottlings, which distinguished it from the B_1 horizon, gave some evidence of podzolization; that is, the presence of an indurated layer immediately below this horizon had caused some leaching of this material. The light color of the B_3 horizon brought out the imperviousness of this indurated layer to percolating waters carrying substances in solution and in the colloidal state. If penetration had not been difficult, the color throughout the B horizon would have been more uniform. The mottling beginning just above this horizon and continuing down through the profile denoted poor drainage conditions. This light color of the B_3 might also serve as an index to the content of silica, iron, and organic matter in the horizon, although the amount of iron may be masked, to some extent, by incomplete oxidation. It is known that soils low in iron and organic matter and high in silica are light gray in color; therefore, the lighter the color, the greater the content of silica and the smaller the amount of iron and organic matter.

While organic matter, due to its low content, does not play a very important part in the coloring of these soils, iron should exert a pronounced effect. One profile, sample number 3, showed more intensive coloring in the indurated layer than any of the other profiles, which indicated that this horizon may contain less silica and more iron than the corresponding horizon in the other samples. The B_4 and C horizons showed very little variation in color, although the C horizon, in general, possessed a slightly deeper color. This uniformity of color suggests that there is very little difference in the chemical composition of these two horizons. The increase in color, over the B_3 horizon, is to be expected as the B_4 horizon is very similar in composition to the incompletely weathered C horizon.

As the texture of the soil horizons is a characteristic feature of the genesis of the soil, it serves as one of the means by which the horizons may be separated. It is apparent from a field study of the Leonardtown profiles that the A horizon is of lighter texture than the horizons below it. All of the soils used, as previously mentioned, were of the silt loam type, and as this classification is based on the texture of the surface soil there should be little variation in the mechanical composition of the A horizons. The same scheme of classification was also used in describing the texture of the other horizons in the profile. Corresponding horizons in these profiles should be fairly uniform in texture, and this was found to be true. The B_1 and B_2 horizons in all six profiles were classified as silty clay loams. Usually the upper sub-horizons of the B, due to the accumulation of eluvial material from above, are heavier in texture than any of the other horizons of the profile. This holds true when the parent material is not a clay. In the profiles examined, where the C horizon ranged from a sandy clay to a clay, the parent material sometimes possessed the heaviest texture. No textural designation was given to the hard, compact B_3 horizon. If such a designation had been given, it would have ranged from a clay loam to a silty clay. The B_4 horizon was in general slightly lighter in texture than the C horizon. It ranged from a silty clay loam to a fine sandy clay.

In Table 2, the field notes on the four Sassafras silt loam profiles are given. Sample number 8 was mapped by the Soil Survey as a fine sandy loam, but it was considered fine enough, in this study, to be classified as a silt loam. The solum depth of the profiles ranged from 28 to 40.5 inches, with a mean depth of 34 inches. Only one profile had a depth greater than 36 inches, and the physical properties of this profile, sample number 10, varied widely from those of the other samples. These variations will be brought out in the following discussion.

The depth of the A horizons ranged from 8.00 to 14.00 inches, with a mean of 11.37 inches. In one profile, number 10, the A was subdivided into an A_1 and A_2 horizon. This was necessary because, although the horizon designated as the A_2 was heavier in texture and deeper in color than the surface horizon, it appeared to be more of a horizon of eluviation than of illuviation. The B horizons varied in thickness from 14.00 to 26.50 inches, with a mean of 22.62 inches. In only one sample, number 7, were there more than two subdivisions made for this horizon, and in this profile there were three. The B_1 horizon ranged in thickness from 3.00 to 20.50 inches, with a mean of 9.87 inches; the B_2 ranged from 6.00 to 15.50 inches, with a mean of 10.00 inches; and the B_3, found only in sample number 7, was 10.00 inches in thickness.

The color of the A horizon ranged from a yellowish-gray to a grayish-brown; the grayish-brown color occurring in three of the four samples. Since the A horizon of sample number 10 has been divided into two sub-horizons, A_1 and A_2, the A_1 is compared in color and texture with the A horizon of the other profiles. The A_2 horizon was yellowish-brown in color, showing a slight increase in color over the A_1. The B_1 horizon ranged in color from a yellowish-brown to a reddish-brown. The color of the B_2 horizon, in general, ranged from a brown to a reddish-brown. One profile, number 8, showed a rust-brown and gray color in this horizon. The basic color of the B_3 horizon, found only in sample number 7, was rust-brown. It was faintly streaked with gray, white, and red. There was a decrease of color in the C horizon, as compared with the B horizon, in all of the profiles except number 10. In this profile, the C had the same color as the B horizon. The color of the C horizon, however, in the majority of the profiles was deeper than in the A. These observations indicate that in three of the four Sassafras profiles the movement of the eluvial material from above has given the B horizon a deeper color than any other horizon.

The textural classification of the corresponding horizons of these profiles, excluding the A horizon, varied in practically every instance. This was somewhat to be expected, due to the difficulty experienced in selecting typical Sassafras profiles. Sample number 10, in which the A horizon was divided into sub-horizons, showed a clay loam texture in the A_2 horizon. The B_1 ranged in texture from a silt loam to a silty clay, and the B_2 from a sandy clay loam to a silty clay. In sample number 7, the B_3 horizon had the same textural designation as the B_1 and B_2 horizons, a sandy clay.

Two samples, numbers 7 and 9, did not show much variation in color or texture in the B_1 horizon when compared with that of the A horizon. As the B_1 horizon of these two soils was very shallow, 3.00 and 5.00 inches respectively, this seems to indicate only slight differences in the chemical composition of the A and B_1 horizons, and perhaps the B_1 should be described as a sub-horizon of the A. A chemical analysis in the laboratory may prove this to be true.

Although the texture of the B horizon varied in these profiles, the variations were not great except in sample number 10. Here the horizon was much heavier, being classified as a silty clay. The C horizon, in general, was of a much sandier nature than the solum above it. It ranged in texture from a fine sandy loam to a silty clay. Even the C horizon of sample number 10 was slightly sandier than the B horizon, but unlike the other profiles was not as sandy as the A horizon. One profile, number 8, had a C horizon that seemed much lighter in texture than the A horizon. This indicated that perhaps this material was not the true parent material of the solum above it.

From the foregoing discussion, it is obvious that sample number 10 differs markedly from the other three Sassafras profiles in its physical properties. This illustrates the wide variations noted in the profiles of the soils mapped as Sassafras silt loams in this area. In the following discussion, a comparison will be made between the Sassafras and Leonardtown profiles.

The outstanding difference between the profiles of the two soil types studied, as they appeared under natural conditions, was the presence of a hard, compact, relatively impervious zone in the B horizon of the Leonardtown soils. This zone was found at a depth ranging from 16 to 29 inches from the surface, and varied in thickness from 8.50 to 23 inches.

The Leonardtown profiles were of greater depth than the Sassafras, having a mean depth of 43.80 inches as compared to 34 inches for the Sassafras. However, the A horizons of the Sassafras were generally deeper than those of the Leonardtown, having a mean depth of 11.37 inches as compared to 7.58 inches for the Leonardtown. Under normal conditions of drainage, the A horizon of the Leonardtown would be expected to be deeper than that of the Sassafras, because it has suffered less erosion and has lain in place for a longer period of time. No comparison of the thickness of the sub-horizons of the B horizon will be attempted, because more divisions of the B have been made in the Leonardtown profiles. It was apparent, however, that the B horizon of the Leonardtown was usually much deeper than that of the Sassafras.

The color of the surface soils did not show much variation, ranging from a yellowish-gray to a grayish-brown. In general, it might be said that the A horizon of the Sassafras was not quite as pale as that of the Leonardtown. This uniformity of color did not appear in the B horizons of the two series; the B horizon of the Sassafras generally being much deeper in color than that of the Leonardtown.

The presence of the numerous streaks and mottles in the C horizon of the Leonardtown makes a color comparison with the C horizon of the Sassafras practically impossible. While the basic color of the C horizon of the Leonardtown is somewhat lighter than that of the Sassafras, its streaks and mottles are usually darker. Sample number 10 showed a much darker C horizon than any other profile. Although streaks also occurred in the C horizon of some of the Sassafras profiles, no mottling was noticeable.

Another distinguishing feature of the Leonardtown profiles, as compared to the Sassafras, was the fineness of texture of the B and C horizons. While one Sassafras profile, number 10, showed a B and C horizon as heavy as the Leonardtown, the other three profiles were much lighter. This profile, just mentioned, greatly resembled a Leonardtown profile, except that it had no hardpan layer. Generally, the Sassafras profiles were of a much sandier nature than those of the Leonardtown. Their B horizons, while lighter in texture than the B of the Leonardtown, were much heavier than their C horizons.

Laboratory Results

Tables 3 and 4 contain the results of the chemical analyses on the two soil types used in this investigation. Some of the constituents of the soil were not determined, because it was assumed that these elements were not tied up

Table 3.—Chemical composition of Leonardtown silt loam soils.

Sample No.	Horizon	Depth	Constituents expressed as percentage of inorganic material (oven-dried soil minus organic matter)							Constituents expressed as percentage of oven-dried soil including organic matter	
			SiO_2	Fe_2O_3	Al_2O_3	TiO_2	CaO	MgO	Combined H_2O	Ignition loss	Organic matter
		Inches									
1	A	½-6	85.59	2.24	6.97	1.25	0.28	0.38	2.41	3.88	1.51
	B_1	6-10	77.85	4.31	11.23	1.20	0.25	0.48	3.87	4.53	0.69
	B_2	10-19	78.88	4.35	10.99	1.15	0.22	0.49	4.16	4.70	0.56
	B_3	19-36	84.60	3.23	8.33	1.17	0.13	0.39	3.05	3.19	0.14
	B_4	36-42	81.27	4.14	9.95	1.18	0.09	0.37	4.56	4.70	0.15
	C	42+	80.00	4.38	9.59	1.26	0.10	0.32	4.61	4.73	0.13
2	A	½-8	87.92	1.84	6.52	1.31	0.12	0.47	2.66	4.49	1.88
	B_1	8-28	83.76	3.08	8.29	1.10	0.11	0.59	2.99	3.47	0.49
	B_2	28-29	85.43	2.63	8.14	0.93	0.09	0.52	3.08	3.31	0.24
	B_3	29-46	86.15	2.76	8.16	1.01	0.04	0.50	3.23	3.38	0.15
	B_4	46-50	79.95	4.50	9.70	1.05	0.04	0.53	4.48	4.68	0.21
	C	50+	80.79	4.11	10.00	1.01	0.04	0.46	4.46	4.63	0.18
3	A	½-5½	86.89	2.19	6.37	1.02	0.15	0.50	2.32	3.67	1.38
	B_1	5½-17½	80.58	3.79	9.76	1.12	0.06	0.27	3.54	4.11	0.59
	B_2	17½-18½	83.04	3.48	8.64	1.21	0.03	0.07	3.66	3.88	0.23
	B_3	18½-27	78.81	3.65	11.91	1.18	0.03	0.02	5.47	5.66	0.20
	B_4	27-29	77.57	3.80	12.94	1.10	0.03	0.08	5.43	5.68	0.26
	C	29+	77.49	3.00	13.23	1.14	0.03	0.06	5.81	5.98	0.18

Table 3. (Continued)

Sample No.	Horizon	Depth	Constituents expressed as percentage of inorganic material (oven-dried soil minus organic matter)							Constituents expressed as percentage of oven-dried soil including organic matter	
			SiO_2	Fe_2O_3	Al_2O_3	TiO_2	CaO	MgO	Combined H_2O	Ignition loss	Organic matter
		Inches									
4	A	½-11	86.65	2.23	7.00	1.09	0.17	0.11	2.29	3.56	1.30
	B_1	11-17	80.48	3.34	9.80	1.10	0.10	0.20	3.33	3.79	0.48
	B_2	17-24	78.14	4.26	11.00	1.15	0.10	0.55	4.72	5.10	0.40
	B_3	24-36	86.12	2.99	6.65	1.13	0.08	0.34	3.97	4.09	0.13
	B_4	36-50	83.74	3.26	8.50	1.03	0.07	0.27	3.87	3.97	0.10
	C	50+	82.11	3.49	8.89	1.05	0.08	0.34	4.00	4.10	0.10
5	A	½-7	87.29	2.36	5.73	1.11	0.13	0.20	2.33	4.27	1.99
	B_1	7-19	84.42	3.00	8.01	1.10	0.13	0.22	2.82	3.38	0.58
	B_2	19-23	85.15	3.26	7.02	1.11	0.09	0.01	2.86	3.09	0.24
	B_3	23-46	82.27	3.78	8.69	0.97	0.03	0.04	3.68	3.79	0.11
	B_4	46-51½	76.07	5.60	12.19	0.90	0.03	0.02	5.33	5.43	0.11
	C	51½+	75.99	5.75	11.58	0.89	0.03	0.01	5.93	6.02	0.10
6	A	½-8	88.85	2.53	4.64	1.11	0.15	0.26	2.24	4.06	1.86
	B_1	8-12½	84.24	3.33	7.76	1.04	0.20	0.42	2.66	3.20	0.55
	B_2	12½-16	84.40	3.26	7.70	1.07	0.07	0.38	2.78	3.16	0.39
	B_3	16-32	84.49	2.95	8.18	1.09	0.06	0.37	3.20	3.34	0.14
	B_4	32-40	80.69	2.94	10.77	1.14	0.03	0.41	4.27	4.45	0.19
	C	40+	80.89	2.16	10.64	1.30	0.04	0.29	4.58	4.74	0.17

Table 4.—Chemical composition of Sassafras silt loam soils.

Sample No.	Horizon	Depth	Constituents expressed as percentage of inorganic material (oven-dried soil minus organic matter)							Constituents expressed as percentage of oven-dried soil including organic matter	
			SiO_2	Fe_2O_3	Al_2O_3	TiO_2	CaO	MgO	Combined H_2O	Ignition loss	Organic matter
		Inches									
7	A	½-8	91.05	2.06	3.95	0.93	0.09	0.40	1.31	2.88	1.59
	B_1	8-11	91.61	1.65	3.84	0.81	0.08	0.07	1.16	1.80	0.65
	B_2	11-20½	78.69	4.03	11.00	0.81	0.07	0.21	4.84	5.19	0.37
	B_3	20½-31½	82.66	3.00	9.35	0.73	0.06	0.16	4.39	4.55	0.17
	C	31½+	85.77	2.59	7.66	0.69	0.02	0.18	3.33	3.44	0.11
8	A	½-9½	89.70	1.83	4.94	0.90	0.20	0.36	2.07	3.51	1.47
	B_1	9½-30	82.28	3.35	8.13	0.94	0.12	0.76	3.12	3.34	0.23
	B_2	30-36	80.94	4.03	8.40	0.85	0.08	0.83	3.69	3.83	0.15
	C	36+	90.32	2.25	4.57	0.69	0.23	0.52	1.23	1.33	0.10
9	A	½-14	88.76	2.78	5.07	1.05	0.13	0.10	1.74	2.88	1.16
	B_1	14-19	89.41	2.39	4.84	1.04	0.11	0.24	1.74	2.06	0.33
	B_2	19-28	87.10	3.23	6.02	1.01	0.08	0.18	2.22	2.53	0.32
	C	28+	85.89	3.51	6.16	1.01	0.05	0.09	2.68	2.86	0.19
10	A_1	½-8	88.26	2.57	5.31	1.26	0.18	0.10	1.62	2.61	1.01
	A_2	8-14	81.29	3.47	9.49	1.21	0.12	0.11	3.07	3.45	0.39
	B_1	14-25	69.00	6.24	15.57	1.06	0.05	0.23	5.32	5.52	0.21
	B_2	25-40½	66.52	7.03	16.87	1.06	0.05	0.49	5.86	6.05	0.20
	C	40½+	67.97	7.56	15.43	0.95	0.07	0.59	5.61	5.76	0.16

with hardpan formation. Then too, most of them were not present in sufficient quantity to be included in the analysis. The mineral constituents were expressed as the percentage by weight of inorganic material, as it was thought that this basis might give a clearer picture of their distribution throughout the profile. Combined water was also calculated on this basis. Organic matter and the loss on ignition, however, were calculated as the percentage by weight of oven-dried material, including organic matter.

A clearer means of expressing some of the changes which have taken place in the horizons through the processes of soil development may be found in Tables 5 and 6. This method of expressing the composition data as molecular equivalents and molecular ratios was suggested by Marbut (17). The molecular equivalents are obtained by dividing the percentage of each mineral by its molecular weight, and the molecular ratios are calculated from the molecular equivalents. As the most significant changes in the materials of these soils concern silica, iron oxide, and alumina, only these three substances are expressed as molecular equivalents. The figures show the relationships of these substances to each other in the various horizons of the soil profile. To express the inter-relationships, the molecular ratios are used. The molecular ratios computed were silica to alumina, silica to iron oxide, iron oxide to alumina, and silica to the sesquioxides. Since the content of silica, iron oxide, and alumina

Table 5.—Molecular equivalents and ratios of Leonardtown silt loam soils.

Sample No.	Horizon	Depth	Molecular equivalent composition			Molecular ratios			
			SiO_2	Fe_2O_3	Al_2O_3	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{Fe_2O_3}{Al_2O_3}$	$\frac{SiO_2}{Al_2O_3+Fe_2O_3}$
		Inches							
1	A	½-6	1.42	0.014	0.068	20.88	101.43	0.206	17.32
	B_1	6-10	1.30	0.027	0.110	11.82	48.15	0.245	9.49
	B_2	10-19	1.31	0.027	0.108	12.13	48.52	0.250	9.70
	B_3	19-36	1.41	0.020	0.082	17.20	70.50	0.244	13.82
	B_4	36-42	1.35	0.026	0.098	13.78	51.92	0.265	10.89
	C	42+	1.33	0.027	0.094	14.15	49.26	0.287	10.99
2	A	½-8	1.46	0.012	0.064	22.81	121.67	0.188	19.21
	B_1	8-28	1.39	0.019	0.081	17.16	73.16	0.235	13.90
	B_2	28-29	1.42	0.016	0.080	17.75	88.75	0.200	17.49
	B_3	29-46	1.43	0.017	0.080	17.88	84.12	0.213	14.74
	B_4	46-50	1.33	0.028	0.095	14.00	47.50	0.295	10.81
	C	50+	1.34	0.026	0.098	13.67	51.54	0.265	10.81
3	A	½-5½	1.45	0.014	0.062	23.39	103.57	0.226	19.08
	B_1	5½-17½	1.34	0.024	0.096	13.96	55.83	0.250	11.17
	B_2	17½-18½	1.38	0.022	0.085	16.24	62.73	0.259	12.90
	B_3	18½-27	1.31	0.023	0.117	11.20	56.96	0.197	9.36
	B_4	27-29	1.29	0.024	0.127	10.16	53.75	0.189	8.54
	C	29+	1.29	0.019	0.130	9.92	67.89	0.146	8.66

Table 5. (Continued)

Sample No.	Horizon	Depth	Molecular equivalent composition			Molecular ratios			
			SiO_2	Fe_2O_3	Al_2O_3	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{Fe_2O_3}{Al_2O_3}$	$\frac{SiO_2}{Al_2O_3+Fe_2O_3}$
		Inches							
4	A	½-11	1.44	0.014	0.069	20.87	102.86	0.203	17.35
	B_1	11-17	1.34	0.021	0.096	13.96	63.81	0.219	11.45
	B_2	17-24	1.30	0.027	0.108	12.04	48.15	0.250	9.63
	B_3	24-36	1.43	0.019	0.065	22.00	75.26	0.292	17.02
	B_4	36-50	1.39	0.020	0.083	16.75	69.50	0.241	13.50
	C	50+	1.37	0.022	0.087	15.75	62.27	0.253	12.57
5	A	½-7	1.45	0.015	0.056	25.89	96.67	0.268	20.42
	B_1	7-19	1.41	0.019	0.079	17.85	74.21	0.241	14.39
	B_2	19-23	1.42	0.020	0.069	20.58	71.00	0.290	15.96
	B_3	23-46	1.37	0.024	0.085	16.12	57.08	0.282	12.57
	B_4	46-51½	1.27	0.035	0.120	10.58	36.29	0.292	8.19
	C	51½+	1.27	0.036	0.114	11.14	35.28	0.316	8.47
6	A	½-8	1.48	0.016	0.046	32.17	92.50	0.348	23.87
	B_1	8-12½	1.40	0.021	0.076	18.42	66.67	0.276	14.43
	B_2	12½-16	1.41	0.020	0.076	18.55	70.50	0.263	14.69
	B_3	16-32	1.41	0.018	0.080	17.63	78.33	0.225	14.39
	B_4	32-40	1.34	0.018	0.106	12.64	74.44	0.170	10.81
	C	40+	1.35	0.014	0.104	12.98	96.43	0.135	11.44

Table 6.—Molecular equivalents and ratios of Sassafras silt loam soils.

Sample No.	Horizon	Depth	Molecular equivalent composition			Molecular ratios			
			SiO_2	Fe_2O_3	Al_2O_3	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{Fe_2O_3}{Al_2O_3}$	$\frac{SiO_2}{Al_2O_3+Fe_2O_3}$
		Inches							
7	A	½-8	1.52	0.013	0.039	38.97	116.92	0.333	29.23
	B_1	8-11	1.53	0.010	0.038	40.26	153.00	0.263	31.88
	B_2	11-20½	1.31	0.025	0.108	12.13	52.40	0.231	9.85
	B_3	20½-31½	1.38	0.019	0.092	15.00	72.63	0.207	12.43
	C	31½+	1.43	0.016	0.075	19.07	89.38	0.213	15.71
8	A	½-9½	1.49	0.011	0.048	31.04	135.45	0.229	25.25
	B_1	9½-30	1.37	0.021	0.080	17.13	65.24	0.263	13.56
	B_2	30-36	1.35	0.025	0.082	16.46	54.00	0.305	12.62
	C	36+	1.50	0.014	0.045	33.33	107.14	0.311	25.42
9	A	½-14	1.48	0.017	0.050	29.60	87.06	0.340	22.09
	B_1	14-19	1.49	0.015	0.047	31.70	99.33	0.319	24.03
	B_2	19-28	1.45	0.020	0.059	24.58	72.50	0.339	18.35
	C	28+	1.43	0.022	0.060	23.83	65.00	0.367	17.44
10	A_1	½-8	1.47	0.016	0.052	28.27	91.88	0.308	21.62
	A_2	8-14	1.35	0.022	0.093	14.52	61.36	0.237	11.74
	B_1	14-25	1.15	0.039	0.153	7.52	29.49	0.255	5.99
	B_2	25-40½	1.11	0.044	0.165	6.73	25.23	0.267	5.31
	C	40½+	1.13	0.047	0.151	7.48	24.04	0.311	5.71

constitutes over ninety percent of the mineral portion of the soil mass in every horizon, the distribution of these substances throughout the profile will be discussed first.

Distribution of Silica. All of the Leonardtown profiles, as shown in Tables 3 and 5, had a higher content of silica in the A horizon than in any other horizon of their profile. While three of the six profiles, numbers 1, 2, and 4, showed an accumulation of silica in the indurated, or B_3, horizon which was nearly as large as the amount found in the A horizon, the other three showed a decided decrease. This did not agree with the results discussed by Marbut (17), in which there was an accumulation of silica in the indurated horizon which exceeded the silica content of the A horizon. From these results, he states that it is possible that the induration may be due to cementation by silica. Although, in some cases, silica may play an important role in the cementation of this horizon, from the results obtained it is evident that this does not always hold true.

The content of silica in the A horizon of these soils was fairly uniform. It ranged from 85.59 to 88.85 percent, with a mean of 87.20 percent. The B_1 horizon showed a much lower silica content than the A horizon, indicating that these soils are being subjected to the podzolic process. In this horizon, the silica content ranged from 77.85 to 84.42 percent, with a mean of 81.89 percent. Sample number 4 was the only profile in which the B_2 horizon had a lower silica content than the B_1 horizon. This general increase in silica in the B_2 horizon, as compared to the B_1, denoted a slightly podzolized layer above the indurated horizon. The content of silica in the B_2 horizon ranged from 78.14 to 85.43 percent, with a mean of 82.51 percent.

As indicated by its more intensive coloring in the field, the B_3 horizon of sample number 3 had less silica present than the corresponding horizon in the other profiles. It also showed the greatest decrease in silica as compared to the A horizon, containing 8.08 percent less silica. Sample number 4 showed the smallest decrease, 0.53 percent, and the mean decrease for the six profiles was 3.46 percent. The content of silica in the B_3 horizon varied from 78.81 to 86.15 percent, with a mean of 83.74 percent. In two of the profiles, numbers 3 and 5, the B_2 horizon had a larger accumulation of silica than the B_3, and in another, number 6, the content was practically the same. Thus, it is evident that other substances besides silica may accumulate in the B_3 horizon.

The B_4 horizon in every profile showed a drop in silica content from that of the B_3. This drop ranged from 1.24 percent in sample number 3 to 6.20 percent in samples numbers 2 and 5, with a mean drop of 3.86 percent. No correlation could be found between the samples having a high content of silica in the B_3 horizon and those having a low content, in regard to their relation to the A and B_4 horizons.

For example, sample number 3, which exhibited the greatest decrease of silica in the B_3 horizon over that of its surface soil, showed a decrease of only 1.24 percent in the B_4 when compared with the B_3 horizon. On the other hand, sample number 5, which had a decrease of 5.02 percent in the B_3 as compared with the A, had a decrease of 6.20 percent in the B_4 when compared with the B_3 horizon. Then too, samples numbers 2 and 4, which had almost the same silica content in the B_3 as in the A horizon, showed a wide variation in relation to the B_4 horizons. The former had a decrease of 6.20 percent in its B_4 horizon, while in the latter the decrease was 2.38 percent. In the B_4 horizons, the silica content ranged from 76.07 to 83.74 percent, with a mean of 79.88 percent.

Very little variation in silica content was found when comparing the B_4 and C horizons. Most of the profiles, however, had a slight decrease in the C horizon. The range in silica content was from 75.99 to 82.11 percent, with a mean of 79.54 percent. Three profiles contained slightly over 80 percent in this horizon, and three between 75 and 80 percent. The C horizons, as to be expected, had a much lower silica content than the A horizons, showing a decrease ranging from 4.54 to 11.30 percent, with a mean of 7.65 percent. They also had a lower content than the B_3 horizons, the decrease ranging from 1.32 to 6.28 percent, with a mean of 4.19 percent. In four of the six profiles, the C horizon had a lower content than either the B_1 or B_2 horizons.

If a comparison is made between tables 3 and 5, and tables 4 and 6, the latter tables expressing the distribution of constituents in the Sassafras profiles, it is apparent that the content of silica in the A horizon of the Sassafras soils is usually greater than that in the Leonardtown soils. This content ranged from 88.26 to 91.05 percent, with a mean of 89.44 percent. With the exception of sample number 10, the C horizons, also, were much higher in silica than those of the Leonardtown soils. In sample number 10, the content in the B_1, B_2, and C horizons was very low. This was abnormal as it did not occur in any of the other profiles. The content of silica in the C horizons, excluding number 10, ranged from 85.77 to 90.32 percent, with a mean of 87.33 percent.

Two of the Sassafras profiles, numbers 7 and 9, had more silica in the B_1 horizon than in the A horizon. Field observations had indicated that perhaps these two horizons were horizons of eluviation and should be subhorizons of the A; laboratory results have proven this to be true. Therefore, the B_1 horizon of samples numbers 7 and 9 should be considered an A_2 horizon. This gives sample number 9 too deep an A horizon and too shallow a B horizon. The most reasonable explanation for the unconformity of material in this profile seems to be that alluvial material has been deposited over the original surface of this soil, giving it an upper horizon lower in silica than the material lying immediately beneath it.

While three of the Leonardtown profiles showed an accumulation of silica in the B horizon, no accumulation was found in the B horizon of the Sassafras profiles. Two of the Sassafras profiles, however, had a higher silica content in the C horizon than in any of the subhorizons of the B, and one of the two, number 8, had a higher silica content in this horizon than in its A horizon. The high percentage of silica in the A horizon is the result of eluviation, while that in the C is influenced by the character of the parent material. Normally the Sassafras soils, due to the rather sandy nature of the parent material, have a higher silica content in the C horizon than in the B horizon.

Distribution of Iron Oxide. All of the Leonardtown profiles except one, number 6, contained less iron oxide in the surface than in any other horizon. In the one exception, the C horizon had the lowest content. The percentage in the surface varied from 1.84 to 2.53 percent, with a mean of 2.23 percent. There was, in every case, a higher content in the B_1 horizon than in the A, which showed clearly that iron oxide had been removed from the surface. The content ranged from 3.00 to 4.31 percent, with a mean of 3.48 percent.

Although the percentage in the B_2 horizon in several profiles was practically the same as in the B_1, the others showed slight variations. Three of the profiles, 1, 4, and 5, had a higher content in this horizon than in the B_1, the percent difference ranging from 0.04 to 0.92 percent; while the other three had a lower content, the percent difference ranging from 0.07 to 0.45 percent. The two profiles, 1 and 4, which had a smaller quantity of silica in the B_2 horizon than the other profiles, as to be expected, had a larger quantity of iron oxide. The content of the B_2 horizon ranged from 2.63 to 4.35 percent, with a mean of 3.54 percent.

Without exception, the B_3 horizon ran higher in its iron oxide content than the A horizon. In only one profile, however, did it exceed the B_1 horizon in its iron content. This profile, number 5, had the largest quantity of iron in its B_3 horizon than any of the other profiles, yet it did not show the smallest quantity of silica. In three instances, the percentage of iron oxide in the B_3 horizon exceeded that in the B_2, the percent difference ranging from 0.14 to 0.53 percent; while in three others it did not, the percent difference ranging from 0.31 to 1.27 percent. The content of iron oxide in the B_3 horizons ranged from 2.76 to 3.78 percent, with a mean of 3.23 percent.

Generally the B_4 horizon showed a decided increase in iron oxide over the B_3 horizon. One profile, number 6, had practically the same content in these two horizons. The content in the B_4 horizons ranged from 2.94 to 5.60 percent, with a mean of 4.04 percent. In three of the profiles, the B_4 horizon had a higher content than any of the other subhorizons of the B horizon.

The C horizons were much higher in iron oxide than the A horizons, and only two profiles, numbers 1 and 5, had a higher content in the C than in any of the subhorizons of the B. While a higher iron oxide content may be expected in the C horizon than in the A, the B horizon should generally contain the largest amount. The addition of material by eluviation is responsible for this increase. The percentage of iron oxide in the C horizons ranged from 2.16 to 5.75 percent with a mean of 3.81 percent. Three of the six profiles had a lower iron content in the C horizon than in the B_4.

The Sassafras profiles, with the exception of number 10, usually showed a smaller content of iron oxide than the Leonardtown profiles. Such a condition indicates that they contained less fine material and more free silica. Samples 7 and 9 showed a decrease of 0.41 and 0.39 percent of iron oxide for horizon B_1 from that of their respective surface horizons. These data coincide with that of silica and indicate that the B_1 layer for these two samples should have been designated as A_2. Two of the Sassafras profiles, numbers 7 and 8, had a normal distribution of iron oxide in their profiles; that is, the B horizon showed the greatest content, and the quantity in the C exceeded that of the A horizon. The other two profiles varied, with the variations in sample number 10 being very great. In this profile, the B horizon had a much larger content of iron oxide than the B horizon of the other Sassafras profiles, and its C horizon contained over twice as much as any other C horizon. There was an increase in iron oxide content with depth in the profile. The B and C horizons of this profile also had a higher percentage of iron oxide than the similar horizons in the Leonardtown profiles. Sample number 9, while showing an increase in the B horizon over the A, also revealed an increase in the C horizon over the B. Even though this increase was not great, 0.28 percent, it was not what should be expected in the profile. The probable explanation seems to be that this profile has not been as fully developed as the others, or, due to some unusual conditions, has developed abnormally.

Distribution of Alumina. The alumina content in both the Sassafras and Leonardtown profiles, in general, was inversely proportional to the silica content, and directly proportional to the iron oxide content; that is, with an increase in silica there was a decrease of iron oxide and alumina, and with a decrease of silica there was an increase of iron oxide and alumina.

The A horizon and parent material of the Leonardtown soils usually possessed a much higher alumina content than that of the Sassafras soils. The content in the A horizon of the Leonardtown soils ranged from 4.64 to 7.00 percent, with a mean of 6.21 percent, while that of the Sassafras soils was from 3.95 to 5.31 percent, with a mean of 4.82 percent. In the C horizon, or parent material, the content in the Leonardtown soils varied from 8.89 to 13.23 percent, with a mean of 10.65 percent, while that of the Sassafras soils, excluding sample number 10, ranged from 4.57 to 7.66 percent, with a mean of 6.13 percent. Sample number 10, which exhibited a wide variation in its silica and iron oxide content in the B and C horizons from that of the other Sassafras profiles, also showed a marked difference in its alumina content. The content in the C horizon of this profile was 15.43 percent, while that of the B was slightly higher. This percentage in the C horizon was over two times as great as the C in any other Sassafras profile, and it was much larger than the C horizon of the Leonardtown profiles.

The B_1 horizon of all of the Leonardtown profiles showed a decided increase in alumina when compared with the A horizon. In general, the B_1 horizon also had a slightly larger quantity than the B_2 horizon. The range in the B_1 was from 7.76 to 11.23 percent, with a mean of 9.14 percent, while than in the B_2 was from 7.02 to 11.00 percent, with a mean of 8.91 percent. Although in three profiles the B_3 horizon exceeded the B_1 horizon in its alumina content, and in four profiles exceeded the B_2, in not one instance did it exceed the B_4 and C horizons in the Leonardtown profiles. The content in the B_3 horizons ranged from 6.65 to 11.91 percent, with a mean of 8.65 percent, and that of the B_4 ranged from 8.50 to 12.94 percent, with a mean of 10.67 percent. In three of the six profiles, the B_4 horizon had a slightly higher alumina content than the C horizon. As to be expected, the C horizon had a much larger percentage of alumina than the A horizon.

The B_1 horizon of the Sassafras profiles, keeping in mind that this horizon in samples 7 and 9 is an A_2 horizon, also showed an increase in alumina over the A horizon. The content in this horizon, excluding sample number 10 which has been discussed previously, ranged from 6.02 to 11.00 percent, with a mean of 8.38 percent. Two of the profiles, numbers 7 and 8, had the greatest content of alumina in their B_1 and B_2 horizons, but in one of the profiles the A horizon exceeded the C horizon in quantity. The higher silica content for the C horizon of this profile, over that of the A, indicated that variations could be expected due to the character of the parent material. In sample number 9 the C horizon contained slightly more alumina than the B horizon. This same profile had also shown a slight increase in iron oxide and a slight decrease in silica for the C horizon when compared to the B horizon.

While the foregoing discussion gives a picture of the distribution of silica, iron oxide, and alumina, and their relationships to each other, in the various horizons of the soil profiles, the following discussion of the molecular ratios should be helpful in bringing out their inter-relationships.

All of the Leonardtown profiles (Table 5) showed a decided increase in alumina, relative to silica, in the B_1 horizon over that of the A horizon. Taking the extremes of the silica-alumina ratios, the B_1 horizon of sample number 1 had a ratio about 43 percent smaller than the A horizon, and that of sample number 2 had a ratio about 25 percent smaller than its A. Essentially the same relationship held for the silica-iron oxide ratios, the B_1 having a much smaller ratio than the A horizon. However, the loss of iron oxide from the A horizon of four of the six profiles, as shown by the iron oxide-alumina ratios, was greater than that of alumina. The B_2 horizons, in general, showed a slight increase in their silica-alumina and silica-iron oxide ratios over the B_1, which indicates either a slightly higher silica content or a slightly lower iron oxide or alumina content for this horizon. The B_2 horizon of sample number 4, however, possessed a smaller silica-alumina and silica-iron oxide ratio than any of the other horizons in the profile. It is apparent, then, that this horizon has the greatest accumulation of iron oxide and alumina in the profile. The iron oxide-alumina ratios usually showed that any movement of iron oxide and alumina from the B_1 horizon into the B_2 had resulted in a greater loss of iron oxide and alumina from the B_1 horizon.

The silica-alumina ratio for the B_3 horizon in three of the profiles was larger than that of the B_1 or B_2 horizon, and in every profile exceeded that of the B_4 or C horizon. In one sample, number 4, the ratio for the B_3 was greater than that of the surface horizon, being about 5 percent larger. The silica-alumina ratios for the B_4 and C horizons were fairly similar and showed a decided decrease over the B_3 horizon. This decrease in the ratio ranged from 11 to 31 percent, with a mean of 23 percent. Four of the six profiles had a lower silica-alumina ratio for the B_4 and C horizons than for any other horizon in the profile. Results of this nature indicate a greater accumulation of alumina, relative to silica, in these horizons than in the horizons above them. Normally the upper horizons of the B should possess the smallest silica-alumina ratio.

The silica-iron oxide ratios for the B_3 horizons were relatively like those of silica-alumina in regard to the upper horizons of the B. Contrary to the silica-alumina ratios, which showed a higher ratio in the B_3 than in the C horizon, the silica-iron oxide ratio in several profiles was lower in the B_3 horizon than in the C. In every case, however, the B_4 horizon showed a lower ratio than the B_3. Any accumulation of iron oxide in the B_1 or B_2 horizon over that in the C was not as great as that lost from the A horizon.

The iron oxide-alumina ratios for the B_3 horizons indicated that alumina usually had accumulated to a greater extent than iron oxide in this horizon over that in the B_2. Three of the profiles had the largest iron oxide-alumina ratio in their B_4 and C horizons. This indicates a greater accumulation of iron oxide, relative to alumina, in these horizons than in any other part of the profile. Two of the other three profiles had a greater accumulation of alumina in these horizons. Sample number 4 had practically the same iron oxide-alumina ratio for the B_2, B_4, and C horizons. In four of the six profiles the iron oxide-alumina ratio for the A horizon was much smaller than that for the C, denoting a higher alumina content for the A, relative to iron oxide, than for the C. A discussion of the silica-sesquioxide ratios is not considered necessary because, in light of the previous discussion on the silica-alumina and silica-iron oxide ratios, these ratios should explain themselves.

The silica-alumina and silica-iron oxide ratios for the B_1 horizons of the Sassafras profiles (Table 6) showed the same relationships in regard to those for the A horizons as those of the B_1 of the Leonardtown profiles. In other words, there was a smaller ratio in the B_1 than in the A horizon, indicating a higher content of iron and aluminum in the B. While one of the subhorizons of the B, the B_3 horizon, always had a higher silica-alumina ratio and usually a higher silica-iron oxide ratio than the C in the Leonardtown profiles, the B horizons of two of the Sassafras profiles showed much smaller ratios. The ratios in the other two profiles were very similar for the B and C horizons. These ratios denote no definite accumulation of silica relative to iron oxide and alumina in the B horizon of the Sassafras profiles. The C horizons, in general, had smaller silica-alumina and silica-iron oxide ratios than the A horizons. The iron oxide-alumina ratios of the B_1 horizons of the Sassafras profiles showed somewhat the same relationships as those of the Leonardtown. In several profiles, however, the surface horizon was higher in this ratio than any of the subhorizons of the B. Only one Leonardtown profile exhibited a similar relationship. Generally, the C horizons had a larger ratio than the A horizons, which denoted a higher content of iron oxide relative to alumina.

Distribution of Titanium. The percentage of titanium, expressed as its dioxide (TiO_2) did not run very high in either of the soil types. Very slight variations were noted between the different horizons of the profiles. The content in the Leonardtown profiles ranged from 0.89 to 1.31 percent, with most values over 1.00 percent. In the Sassafras profiles, the range was from 0.69 to 1.26 percent. Two of the profiles, numbers 7 and 8, had no horizon with a content as great as 1.00 percent, while the other two usually showed a content of over 1.00 percent in all of their horizons. Generally the Sassafras profiles exhibited a slight decrease of titanium with depth, but this did not hold true for the Leonardtown profiles. From these observations it seems apparent that titanium plays no part in the formation of an indurated layer, but indicates that there may be a difference in the parent material.

Distribution of Calcium and Magnesium. The percentage of calcium and magnesium, expressed as their oxides, was very low in both soil types. With such a small quantity of these constituents present, the possibility of analytical error was necessarily large.

The percentage of calcium oxide in the various horizons of the Leonardtown profiles ranged from 0.03 to 0.28 percent, while that in the Sassafras ranged from 0.02 to 0.20 percent. In general, in both soil types the percentage of calcium oxide decreased with depth. The higher content of the A horizon was probably due to the presence of more organic matter in this horizon than in any other horizon of the profile. This organic matter, with its high exchange capacity, is able to take in the calcium released from the decomposition of fresh organic material overlying these soils.

The percentage of magnesium oxide throughout the various horizons of the profiles was generally much higher than that of calcium. In the Leonardtown profiles, the content ranged from 0.01 to 0.59 percent, while in the Sassafras it ranged from 0.07 to 0.83 percent. This seemingly higher percentage in the Sassafras profiles is misleading, because the content in the Leonardtown profiles was usually higher than that in the Sassafras. Sample number 8, a Sassafras profile, however, showed a much greater accumulation in its B horizon than any other profile. Whereas the concentration of calcium was generally greater in the A horizon of these profiles, that of magnesium, especially in the Leonardtown profiles, was usually greater in the B. The concentration of both of these constituents in any of the horizons of both soil types was very slight and did not seem to result from a consistent process in profile development.

Distribution of Combined Water. All of the Leonardtown profiles, as to be expected, contained the smallest amount of combined water in the A horizon. In general, it may be said that the quantity of combined water increased with depth, although in two of the profiles the B_3, or indurated horizon, showed a lower content than that of the horizon above it. The clay content in these two profiles was also lower for this horizon than the horizon above it, whereas all of the other profiles showed a higher clay content. The percentage of combined water in the A horizon of the six Leonardtown samples was fairly constant, ranging from 2.24 to 2.66 percent, with a mean of 2.38 percent. The other horizons did not show as close a relationship as the A horizons, but the C horizon in the majority of the profiles showed a greater content of combined water than any other horizon.

The percentage of combined water in the A horizon of the Sassafras profiles was lower than in the Leonardtown. One profile, number 10, in which the A horizon is subdivided, had a higher content in the A_2 horizon than the A horizons of the Leonardtown. Two of the other profiles, 7 and 9, in which the B_1 is really an A_2 horizon, showed the same or a slightly lower content than the surface horizon. The range in the surface horizons was from 1.31 to 2.07 percent, with a mean of 1.68 percent. In every instance, the content of combined water in the various horizons of the Sassafras profiles varied inversely with the amount of silica present, and directly with the sesquioxides present. While the Leonardtown profiles showed somewhat the same relationships, there were several profiles in which this relationship was not consistent. Only one Sassafras sample, number 9, had a higher content of combined water in the C horizon than in any other horizon. Another, number 8, showed a lower quantity in the C than in the A horizon. The C horizon of this profile was also higher in silica and lower in clay than the A horizon.

There seemed to be no uniformity between the Sassafras profiles, as in the Leonardtown, in their content of combined water with increased depth, but, in general, the greatest quantity was found in the lower part of the B horizon. This nonconformity probably was caused by the variation in texture.

Ignition Loss. The loss on ignition is assumed to be the loss of combined water plus organic matter. The Leonardtown soils contained very little organic matter. The greatest amount was found in the A horizon. In general, below the B_2 horizon the content of organic matter was so small that it entered very little into the loss on ignition. The loss then, below the B_2, was almost entirely combined water. In three of the Leonardtown profiles, where the organic matter content for the A horizon ranged between 1.85 and 2.00 percent, the ignition loss was greater for this horizon than for the B_1. In the other three profiles, which had an organic matter content for the A horizon of 1.30 to 1.51 percent, the ignition loss was greater in the B_1. This is to be expected, as the previous observations have shown that these soils have been subjected to some podzolization. With the removal of some of the fine-textured material from the A horizon, their ability to retain combined water is lessened. Any higher ignition loss in the A horizon, therefore, is due usually to a larger content of organic matter.

The Sassafras soils, which are supposedly younger soils than the Leonardtown, also contained very little organic matter. The ignition loss was not as great for their A horizons as the similar horizons of the Leonardtown soils. This is due to the finer texture of the Leonardtown soils and the resulting increase in combined water. The surface horizons in two of the four profiles showed a greater ignition loss than the B_1. As all of the profiles had their greatest content of organic matter in the surface horizon, any higher ignition loss in the B_1 horizon was caused by an increase in combined water. Two of the profiles, numbers 8 and 9, had a smaller ignition loss for the C than for the A horizon. In number 8, the sandy nature of the parent material and its lower content of combined water accounted for this smaller loss, while in number 9, although the combined water in C was greater than in A, the organic matter content was so much greater in the surface that the ignition loss was larger. The ignition loss for the C horizons of the Leonardtown profiles always exceeded that for the A horizons due to the large amount of combined water present.

Distribution of Organic Matter. The content of organic matter in the profiles of both soil types, in general, decreased with depth. The surface horizon in every sample showed the largest amount present. This concentration in the surface was from about two to five times as great as that in the horizon below it. The range in the surface horizons of the Leonardtown soils was from 1.30 to 1.99 percent, with a mean of 1.65 percent, while that in the surface horizons of the Sassafras soils was from 1.01 to 1.59 percent, with a mean of 1.31 percent. The B_1 and B_2 horizons of the Leonardtown profiles usually showed a greater concentration of organic matter than the B_3 horizon. From the B_3 horizon, downward, the content was practically the same, and very small. The content in the C horizons of either soil type did not exceed 0.19 percent. It is obvious from the small content of organic matter present in the indurated layer that this material plays no part in the formation of the hardpan.

Mechanical Analysis. From a study of Tables 7 and 8, which show the mechanical composition of the Leonardtown and Sassafras profiles, it will be observed that the Leonardtown profiles usually contain a smaller percentage of sand and a

Table 7.—Mechanical composition and pH value of Leonardtown silt loam soils.

Sample No.	Horizon	Depth	Dispersed analysis			pH
			sand	silt	clay	
		Inches				
1	A	½-6	22.0	49.4	28.6	4.32
	B1	6-10	15.6	47.4	37.0	4.25
	B2	10-19	21.8	42.4	35.8	4.41
	B3	19-36	30.0	36.8	33.2	4.75
	B4	36-42	31.6	29.6	38.8	4.68
	C	42+	40.0	23.8	36.2	4.67
2	A	½-8	30.4	42.4	27.2	4.34
	B1	8-28	28.4	38.0	33.6	4.52
	B2	28-29	33.0	33.0	34.0	4.53
	B3	29-46	38.0	26.4	35.6	4.55
	B4	46-50	38.6	16.4	45.0	4.57
	C	50+	41.8	19.4	38.8	4.58
3	A	½-5½	31.0	43.8	25.2	4.52
	B1	5½-17½	23.8	38.8	37.4	4.53
	B2	17½-18½	32.4	29.6	38.0	4.64
	B3	18½-27	25.6	27.4	47.0	4.65
	B4	27-29	31.6	21.2	47.2	4.53
	C	29+	33.0	20.2	46.8	4.52
4	A	½-11	31.2	37.6	31.2	4.42
	B1	11-17	21.0	44.6	34.4	4.48
	B2	17-24	23.8	38.0	38.2	4.52
	B3	24-36	37.0	31.4	31.6	4.63
	B4	36-50	39.2	27.0	33.8	4.73
	C	50+	41.4	24.6	34.0	4.78
5	A	½-7	32.8	42.6	24.6	4.32
	B1	7-19	26.0	42.4	31.6	4.42
	B2	19-23	32.6	38.0	29.4	4.62
	B3	23-46	31.6	30.4	38.0	4.66
	B4	46-51½	39.8	22.8	37.4	4.82
	C	51½+	43.4	18.4	38.2	4.85
6	A	½-8	44.2	35.0	20.8	4.22
	B1	8-12½	31.4	38.8	29.8	4.48
	B2	12½-16	32.0	36.6	31.4	4.51
	B3	16-32	33.2	31.4	35.4	4.55
	B4	32-40	37.2	24.6	38.2	4.52
	C	40+	42.0	24.0	34.0	4.52

Table 8.—Mechanical composition and pH value of Sassafras silt loam soils.

Sample No.	Horizon	Depth	Dispersed analysis			pH
			sand	silt	clay	
		Inches				
7	A	½-8	53.2	28.2	18.6	4.41
	B_1	8-11	59.8	22.6	17.6	4.58
	B_2	11-20½	58.2	9.2	32.6	4.71
	B_3	20½-31½	60.6	9.0	30.4	4.63
	C	31½+	71.8	6.4	21.8	4.67
8	A	½-9½	62.6	19.8	17.6	5.16
	B_1	9½-30	54.2	19.0	26.8	4.57
	B_2	30-36	52.4	21.4	26.2	4.55
	C	36+	81.2	8.4	10.4	4.38
9	A	½-14	48.4	30.0	21.6	4.94
	B_1	14-19	53.2	25.8	21.0	4.66
	B_2	19-28	52.0	22.4	25.6	4.58
	C	28+	57.8	17.6	24.6	4.68
10	A_1	½-8	31.6	45.0	23.4	4.51
	A_2	8-14	22.8	44.8	32.4	4.43
	B_1	14-25	18.6	36.2	45.2	4.53
	B_2	25-40½	24.8	32.0	43.2	4.58
	C	40½+	28.0	31.2	40.8	4.48

larger percentage of silt and clay than the Sassafrass profiles. Furthermore, if the various soil horizons were classified texturally into soil classes on the basis of the percentage composition of sand, silt, and clay (7), a discrepancy would be found between the field and laboratory classifications. In the Leonardtown profiles, there was a tendency to underestimate the content of clay throughout the profile in the field classification; therefore, this classification gave a lighter textural horizon than that actually present. For example, the A horizons of the Leonardtown profiles were classified in the field as silt loams, but the mechanical analysis in the laboratory would classify five of the six as clay loams, and one as a clay. This discrepancy between the field and laboratory classifications of the horizons may be due to the fact that in such a soil it is practically impossible in a field examination to obtain a complete dispersion of its clay fraction. In the Sassafras profiles, there was a tendency to underestimate the content of sand throughout the profile; therefore, the textural classification in the field was usually heavier than that shown by a mechanical analysis.

Three of the Leonardtown profiles had a higher sand content in their B_3 horizon than in their A. The same profiles had also shown, by their chemical analysis, a decided increase in silica in the B_3 over the B_1 or B_2 horizons. The content of sand in the A horizon of the Leonardtown soils ranged from 22.00 to 44.20 percent, with a mean of 31.90 percent, while that of the B_3 ranged from 30.00 to 38.00 percent with a mean of 32.60 percent. Every Leonardtown profile had its lowest content of sand in the B_1 horizon, and usually its highest in the C horizon. Sample number 6, the exception, had a slightly larger sand content in the A horizon, but the quantity in the C exceeded that of any of the subhorizons of the B. The range in the B_1 was from 15.60 to 31.40 percent, with a mean of 24.40 percent, while that in the C was from 33.00 to 43.40 percent, with a mean of 40.30 percent. The sand content of the B_4 horizon always exceeded that in the B_3, but the B_4 always had a lower content than the C horizon. The range in this horizon was from 31.60 to 39.80 percent, with a mean of 36.30 percent. In the other transition layer, the B_2 horizon, the sand content was smaller in four of the profiles than that in the B_3 horizon. The range was from 21.80 to 33.00 percent, with a mean of 29.30 percent.

It may be said, in general, that the percentage of silt in the Leonardtown profiles decreased with depth. The drop in passing from the B_2 horizon to the B_3 was usually slightly greater than that in passing from the B_3 to the B_4 horizon. In four profiles, the silt content in the C horizon was less than one-half that of the A. The range in the A horizons was from 35.00 to 49.40 percent, with a mean of 41.80 percent, while that in the C was from 18.40 to 24.60 percent, with a mean of 21.70 percent. The content in the

B_3 horizon ranged from 26.40 to 36.80 percent, with a mean of 30.60 percent.

In every Leonardtown profile the B_3 horizon showed an increased clay content over that of the A horizon. Four of the profiles had a higher clay content for this horizon than that of any horizon above it. Samples 1 and 4 showed a decrease in clay over that in the B_1 and B_2 horizons. The range in the A horizons was from 20.80 to 31.20 percent, with a mean of 26.30 percent, while that of the B_3 was from 31.60 to 47.00 percent, with a mean of 36.80 percent. The B_1 and B_2 horizons did not vary a great deal in their clay content, but usually a slightly larger amount was found in the B_2. There was always a decided increase in the B_1 and B_2 horizons over that in the A, but, as previously mentioned, their clay content generally did not exceed that of the B_3 horizon. Five of the six profiles showed an increased clay content in the B_4 horizon over that in the B_3, and in the other it was practically the same as that of the B_3. Generally, this horizon possessed the largest quantity of clay in the profile. The range for the B_4 horizons was from 33.80 to 47.20 percent, with a mean of 40.10 percent. The C horizon, in most profiles, had practically the same clay content as that of the B_4. In every instance, as to be expected, it was higher than that of the A horizon. This difference, in five of the profiles, was very pronounced, the content in the C horizons being from 26.60 to 87.70 percent greater than that in the A horizons.

In profiles 3 and 6, the B_3 horizon had a slightly higher clay content than that of the C.

Every Sassafras profile, except number 10, had a higher sand content in the C horizon than in any other horizon. Similar results were generally obtained in the Leonardtown profiles. One profile, number 8, had a much larger content of sand in its C horizon than the C horizon of any other profile. Chemical results had indicated the sandy nature of this horizon by the high percentage of silica, the low percentage of iron oxide and alumina, and the small loss on ignition, found in the horizon. Sample number 10 was very similar to a Leonardtown profile in its content of sand, silt, and clay; that is, it was low in sand and high in silt and clay. The A_2 horizon of this profile showed evidence of the addition of eluvial material from above, but the accumulation was much smaller than that for the B_1 horizon. Therefore, although the A_2 horizon might be more correctly designated as a B_1 horizon, it will be considered a subhorizon of the A. As field observations and chemical results have indicated, the B_1 horizons of samples 7 and 9 were found by their mechanical composition to be subhorizons of the A. The B horizon of these two profiles, then, contains one less subhorizon than those listed in table 8.

Not much uniformity prevailed in the sand content of the A ane B horizons of the Sassafras soils. Two profiles, numbers 7 and 9, had a greater concentration of sand in the revised B_1 horizon than in the surface horizon, but this content did not exceed that found in the former B_1 horizon. The other somewhat typical Sassafras profile, number 8, had a higher sand content in the A horizon than in the B_1 or B_2 horizons. Because of these variations in the different horizons of the Sassafras profiles, the range in sand content will not be discussed, but may be obtained by referring to table 8.

The percentage of silt in the Sassafras profiles, just as in the Leonardtown, generally decreased with depth. In profiles 7 and 8, the percentage of silt in the C horizon was very low. As previously mentioned, the content throughout the profiles was much lower than in the Leonardtown profiles. The greatest percentage of silt (30 percent), excluding sample number 10, was found in the A horizon of sample number 9.

The greatest content of clay in the Sassafras profiles was found in the B horizons. Generally, the Leonardtown profiles showed the greatest concentration in their B_4 horizons. The decrease in clay in their C horizons, however, usually was not as great as that occurring in passing from the lower subhorizon of the B to the C horizon of the Sassafras profiles. One profile, number 8, had a very low clay content in its C horizon. This was the only profile showing a smaller percentage in the C horizon over that of the A.

Profile Reaction. The data on the reaction of the various horizons of the Leonardtown and Sassafras profiles are found in tables 7 and 8. It is apparent from the low pH throughout the profiles that both soil types have been subjected to intensive leaching of their bases, and are very acid in nature.

All of the Leonardtown profiles (Table 7) showed a higher pH, or decreased hydrogen ion concentration, for the B_3 horizon than for any horizon above it. The general tendency was a higher pH with increased depth down to, and including, the hardpan. Below the hardpan, variations were found in the pH; three profiles had a lower pH in the B_4 and C horizons than in the B_3, and three had a higher pH. In every profile the pH of the B_4 and C horizons was practically identical.

The pH for the A horizons of the Leonardtown soils ranged from 4.22 to 4.52, with four falling between the range of 4.22 and 4.34. Only one profile, number 1, had a lower pH in the B_1 horizon than that in the A. The increase in pH in the B_2 horizons over that in the B_1 ranged from 0.01 to 0.20 of a pH unit. The range in pH in the B_2 was from 4.41 to 4.64, with most values over 4.50. In the B_3 horizons, the pH in five of the profiles fell between 4.55 and 4.66. This range was slightly lower than the pH (4.8 ± 0.1) set by Skeen (27) for the formation of a hardpan in an acid clay soil. He did state in his work, however, that below this pH a hardpan may or may not be present. The pH of the B_3 horizon of the other Leonardtown profile was 4.75. As a rule, the pH of the B_2 horizons was from 0.01 to 0.26 lower than the B_4 horizons. One profile, number 3, had the same pH in its C horizon as that in the A, but all others showed a higher pH in the C horizon. The higher pH of the B_3 horizon over that of the horizons above it could not be due to the content of calcium and magnesium, because usually their concentration was greater in the upper horizons of the profile.

Three of the Sassafras profiles (Table 8) had a higher pH in the surface horizon than in the C. Such a condition can be attributed only to the character of the parent material. In two of these profiles, however, the pH of the surface horizon exceeds that of any other horizon. This is abnormal as soils of this type falling in the podzol zone generally show a higher pH in the B horizon than in the A. In two Sassafras profiles, numbers 7 and 10, the reaction downward seemed to be a consistent process; that is, the pH increased with depth down to a certain point, and then showed a decrease, but in the other two profiles no such consistency occurred.

The reaction data is very valuable in pointing out that pH alone was not the cause of the formation of the indurated layer. For example, the B_2 horizon of profile number 8 had the same pH as the indurated layer in two of the Leonardtown profiles.

GENERAL DISCUSSION

To anyone familiar with the soil classification system developed by Marbut in this country, it is evident that soils within a soil type may vary in their chemical composition. Usually the variations encountered in a soil type of a specific locality are small. If, however, a characteristic feature in the profile development of a soil, such as the formation of a hardpan, is caused by the accumulation of some mineral constituent, or constituents, every soil of this type should exhibit this feature.

The results which have been presented in this investigation indicate that the hardpan layer found in the Leonardtown soils does not result from an accumulation of one or more elements. This is illustrated by the inconsistent variation in the content of silica, alumina, and iron oxide, which constitute the greater part of this horizon. Contrary to the data presented by Marbut, the presence of this layer was not always found to be associated with an accumulation of silica.

The higher percentage of silica and the lower percentage of iron oxide and alumina usually found throughout the Sassafras profiles leads one to doubt whether the Leonardtown and Sassafras soils have developed from similar parent material. While the Sassafras soils, with their good internal drainage, may be subjected to a greater loss of iron oxide and alumina than the poorly drained Leonardtown soils, it is doubtful whether this loss through leaching would be very great.

A mechanical analysis of the profiles of both soil types generally shows the Leonardtown profiles to be much finer in texture. Although these soils have lain in place for a longer period of time and have been subjected to more weathering and less erosion than the Sassafras soils, their elevation points to a dissimilar parent material. The Sassafras soils were always found at a lower elevation above sea level than the Leonardtown soils. Of the Sassafras soils sampled, the elevation ranged from 120 to 130 feet with a mean of 122.50 feet, while that of the Leonardtown soils ranged from 180 to 240 feet with a mean of 218.30 feet.

A study of the geologic history of this region shows that it has undergone many elevations and subsidences, and as a result five general topographic features have developed. These are characterized by the different elevations at which they lie. The tide marshes, naturally, occupy the lowest levels. This area is followed by a series of plains, each one extending upward until it is usually separated from the next higher plain by an escarpment. There are four such plains in the Coastal Plain region of this section: the Talbot, Wicomico, Sunderland, and Brandywine (16, 21). They have been named in the order of their age and their elevation above sea level; that is, the Talbot formation lies closer to sea level and is much younger in age than the formations which follow it.

The Leonardtown soils were, in practically every instance, confined to the Brandywine formation, while the Sassafras soils were, in general, confined to either the Sunderland or Wicomico formations. The Brandywine which is the oldest of the three formations has had a longer time to weather and break down, thus becoming more clayey, while the two later formations, the Sunderland and Wicomico, are younger in age and partly derived from the Brandywine. In all probability, during the deposition of the Sunderland and Wicomico, the clayey fraction of the Brandywine material was carried away by the water, leaving a more sandy soil.

The Leonardtown soils differ markedly from the poorly drained Elkton soils of the Eastern Shore. Although both soils occur on relatively flat surfaces, the Elkton soils are found at a much lower elevation above sea level. Because of their low position and poor drainage, these soils have not developed normal soil profiles. Here the profile development has been retarded by excessive moisture, whereas in the Leonardtown soils a normal profile developed before internal drainage was retarded by fine material. While the Elkton soils possess a heavy textured B horizon, there is no evidence of a hardpan. If, as Marbut assumes, the formation of the indurated layer in the Leonardtown soils is the result of a high water table, one should expect a similar formation in the Elkton soils. Perhaps the argument may be advanced that they are much younger in age than the Leonardtown soils, and a hardpan has had no chance to form. This may be true, but it seems unlikely that these soils have not lain in place for a sufficient period of time to exhibit some induration if it is to occur. In places, where the water table of the Elkton soils has been lowered by some system of drainage, Keyport or Sassafras soils have developed. While artificial drainage may slightly improve the physical condition of the Leonardtown soils, the benefits of such a system are only temporary. This, in itself, seems to indicate that a high water table played little part in the formation of the indurated layer.

Throughout this paper, the indurated layer of the Leonardtown soil has been referred to as a hardpan. If the definition submitted by Shaw (26) to the American Soil Survey Association is followed, this layer could not be called a hardpan. He defines hardpan in the following manner, "An horizon of accumulation that has been thoroughly cemented to an indurated, rock-like layer that will not soften when wet." In the Leonardtown soils the indurated layer is not thoroughly cemented, and will soften if soaked in water. Such properties make it greatly resemble a claypan, but it has too high a sand content to be called a true claypan. Also, in practically every instance, the horizons lying below the indurated layer possess the largest clay content in the profile. Shaw defines a claypan as "An horizon of accumulation or a stratum of stiff, compact and relatively impervious clay." Thus, it is evident that the indurated layer is neither a hardpan nor a claypan. However, as it is commonly referred to in the literature as a hardpan, that terminology is used in this study.

SUMMARY

Typical samples of Leonardtown and Sassafras silt loam soils from three counties of southern Maryland were collected for a laboratory study. The study was conducted for the purpose of establishing, if possible, some chemical criteria for the cause of hardpan formation in the Leonardtown soils. The data reported concern the field observations, the chemical composition, the mechanical analysis, and some of the properties of the horizons found within the profiles of these soil types. From the results, the following general conclusions have been derived:

1. The indurated layer in the Leonardtown profiles is found at a depth ranging from 16.00 to 29.00 inches from the surface, and varies in thickness from 8.50 to 23.00 inches.

2. The Leonardtown profiles are of greater depth than the Sassafras, having a mean depth of 43.80 inches compared to 34.00 inches for the Sassafras.

3. A great deal of the soil mapped as Sassafras silt loam in this section seems to be a transition stage between the Leonardtown and Sassafras soils.

4. All of the Leonardtown profiles have their highest content of silica in the A horizon. While three

profiles show an accumulation of silica in the B_3, or indurated, horizon almost equal to that in the A, hardpan formation does not seem to be characterized by such an accumulation. The Sassafras soils have no accumulation of silica in their B horizons.

5. Both the Leonardtown and Sassafras soils have their smallest content of iron oxide and alumina in the A horizon. The quantity present throughout the various horizons of the profiles is inversely proportional to the silica content. The Sassafras profiles contain smaller quantities of these elements than the Leonardtown. This indicates less fine material and more free silica. While the percentage of iron oxide and alumina in the B_3 horizon of several Leonardtown profiles exceeds that of the B_1 horizon, it is rarely greater than that of the B_4 or C horizon. The indurated layer of the Leonardtown profile, therefore, is not characterized by an accumulation of these elements.

6. The B_3 horizons of the Leonardtown soils always have a higher silica-alumina and usually a higher silica-iron oxide ratio than the C horizons, whereas the B horizons of the Sassafras have very similar or smaller ratios. Any movement of iron oxide or

alumina into the B_1 or B_2 horizons of the Leonardtown results in a greater loss of iron oxide than alumina. The B_3 horizons show that alumina, relative to iron oxide, has increased over that in the B_2 horizons. Although several Leonardtown profiles have an increase in iron oxide and alumina in the B_1 and B_2 horizons over that in the C horizon, this gain is not as large as that lost from the A horizon.

7. The percentage of titanium, calcium, and magnesium is not high in either soil type. The small quantity makes the possibility of analytical error great. Whereas the concentration of calcium is greater in the A horizon, that of magnesium, especially in the Leonardtown soils, is greater in the B horizon. Only slight variations occur in the content of titanium in the various horizons of the profiles. These elements are present in such small quantities that they play no part in the formation of a hardpan.

8. The amount of combined water in the various horizons of the Sassafras profiles varies inversely with the silica and directly with the sesquioxides present. The Leonardtown profiles show somewhat the same relationship, but in several profiles this relationship is not consistent.

9. The content of organic matter in both soil types decreases with depth. The concentration in the A horizon is from two to five times as great as that in the horizon below it. It is obvious from the small quantity of organic matter present throughout the profiles that this material plays no role in the formation of the hardpan.

10. The Leonardtown profiles contain a smaller percentage of sand, and a larger percentage of silt and clay than the Sassafras profiles. Every Leonardtown soil has its smallest quantity of sand in the B_1 horizon, and usually its largest in the C horizon. Little uniformity in sand content prevails in the A and B horizons of the Sassafras soils. Usually, the C horizons contain the largest quantity of sand. The percentage of silt in both the Leonardtown and Sassafras profiles decreases with depth. The content throughout the Sassafras profiles is much smaller than that of the Leonardtown. In the C horizons of the Leonardtown, the silt is less than one-half that of the A horizons. While the B_3 horizon of the Leonardtown exceeds the horizons above it in clay content, the B_4 and C horizons contain the greatest quantity of clay.

11. pH alone is not responsible for the hardpan formation in the Leonardtown soils.

The hardpan layer in the Leonardtown soils is not characterized by an accumulation of silica, iron oxide, or alumina, although these three oxides comprise over ninety-four percent of the mineral mass. There are such small quantities of other elements present in the layer that any possibility of their entering into hardpan formation may be disregarded. The high content of iron oxide and alumina immediately below the hardpan indicates more colloidal material present in this horizon than in the hardpan. A mechanical analysis proves this to be true. From the laboratory results, therefore, the probable explanation for the formation of the hardpan is as follows:

The Leonardtown soils are derived from finer materials than the Sassafras soils. During the genesis of the soils, clay-like materials are carried downward and deposited in the lower part of the B. As this deposition gradually takes place, drainage becomes more and more difficult. Under such conditions of drainage, and during periods of heavy rainfall, the soil particles lying immediately above this zone of illuviation are arranged, by pressure from above and the excess water present, into a compact structure.

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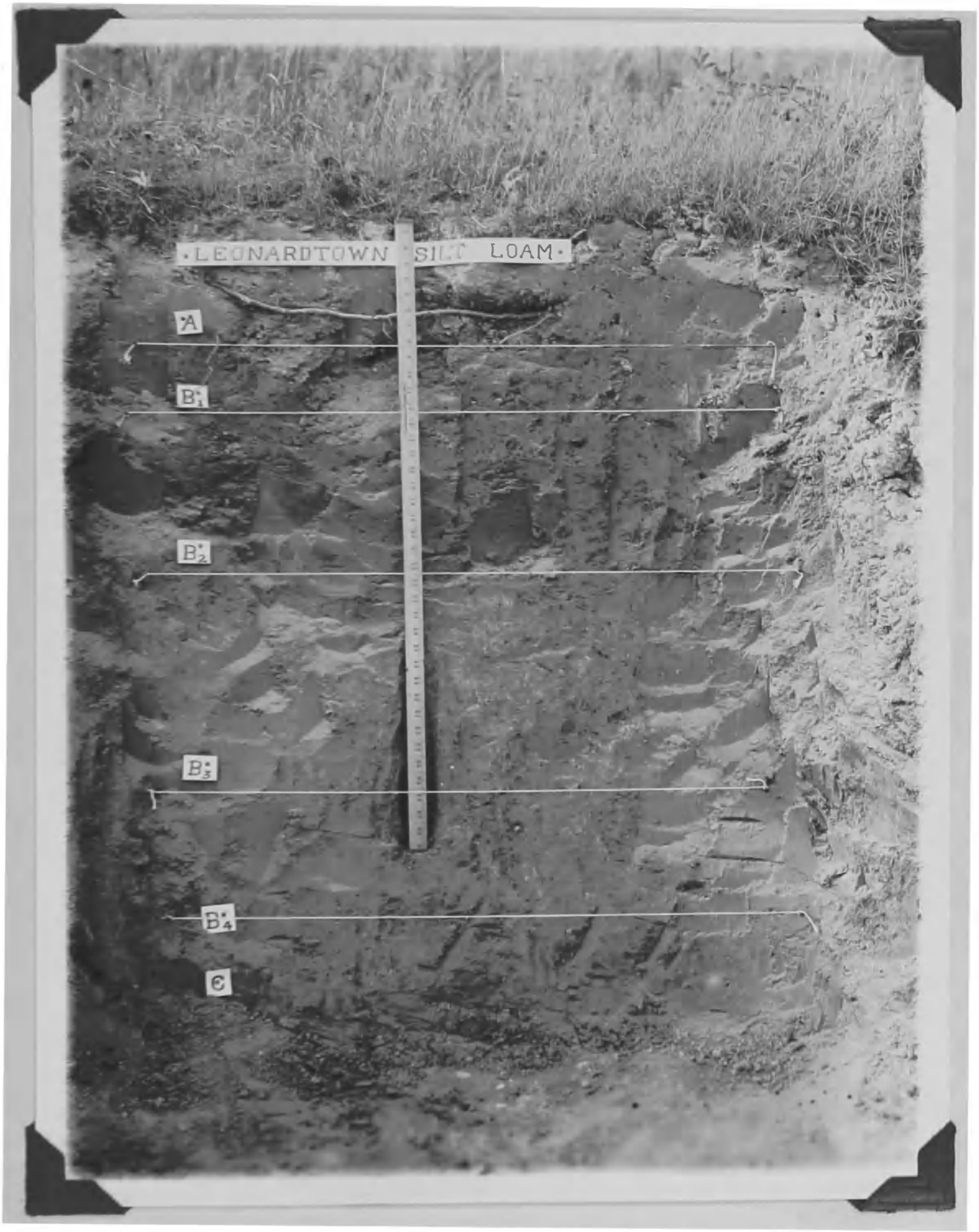
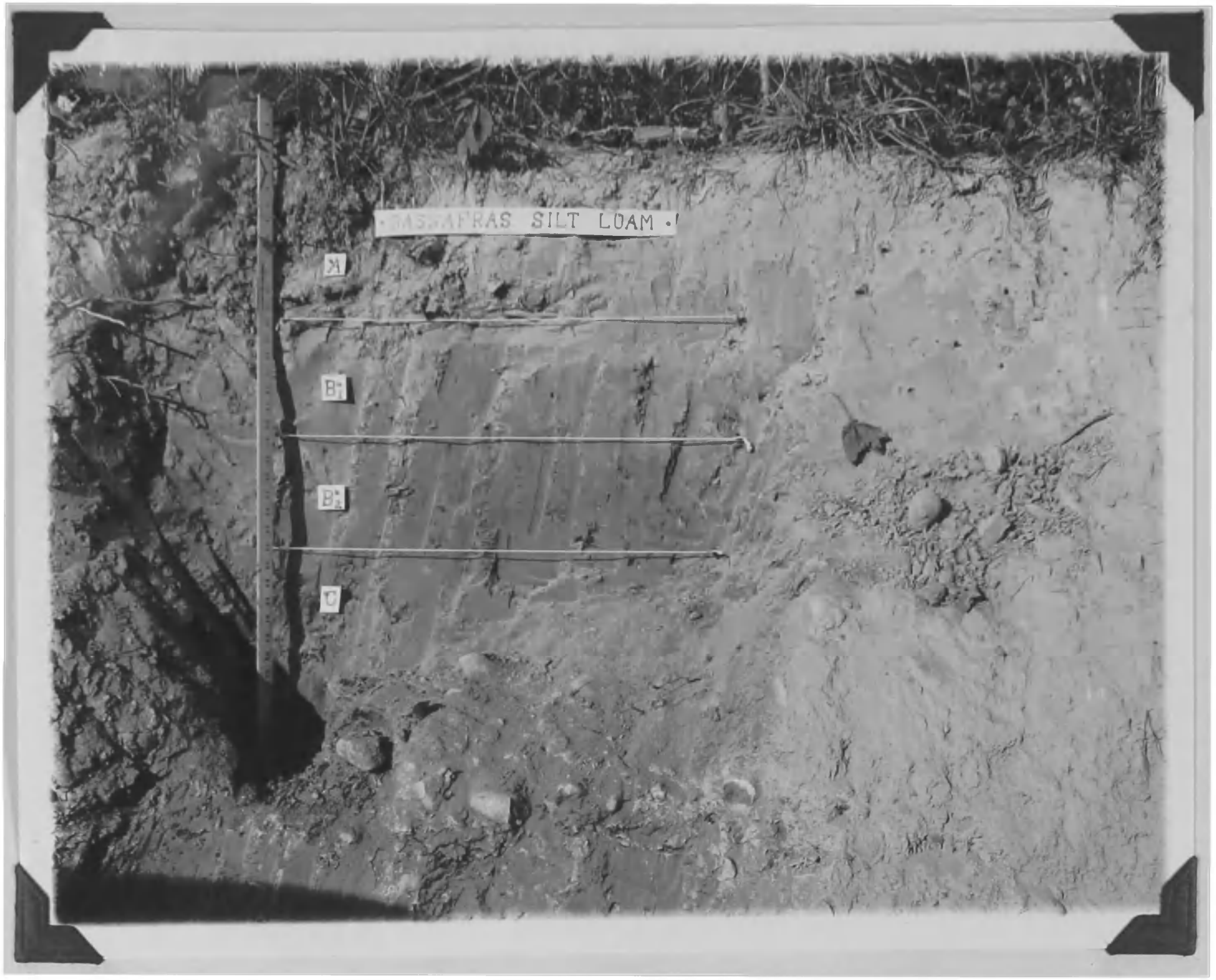
PLATE I



A typical Leonardtown silt loam profile showing the horizons sampled and the compact nature of the B_3 horizon.

PLATE II



A typical Sassafras silt loam profile showing the horizons sampled when no further subdivisions were made.

PLATE III

Material from the B_3 horizon of a Leonardtown silt loam showing its compact, laminated structure.