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A PHYSICO-CHEMICAL STUDY OF WEATHERING PRODUCTS IN THE PAYSON SOIL SERIES

by

Lowell A. Douglas

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of the requirements for the degree

of

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in

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Lowell A. Douglas

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INTRODUCTION

A knowledge of the clay minerals in a particular soil series would aid in the characterization and classification of that soil. The physical and chemical properties of a soil are largely controlled by the properties of the clay minerals in the soil.

This thesis presents the results of a study of the weathering products in a calcareous soil, with a B horizon high in clay content, attempting to determine if the clay accumulation is a product of *in situ* weathering. It was decided to study soil profiles from within the Bonneville Basin, since a fair estimate of time of *in situ* weathering could be made. This thesis is confined to studies of the clay materials found in three profiles of the Payson soil series. The Payson soil occurs on the low lake terraces of prehistoric Lake Bonneville and is extensive. Profiles selected for this study were taken from Davis and Weber Counties, Utah.

Clays are composed of two groups of minerals: those which are the remnants of larger, partially decomposed minerals (primary minerals), and recrystalization products (secondary minerals). Clay minerals are secondary minerals that are essentially hydrous aluminum silicates, or occasionally hydrous magnesium silicates (23). Clay, or clay material, characterizes minerals of very small size which may be clay minerals. Clay minerals occur in most clay materials in particles less than 5 (.005 mm.) in diameter.

Clay minerals are products of chemical weathering. The relation of clay minerals to chemical weathering in calcareous soils has long been a moot question. Reiche (56) states, "Chemical weathering, under calcification, is retarded; and there is some suggestion from the laboratory that bentonitic, rather than kaolinitic clay minerals, may be the normal end-products." Grim (21, p. 343) believes there can be no silicate alteration until all calcium has been leached out; which can be interpreted as meaning that clay minerals can not decompose or precipitate in the presence of calcium. Jenny (38, p. 71) concluded that ". . . only after the removal of the carbonates are the characteristic regional profile differentiations instigated." Most authors agree that weathering in calcareous soils will proceed slowly, if at all.

REVIEW OF LITERATURE

Many authors have proposed weathering sequences including Reiche (56), Dryden and Dryden (14), Polynov (54, p. 163), and Jackson et al (35). Jackson's "Weathering sequence of clay-size minerals in soils and sedimentary deposits" is given in Table 1.

The following generalizations were made by Jackson et al. (35).

> 1. From three to five minerals of the weathering sequence are usually present in the colloid of any one soil horizon, one or two minerals being dominant and other adjacent minerals in the sequence decreasing in amounts with remoteness in the sequence.
>
> 2. The percentage of the minerals of the early stages of the weathering sequence decreases, and of the successive members increases, with increasing intensity of weathering.
>
> 3. Intermediate stages may occasionally be absent, giving a bimodal curve, and secondary deposits such as calcite or gypsum may occur out of sequence.
>
> 4. The weathering equations are considered reversible, moving largely to the right in soils, and to the left in sedimentary deposits. However, alluvial and aeolian sediments which remain exposed to continued weathering continue the sequence as of their parent soils.
>
> 5. The mineralogical composition of the soil colloids varies according to three analogous sequence: viz., according to geographic (climatic) variations, particle surface function, and proximity to surface of the soil.
>
> 6. The stability factor of the minerals is a resultant both of crystal structure and of the specific isomorphous elements. Lack of stiochiometry between successive stages arises through processes of eluviation and illuviation. The course or direction of the sequence is unaffected by parent material, although the stage may be.
>
> 7. Podzolization and laterization are considered to differ principally in the degree of oxidation and in summation of "weathering intensity X time," but to be

Table 1. Weathering sequence of clay-size minerals in soils and sedimentary deposits

Weathering stages	Clay-size minerals occurring at various stages of the weathering sequences
1	Gypsum (also halite, etc.)
2	Calcite (also dolomite, aragonite, etc.)
3	Olivine-hornblende* (also diopside, etc.)
4	Biotite** (also glauconite, chlorite, antigorite, nontronite, etc.)
5	Albite (also anorthite, microcline, stilbite, etc.)
6	Quartz (also cristobalite, etc.)
7	Illite (also muscovite, sericite, etc.)
8	Hydrous mica-intermediates ("X")
9	Montmorillonite (also beidellite, etc.)
10	Kaolinite (also boehmite, etc.)
11	Gibbsite (also boehmite, etc.)
12	Hematite (also goethite, limonite, etc.)
13	Anatase (also rutilte, ilmentite, corundum, etc.)

*Silicate groups I to V, with structures ranging from independent tetrahedra (i) to the line hexagonal structure of the amphiboles (v).

**Silicate group VI containing Fe^{+++} or Fe^{++} and Mg^{++} in the octahedral layer.

> following through the sequence as otherwise fundamentally similar desilication processes in an acid regime. It is at a steady stage as embodied in the concept of the "normal" soil, may be even now slowly advancing in the weathering stage.

Weathering stages one and two are closely related. Stage two relates to calcification. Carbonates dissolved from the upper horizons during the downward movement of water are reprecipitated in the horizons of calcium accumulation or C_{ca} horizon. Jenny (38, p. 122) states that it is generally assumed that the depth of the C_{ca} horizon marks the average depth of penetration of surface water. Reiche (56) believes that under calcification the colloidal composition of soil profiles is essentially homogenous, except for the strong concentration of colloidal $CaCO_3$ in the base of the soil mass.

Leaching does not always follow a downward direction. When a soil profile is immediately over a water table the dominant water movement may be upward. When leaching is downward the C_{cs} penetrates deeper than the C_{ca} (63, p. 267), whereas, when the soil solution moves upward, the $CaSO_4$ rises higher than the $CaCO_3$.

Jeffries, Rolfe, and Kunze (37) have proposed a mica weathering sequence of: "Mica-mica intermediate chlorite intermediate-chlorite-kaolin." This mica weathering sequence approximated Jackson's stages four to ten. Jackson et al. (36) further investigated the mechanism of chemical weathering of layer silicates from stages four and seven to nine, proposing: "Mica-illite-intermediates-vermiculite-montmorillonite." Mica weathering was found to take place along a "preferential weathering plane" involving the removal of potassium from a single plane in the crystal lattice. Jackson et al. (36) proposed four chemical weathering reactions, "The four chemical weathering reactions which effect weathering of layer silicates are: Depotassication, hydroxylation, dealumination, and desilication."

Dyal and Hendricks (15) have demonstrated that the formation of mixed layer minerals by potassium fixation in montmorillonite results in a decrease in surface area of the mineral. Page and Baver (55) explained the specificity of potassium fixation by the closeness of the size of the potassium ion to the size of certain free spaces on illite inner layer surfaces. Wear and White (71) also related potassium fixation in clay minerals to crystal structure. Beidellite and illite have more tetrahedral than octrahedral charges, giving rise to strong attractive forces at the surfaces. When a clay mineral is dried with exchange positions occupied by potassium ions held by randomly distributed "strong" forces, a configuration is formed with each potassium ion in 14-coordination. If enough of these stable configurations exist between two adjacent sheets, the bonding action overcomes the forces tending to separate the sheets. The 14-coordination of potassium is more stable when the potassium ion neutralizes a tetrahedral charge, because the electrostatic valence is satisfied over a shorter distance.

Illite is usually defined as a clay mineral with a (001) spacing of 10 Å. Montmorillonite has an expanding lattice with a (001) spacing of 12 to 20 Å. Bradley (8) found that many illite-like clay minerals contain expanded layers. Negelschmidt (51) found that when illite is treated with $CaCl_2$ portions of the non-expanded layers expanded. White (74) has shown that by treating illite with $MgCl_2$ and precipitating the potassium in solution with cobaltinitrite, the illite expands and gives a montmorillonite X-ray pattern. Beidellite, a montmorillonite type mineral, contains some non-expanded layers which are indicated by the presence of potassium in the chemical analyses.

Many of the 2:1 dioctahedral clay minerals contain both expanded and non-expanded layers and it is relatively easy to change their state of expansion. There is little doubt that these processes can work in nature forming an expanded clay mineral from a non-expanding clay mineral. Weaver and Bates (72), because of the similarity of the structural formulas of illite and montmorillonite, have proposed a classification of the 2:1 clay minerals based on the amounts of substitution in tetrahedral or octahedral positions.

Van Houten (68) has pointed out that minerals of the kaolinite group predominate in soils of warm, humid regions, while minerals of the montmorillonite and illite groups are prevalent in the soils of cooler or drier regions. Holms and Hearn (32) showed that illite is the principal clay mineral in the alluvium of the Mississippi drainage basin. Van Houten's review (68) presented the hypothesis that clay minerals are commonly inherited from the parent material in soils formed on sedimentary rocks. Some of the montmorillonite in soils of the western Great Plains has been inherited from montmorillonite-rich parent rocks. Illite is a common clay mineral in soils developed on illite-rich glacial deposits and marine shale. Illite is abundant in many kinds of sedimentary materials, consequently, illite is often the dominant clay mineral in soils formed on sedimentary deposits.

The formation of montmorillonite is favored by an alkaline environment (60). In some soils the formation of montmorillonite type clay minerals depends upon the presence of iron compounds. Montmorillonite and illite are often interlayered with other clay minerals. This is true with "Putnam" clay, montmorillonite being interlayered with illite as a mixed-layer clay mineral. "Rothamsted" clay is probably a montmorillonite-kaolinite mixed layer mineral.

Ross and Hendricks (60) reported that montmorillonite is a prominent constituent of clay fractions of soils derived from calcareous glacial materials in western United States and Canada, and in central Russia. The B horizons of these soils have clay minerals produced by weathering of feldspars in place. These investigators stated that "black-alkali" soils and "slick" spots, as found in western United States, are usually due to a sodium-saturated montmorillonite clay mineral.

The most extensive investigations of clay minerals in calcareous soils have been made by Kelley and his co-workers (42, 43). Kelley _et al_. concluded San Joaquin colloids are composed of kaolinite and an "X" mineral (probably illite) and montmorillonite is absent. It should be mentioned that the experimental methods of Kelley would not detect small amounts of montmorillonite. Kelley, Dore, and Page (42) studied the colloidal constituents of alkali soils. Their white-alkali soils contained mixtures of montmorillonitic, kaolinitic, and mica-like clay minerals. Mica-like minerals (probably illite) predominate in their black-alkali soils. Clay minerals of horizons showing solonetz structure were found to be chiefly mica-like. No evidence was found to indicate that clay minerals peculiar to alkali soils are produced.

Alexander, Hendricks, and Nelson (2) found kaolin, hydrous mica and montmorillonite in both a prairie soil and a chernozem soil. The same investigators identified calcite, kaolin and a hydrous mica-montmorillonite mixed layer type in a desert soil.

Little work has been done investigating the genesis of clay minerals in calcareous soils. Weathering sequences of clay minerals have been applied to soils, but most investigators have implied that most of the clay minerals in calcareous soils have been inherited from parent material.

PAYSON SOIL SERIES

The Payson soils are solonetz soils which occur in the Brown and Chestnut soil zones on lake sediments of old, extinct Lake Bonneville. The Payson soil series is described by the Soil Survey Staff of the Soil Conservation Service as follows:

> The Payson soils are intrazonal degraded Solonetzes of the Brown and Chestnut soil zones. They are moderately fine-textured soils that occur on alluvium or lacustrine material that was deposited in or near Lake Bonneville during the Pleistocene epoc. These deposits, after being reworked by water, were subjected to poor drainage and salization. Parent rocks are mainly quartzite, shale, and limestone from the Wasatch Mountains. The Payson soils are associated with the Terminal, Airport, and tentative Leland and Kirkham series. They are more strongly defined Solonetz and of finer texture than Leland soils, higher in organic matter than Terminal Soils, and lack the hardpan of that series.

Soil Profile: (Payson silt loam)

			Range in thickness
$A1_v$	0-3"	Light brownish-gray (10YR 6/2) dry, grayish-brown (4/2) moist: moderately calcareous: weakly vesicular: thin platy silt loam. This is slightly hard when dry, friable when moist; pH 8.5 and organic matter about 2.6 percent.	2-4"
$A1_2$	3-7"	Similar to surface horizon in color, weakly defined coarse platy silt loam or fine-textured silt loam: moderately calcareous: slightly hard when dry, friable when moist: pH 8.7 and organic matter about 1.7 percent.	3-6"
B_1	7-10"	Pale brown (10YR 6/3) dry, dark grayish-brown (4/2) moist; silty clay loam; weakly defined medium blocky; moderately calcareous; very hard when dry, firm when moist; pH 9 and organic matter about 1.3 percent.	1-4"

B_2	10-18"	Grayish-brown (10YR 5/2) dry, dark grayish-brown (4/2) moist; silty clay; strongly defined medium prisms or columns that crumble easily in the hand to medium blocky aggregates. These are very hard when dry, firm when moist. The outer sides of the columns are darker than the inside part of an aggregate, indicating a straining by organic colloids on the outer sides and inward leaching. Many of the columns have a core of white lime carbonate. pH is about 9.6 and organic matter about .8 percent. This may contain a slight to moderate quantity of soluble salts.	4-12"
B_{3ca}	18-32"	Very pale-brown (10YR 7/4) dry light yellowish-brown (6/4) moist; weakly defined medium blocky silty clay with much segregated lime which occurs at mottlings and as soft nodules. This horizon is very hard when dry, firm when moist, and sticky when wet. It is very slowly permeable, has a pH of about 9.4 and contains about .54 percent organic matter. This may range from .2 to .6 percent soluble salts.	10-20"
C	32-42"	This is similar to the horizon above, but lacks the lime mottling and nodules. It usually contains .6 to .9 percent soluble salts and had a pH of 9 or higher.	

Range in Characteristics: The surface soil may range from pale-brown to grayish-brown when dry, to very dark grayish-brown (10YR 3/2) moist. The content of salt may range widely in all parts of the profile.

Topography: Smooth; nearly level to undulating. Slopes range up to about 3 percent.

Drainage: Runoff is slow to rapid, depending on slope and cover. Water stands on surface in places. Internal drainage is very low or entirely lacking.

Vegetation: Greasewood with some shadscale, saltgrass, cheatgrass, and some annual weeds. A large part of the surface may be barren.

Use: Mainly for range-carrying capacity is low to very low. A few areas under irrigation are being improved by use of good reclamation practices.

Distribution: Central and northern part of Utah.[1]

The Payson profiles studied were associated with the Saltair, Airport, Warm Springs, Terminal, and Leland soil series. The Saltair series represents a strong Solonchak. Saltair soils develop under conditions of high salt concentrations and high water tables. The 0 to 10 inch horizon has a fine, weak granular structure. Below 10 inches the profile is massive. As drainage improves, the Saltair soil grades into the Airport soil series. The Airport series is similar to the Saltair series except that: the water table is a little deeper, the soluble salt concentration is not as high, and the granular structure is found as deep as 20 inches in the Airport series. The Warm Springs soils differ from the Airport soils in that the Warm Springs is medium textured in the subsoil horizons. The subsoil horizons of the Airport series are loams to clays while the same horizons of the Warm Springs series are fine sandy loam to loamy sands. The Payson, Terminal, and Leland series are very similar structurally and as to salt content. The Terminal soils have a lime-cemented hardpan in the subsoil. The Leland soils have subsoils similar to the Warm Springs series, while the Payson subsoils are similar to the Airport series.

De Sigmond (64, p. 268) has objected to the use of term Solonetz, believing present usage is not consistent with the original Russian

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[1] Harper, W. G., Personal Communication, October 1955.

meaning. The original Russian Solonetz had the connotation of a sodium saturated, columnar or prismatic structure. Present usage of Solonetz often gives more import to structure and less to the exchange cation composition.

Westin (74) found that certain Solonetz soils occupy slight depressions within areas of zonal soils in eastern South Dakota. A reduction in volume accompanies solonization so that depressions containing Solonetz soils would continue to deepen. Westin concluded that Solonetz soils may degrade into Solods, but may not develop into zonal soils and that solods remain depressional soils in their moisture relations and morphology.

Several investigators have reported "Magnesium Solonetz" soils. These soils are relatively low in exchangeable sodium and calcium and high in exchangeable magnesium. Riechen (60) proposed that Magnesium Solonetz soils might be explained in the relationship between the rate of weathering of the secondary and primary minerals, and to uptake of magnesium ions and calcium ions by the vegetation. Riechen pointed out that most vegetation has a larger calcium than magnesium content.

U. S. Department of Agriculture Handbook 18 (65, p. 342) states that Solonetz soils are formed by leaching of Solonchak soils.

> When drainage improves during the ages and the excess salts leach out, enormous differences may develop. The calcium-clays remain flocculated, granulated; whereas, the sodium-clays become easily dispersed and puddled, or "run together." The soil becomes highly alkaline--so much so that part of the organic matter is dissolved and may form a dark coating around the soil grains or aggregates. Some sodium ions of the colloid are disassociated to form sodium hydroxide and finally sodium carbonate. Since the colloids are easily dispersed, some of them start to move downward, out of the surface layers, and accumulate beneath. The

puddled soil cracks on drying. The next rain causes more dispersion, and fine material moves down. After long periods, this results in an accumulation of fine material in the B horizon, with the silt and sand left in the A. Besides, continued weathering of minerals within the B horizon contributes to its high content of clay.

The B horizon has a characteristic columnar structure; the soil exists in hard vertical prisms with rounded caps. This process of change is sometimes called "solonization," and the resulting soil is called a Solonetz. Thus in contrast to Solonchak, the Solonetz has a striking structure profile.

Climatology

The Payson soil series profiles studied are located on low lying lake terraces, below the Stansberry level, of Lake Bonneville. The area lies east of Great Salt Lake and west of the foot of the Wasatch Mountains. The Basin and Range Province extends from the foot of the Wasatch Mountains westward to the foot of the Sierra Nevada. The area studied lies near the extreme eastern edge of the province. Below the highwater level of the old Lake Bonneville, about 5,100 feet in altitude, the land forms are mostly those built of lake deposits. The Wasatch Mountains, rising more than a mile higher than the valley floor are on the eastern edge of the basin.

The importance of climate in soil genesis has been pointed out by many investigators including Glinka (18, p. 23), Hilgard (31), Jenny (38, Chap. 6), and De Sigmond (64, Chap. 2). The present climate of the area is semiarid. The Wasatch Mountains receive Utah's largest annual precipitation. The least precipitation of the state occurs in the Great Salt Lake Desert, some 75 to 125 miles west of the Wasatch Mountains. The annual precipitation decreases westwardly from the Wasatch Mountains. Weather data from stations near the locations of the profiles studied are given in Table 2 (4, pp. 1147-1158).

Snowfall is moderately heavy in the Wasatch Mountains. As a rule, the areas along the base of the mountains receive snow which seldom remains on the ground for any long period of time. When the snow melts in the mountains, during spring and early summer, the low lying lake terraces are often flooded by run-off water. This flooding may continue for several weeks.

Profile descriptions

Three soil profiles were studied. The altitude at sampling sites varied from about 4300 to 4400 feet above sea level. Each profile was considered to be typical and representative of a rather large area of Payson soil. Individual profiles were sampled according to morphological horizons observed in the field. All samples were taken near mature bushy plants to insure that the sampling sites had not been recently disturbed.

Site 2 was along the south edge of S.20, T. 5N, R. 2W., about 800 feet east of the southwest corner. Field observations of this profile were: (see next page)

Sample No.	Horizon	Depth	Description
20	A_1	0-5½"	Light brownish-gray; non-calcareous; strong platy, weakly vesicular.
21	A_2	5½-6"	Ashy gray; highly calcareous; powdery.
22	B_1	6-10"	Black at top lightening to dark brown at 9 inches; strongly calcareous; strong columns which are dark around sides, much lighter color inside columns; columns have rounded tops.
23	B_2	10-11½"	Reddish-brown columns; calcareous, calcareous mottling and nodules.
24	B_3	11½-18"	Light red; weak columns degrading to blocky at 18"; highly calcareous.
25	C	18-22"	Pale brown; calcareous, weakly blocky.
25	C	22-30"	Pale brown; calcareous; stratified.

Table 2. Weather data from stations near the Payson soil profiles studied

County	Box Elder	Davis	Salt Lake	Salt Lake	Salt Lake	Weber
Station	Brigham City	Farmington	Saltair	Salt Lake City	Silver Lake	Ogden
Temperature, °F						
Jan. average	25.4	28.4	28.0	30.1		27.4
July average	75.8	74.5	76.5	77.0		74.7
Maximum	108	106	103	105		105
Minimum	-27	-20	-22	-20		-27
Growing Season						
Length, days	162	157	194	192		155
Precipitation, inches						
January	1.64	2.16	1.01	1.31	4.90	1.80
February	1.75	2.22	1.10	1.55	5.67	1.89
March	1.80	2.19	1.46	2.00	5.20	2.06
April	2.03	2.22	1.41	1.85	4.01	1.87
May	1.68	2.19	1.52	1.95	2.52	1.93
June	.93	.92	.82	.74	.99	.87
July	.66	.74	.66	.57	1.67	.58
August	.84	.93	.75	.91	2.19	.96
September	1.22	1.22	.91	.95	2.39	1.14
October	1.74	1.66	1.44	1.43	2.91	1.63
November	1.36	1.74	1.34	1.28	3.65	1.52
December	1.68	2.02	1.00	1.26	4.72	1.67
Annual	17.33	20.21	13.42	15.79	40.82	17.92

Site 3 was 1000 feet south of the center of Section 3, T. 1N, R. 1W. This location was 3/4 mile east of the Jordan River and two miles north of the Davis County-Salt Lake County boundary line.

Sample No.	Horizon	Depth	Description
30	A_1	0-6"	Light brownish-gray; non-calcareous; strongly vesicular.
31	A_2	6-9½"	Dark gray; moderately calcareous; moderately vesicular, weakly platy.
32	B_2	9½-17"	Dark gray; strong columns with caps at 9½", columns weak to blocky at 17"; columns darkly stained on sides, lighter colored inside of columns; strongly calcareous.
33	C	17-27"	Light gray; calcareous; weak blocky structure.

Site 4 was 100 feet east of U. S. Highway 91, 1½ miles south of the junction of U. S. Highways 91 and 30S, north of Ogden, Utah, and about 500 feet south of the center of the SE ¼ of S. 23, T. 7N, R. 2W.

Sample No.	Horizon	Depth	Description
40	A_1	0-4"	Reddish-brown, moderately calcareous; strongly thin platy.
41	B_2	4-7"	Dark reddish-brown; strongly calcareous, strong columns, darker outside than in center.
42	B_2	7-14"	Pale reddish-brown; strongly calcareous; weak columns, little dark staining on columns; calcareous mottling and nodules.
43	B_3	12-20"	Light reddish brown; strongly calcareous; medium weak blocky.
44	C	20-30"	Light reddish-brown; strongly calcareous; stratified.

Plate 1 shows a general view of the profile at site 2 and the vegetation comprising the ground cover. Plate 2 is a close view of Profile 2. Plate 3 is a close view of the columns comprising the B_3 horizon at the same site. These columns have been removed from the profile and placed on the soil surface in such a manner that the columns have separated from each other.

Parent material

Parent material at the three sites studied consisted of lake laid sediments eroded from the Wasatch Mountains. The Wasatch Range, near the area studied, consists of sandstones, limestones, shales, conglomerates, and quartzites (19).

Hunt and Sokoloff (33) report a paleosol of pre-Wisconsin Pleistocene age in the Lake Bonneville Basin, above the Bonneville level, and also in the Denver Basin. Profiles of this paleosol are also reported in several locations indicating it is probably widespread in the Rocky Mountain region and the Great Basin. These soils range in altitude from 5,000 to more than 8,500 feet. Mineralogical studies were made on several profiles by Hunt and Sokoloff. The clay layer contains considerable iron oxide. Hydromica was found to be the principal clay mineral in the paleosol at nine sites. A minor quantity of montmorillonite was found. Montmorillonite was found dominant in the paleosol at four localities. Four samples of alluvium, three of which were from clayey alluviar deposits believed to have been derived by erosion of the paleosol, were analyzed. Montmorillonite was the dominant clay mineral found in all the alluvia samples. Hunt and Sokoloff (33)

Plate 1. Payson soil profile at Site 2.

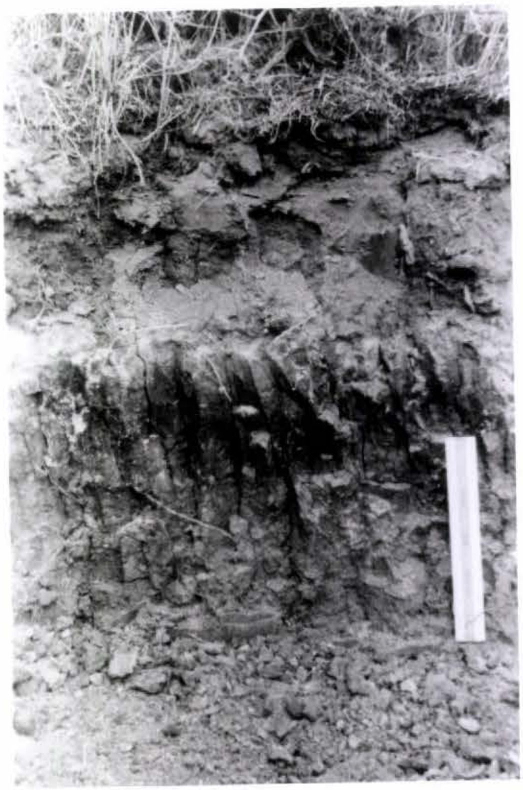

Plate 2. Close up of Payson soil profile at site 2.

Plate 3. Solonetz structure of the B_{23} horizon at site 2.

suggest that the paleosol might be composed rather consistently of illitic clay regardless of differences in the kind of parent material from which it was formed. It has been suggested that these profiles described by Hunt and Sokoloff are not paleosols, but are the soils produced by weathering during present time. Much work remains to be done before the genesis of these paleosols will be fully understood.

The parent materials of the Payson soil series consist of lake laid sediments eroded from the Wasatch Mountains. Erosion of land surfaces now covered by soils similar to those described by Hunt and Sokoloff (33) undoubtedly contributed to the sediments of Lake Bonneville.

EXPERIMENTAL METHODS

Soil samples, collected in the field, were placed in plastic bags and taken to the laboratory where the soils were allowed to air dry. When dry, the soil samples were crushed with a rolling pin to pass a two mm. screen, thoroughly mixed, and placed in two quart glass jars. Subsamples were used for analysis.

The following groups of experimental methods were used in this study: chemical analysis to characterize the chemical environment of the individual samples; mechanical analysis to characterize the particle size distribution of the individual samples; and powder diffraction X-ray analysis and differential thermal analysis to identify the principal minerals composing the clay fraction of the individual samples.

Chemical analysis

The conductivity of the saturation extract (59, p. 89) was determined. Exchangeable sodium and potassium and cation exchange capacity was determined (7). This method consists of determining total cations in an ammonium acetate leachate. The corresponding cation concentraton of the saturation extract is determined and exchangeable cations determined by difference. Cation exchange capacity was obtained by saturating the soil with sodium and replacing the sodium with ammonium and determining sodium with a flame photometer. Total lime ($CaCO_3$) was determined by a rapid approximate method (50, p. 1). Organic matter was determined in the surface horizons by Walkley's rapid method (70, 71).

Soil-water extracts of all samples were analyzed. Calcium and magnesium were determined by Versenate (12, 13) titration. Sodium and potassium were determined using the Perkin-Elmer Model 52 flame photometer. Chloride was determined by titration with silver nitrate (58, p. 98). Carbonate and bicarbonate ions were determined by titration with sulfuric acid (5). Sulfate was determined by precipitation with barium (50, p. 550).

Soil pretreatment

All soil samples on which mechanical analysis or mineralogical determinations were made were treated with 30 percent hydrogen peroxide (34, p.168) to remove organic matter. Samples so treated are called "non-acid treated samples" in this thesis. Subsamples of the non-acid treated samples were treated with one normal hydrochloric acid to remove carbonates. The acid was added to a 1:2 soil and water mixture dropwise until a pH of 4 to 4.5 (brome phenol blue external indicator) was maintained. Samples treated to remove both organic matter and carbonates are called "acid treated samples" in this thesis. Although this H_2O_2-HCl treatment dissolved some of the silica (6) the quantity dissolved and effect on the clay minerals was considered insignificant.

Clay minerals were further concentrated by sedimentation. Twenty grams of treated soil was placed in an eight ounce nursing bottle with eight ounces of distilled water. Twelve cc. of 0.5 N. NH_4O was added as a dispersing agent and the sample shaken overnight in a mechanical shaker. The sample was dispersed in two liters of distilled water. Samples of clay materials less than two microns in diameter were collected by sedimentation. The suspension was siphoned off, the liquid evaporated, and the remaining material used for mineralogical studies.

Particle density determinations were made on some of these clay separates and the resulting density used in all calculations where particle density was used. The density of the clay separates was found to be 2.65 grams per cubic cm.

Mechanical analysis

Gravenor (20) has shown that a break in mechanical composition of overlying horizons can mean a change in type of sediment. Mechanical analyses were made of all samples in order to characterize the textural features of the horizons and profiles. Mechanical analyses were made on both acid treated samples and non-acid treated samples, attempting to ascertain the principal sizes of carbonate minerals, as well as other soil minerals.

The pipette method of mechanical analysis (48) was used because this method is more accurate (11) than the hydrometer method. The procedure followed consisted of: placing a soil sample (10 to 11 grams, accurately weighed) in an eight ounce nursing bottle, to which was added 200 ml. of distilled water. Five ml. of 0.5 N. sodium hexametaphosphate (67) was added as a dispersing agent. The bottle was stoppered and placed in a mechanical shaker. After overnight shaking the sample was washed through a 300 mesh sieve into a hydrometer cylinder. The sand fraction, retained on the sieve, was dried at 105° C. and weighed. The sample in the cylinder was diluted to about 1100 ml. The cylinder was placed in a constant temperature bath and allowed to come to temperature.

The sample was agitated for at least one minute by end over end movement and replaced in the constant temperature bath. The suspension was then sampled at intervals with a Lowery pipette. The sampled suspension was dried to constant weight at 110° C. and weighed, the weight being corrected for a blank determination. Oden curves (3) were drawn and particle size distributions calculated.

Differential thermal analysis

The differential thermal method of analysis has as its basis the heat effects accompanying the reactions which occur in many substances upon heating. When a material is heated, it may undergo one or more reactions which either give off heat (exothermic) or absorb heat (endothermic). Many minerals undergo characteristic reactions, such as loss of water (dehydration), loss of hydroxyl ions (dehydroxylization), breakdown of the crystal structure, mineral inversion, crystalization, etc., at known temperatures, and these reactions form the basis for their identification. Clay minerals are hydrated alumina-silicates which lose water of constitution (usually hydroxyl groups in the crystal structure) when heated. This loss is usually an endothermic process characteristic of the particular clay. Recrystalization processes often occur at higher temperatures, giving rise to exothermic effects. Grim (21, p. 26) has reviewed the history of differential thermal analysis.

Small quantities of the substance to be examined, and a neutral substance, were packed separately into two adjacent sample holders and heated in an electric furnace. A thermocouple with one junction in each substance recorded any temperature differences arising from reactions in the one under investigation. A separate thermocouple recorded the temperature of either the neutral substance or the sample holder.

A differential thermal-analysis apparatus patterned after one used by Norton (53) was constructed for use in this study. The apparatus consisted of (a) power control unit, (b) a furnace, (c) a sample holder, and (d) temperature measuring devices.

Power control unit.--Two auto transformers ("transtats"), one Bodine constant speed motor and one 150-to-1 reduction gear composed the components of the power control unit. The motor was connected to the shaft of one of the stranstats through the reduction gear. Figure 1 is a schematic sketch of the thermal analysis control circuit. The two transtats are labeled "A" and "B". Transtat "B" was driven by the constant speed motor through a speed reducing gear. The reduction gears were designed so that one revolution of the rotor of transtat "B" required 95 minutes.

The input of transtat "B" was connected to transtat "A". The input of transat "A" was connected to the 110-115 volt supply. With sliding contact 2' set at the starting point of its travel, that is at the left end of "B" in the sketch, the voltage applied to the furnace was the voltage drop across that part of "A" lying between terminal 1 and slider contact 2. The voltage drop across the remainder of "A", that between 2 and 4, was applied as the input of transtat "B". As the sliding 2' was driven from left to right by the driving mechanism the remainder of the full voltage across "A" was gradually applied to the furnace.

The transtats are made with a terminal "3" tapped in a few turns from one end of the winding so when an input voltage is applied across 1-3, the

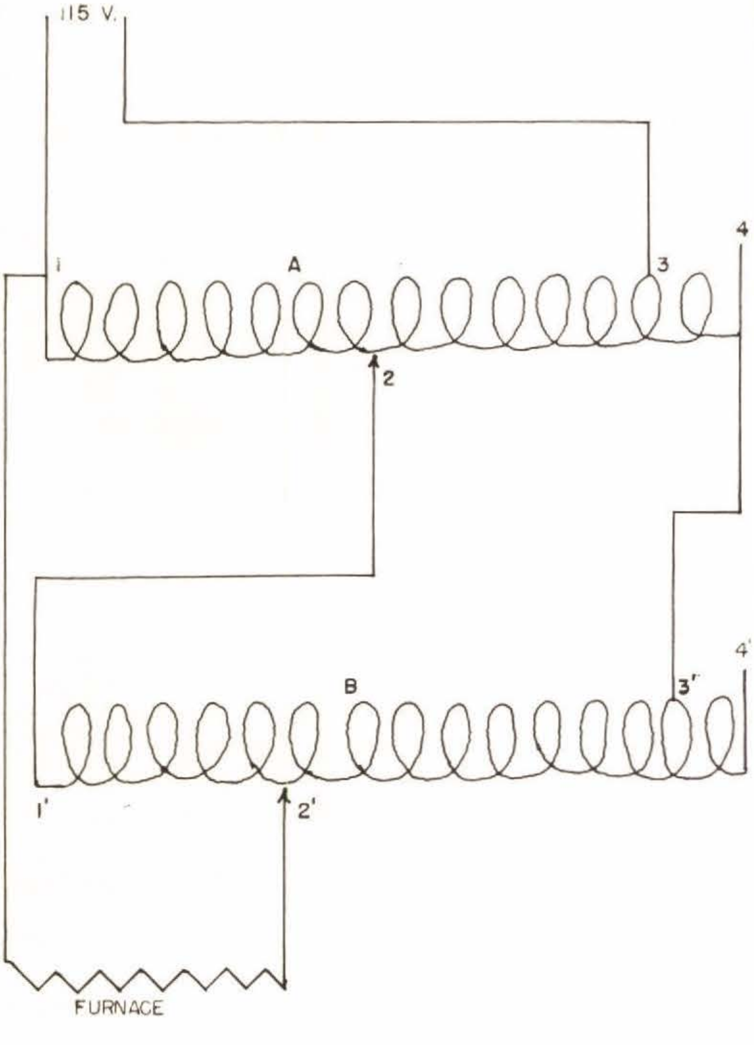

Figure 1. Schematic diagram of the differential thermal analysis control circuit

maximum output is about 130 volts. With the input voltage across 1-4, the maximum output voltage was the same as the input voltage. The best arrangement for connections 3 and 4 and 3' and 4' was found by experiment, as well as the best point at which 2 was set on transtat "A". A limit switch was located on the shaft of transtat "B" to cut off the power when the transtat commutator reaches the end of travel, to prevent breakage of the transtat.

The heating rate in differential thermal analysis should be constant through the range to be investigated. This facilitates measurement and makes it possible to compare thermograms obtained on different instruments. The curvature of the heating rate curve was controlled by the setting of transtat "A". If the temperature-time curve was convex upwards the starting voltage was too high, while if the curve was concave upwards, the starting voltage was too low. By changing the leads, heating rates of from 8 to 16 degrees C. per minute were possible. A heating rate of 11.3^{0} C. per minute was used in this study.

Furnace.--The furnace consisted of a heating element enclosed in a large insulator. The furnace was mounted on a track so that it would slide forward over the sample holder.

The heating unit was a porcelain tube, two inches in diameter and 10 inches long, wrapped with 54 turns of 22 gauge nicrome wire wound around the central six inches of the tube. This tube was enclosed in a cylinder of refractory bricks, 10 inches in diameter and eight inches long. A sheet metal shell enclosed the bricks. One inch transite formed the ends of the furnace. A refractory brick plug was placed in one end of the procelain tube. The furnace was bolted to brass end plates. The lower edges of the end plates were grooved to fit a track. The track consisted of two parallel 3/4 inch steel rods welded on a steel plate which formed the base.

Sample holder.--Several types of sample holders are described in the literature (21, p. 201; 22, 25, 29, 66). All sample holders incorporate certain essential features: a holder for the substance being investigated, and a similar holder for a similar amount of inert substance. The main differences in sample holders are: bulk and kind of material, and method of measure furnace temperature. Stone (66) showed that, although holders of low heat capacities better show the individual factors characteristic of the sample, solid holders of larger heat capacity tend to smooth out any drift and give a neater and more easily interpreted thermogram with respect to chemical reactions.

The sample holder used in this investigation was designed after the holders described by Norton (53), and by Hauth and Davidson (29). The holder was made from a chrome-nickel block one inch in diameter and 5/8 inch in height. Chrome-nickel alloys make good sample holders because they show little scaling and have no Curie points between 25° and 1200° C. Two vertical holes $\frac{1}{4}$ inch in diameter and $\frac{1}{2}$ inch deep were drilled midway between the ends and parallel to the center line. These holes were to hold the sample and the inert references material. A 1/8 inch horizontal hole 3/8 inch long was drilled at the center point on one end. The bead of one thermocouple was placed in this hole, so that it was midway between the two $\frac{1}{4}$ inch holes. Two horizontal 3/32 inch in diameter holes were drilled the length of the sample holder. These

3/32 inch holes made it possible to place thermocouple beads in the center of the sample and reference material.

Temperature measurement.--All difference temperatures and furnace temperatures were measured with chromel-alumnel thermocouples. The thermocouple used to measure difference temperatures had one junction in the center of each of the vertical holes in the sample holder. The thermocouples were insulated from the sample holder with alumina tubes. One junction of the temperature measuring thermocouple was placed in the horizontal hole midway between the sample and the inert material. The second junction of the temperature measuring thermocouple was inside a double-walled glass tube located about four feet away from the furnace. This location of the junction (not in a melting ice bath) probably caused slight errors in the recording of furnace temperatures, but the magnitude of these errors was insignificant compared with the differences being investigated. The thermocouple leads led to reflecting galvanometers. Temperature differences between thermocouple junctions gave a resulting e.m.f., the magnitude of which was proportional to the temperature difference and the direction of which is dependent upon the relative temperatures. The relative magnitude of galvanometer deflections was controlled by variable resistances in series with the thermocouple. The sensitivity of the apparatus was controlled by a variable resistance in series with the galvanometer. The deflections of the galvanometers were recorded manually, recording the reflections reflected on meter sticks. Individual deflection records were made every 15 seconds to two minutes.

Plate 4 is a photograph of the differential thermal analysis furnace

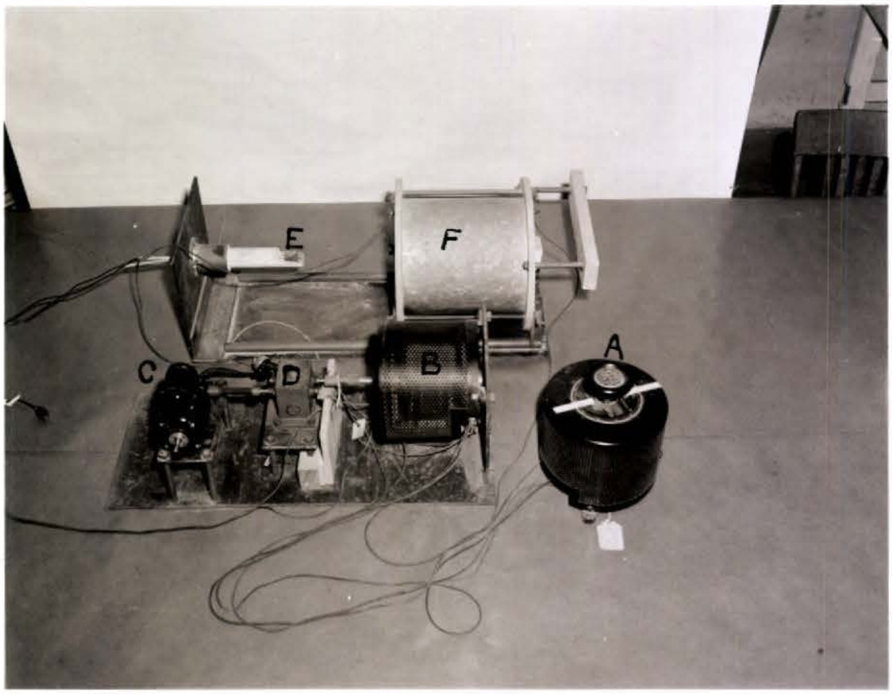

Plate 4. Differential thermal analysis furnace.

and control units used in this study. A and B were transtats. C is the Bodine constant speed motor. D is a reduction gear. E is the sample holder. F is the metal cylinder enclosing the furnace.

For differential thermal analysis the sample holder was filled by pouring the sample into the holder and lightly tamping with a glass stirring rod (25). It was found that much care was needed in filling the sample holder in order to obtain reproducible thermograms. The filling and tamping operations had to be uniform so that the samples were similarly packed. If replications were not similarly packed the thermograms were not reproducible, the areas of loops not being consistent.

The series (A-A) of dots in Figure 2 represents a thermogram as initially plotted from galvanometer readings. Each dot represents an individual observation. Line B-B in Figure 2 is the thermogram produced by connecting the dots in A-A. It was found that when an inert substance (calcined Al_2O_3) was placed in both receptacles of the sample holder, the temperature within the unknown holder rose slowly, line C-C of Figure 2. To correct for the varying temperature differences between receptacles in the sample holder, raw thermograms (as B-B) were plotted over the correction curve (C-C), the distances D-D measured, and the thermograms replotted as the corrected thermogram E-E in Figure 2. All the thermograms presented have been corrected in this manner.

The vertical scale of the thermogram (D-D), Figure 2, is the relative temperature difference between the sample (clay material) and the inert reference material (calcined Al_2O_3). Since the temperature differences between sample and reference material was not measured on any

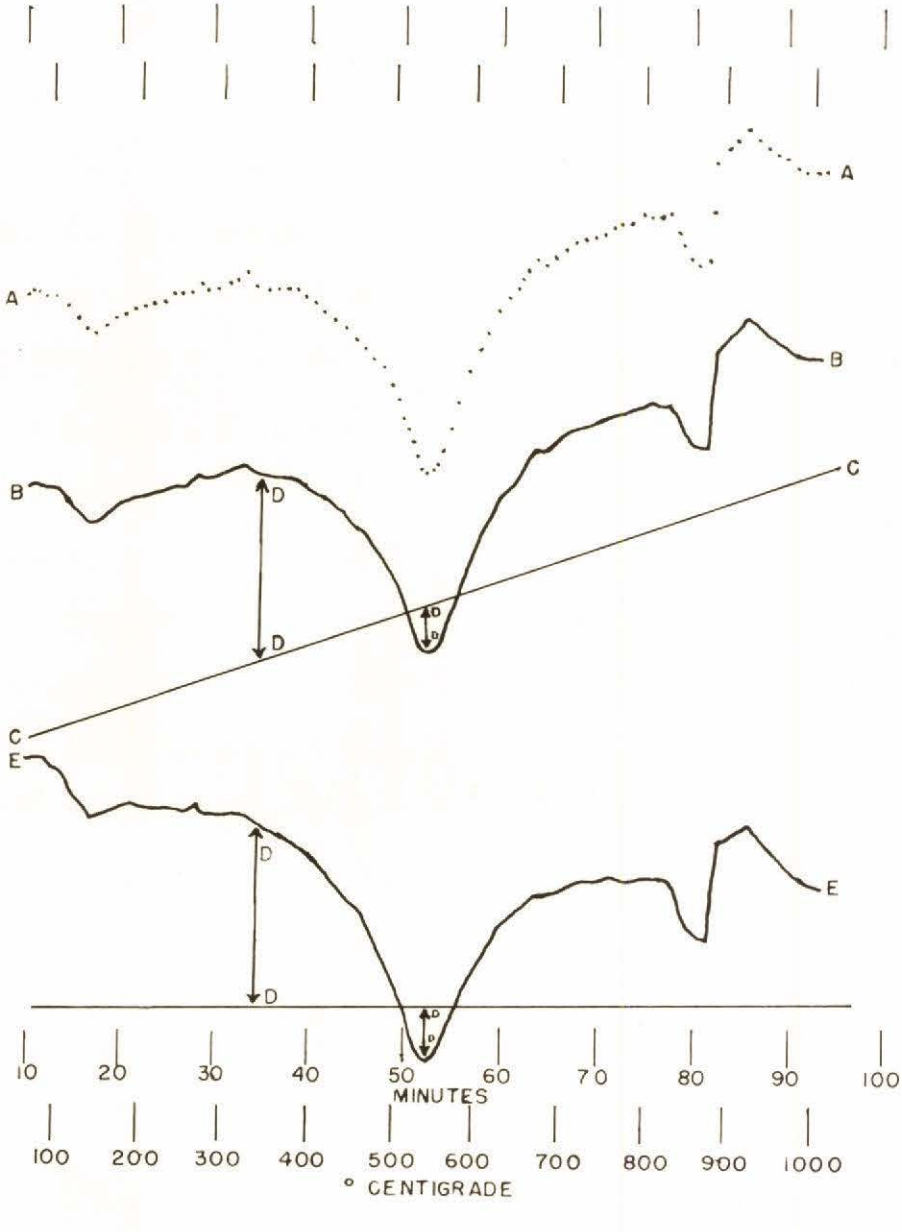

Figure 2. Graphic correction method used to correct DTA data for sample holder differences

temperature scale no units can be assigned to these distances in the thermograms.

In Figure 2 the horizontal scale for line B-B is minutes, while the scale for line E-E is °C. Temperature calibration of the differential thermal analysis apparatus was accomplished by comparing thermograms of heated samples with thermograms (27, 28, 46) in the literature of similar substances. The thermograms developed for calibration purposes are shown in Figure 3. The montmorillonite and halloysite samples were obtained from Wards Natural Science Supply Company. Thermograms of similar samples from the same deposits are given by Kerr et al (45, 56). The K_2SO_4 and K_2CO_3 samples were "C.P." samples and were compared with thermograms (27, 28) published by Gruver.

It was found that the heating rate was 11.3° C. per minute. Table 3 gives the temperature given in the literature and the comparable temperature of the peaks of DTA loops as found when calculated at a heating rate of 11.3° C. Table 3, in effect, shows the relative error of thermogram temperatures in this study. The calculated temperatures of Table 3 are based on the formula:

$$R= \frac{T-22}{D-5.5}$$

R is the heating rate of 11.3° C. per minute.

T is the temperature in °C.

D is the displacement along the heating rate curve (furnace temperature curve) at with "T" occurs.

22 is the assumed room temperature in °C.

5.5 is the intersect of the straight line extension of the heating

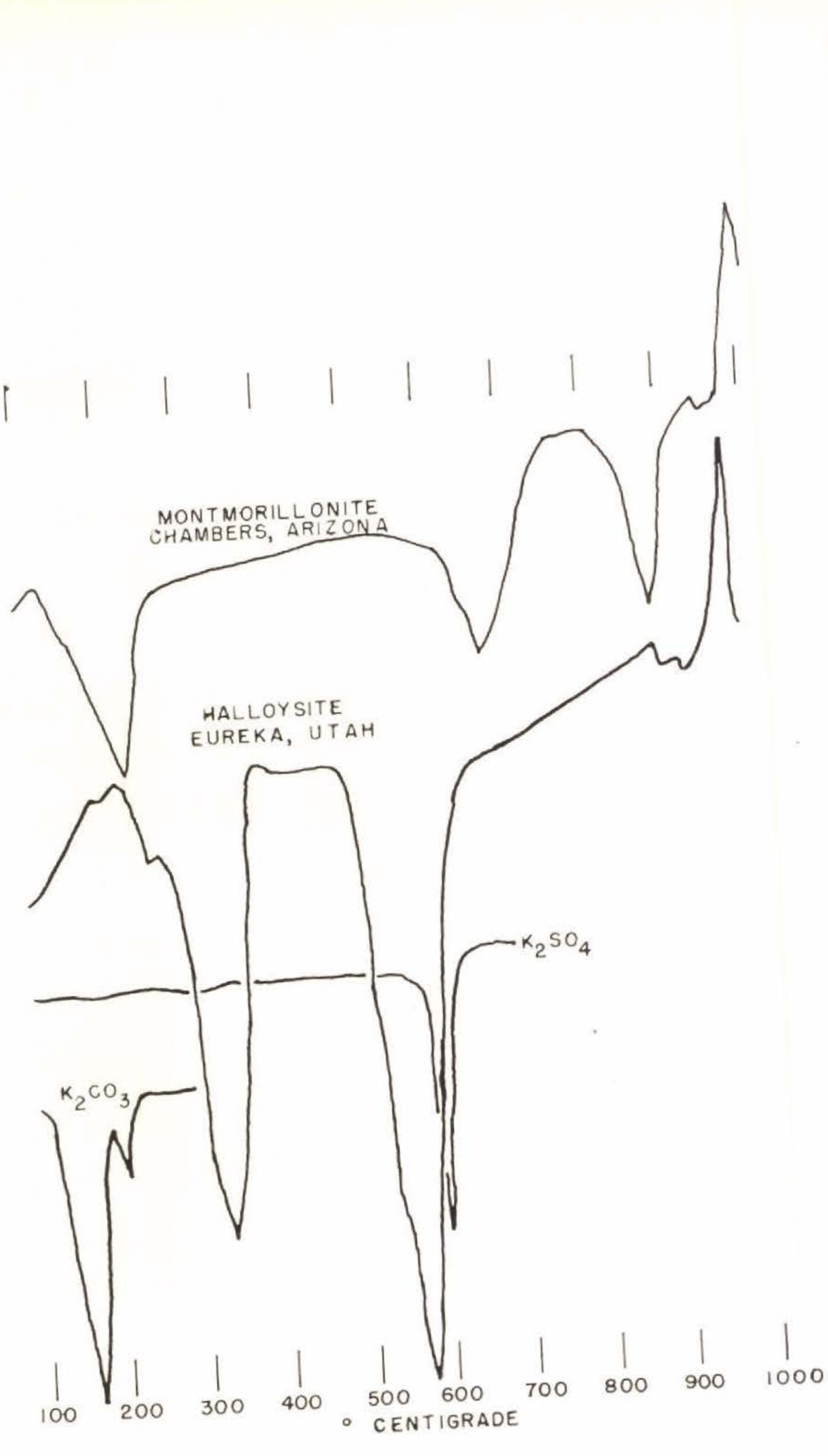

Figure 3. Thermograms used to calibrate the DTA apparatus

Table 3. Relative error of thermogram temperatures in this study

Substance	Literature reference	Peak temperature from literature	Peak temperature calculated
K_2CO_3	(27)	160° C.	165° C.
Halloysite	(45)	595° C.	583° C
K_2SO_4	(28)	600°C.	596° C.
Montmorillonite	(46)	670° C.	673° C.
Montmorillonite	(46)	880° C.	888° C.
Halloysite	(46)	990° C.	978° C.
Montmorillonite	(46)	1000° C.	1002° C.

rate curve.

Thermogram loops may be separated into three groups according to temperature. The low-temperature loop, covering up to 300° C., is dependent on the clay mineral species for its presence; on the type and amount of exchange cations for its shape; and on the moisture content prior to analysis for its size (30, 54 p. 153). Vermiculite has two strong low temperature endothermic loops indicating that water is removed in two steps.

The midrange endothermic loop is usually associated with the loss of hydroxyls from the octahedral layer, and varies considerably from clay to clay. This midrange loop is usually thought to be irreversible. Grim and Bradley (24) have shown that clays heated to a temperature just below the end of their thermogram dehydration loop will reabsorb a considerable amount of water as hydroxyls when exposed to moist air over a period of time.

High temperature loops are the combined effect of both endothermic and exothermic reactions. Most of the three-layer lattice clay minerals undergo an endothermic reaction associated with the final breakdown of the mineral lattice (54, p. 154). High temperature loops are accompanied by the formation of either spinel, mullite, quartz, cristobalite (9) and sometimes olivine (10, p. 192). The species of exchange ion effects the variety of mineral formed. Some magnesium-bearing minerals, such as talc and chlorite, lose their hydroxyls at temperatures somewhat higher than encountered in materials consisting primarily of aluminum in the octahedral layer. The high-temperature zone for members of the illite and montmorillonite group is largely controlled by the chemical composition of the mineral.

Clay mineral identification was accomplished by comparing thermograms of samples investigated with thermograms published in the literature (1, 9, 10, 16, 17, 22, 24, 26, 27, 28, 29, 41, 42, 45, 59, 63, 66). Table 4 shows thermogram loop peak ranges for several materials.

X-ray analysis

A crystal may be thought of as consisting of a multitude of layers or planes of atoms, each plane separated from its neighbor by a space, d, characteristic of the crystal. These many layers may cooperate in such a way that the atomic planes appear to an incident X-ray beam very much the same as does an ordinary mirror to a beam of light. If, then, a monochromatic beam of X-rays of wave length $N\lambda$ is incident on these atomic planes at an angle θ, reflections will occur provided in addition, the following condition is satisfied:

$$N\lambda = 2\,d\,\sin\theta$$

In this, the Bragg equation, N is an integer, called the order of the reflection and in practice rarely exceeds 4 or 5. If the incident beam is heterogeneous in wave length, only those wave lengths satisfying this equation will be reflected for any given angle of incidence.

Since X-ray diffraction patterns are related to crystal structure, X-ray identification is, in principal, better suited to recognition of structural groups and varieties (54, p. 119), than of chemical species. It being rather easy to differentiate between kaolinite, mica, and chlorite with basil spacings of 7.2Å, 10Å and 14Å respectively; but very difficult to differentiate between mica and illite, both having a basil

Table 4. Characteristic DTA loops of several minerals

Substance	Direction	°C.	
Quartz	Endothermic	573	Weak
Gibbsite	Endothermic	300–350	Strong
Illite	Endothermic	100–200	Weak
	Endothermic	500–600	
	Endothermic	850–900	Small
	Exothermic	875–1025	Weak
Kaolinite	Endothermic	550–600	Strong
	Exothermic	950–1000	Strong, moderately
Halloysite	Endothermic	100–200	Hydrated
	Endothermic	550–600	Strong
	Exothermic	950–1000	Moderately strong
Montmorillonite	Endothermic	100–250	Hydrated
	Endothermic	600–700	Strong
	Endothermic	900	
	Exothermic	1000	
Ferric iron hydrate	Exothermic	400	
Muscovite	Exothermic	300–400	Weak, several small peaks
	Endothermic	750–950	
Talc	Endothermic	825–1000	
Pyrophyllite	Endothermic	600–850	
Attapulgite (Polygorskite)	Endothermic	100–200	
	Endothermic	350–600	Doublet
	Endothermic	750–850	Weak
	Exothermic	850–1000	
Amorphous hydrous aluminum silicate	Endothermic	250	
	Exothermic	925	Not always present
Chlorite	Endothermic	550–600	
	Endothermic	800	
	Exothermic	7800	Not always present

Table 4 (continued)

Substance	Direction	°C	
Vermiculite	Endothermic	153	
	Endothermic	115	Weak
	Endothermic	272	
	Endothermic	850	Broad and shallow
	Exothermic	882	
Calcite	Endothermic	750–900	
Magnesite	Endothermic	650–725	
Dolomite	Endothermic	700–850	
	Endothermic	825–950	
Goethite	Endothermic	400–450	
Limonite	Endothermic	300–350	

spacing of 10Å.

The X-ray diffraction apparatus used in this investigation employed a gas filled tube with an iron target, and a manganese dioxide filter. This supplied filtered Fe radiation with a wave length of 1.934Å. The X-ray tube window was composed of a thin lithium sheet about 0.1 cm. thick. The camera was based on the Deybe-Hull-Sherrer powder method. The sample was coated on a glass thread-like rod. The diameter of the rod and sample was 0.3 to 0.5 mm. The end of the sample rod was centered in modeling clay. The modeling clay was on the end of the shaft of a small electric motor which rotated the sample during exposure. X-ray film was placed along the inside of the camera, so that it formed a circle around the sample. The diameter of the camera was 2.24 inches.

Mineral identification was accomplished by comparing the powder diffraction spacings and intensities observed with those given in the literature (10, 43, 47, 68).

EXPERIMENTAL RESULTS

Chemical analysis

All chemical analyses were made by personnel of the Utah Agricultural Experiment Station-Soil Conservation Service cooperative soil testing laboratory, Logan, Utah.

Table 5 summarizes the chemical analyses of the three Payson profiles. All profiles studied contained excessive soluble salts. Exchangeable sodium was high in all profiles. All three profiles were saline-alkali (59, p. 5). Profiles 2 and 3 are more mature than profile 4, as shown by the degree of lime leaching from the A_1 horizons. Each of the profiles investigated had sulfate accumulations, lower than the lime accumulations in the same profiles, indicating that the present dominant water movement within these profiles is downward. Several investigators (60, 74) have reported accumulations of exchangeable magnesium in solonetz soils. In this investigation it was impossible to determine the quantity of exchangeable magnesium (7) because of the lime present. Samples 20 and 21 had a very sharp break in lime content.

Mechanical analysis

Particle size distribution determinations were made on both acid treated samples and non-acid treated samples. Sand was collected on a 300 mesh sieve. Silt and clay were determined using a pipette method similar to that of Kilmer and Alexander (48), plotting Oden curves and tangents to the Oden curves (3), to obtain the distributions. Tables 6 and 7 give the results of these mechanical analyses with an accuracy

Table 5a. Chemical analysis data of three profiles of Payson soils

Sample no.	Depth inches	pH paste	EC_ex10 @25° C.	Organic matter %	Lime %	TDS %
20	0–5½	8.2	0.8	2.2	3	0.052
21	5½–6	8.5	2.6	1.4	35	0.133
22	6–10	9.1	6.0		34	0.312
23	10–11½	9.6	9.5		24	0.540
24	11½–18	9.8	11.3		19	0.532
25	18–22	9.7	10.3		24	0.567
26	22–30	9.5	6.2		20	0.466
30	0–6	7.9	0.8	2.6	1	0.065
31	6–9½	8.5	2.6	1.0	11	0.152
32	9½–17	8.8	3.9		28	0.289
33	17–27	9.4	6.5		13	0.382
40	0–4	8.3	7.2	2.1	15	0.259
41	4–7	9.8	14.2	0.6	24	0.628
42	7–14	10.2	13.9		22	0.923
43	14–20	10.2	16.8		22	1.029
44	20–30	10.2	14.4		22	1.100

Table 5b.

Sample no.	Exchangeable cations Na meq./100g.	Na %	K %	Cation exchange capacity Whole soil meq./100g.	Acid treated clay meq./100g
20	0.36	2	2.1	14.9	
21	2.5	22	2.5	11.1	
22	9.3	54	4.3	17.2	
23	13.0	70	4.5	18.5	
24	10.4	61	3.7	17.0	
25	10.2	65	3.5	15.6	
26	12.0	65	3.6	18.5	
30	0.16	1	2.3	14.8	
31	3.4	23	3.4	14.8	
32	9.3	51	3.2	18.2	
33	11.6	77	1.8	15.1	
40	3.3	31	1.5	10.7	46.8
41	16.2	89	2.3	18.2	50.0
42	17.7	83	1.9	21.3	57.0
43	17.4	95	1.6	18.4	55.0
44	18.3	95	1.3	19.2	59.0

Table 5c. Analysis of 1:, soil:water extract

Sample no.	Ca epm	Mg epm	Na epm	K epm	Cl epm	SO_4 epm	CO_3 epm	HCO_3 epm	Na %
20	1.41	1.21	2	1.74	0.3	0.54	0	7.24	31
21	0.81	0.31	14	2.31	4.89	1.41	0	14.0	80
22	1.09	0.41	42	3.13	23.9	1.97	1.81	22.6	90
23	0.85	0.27	79	4.00	46.9	6.85	9.03	21.3	94
24	1.62	0.77	81	3.44	60.8	7.71	0	22.6	93
25	1.25	1.22	91	3.38	62.5	7.54	0	19.4	94
26	0.85	1.77	74	2.87	53.9	7.33	0	20.2	93
30	0.65	0.1	3	1.08	0.44	0.73	0	5.25	62
31	0.65	0.17	17	1.05	3.9	2.06	0	14.9	90
32	0.77	0.28	38	1.31	14.1	4.80	1.81	24.4	94
33	0.81	0.2	51	1.05	24.8	7.88	3.63	19.9	96
40	2.3	0.48	33	1.21	18.8	2.36	0	18.6	92
41	5.25	1.0	94	1.54	62.5	7.75	0	33.0	92
42	0.89	0.56	152	1.08	78.6	15.81	16.5	30.3	98
43	0.77	0.2	160	1.15	92.7	22.19	22.7	26.7	99
44	0.81	0.91	180	1.38	89.7	20.73	36.3	22.6	98

Abbreviations:

$EC_e 10^3 @ 25^\circ$ C. - Electrical conductivity of the saturation extract in millimhos per cm. at 25° C.

$\frac{\text{meq.}}{\text{100g}}$ - Milliequivalent per 100 grams of air dry soil.

epm - Equivalents per million in a 1:5 soil:water extract.

of 1 percent, all results rounded to the nearest 0.5 percent. Figures 4, 5, and 6 graphically depict this same data. The lime contents of the same horizons are also plotted on the same figures.

Profile 2 has a sharp change in texture between horizons 23 and 24, especially in the sand fractions. Horizon 24 has 11.5 percent more sand than horizon 23 and 6.5 percent more sand than horizon 25. These differences indicate depositional difference or stratification of the parent material at site 2. Profile 3 has no abnormal changes in texture. Profile 4 reflected its immature state texturally. Each profile had a clay accumulation in the B horizons, the amount of accumulation paralleling the apparent maturity of the profile as manifested by lime content and distribution. The lime content of the horizons, the clay content of the same horizons, in the non-acid treated samples, show a high degree of correlation.

The mechanical analysis of the acid treated samples gave results similar to the non-acid treated samples for the sand fraction. The acid treatment reduced the amounts of clay in the B and C horizons, and caused an apparent increase of sand content in the same horizons. Much of the lime must be crystalized into particles falling within the clay size range. From the mechanical analysis of the samples 20 and 30, low lime A_1 horizons, it appears that more than just lime was dissolved by the acid. Clay accumulations occur in those horizons containing lime accumulation. The acid treatment to remove lime dissolved most of the minerals causing the apparent clay accumulations.

Differential thermal analysis

Thermograms were made of clay fractions from acid treated soils from

Table 6. Textural composition data of three non-acid treated Payson soil profiles

Sample no.	Sand	Silt		Clay	Texture
	.05 mm. %	.05-.005 mm. %	.005 .002 mm. %	.002 mm.	
20	34.0	33.5	14.5	18.0	Loam
21	25.0	30.0	24.0	20.5	Silt loam
22	20.0	29.5	20.0	30.5	Clay loam
23	17.0	33.0	20.5	29.5	Silty clay loam
24	28.5	35.0	18.5	20.5	Silt loam
25	22.0	41.5	20.0	16.5	Silt loam
26	33.0	37.5	20.0	19.0	Silt loam
30	29.0	47.0	15.5	8.5	Silt loam
31	25.0	33.5	11.0	31.0	Clay loam
32	22.0	32.0	11.0	35.5	Clay loam
33	24.0	28.5	8.0	29.5	Clay loam
40	31.0	37.0	6.5	25.5	Loam
41	16.5	30.5	12.0	40.0	Silty clay
42	10.0	39.5	11.0	39.0	Silty clay loam
43	11.5	88.5	14.5	35.5	Silty clay loam
44	9.0	34.0	23.0	34.0	Silty clay loam

Table 7. Textural composition data of three "acid treated" Payson soil profiles

Sample no.	Sand .05 mm. %	Silt		Clay .002 mm.	Texture
		.05-.005 mm. %	.005 .002 mm. %		
20	32.0	28.0	26.0	14.0	Silt loam
21	30.5	28.5	25.0	16.0	Loam
22	27.0	32.0	24.5	17.5	Silt loam
23	25.0	28.5	22.0	24.0	Silt loam
24	28.0	23.5	21.0	27.0	Clay loam
25	22.5	26.5	30.0	30.5	Silt loam
26	21.0	35.0	22.5	21.0	Silt loam
30	29.0	44.5	13.5	13.0	Silt loam
31	24.0	35.0	24.0	16.5	Silt loam
32	25.0	41.0	19.5	14.5	Silt loam
33	34.5	19.5	21.5	24.5	Silt loam
40	29.5	32.5	22.5	15.5	Silt loam
41	18.0	29.0	30.0	23.0	Silt loam
42	11.0	33.5	22.5	33.0	Silty clay loam
43	10.5	40.5	15.0	33.5	Silty clay loam
44	10.5	44.0	12.5	33.0	Silty clay loam

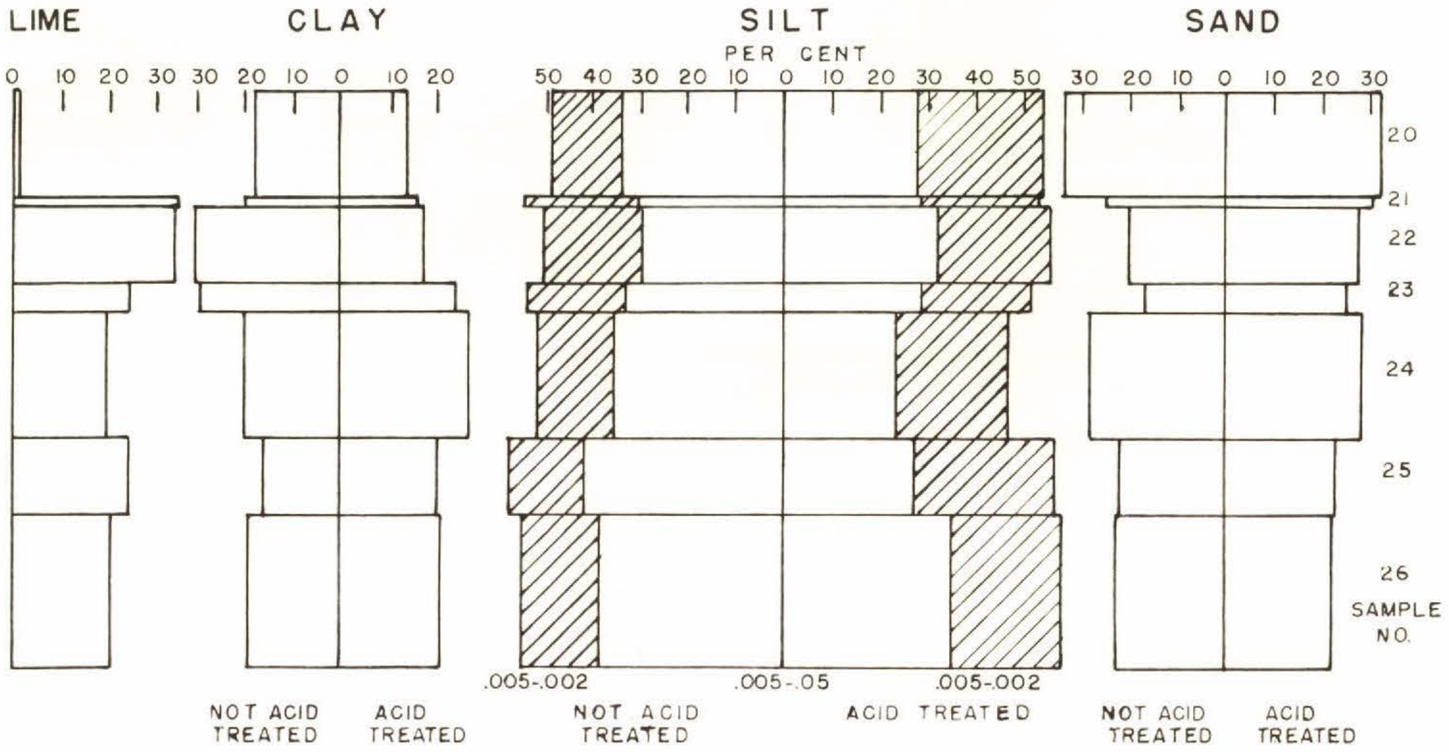

Figure 4. Size distribution of soil particles in profile 2

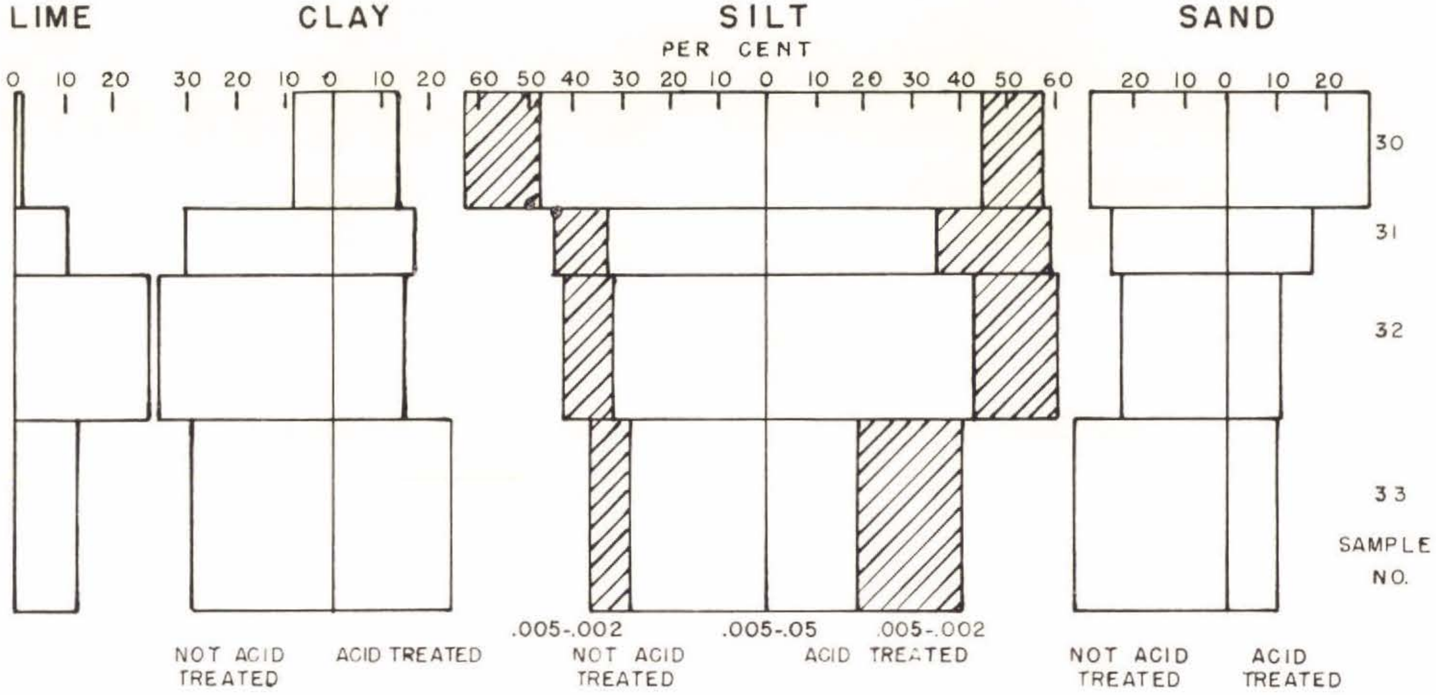

Figure 5. Size distribution of soil particles in profile 3

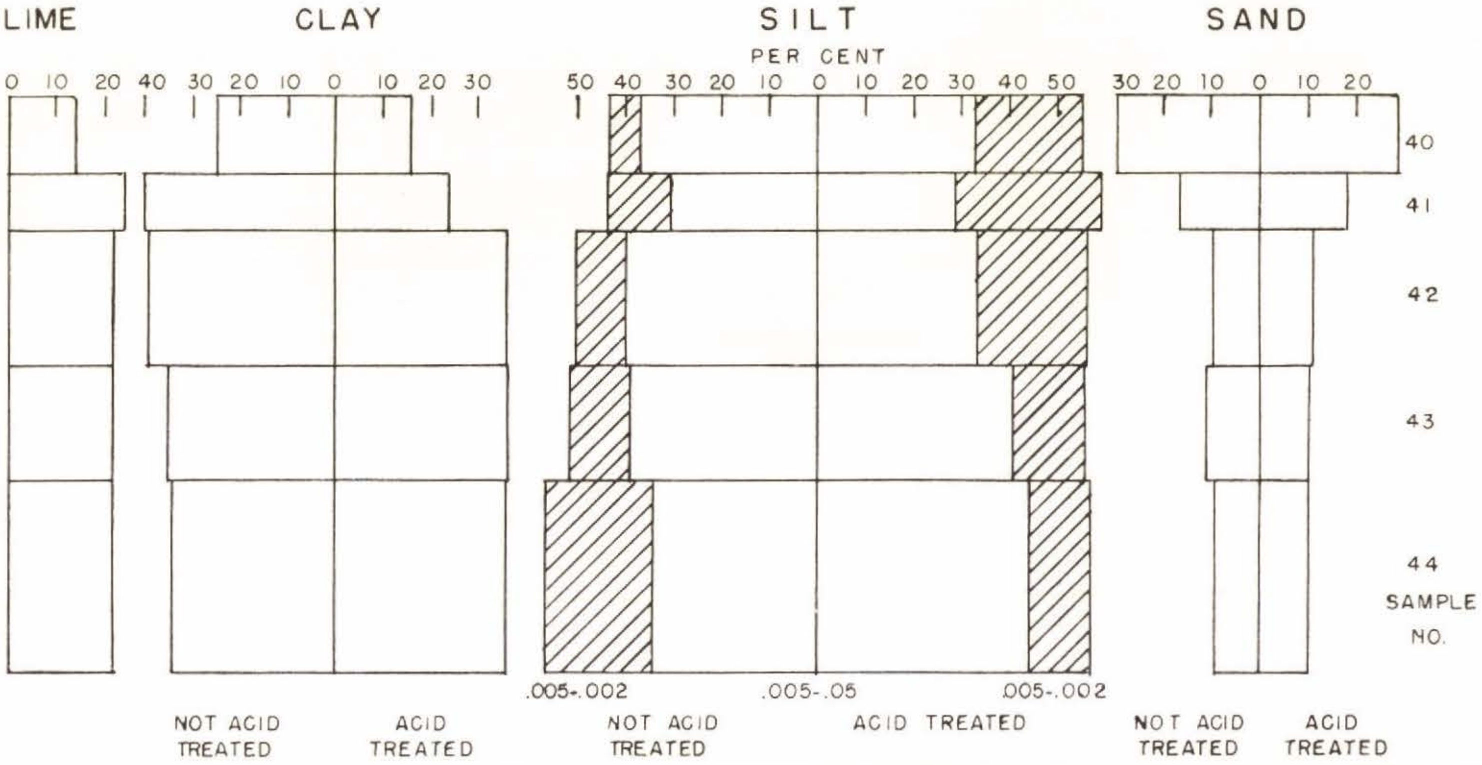

Figure 6. Size distribution of soil particles in profile 4

all horizons. Thermograms were also made of clay fractions from non-acid treated soils from several horizons. All soils had been treated with hydrogen peroxide to remove organic matter.

Figure 7 gives thermograms of the acid treated clay samples from profile 2. The sharp exothermic peaks in samples 20 and 21 at 475° C. were caused by organic matter, the peroxide treatment having not removed all of the organic matter. The endothermic loops at 100 to 250°C. and endothermic peaks at 540° C. are typical illite characteristics. The small endothermic loops between 600°C. and 700° C. suggest the presence of small amounts of montmorillonite. Comparing these loops with thermograms of Grim and Rowland (25), prepared from known mixtures of illite and montmorillonite, indicate that they represent less than 10 percent montmorillonite. The clay materials of profile 2, identifiable by differential thermal analysis of acid treated samples, are principally illite with a small amount of montmorillonite.

The thermograms shown in Figure 8 are of the acid treated clay samples from profile 3. The low temperature endothermic loops between 100° C. and endothermic peaks at 550° C. and 850° C. and exothermic peaks at 910° C. are typical illite characteristics. A small endothermic loop at 700° C. is present indicating the presence of montmorillonite. Comparing with quantitative curves (25) indicates that about 5 percent of the clay materials in profile 3 is montmorillonite.

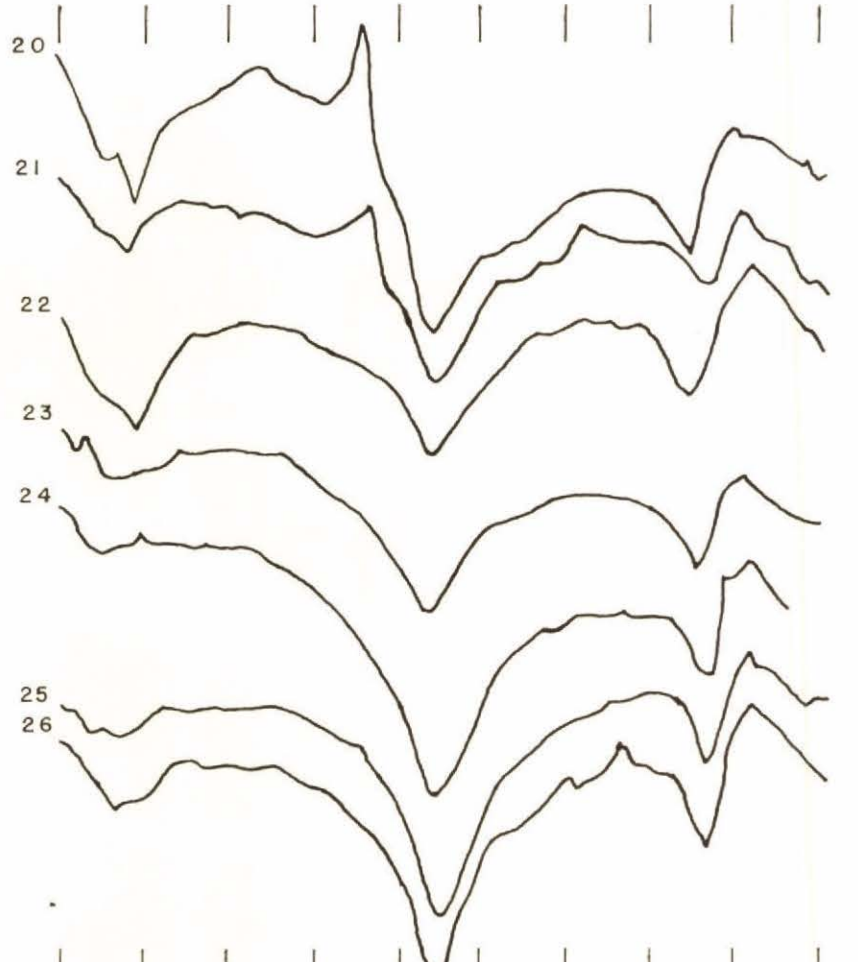

Figure 7. Thermograms of acid treated clay samples from profile 2

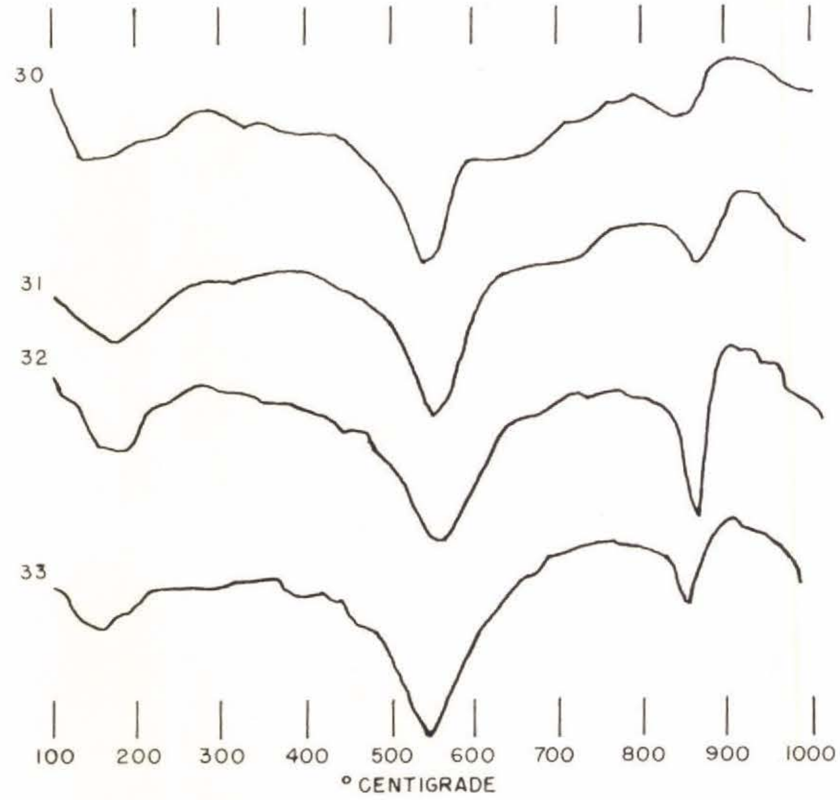

Figure 8. Thermograms of acid treated clay samples from profile 3

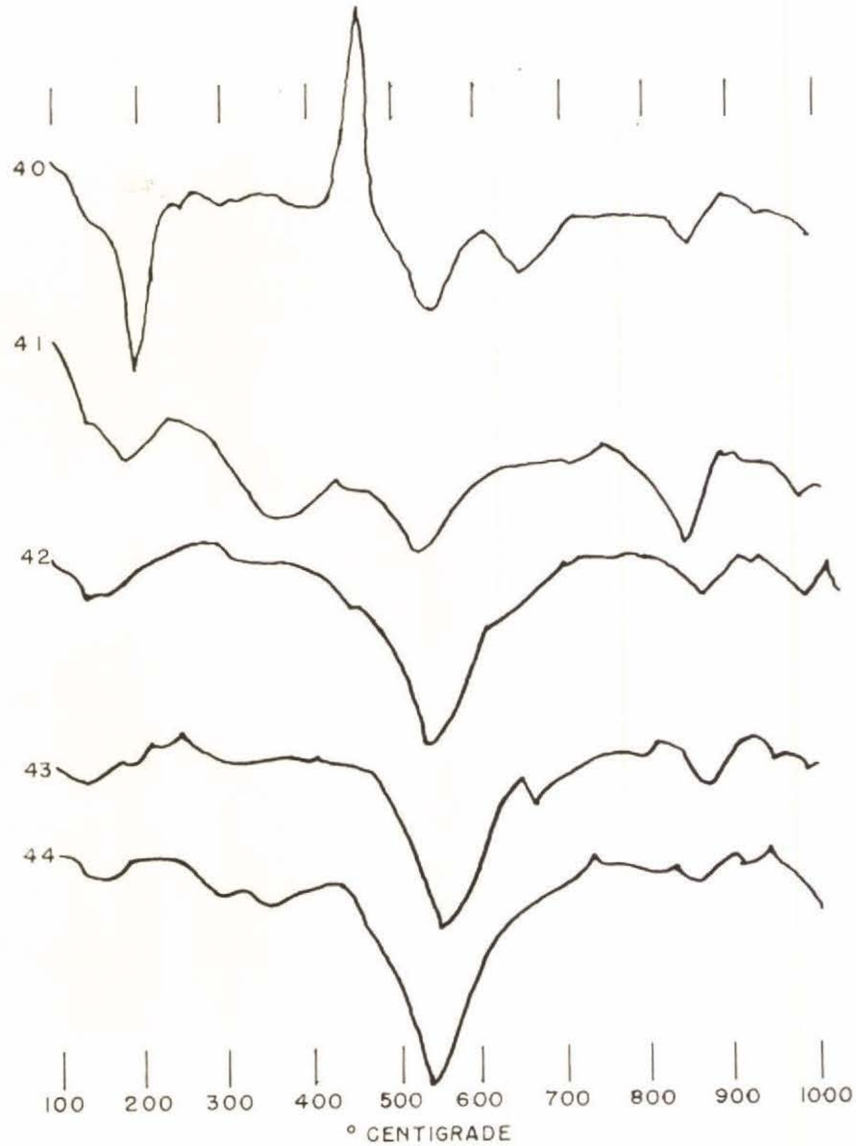

Figure 9. Thermograms of acid treated clay samples from profile 4

Thermograms of the acid-treated clay samples from site 4 are shown in Figure 9. The exothermic peak of sample 40 at 470° C. is probably due to organic matter. Otherwise the curves are typical of illite-montmorillonite mixtures. It is interesting to note that by comparison with Grims curves (25), sample number 40 contains between 25 and 50 percent montmorillonite, while the deeper horizons contain less than 10 percent montmorillonite.

Thermograms of non-acid treated clay samples number 20 and 25 are shown in Figure 10. Essentially, the non-acid treated clay samples and acid treated clay samples produced the same thermograms. It is interesting to note the small differences between thermograms. The thermogram of the non-acid treated clay sample 20 has a larger 670° C. endothermic loop than that of the acid treated sample, indicating the presence of a montmorillonite clay soluble in dilute acid. There is a small endothermic loop at 800° C. in the non-acid treated sample 20, probably due to chlorite. This loop is not present in sample 25. The endothermic break after the exothermic peak at 930° C. is sharper, due to calcite or dolomite.

Figure 11 presents the thermograms of the clay samples from the non-acid treated samples of profile three. The endothermic loops below 300° C. are the result of montmorillonite dehydration. The endothermic loops between 320° C. and 450° C. in samples 30 and 31 are probably due to brucite (41). The exothermic peak at 460° C. in sample 30 is organic matter oxidation. The typical illite loop is present at 540° C. The loop at 600° C. in sample 30 is due to montmorillonite. The endothermic loops at 700° C. and exothermic loops at 860° C. in samples 31 and 32 are due to chlorite.

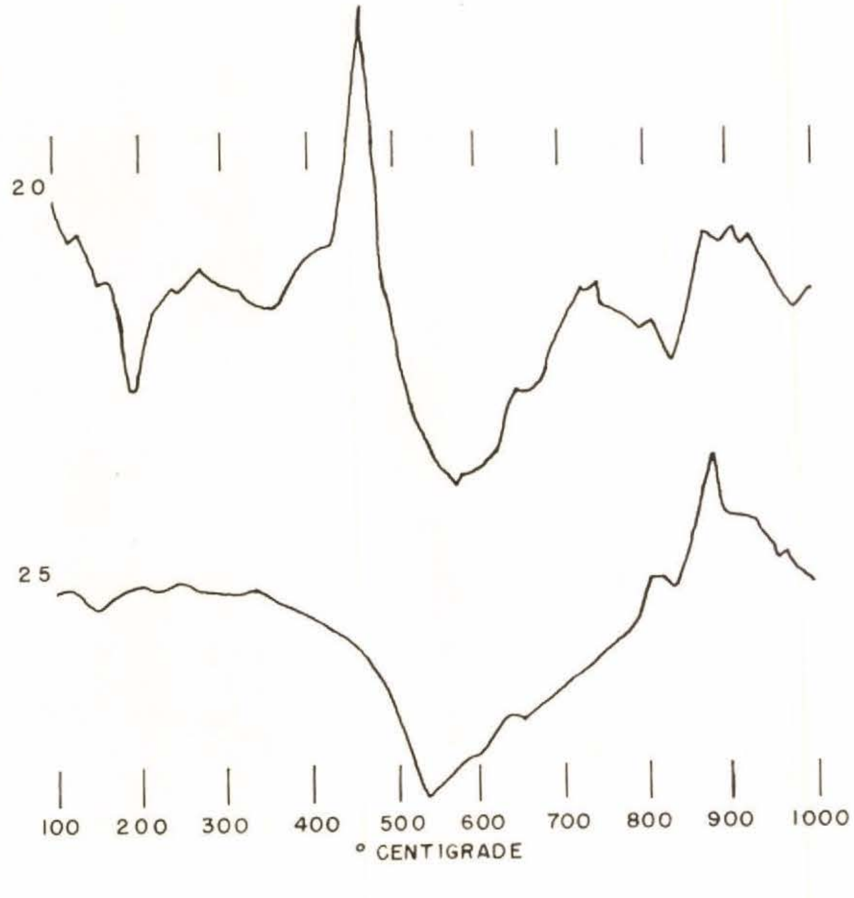

Figure 10. Thermograms of non-acid treated clay samples 20 and 25

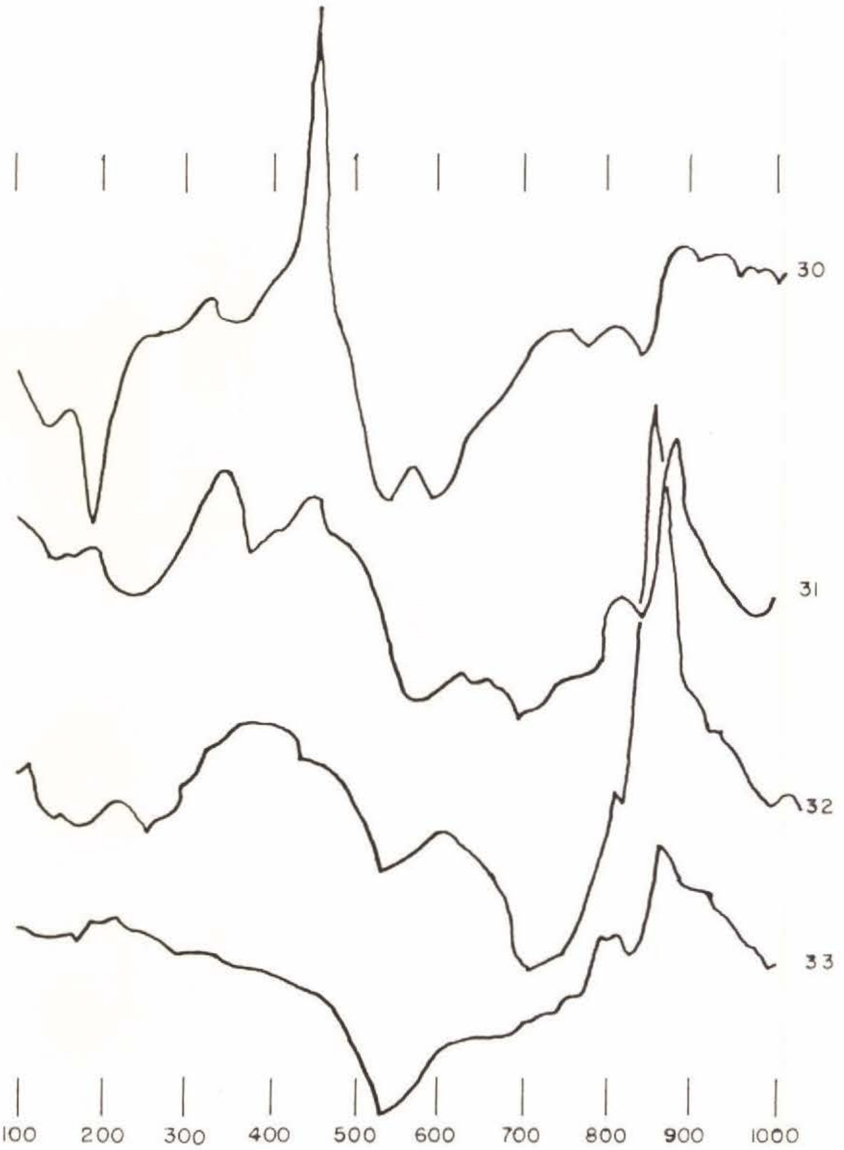

Figure 11. Thermograms of non-acid treated clay samples from profile 3

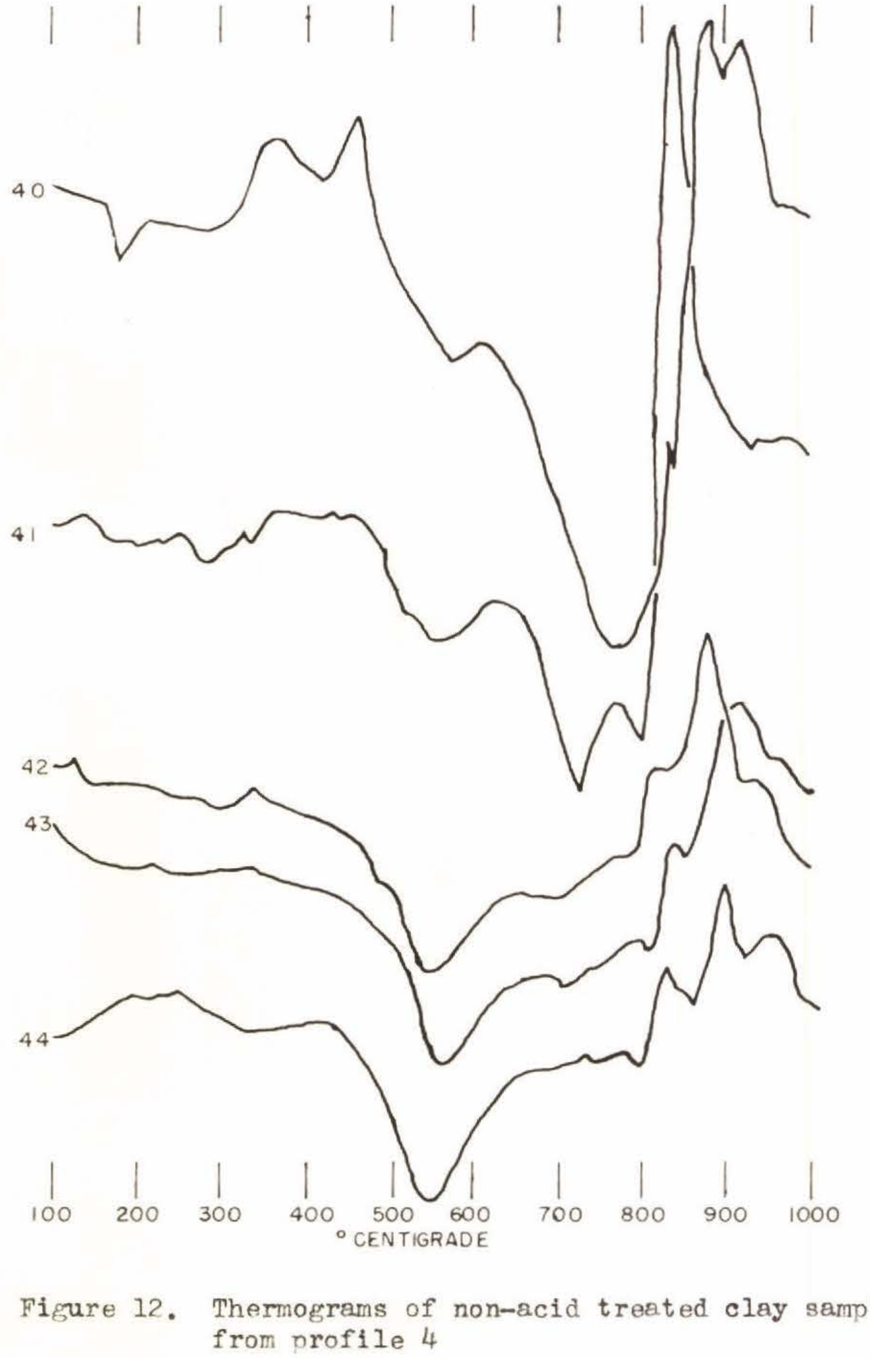

Figure 12. Thermograms of non-acid treated clay samples from profile 4

X-ray analysis

Mineral identification by X-ray diffraction was accomplished by comparing powder diffraction pictures with powder diffraction pictures of reference clay samples, and with published X-ray data (10, 47, 54, pp. 119-130, 68). X-ray diffraction pictures were made of montmorillonite, illite, kaolinite, and halloysite reference samples. Powder diffraction pictures of reference clay minerals contained strong first order reflections of the (001) planes. The 15Å spacing of montmorillonite was very near the limit of the camera used.

Tables 7, 8, 9, 10, 11, 12, and 13 show the X-ray diffraction data obtained from non-acid treated clay samples 30, 33, 40, 41, 42, 43, and 44. Table 14 presents the X-ray diffraction data from acid treated clay sample 41. The first column of these tables contains the observed spacings (nλ in the Bragg equation). The second column contains the observed intensities. The following columns of the X-ray diffraction tables contain intensities for the corresponding line, as found in the literature. Only those lines representing spacing greater than 1.5Å were catalogued.

None of the X-ray pictures taken of samples under investigation contained distinct lines representing spacings greater than 10.1Å. The region above 10.1Å contained a dark, shaded area, characteristic of mixed-layer mineral types. All photographs contained a weak 10.1Å line, the (001) illite line. A weak line was observed at 7.3Å. This 7.3Å line was probably a second order chlorite line. It is doubtful if this was a kaolinite (001) line since the spacing is greater than the 7.1Å to 7.2Å characteristic of kaolinite (11, p. 48). The mineral responsible for this 7.3Å spacing was probably an iron rich chlorite. In chlorite, when iron is substituted for Mg in octahedral positions, the intensities of the (001) and (003) lines are reduced relative to the (002) and (004) lines (10, p. 189).

Dioctahedral silicates have a spacing of 1.50Å (54, p. 123). Such spacings were present in all samples. The 1.50Å line was more of a band than a line, which, along with a band at 4.33Å indicates amorphous silica (10, p. 307). The 4.33Å band was present in several photographs, indicating that more than 25 percent of the clay materials consisted of amorphous silica.

Characteristic spacings of illite, montmorillonite, chlorite, quartz, and calcite were identified. Several photographs had unidentified weak lines at 5.58Å to 5.65Å and at 6.55Å. These spacings are typical of polygorskite (attapulgite), an altered montmorillonite (10, p. 242). The first order (001) spacing of polygorskite corresponds with that of illite. The few lines present were not considered sufficient to positively identify polygorskite. It is difficult to differentiate between the mica type minerals with 10Å (001) lines. Van Der Marel (68) states that illite and muscovite may be separated on the basis of illite's 3.03Å and 2.82Å lines and muscovite's 3.19Å and 2.97Å lines. These weak lines were not present in the pictures used in this study. It is therefore necessary to consider illite as Bradley recommends (10, p. 4), "Clay minerals similar in structure to mica (muscovite), generally termed illites . . . ."

Comparing non-acid treated samples 30 and 33 one finds the chlorite lines more intense in sample 30. Positive identification of calcite was not possible in sample 30, although it is a major component of sample 33. The 4.32Å line, representing amorphous silica, was more intense in sample 30.

Comparing the intensities of lines on the non-acid treated clay samples from site 4, one observes that the calcite lines are more intense in samples 40 and 41 than in samples from lower horizons. This indicates that <u>in situ</u> processes are causing calcite to be reprecipitated in the clay-size fraction. The 4.69Å chlorite spacing was apparent only in sample 40. The other lines which are marked in the chlorite are spacings common to many mica-type minerals. The calcite lines do not appear in the X-ray diffraction photographs of acid treated samples. All chlorite lines, except the 7.3Å spacing, were spacings common to many mica-type minerals. In the acid-treated sample many of the characteristic mica-type mineral lines were relatively intense.

Caution should be used when attempting to make quantitative estimates of interstratified minerals. Several spacings are common to many clay minerals, resulting in reinforcement, and the (001) spacing line is either missing or displaced (10, p. 151). Another factor which introduces uncertainties in estimating a given mineral in a mixture is the presence of substances, such as calcite, which highly absorb X-rays (54, p. 126). The X-ray diffraction photographs substantiated the clay mineral identifications made by DTA.

Table 8. X-ray data of non-acid treated clay from sample 30

Crystal spacing Å	Observed intensity	Intensities found in literature				
		Illite	Mont.	Chlorite	Quartz	Calcite
10.1	v.w.*	10				
7.31	v.w.			10		
5.243	v.v.w.		8			
4.54	4		6-10			
4.321	1					
3.71	v.w.	8				
3.35	10	9			10	
3.234	1		1			
2.989	v.w.	9				
2.565	5	7	2-10			
2.455	1	w.		2-6	3	
2.395	v.w.	1				
2.283	v.w.		1-2		3	7
2.208	v.w.	1		2-8		
2.131	v.w.	9			3	
1.91	1					9
1.818	2	5			8	
1.665	1	2-7	1-5		3	
1.54	4	1		2-8	6	
1.508	3	7	2-10			

*Observed intensity, weakest to strongest: very, very weak (v.v.w.), very weak (v.w.), weak (w.), 1, 2, 3, 4, 5, 6, 7, 8, 9, 10.

Table 9. X-ray data on non-acid treated clay from sample 33

Crystal spacing	Observed intensity	Intensities found in literature				
		Illite	Mont.	Chlorite	Quartz	Calcite
Å						
10.1	v.v.w.*	10				
7.3	v.v.w.			9		
4.54	3		6–10			
3.35	10	10			10	
3.235	v.w.	9	1			
3.049	1					10
2.89	1	8				
2.58	4	7	2–10	1–7		
2.395	v.w.					
2.283	v.w.		1–2		3	7
2.208	v.w.	1			2–8	
2.131	v.w.	9				
1.91	1					9
1.818	2	.5			8	
1.665	1	2–7	1–5			
1.54	4	1		2–6	6	
1.508	3	7	2–10			

*Observed intensity, weakest to strongest: very, very weak (v.v.w.), very weak (v.w.), weak (w.), 1, 2, 3, 4, 5, 6, 7, 8, 9, 10.

Table 10. X-ray data of non-acid treated clay from sample 40

Crystal spacing	Observed intensity	Intensities found in literature				
		Illite	Mont.	Chlorite	Quartz	Calcite
Å						
10.1	v.v.w.*	10				
7.3	v.v.w.			9		
5.565	1					
4.69	w.			9		
4.322	w.	1	3–10			
3.91	w.		1			
3.77	v.v.w.		w.			
3.268	v.v.w.		1			
3.353	8	5–10			10	
3.28	v.v.w.					
3.036	10					10
2.998	v.v.w.	9				
2.8817	v.v.w.					
2.625	1					
2.522	3			2–6		
2.445	v.v.w.	1	v.w.	2–6	3	
2.395	v.w.	1				
2.291	6		1		3	7
2.00	v.v.w.			2–8		
1.921	3					9
1.88	3	0.5				8
1.836	v.w.			0.5	8	
1.75	v.v.w.	2				
1.665	v.v.w.	1	1–5		3	
1.616	w.	1				4
1.599	1			3–7		5
1.54	v.v.w.	1			6	
1.525	v.w.	2		2–8		
1.50	w.	7	2–10			

*Observed intensity, weakest to strongest: very, very weak (v.v.w.), very weak (v.w.), weak (w.), 1, 2, 3, 4, 5, 6, 7, 8, 9, 10.

Table 11. X-ray data of non-acid treated clay from sample 41

Crystal spacing	Observed intensity	Intensities found in literature				
		Illite	Mont.	Chlorite	Quartz	Calcite
Å						
10.1	v.v.w.*	10				
7.30	v.v.w.			9		
5.62	v.v.w					
4.475	w.	10	6–10			
4.322	v.v.w.	1				
3.855	v.v.w		1			6
3.38	6				10	
3.049	10					10
2.58	v.w.	7	2–10	1–7		
2.48	w.	v.w.				6
2.345	v.v.w.	1				
2.27	3		1			7
2.095	2					7
1.97	v.v.w.	9			2	
1.91	3					
1.858	3	0.5				8
1.61	v.v.w.					4
1.591	v.w.			3–7		5
1.54	v.v.w.	1		2–8	6	
1.50	w.	7	2–10			

*Observed intensity, weakest to strongest: very, very weak (v.v.w.), very weak (v.w.), weak (w.), 1, 2, 3, 4, 5, 6, 7, 8, 9, 10.

Table 12. X-ray data of non-acid treated clay from sample 42

Crystal spacing	Observed intensity	Intensities found in literature				
Å		Illite	Mont.	Chlorite	Quartz	Calcite
10.1	v.v.w.*	10				
7.3	v.w.			9		
6.55	w.					
5.05	v.v.w.					
4.495	5	10	6-10			
4.24	v.w.					
3.34	10	9			10	
3.19	v.v.w.					
3.035	8					10
2.89						
2.795	v.v.w.	8		1-6		
2.685	v.v.w.	8				
2.565	4	7	2-10	2-6		
2.47	v.w.	v.w.		2-6		
2.41	v.v.w.					
2.365	v.v.w.	7				
2.27	1		1			7
2.225	v.v.w.	1	1			
2.13	v.w.					
2.075	w.			2-8		7
1.98	w.	9		2-6		
1.90	1					
1.86	1					8
1.81	1				8	
1.65	v.v.w.	2-7	1-5			
1.585	w.			3-7		
1.535	1	1		2-8	6	
1.50	w.	7	2-10			

*Observed intensity, weakest to strongest: very, very weak (v.v.w.), very weak (v.w.), weak (w.), 1, 2, 3, 4, 5, 6, 7, 8, 9, 10.

Table 13. X-ray data of non-acid treated clay from sample 43

Crystal spacing	Observed intensity	Intensities found in literature				
		Illite	Mont.	Chlorite	Quartz	Calcite
Å						
10.1	v.w.*	10				
7.31	v.v.w.			9		
5.62	v.w.					
4.518	5		3-10			
4.22	2				7	
3.352	10	10			10	
3.18	v.v.w.	9				
3.93	8					10
2.19	2					
2.80	v.v.w	8		1-6		
2.683	v.v.w.	8				
2.565	4	10	2-10	1-7		
2.435	v.w.	1		2-6		
2.375	v.w.	1				
2.27	1		1			7
2.138	v.v.w.					
2.085	v.w.					7
1.985	w.	9			2	
1.91	1					9
1.86	1	0.5				
1.81	2			1-3	8	8
1.70	v.v.w.					
1.65	v.v.w.	2-7				
1.59	w.					5
1.56	1			3-7		
1.54	v.v.w.	1		2-8	6	
1.50	4	7	2-10			

*Observed intensity, weakest to strongest: very, very weak (v.v.w.), very weak (v.w.), weak (w.), 1, 2, 3, 4, 5, 6, 7, 8, 9, 10.

Table 14. X-ray data of non-acid treated clay from sample 44

Crystal spacing	Observed intensity	Intensities found in literature				
		Illite	Mont.	Chlorite	Quartz	Calcite
Å						
10.1	v.v.w.*	10				
7.30	v.w.			9		
4.955	v.v.w.			9		
4.475	4		6–10			
4.22	v.v.w.				7	
3.71	v.v.w.					
3.34	10				10	
3.213	v.v.w.					
3.016	6					10
2.565	5	10	2–10			
2.455	v.v.w.			2–6	3	
2.35	v.v.w.					
2.28	3				3	7
2.268	3		1			7
2.084	v.v.w					7
2.00	v.v.w.			2–8		
1.915	v.v.w.					9
1.856	v.v.w.	0.5				8
1.815	v.v.w.				8	
1.65	v.v.w.	2–7				
1.585	v.v.w.			3–7		5
1.531	1	1		2–8	6	
1.50	v.v.w.	7				
1.488	5		2–10			

*Observed intensity, weakest to strongest: very, very weak (v.v.w.), very weak (v.w.), weak (w.), 1, 2, 3, 4, 5, 6, 7, 8, 9, 10.

Table 15. X-ray data of acid treated clay from sample 41

Crystal spacing	Observed intensity	Intensities found in literature				
		Illite	Mont.	Chlorite	Quartz	Calcite
Å						
10.1	v.w.*	10				
7.3	v.v.w.			9		
5.58	v.w.					
4.96	v.v.w.	9		9		
4.495	9	10	6-10			
4.33	v.v.w.					
4.428	w.	1				
3.395	v.v.w.		1			
3.71	v.w.	8				
3.37	10				10	
2.94	v.v.w.					
2.80	v.w.	8		1-6		
2.685	v.v.w.	8				
2.565	5	1	2-10			
2.43	w.	1		2-6		
2.36	v.w.	1				
2.239	v.v.w.	1	1		1	
2.16	v.v.w.	1				
2.095	v.v.w.					7
1.965	w.	9				
1.80	v.w.				8	
1.705	v.v.w.					
1.681	v.v.w.		5		3	
1.568	v.v.w.	1		3-7		
1.54	v.v.w.	1		2-8	6	
1.50	w.	7	2-10			

*Observed intensity, weakest to strongest: very, very weak (v.v.w.), very weak (v.w.), weak (w.), 1, 2, 3, 4, 5, 6, 7, 8, 9, 10.

DISCUSSION

Parent material

The parent material of the Payson soil series consists of sediments deposited in Lake Bonneville. These materials varied texturally, from site to site. The clay materials contained in the lake sediments were very similar in the three Payson profiles studied, although the parent materials of profile 3 did not contain as much lime as either profile 4 or 5. Site 20 was affected by stratification at time of deposition of the sediments. At site 3 the sediments were probably texturally homogenous. The texture of site 3 horizons is as one would expect, that is to agree with Weston's theory (83) of increasing bulk density with increasing clay concentration in Solonetz soils (see Figure 5). Sediments at site 4 probably were texturally homogenous, with the exception of the surface horizon at time of deposition. Sample 40, however, had a relatively large amount of sand when one considers the small amount of lime movement within the profile (see Figure 6). The clay fraction of sample 40 was the only sample with more than 10 percent non-acid soluble montmorillonite, having 25 to 50 percent non-acid soluble montmorillonite (see Figure 9). The parent materials composing sample 40 did not originate from the same source as the parent materials for the rest of this profile, as it is not similar to the rest of the profile texturally or in clay mineral composition.

The present illite and acid insoluble montmorillonite complex is inherited from the sediments composing the parent materials. Calcite, quartz, and amorphous silica also occur as parent materials within the clay size range. The amorphous silica composed more than 25 percent of the clay materials in all clay samples.

Clay development

The clay materials significant in profile morphology in the profiles studied are from two sources: in situ weathering and inherited from parent material. The clay materials present that were products of in situ weathering were calcite, chlorite, and small amounts of acid soluble montmorillonite. Illite (mica), acid insoluble montmorillonite, quartz, and amorphous silica have been inherited from the parent material.

Calcite is being dissolved by downward moving water and then being reprecipitated at depth. Much of this reprecipitated calcite crystalizes within the clay size range. At site 3 the zone of maximum chlorite accumulation was also the zone of maximum clay accumulation (see Figure 10). An acid-soluble montmorillonite composed about 25 percent of the surface sample. At site 4, weakly developed according to lime movement, the highest chlorite concentration was in the surface sample. These chlorite and acid soluble montmorillonite concentrations are as one would expect, the mineral representing the most advanced in situ weathering stage being in the most weathered horizon. Site 3 has either been subjected to more intense weathering than site 4 or site 3 contained fewer carbonates than 4 from the parent material, the latter seeming more probable.

Two methods of chlorite formation are reported in the literature. Chlorite may be formed by the diagenes of montmorillonite (21, p. 322).

In this process a brucite layer is formed between the interlayer surfaces of the montmorillonite. Chlorite may be formed as recrystalization product (51) of silicates containing aluminum, ferrous iron, and magnesium. If chlorite, in the profiles studied, was produced by diagenesis of montmorillonite, the montmorillonite content should have decreased as chlorite content increased. There was no apparent change in acid insoluble montmorillonite content as chlorite increased. On further weathering,chlorite decreased as acid soluble montmorillonite increased. It also seems unlikely that the chlorite found is a recrystalization product of a silicate. The solubility of aluminum is so low at the soil pH's found that there would not be enough aluminum in solution to form chlorite on recrystalization. Chlorite was probably formed by the attacking of a preferential weathering plane (36) in mica. Chlorite formation by weathering of a preferential plane in mica would take place if a potassium interlayer was replaced by a brucite layer. Although no direct evidence of weathering on a preferential plane was obtained in this study, this method of chlorite formation is the only method that will fit the mineral environment found. The chlorite found is an intermediate between mica and the acid-soluble montmorillonite.

mica → chlorite → acid-soluble montmorillonite

When weathering is intense enough to weather chlorite to montmorillonite in the A horizon, considerable chlorite is also found in the B horizon.

The three Payson profiles studied represented three different conditions of parent material deposition. Profile 2 was stratified, profile 4 was homogenous except for the surface horizon, and profile 3 showed no signs of stratification at time of deposition of the sediments composing the parent materials. Although sedimentation differences were found, the profiles were very similar morphologically. This was due to the dominant effects of authegenic calcite and chlorite.

Profile development

Three profiles of an inter-zonal soil associated with Chestnut or Brown soils were investigated. The profiles at sites 2 and 3 were solidized-Solonetzs. The profile at site 4 was a Solonetz, the difference being the amount of carbonates leached out of the A horizon. These soils have been developed by the leaching of a Solonchak.

The movement of calcite is the first mineralogical change the profiles weathered. Calcite starts to move from the A horizon to the B horizon, much of the calcite reprecipitating in the clay size range. Before all the calcite moves out of the A horizon, some of the mica in the A is altered to chlorite. When weathering is intense enough to remove most of the calcite from the A, some of the chlorite in the A weathers to an acid-soluble montmorillonite.

SUMMARY

Three profiles of the Payson soil series were studied in an attempt to learn the origin and genesis of a clay B horizon in a calcareous soil. Chemical analysis, differential thermal analysis, and X-ray diffraction were used to characterize the soil profiles and identify the clay materials present. The clay fractions of the parent materials were found to include principally calcite, an illite, and acid-insoluble montmorillonite interlayered clay mineral, quartz, and amorphous silica. It was not possible to identify mica in the presence of the interlayered mineral.

The parent materials of the profiles studied were stratified in varying amounts. Morphologically the profiles were very similar. The weathering in all three profiles consisted of movement of calcite from the A to the B horizon. As weathering proceeded, chlorite was formed and under more intensive weathering an acid-soluble montmorillonite formed. The weathering sequence proposed is: mica → chlorite → acid-soluble montmorillonite.

The clay B horizons, having more clay than horizons above or below, was due to the reprecipitation of calcite in the clay size range. This weathering action dominated the profiles texturally, and accounted for the similar profiles even though the parent materials were stratified.

The conclusions of this study may be summarized as:

1. The three Payson profiles investigated were affected to varying degrees by stratification at time of deposition of the sediments which compose the parent material.

2. The parent materials contained illite, montmorillonite, calcite, quartz, and amorphous silica within the clay size range. Montmorillonite composed 5 to 10 percent of the clay fraction. Amorphous silica accounted for more than 25 percent of the clay fraction. Illite was the most prominent layer silicate in the clay fraction.

3. Authigenic calcite and chlorite, to a large degree, dominate the present morphology of the three Payson profiles investigated.

4. The chlorite, present in the more weathered horizons only, is a product of weathering on a preferential plane, a potassium interlayer in mica being replaced by a brucite layer. The following weathering sequence is proposed for the profiles studied: mica → chlorite → acid-soluble montmorillonite.

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