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CHARACTERISTICS OF MANILA AND RELATED SOIL SERIES

by

Flayeh H. Altaie

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Soil Classification

UTAH STATE UNIVERSITY
Logan, Utah

1958

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Flayeh H. Altaie

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INTRODUCTION

In many parts of the world soils have been found that have apparently been formed under climatic conditions that no longer exist. In many places in northern Utah in areas associated with ancient Lake Bonneville, deep soils, fine-textured and non-calcareous, have been observed immediately above the highest shore line of the ancient lake. These soils have essentially no free carbonates to depths ranging from 4 to 15 feet, even though they exist on relatively steep slopes. In Davis and Utah Counties, soils having these characteristics have been given the tentative series name, Manila.

Soils studied for this thesis include one series tentatively referred to as Manila and which is located above the highest level of the ancient Lake Bonneville and one series, Avon, which is located on lake sediments below the highest level of the lake. The third profile studied, the Paradise soil, occurs approximately at or just below the old lake level.

A study of these soils should aid in understanding their genesis. The findings should facilitate the correct and useful classification of such soils in present and future soil surveys.

Nature of the problem

The Manila soils are deep, fine-textured, and well-developed. They are free of lime to a considerable depth. These soils occur in upland settings, above the highest level of ancient Lake Bonneville. It has been suggested that these soils are paleosols, or soils that have characteristics that reflect an environment which no longer exists. A detailed study, therefore, is necessary for their correct classification and for a better understanding of their genesis.

The Avon soil series and other soil series, which developed on the lake deposits below the lake level, are believed to reveal the influences of the present climate (semi-arid) in their characteristics. They are leached, if any, to shallower depth, are more likely basic in reaction, and some may even show salt accumulation.

Objectives

This investigation will attempt the following:

1. How do the soil characteristics of the Manila and Paradise soil series differ from those of normal soils (Avon soils)?

2. Could Manila and Paradise soils be produced under present conditions? If not, what conditions likely prevailed during their formation?

3. Characterize the Manila, Paradise, and Avon soils with reference to chemical and mineralogical composition.

SOIL FORMATION

Soils are the product of two groups of processes, (1) weathering, and (2) profile development. As a result of weathering, unconsolidated parent material is produced. From this parent material, through the action of soil-forming factors, soils develop.

Weathering

Weathering is the disintegration and decomposition of rocks and minerals. Forces of weathering can be grouped into two types, (1) mechanical, and (2) chemical. In soils where weathering is quite active, both of these groups of forces are active simultaneously.

Mechanical weathering forces include the pressures exerted by freezing water, increased temperature, and the action of plant roots. Relatively, mechanical weathering is slower than chemical weathering and normally produces coarser soils.

Chemical weathering forces are the dominant weathering forces in most regions of sub-humid and humid climates. Oxidation, carbonation, and the various actions of water are the prominent chemical forces. Water is especially active. As the mineral is exposed to moisture, hydrolysis and hydration result in solution of the mineral surface and in a lowering of the mineral's resistance to weathering. The solvent action of the water by dissolved carbon dioxide further hastens mineral decomposition. The action of dissolved carbon dioxide, called carbonation, is a dissolving of minerals partly by forming soluble bicarbonates of the calcium and magnesium from slightly soluble simple salts and from their insoluble mineral forms. The amount and type of vegetation influences chemical weathering. The release of carbon dioxide and organic acids by both the plant roots and the decomposing plant residues commonly speeds the process of weathering by increasing carbonation.

A change in climate, either temperature or moisture, changes the vegetation and will result in different effectiveness of various weathering forces. A given soil profile formed under the influence of a pre-existing climate may or may not exhibit profile properties to indicate such a happening.

Profile development

During soil profile development, translocation of many different constituents may occur in the soil. Clay, organic colloid, silica, alumina, iron oxide, gypsum, lime, and other minerals may move downward and accumulate in lower depths. Soluble salts may either move down through the soil or, under other conditions, may move up to the surface and accumulate. Organic matter may accumulate in the surface soil and the colloidal fraction, gradually formed, may move to a lower layer. Other soil properties will also change such a structure, color, and pH. As a result of these changes, distinctive soil layers (horizons) are formed.

The quality and degree of such changes, and the depth to which these changes occur are a result of the environment, i.e., climate, biological activities, relief, time, and parent material.

Factors of soil formation

Climate. Climate is a dominant soil-forming factor, particularly in very old soils. In fact, the effects of other soil-forming factors depend largely on the moisture and temperature (climate).

Rainfall varies in different parts of the world. It ranges annually from a very few inches in some locations to several hundred inches in other areas. Accordingly, soil properties are greatly modified by the amount of rainfall the soil receives. Soils can be highly leached under high rainfall, if large quantities of rain water move through the soil. In humid, cool climates, supporting good vegetation, organic matter increases in the soil. The excessive leaching and acid vegetation that is common in these areas result in an acid soil. On the other hand, soils of the arid regions are slightly leached, if at all. They tend to be low in organic matter, high in pH, high in lime, and sometimes high in soluble salts.

Temperature also varies from place to place. Van't Hoff, cited by Jenny (16), stated that for every ten degrees centigrade rise in temperature, the velocity of a chemical reaction increases by a factor of 2 to 3. This fact explains why the intensity of weathering is great in the tropical climates and gradually decreases as the temperature decreases.

Soil color, soil organic matter content, clay content, and other soil properties are greatly influenced by the temperature. The nitrogen and organic matter content of the soil decrease as the annual temperature increases. It has also been found that the clay content in soil increases with increase in temperature (16).

Climate is so dominant a factor in soil formation that soils have been classified according to climate into zonal great soil groups. Some soils of a given climatic region are found to have definite characteristics regardless of geographical, geological, and topographical differences. For example, podzols which develop in humid, cool climates, occur on moraines, alluvial sands, granites, gneisses, diorites, loess, peaty deposits, and even on limestones. They are also formed on flat topography as well as on slopes, under forest as well as under grassland vegetation (16).

Biological activities. Biological activity is also considered as an important soil-forming factor. Plants and animals add organic residues to the soil. Deep-rooted plants facilitate leaching in the soil. Earthworms help in mixing the soil in which they live. Rodents and other burrowing animals aid in mixing various horizons of soil together.

Microorganisms play a big role in decomposing the plants and animal residues. Some organic acids are produced in this process which further aid in decomposing minerals in the soils. Some bacteria fix nitrogen of the air. Other bacteria attack minerals and other inorganic compounds in the soil to get the energy they need. Nitrogen compounds, sulfur, inorganic sulfur compounds, iron compounds, and other compounds may be attacked by different kinds of bacteria (32).

Man, in many different ways, has affected the soils through his use of irrigation, plowing, forest cutting, fertilization, and many other activities (16).

Relief. Relief influences soil formation through its controlling effect upon water percolation, water run-off, temperature, and erosion. Soil profiles are rarely mature or strongly developed on steep slopes, except in areas of high rainfall and dense vegetation, because of erosion (removal of weathered portions of the soil) and reduced percolation of water through the soil (5).

Parent material. Parent material shows great influences on soil properties, especially in the early stages of formation. Soils formed from shale, naturally, will contain large amounts of clay. Others formed from sandstone will commonly contain large amounts of sand. Basic rocks may be developed into a type of soil different from that which is formed from acid rock even though the climate and relief may be the same (16).

Scherf, cited by Jenny (16), observed in northern Europe that brown forest soils formed on heavy ground moraines, while strongly podzolized soil formed on adjacent sand.

Time. Time is a very important factor in soil formation. As time proceeds a soil continues to develop until it reaches a dynamic equilibrium with the environment. The time required to reach this equilibrium depends largely on other soil-forming factors. Soil develops in less time in a humid tropical climate than in cool desert climates. Soil normally requires a longer time to develop well-defined horizons from a clayey-textured parent material than from a sandy-textured one. Soils of high and steep mountains are normally young because of rapid erosion of weathered top soil. On flood plains, the soil is slightly developed because of continuous accumulation of new material. In general, the older the soil, other factors constant, the more it shows well-defined horizons.

USE OF PROFILE CHARACTERISTICS TO DETERMINE PAST ENVIRONMENT

Old soils that have been formed in an environment which may or may not differ from the present, were given many names. Paleosols, ancient soils, buried soils, and fossil soils are some of the terms used for these older soils. Some of these terms are synonyms; others are different.

The first time that fossil soils were recognized was in the Eighteenth Century in various parts of Russia. Since then, in North America, early fossil soils have been observed by geologists who were interested in establishing stratigraphic datum, physiographic history of the area, or an interpretation of past climatic regime. Only recently have soil scientists of North America become interested in studying these soils (30).

In southern Iowa, Simonson (26) described many buried soil profiles. In one area he found a light-colored band underlying loess deposits. He interpreted it as an A_2 horizon of a buried soil profile. In some other regions he was able to find the complete buried soil profile. After analysis, he found that it belonged to the planosol soil group and had many similarities to the planosols now existing on the land. So he concluded that soil processes which prevailed at the time of formation of these buried soils were the same as those processes of the present time.

Bryan and Albritton (4) studied a complex soil in Davis Mountain, Texas, to unlock a sequence of climatic changes in that area. In one locality they found three stages of caliche depositions, formed under relatively arid conditions, intervening with two periods of a humid climate, during which part of the caliche dissolved.

Joffe (17) studied, morphologically and chemically, soil profile of the Colts Neck soil series that had formed on coastal plain materials. He found that this soil series because of their lateritic characteristics, is most likely formed under sub-tropic conditions. Other soil series of that region are either podzols or podzolic. He also found other evidence of laterization after analysis of a Montalto soil which has been derived from Triassic basalts. From the facts that Fe_2O_3, Al_2O_3 and clay percentages increased in the B horizon and an increase of silica percentage occurred in the A horizon, he concluded that this soil is podzolic. It formed under a humid temperate climate. But because the C horizon is rich in aluminum, iron, and magnesium and low in silica, he concluded that "at one time this horizon was undergoing lateritic weathering and was subjected to the lateritic type of soil formation." This means that at the time of formation, a sub-tropical climate existed. Also, a comparison of the high aluminum content of the C horizon to the amount in the weathered basalt indicates that the climate was sub-tropical. The weathered basalt has less silica than the fresh basalt which also indicates lateritic conditions.

A BRIEF GEOLOGICAL HISTORY OF CACHE VALLEY

Location and description

Cache Valley lies between the northern part of the Wasatch Mountains, the Malad Range, and the Bear River Range. It is elongated (60 miles long), running north and south, and the widest part, which is near the Utah-Idaho boundary, is 17 miles (33).

The valley is described as a graben (depression bounded on at least two sides by faults), bounded by Tertiary faults. Williams (33) indicated that the major faulting in this area took place previous to the deposition of the Salt Lake Group (a limestone, sandstone, and tuff conglomerate).

Glaciation

Evidence of Pleistocene glaciation (the most recent glacial period) has been found in many localities in the Wellsville Mountains and the Bear River Range. One or more of the glacial features has been found. These features are cirques (steep-walled depressions in the mountain side), U-shaped valleys, lakes, moraines, and tills.

Church (6), in his examination of glacial features on Wellsville Mountain, estimated that there were at least 12 glaciers during the Pleistocene time.

In the Bear River Range, Young (37) found the glaciation to be of two epochs separated by an interglacial period. On the western side of the front ridge of the Bear River Range, three small cirques are found. Also, 15 glaciers existed in the western tributaries of the Logan Canyon. The glaciers on the east slope of the front ridge descended to a 6,100 foot elevation and the glaciers on the west slope reached 7,000 feet.

Gilbert (7) stated that the climate (cool and a high precipitation) which favored the formation of glaciers also favored the existence of ancient Lake Bonneville.

Lake Bonneville

Lake Bonneville was a vast Pleistocene lake. It occupied an area of 20,000 square miles, including what is now Cache Valley, and had a depth of 1,000 feet above the present level of the Great Salt Lake.

From the well-developed shore features at the highest level of the lake, Williams (33) suggested that the lake level was maintained by outflow.

The overflow of the substages of Lake Bonneville was through the Red Rock Pass at the northern end of the lake. The substages have left distinctive equivalent terraces. These terraces are very apparent east of Logan City where the Logan River discharged into the lake (figure 1).

Four cycles of Lake Bonneville have been recognized. These are summarized in table 1.

Table 1. Summarization of the cycles of Lake Bonneville*

Cycles	Substage	Relative level	Elevation
First	Alpine	Intermediate - high Recession (4,600 or less)	----
Second	Bonneville	Highest Recession 4,290 or less)	5,135
Third	Provo I	Intermediate - low Recession (4,700 or less)	4,800
Fourth	Provo II	Low	----

*After Hardy (10)

4500 - 5100

Figure 1. Terraces which show the substages of Lake Bonneville, located east of Logan City where the Logan River discharged into the lake.

EXPERIMENTAL METHODS AND PROCEDURES

Field methods

Bonneville shore line. An attempt was made to draw the shore line of ancient Lake Bonneville. In some areas it was rather easily located by the sea cliffs which the waves had made. In other areas these marks were either eroded away or buried. Because of this the shore line was partially drawn. (See figure 2.)

General information of soils below old shore line. Wilson, *et al*. (35) have described the Avon soil series as well-drained, moderately fine-textured zonal Chernozem soils developed from lacustrine sediments. The contributing rocks are principally limestone, sandstone, and shale with some quartzite. The soils occur mainly on lake terraces of old Lake Bonneville in Cache Valley.

The slope of the Avon soils ranges from 2 to 10 per cent. The soil is mostly cultivated. Native vegetation was probably bunch grasses with lesser amounts of scattered sagebrush.

Detailed description of Avon soils. Profile number one (Avon loam) was sampled and described by Wilson, *et al*. (35) as follows:

Horizon	Depth (inches)	Description
A_1	0-7	Black (10YR 2/1) moist, loam, dark gray (10YR 4/1) dry; moderate fine platy structure that breaks easily to moderate fine granular, slightly hard dry, friable, non-calcareous; mildly alkaline.
B_1	7-28	Very dark gray to black (10YR 2.5/1) moist, clay loam, gray to dark gray (10YR 4.5/1) dry; weak medium prismatic, breaking to moderate medium sub-angular blocky structure; hard dry, firm moist; non-calcareous; mildly alkaline.

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Figure 2. Aerial photograph of southern Cache Valley with the location of the highest level of ancient Lake Bonneville (red line) and of the sampling sites used (numbered dots).

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Horizon	Depth (inches)	Description
B_2	28-35	Very dark grayish brown (10YR 3/2) moist, clay loam, gray (10YR 5/1) dry; weak medium prismatic structure breaking to moderate medium sub-angular blocky with moderate continuous clay skins. Very hard dry, firm moist; non-calcareous; mildly alkaline.
B_3 ca	35-38	Grayish brown (10YR 5/2) moist, clay loam, pale brown (10YR 6/3) dry; massive to weak medium sub-angular blocky structure; hard dry; firm moist; moderately to strongly calcareous with white lime mottlings; moderately alkaline.
C_{ca}	38-44	Light brownish gray (10YR 6/2) moist loam, white (10YR 8/2) dry; massive hard dry; firm moist; strongly calcareous with lime segregated; moderately alkaline.
C	44-72	Dark grayish brown (10YR 4/2) moist, sandy loam, light brownish gray (10YR 6/2) dry; massive; hard dry; firm moist; strongly calcareous; moderately alkaline.

General information on soils above old shore line. The Manila soils are well-drained, deep, fine-textured soils. They are free of lime to a considerable depth, and occur mainly on steep slopes. The principal native vegetation consists of Bromus tectorum (chest grass) and Artimisia tridentata (sagebrush).

Detailed description of Manila soils. The Manila soil was sampled and described above the shore line (see figure 2). Profile number two is a typical Manila soil (see figure 3). Profile number two (Manila clay loam) is located about three miles southwest of Hyrum City (see figure 2) on a slope of 32 per cent, on an eastern exposure. Its detailed description is as follows:

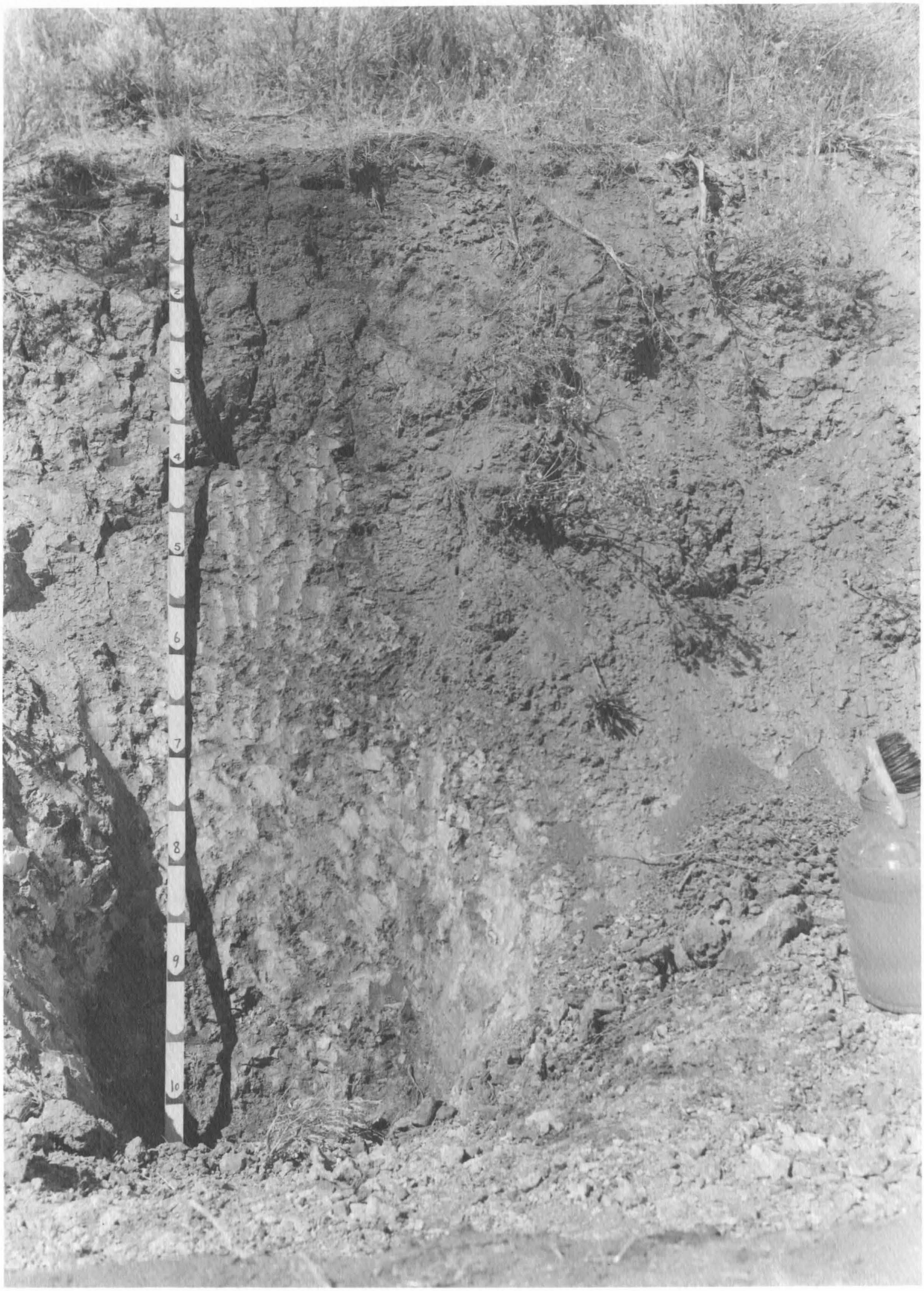

Figure 3. Profile number two (Manila). Divisions on stick represent one foot each.

Horizon	Depth (inches)	Description
A_{11}	0-4	Very dark gray (10YR 3/1) moist, clay loam, gray (10YR 5/1) dry; weak fine platy structure; soft dry, very friable moist; unstable; non-calcareous; neutral.
A_{12}	4-11	Very dark gray (10YR 3/1) moist, clay loam; gray (10YR 5/1) dry; moderate, angular blocky; slightly plastic wet; non-calcareous; slightly acid.
B_{21}	12-22	Dark brown (10YR 3/3) moist, clay, brown (10YR 5/3) dry; strongly coarse, prismatic structure with clay skins; very hard dry, very firm moist, sticky and plastic wet; stable; non-calcareous; medium acid.
B_{22}	22-33	Dark brown (10YR 3/3) moist, clay brown (10YR 5/3) dry; strongly coarse, prismatic structure with moderate clay skins; very hard dry, very firm moist, sticky and plastic wet; stable; non-calcareous; medium acid.
B_{23}	36-45	Dark brown (10YR 4/3) moist, clay loam, dark brown (10YR 4/3) dry; light yellowish brown and very dark grayish brown (10YR 6/4, 3/2) common, fine, faint mottlings; coarse prismatic structure with occasional thin clay skins, very hard dry, very firm moist, slightly sticky, slightly plastic wet; stable; non-calcareous; medium acid.
B_{24}	45-55	Dark brown (10YR 4/3) moist, clay loam, brown (10YR 5/3) dry; very pale brown (10YR 7/3) many medium, distinct mottlings; weak prismatic with thin clay skins; hard dry, firm moist, slightly sticky, slightly plastic wet; stable; non-calcareous; slightly acid.
C? D?	60-100	Light brown gray (2.5Y 6/2) moist, white 2.5Y 8/2) dry; sandy loam; massive structure coated with thick white clay skins the color of the B24 horizon.

Detailed description of Paradise soils. Profile number three was given the tentative name of Paradise. This sample site is approximately at the highest lake level, probably just below the level. The profile has the calcareous substratum similar to that of the Avon, and a solum that is quite similar to, although shallower than, that of the Manila. Profile number three (Paradise silty clay) is located about 4 miles southwest of Hyrum City (see figure 2), on a slope of 7 per cent, on a northern exposure. Its detailed description (see figure 4) is as follows:

Horizon	Depth (inches)	Description
A_{11}	0-1½	Very dark gray brown (10YR 3/2) moist, silty clay, very dark gray brown (10YR 3/2) dry; moderate very fine granular structure, soft dry, firm moist, sticky, slightly plastic wet; non-calcareous; neutral.
A_{12}	1½-5½	Very dark brown (10YR 2/2) moist silty clay, dark gray brown (10YR 4/2) dry; moderate coarse blocky stucture breaking to moderate fine sub-angular blocky stucture; hard dry, firm moist, sticky and plastic wet; stable; non-calcareous; neutral.
B_{21}	5½-19	Dark brown (10YR 4/3) moist, clay, brown (10YR 5/3) dry; black (10YR 2/1) common coarse distinct mottlings; strong coarse prismatic structure breaking to moderate medium angular blocky structure with clay skins; very hard dry, firm moist, sticky and plastic wet; stable; non-calcareous; slightly acid.
B_{22}	19-27	Brown (7.5YR 5/3) moist, clay, brown (7.5YR 5/3) dry; very dark gray (10YR 3/1) common coarse distinct mottlings; strongly coarse prismatic structure breaking to moderate medium angular blocky structure with clay skins; very hard dry, firm moist; sticky and plastic wet; unstable; non-calcareous; neutral.
II B_{23} D_1	27-28½	Light olive gray (5Y 6/2) moist, clay, light gray (5Y 7/1) dry; black (10YR 2/1) few medium size distinct mottlings; weak medium prismatic structure breaking to

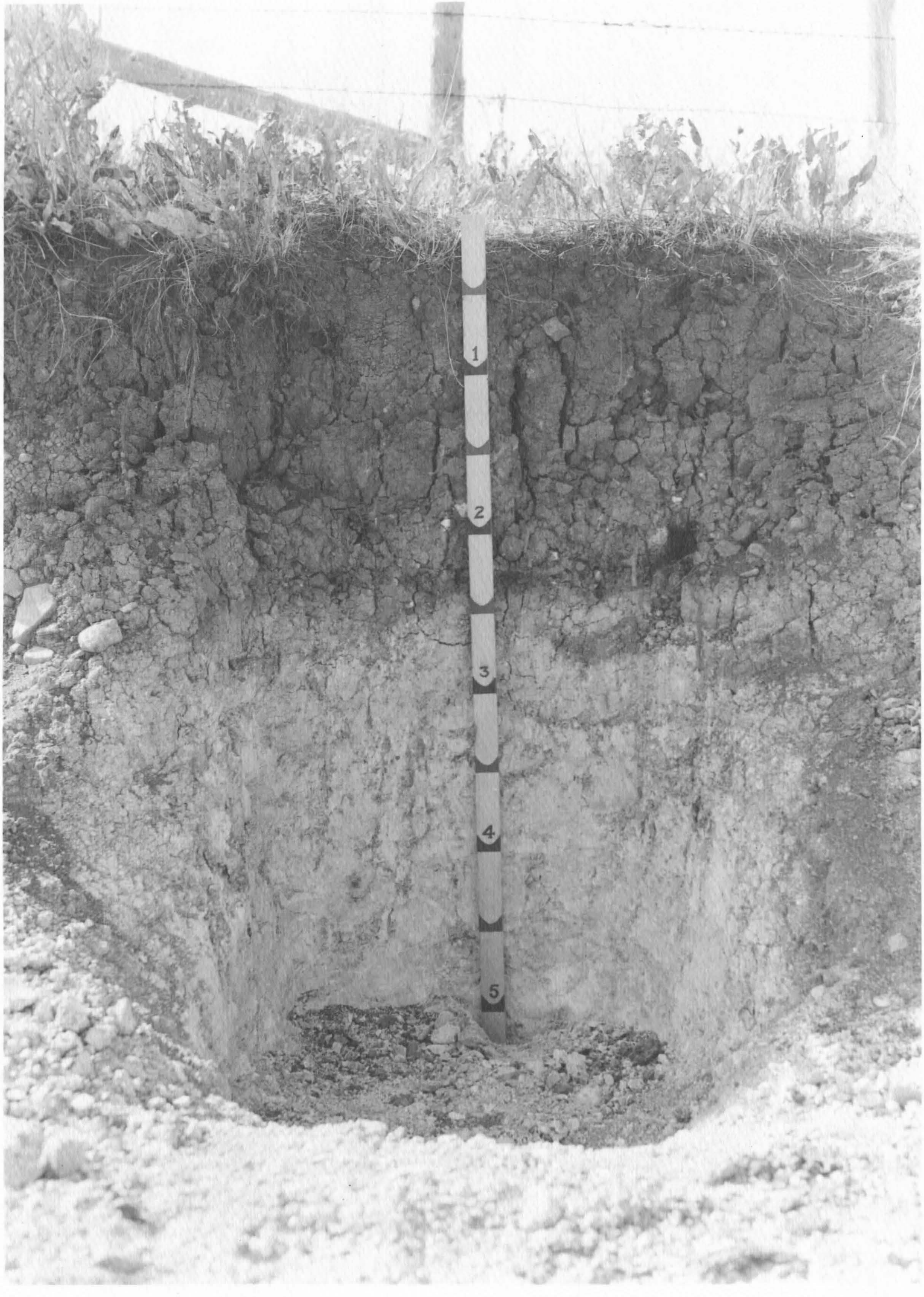

Figure 4. Profile number three (Paradise). Divisions on stick represent one foot each.

Horizon	Depth (inches)	Description
		moderate fine sub-angular blocky structure; hard dry, firm moist, sticky and plastic wet; stable; slightly calcareous; neutral.
D_2	28½-37	Light gray (2.5Y 7/2) moist, silty clay; white (2.5Y 8/2) dry, massive structure and coated with clay skins; mildly alkaline; highly calcareous.
D_3	60-72	White (10YR 8/2) moist, white(7.5YR 8/1) dry, clay loam; massive structure; mildly alkaline; highly calcareous.

Laboratory methods

Chemical, physical, and mineralogical studies of the three soil profiles were made. Some of the chemical analyses for profile number one (Avon) were made by the Soil Testing Laboratory. A brief description of the method or methods used for these tests follow.

Total soluble salts. Total soluble salts were determined by two methods, both proposed by the United States Salinity Laboratory staff (31). One method consists of measuring the electrical resistance of the soil paste by use of a Wheatstone bridge. The second method involves measuring the conductivity of the saturation extract with a pipette conductivity cell. Both methods used the Model RC-1B conductivity (Wheatstone) bridge manufactured by Industrial Instruments, Incorporated.

Soil reaction. Soil reaction was determined by the Beckman Model H-2 pH meter on the saturated soil paste and on a 1:5 soil:water suspension.

Alkaline-earth carbonates. The percentages of alkaline-earth carbonates were determined by the gravimetric loss of carbon dioxide by the method given by the United States Salinity Laboratory staff (31). A weighed soil sample is added to an Erlenmeyer flask containing a suitable amount of HCl. The weight of the flask plus acid was previously determined. The CO_2 lost at the end of a two-hour period is obtained by the difference in the total initial and total final weights of soil plus flask plus acid.

The $CaCO_3$ equivalent in per cent is equal to (wt. of CO_2 lost) x (227.4)/(wt. of soil sample used).

Organic matter. A modification of Schollenberger's method (31) was used for organic carbon determination. This method is based on the oxidation of organic carbon by potassium dichromate in sulfuric acid. Excess ferrous ammonium sulfate was added to reduce the dichromate not used in the oxidation. Finally, the excess ferrous ammonium sulfate was oxidized by titration with potassium permanganate.

The organic carbon was calculated on the following assumptions:

Milliequivalent weight of carbon is 0.003.

Organic carbon in organic matter is 58 per cent.

Organic carbon recovered is 89 per cent.

The per cent of organic carbon is equal to (0.003) (normality of $KMnO_4$) (ml $KMnO_4$ used) (100)/(0.89) (weight of soil sample used).

Total nitrogen. For determination of total nitrogen, the modified Kjeldahl method of Perrin (23) was used. The soil sample was placed in a 800 ml. Kjeldahl digestion flask. Sodium sulfate and the digestion mixture of selenium oxychloride and sulfuric acid were added. The organic nitrogen of the soil is changed to ammonium sulfate. After digestion, dilution, and cooling, sodium hydroxide and a few grams of zinc were added and the ammonium evolved on distillation was received in saturated boric acid solution. Then the solution was titrated with standard H_2SO_4.

Cation exchange capacity. The procedure followed was that given by the United States Salinity Laboratory staff (31). In this method, soil samples were extracted with N sodium acetate and washed with ethanol. The adsorbed sodium is then replaced with ammonium by extracting the soil with N ammonium acetate. Sodium was determined in this study by the Perkins-Elmer Model No. 52C flame photometer using lithium nitrate as the internal standard. A standard curve was prepared using sodium chloride solutions.

Iron determination. The method of Aguilera and Jackson (2) for the removal of free iron oxide was incorporated into the method of particle fractionation. In their procedure the free iron oxide coatings are reduced by sodium dithionite ($Na_2S_2O_4$) in a sodium citrate buffer solution to the ferrous iron form. The solution is removed from the tube and hydrogen peroxide is added to destroy the citrate and dithionite ions and to oxidize the iron to the ferric state. The concentration of iron is then determined colorimetrically in hydrochloric acid solution using potassium thiocyanide.

Fractionation of the soil. The method used was the one adopted by Dr. J. A. Kittrick, soil mineralogist at the State College of Washington and given by Miller (20). The sodium carbonate dispersion technique is essentially that of Jackson et al. (15). The settling times were calculated from the equation given by Tanner and Jackson (28). Free iron oxide removal was made by the procedure of Aguilera and Jackson (2). The generalized procedure follows:

Carbonates and soluble salts were removed from the soil by addition of hydrochloric acid and subsequent centrifuge washings. Organic matter was removed by oxidation with 30 per cent hydrogen peroxide in acid medium.

The free iron oxide coatings were reduced by sodium dithionite to the ferrous state and removed by centrifuge washing.

After removal of free iron oxide and organic matter, dispersion of the soil was accomplished by heating with sodium carbonate.

Particle size separation was performed by the centrifuge method, using 250 ml. bottles and sedimentation times calculated from the equation by Tanner and Jackson (28).

Preparation of separates for X-ray studies. The 0-0-2 μ and 0.2-2 μ clays and the 5-20 μ silt fraction of selected horizons were prepared for X-ray determinations. The method follows:

The separated fractions were not allowed to dry. Fifty-milligram portions of each clay sample were washed three times with N calcium acetate to effect saturation with calcium. Potassium saturation was done similarly using N potassium acetate. The fractions were given two small washings with distilled water to remove excess salts. To control the expansion of the clays, 1 drop of glycerol was added to each 50 mg. sample of calcium-saturated clay. The silt fraction was left sodium-saturated. Each 50 mg. sample was concentrated to a 3 to 4 ml. volume.

Slides were prepared by dropping about 10 to 15 drops of the suspension on a glass slide suitable for the X-ray holder. X-ray diffraction traces of all samples were obtained under the direction of Dr. J. A. Kittrick at the State College of Washington. A North American Philips X-ray diffractometer equipped with a wide angle goniometer, a copper target X-ray tube, and a manganese filter was used.

Mechanical analysis. The hydrometer method of mechanical analysis was used. Modified hydrometers and the procedure used by the Soil Testing

Laboratory at the Utah State University were used. In brief, the method involves hydrogen peroxide to destroy organic matter, followed by dispersion of the sample with Calgon and sodium silicate.

Petrographic study. Petrographic study of the very fine sand fractions (0.1 - 0.05 mm.) was performed on the surface and substratum horizons of the three profiles by Donald R. Olsen.*

*Geology Department, Utah State University, Logan, Utah

RESULTS

Table 2 shows the partial chemical analysis of the three profiles--Avon, Manila, and Paradise. Table 3 shows the mechanical analysis for these soils. Table 4 presents the mineral content as identified by the petrographic method for the surface soil and substratum of the three profiles. The results of X-ray are indicated in tables 5, 6, and 7.

Table 2. Partial chemical analysis of Avon, Manila, and Paradise profiles

Profile	Depth (inches)	pH: Paste	pH: 1:5 suspension	Total soluble salts: Paste	Total soluble salts: Saturation extract millimhos per cm.	Organic carbon %	Total nitrogen %	Carbon: nitrogen ratio	Calcium carbonate %	Cation exchange capacity meq/100g	Iron %
Avon	0-7	6.7	7.2	0.03	0.50	2.94	0.201	14.6	0.6	26.0	1.41
	7-17	6.7	7.3	0.04	0.56	1.96	0.148	13.2	tr.	26.2	----
	17-27	6.8	7.5	0.05	0.43	1.26	0.107	11.8	0.6	26.2	1.36
	28-35	6.6	7.4	0.06	0.33	0.85	0.078	10.9	0.6	27.5	----
	35-38	7.4	8.3	0.05	0.54	1.07	0.099	10.8	10.6	25.3	1.41
	38-44	7.7	8.7	0.05	0.48	0.62	0.062	10.0	40.7	22.5	----
	44-60	7.7	8.6	0.06	0.46	0.31	0.238	8.2	24.9	22.3	0.06
	60-72	7.8	8.9	0.03	0.46	0.10	0.012	8.3	19.4	15.2	----
Manila	0-4	6.6	7.1	0.02	0.44	2.82	0.192	14.6	0.3	25.7	1.85
	4-11	6.5	7.1	0.02	0.43	1.61	0.131	12.2	0.2	23.5	1.82
	12-22	6.0	6.9	0.05	0.30	0.66	0.080	8.3	0.2	26.9	----
	22-33	5.8	6.8	0.05	0.26	0.53	0.071	7.5	0.2	29.7	2.83
	36-45	6.0	6.8	0.05	0.27	0.56	0.057	9.8	0.3	28.7	----
	45-55	6.2	7.0	0.05	0.40	0.45	0.013	8.2	0.2	28.0	----
	60-100	6.7	7.3	0.04	0.23	0.03	0.009	3.4	0.2	26.0	0.69
Paradise	0-1½	7.0	7.5	0.07	0.93	3.58	0.250	14.3	0.2	46.3	----
	1½-5½	6.6	7.4	0.08	0.88	2.40	0.172	14.0	0.2	46.3	----
	5½-19	6.6	7.6	0.08	0.53	0.77	0.060	12.8	1.0	48.0	----
	19-27	6.7	7.6	0.08	0.49	0.52	0.038	13.8	1.0	46.7	----
	27-28½	7.1	8.2	0.09	0.47	0.40	0.043	9.3	1.6	48.2	----
	28½-37	7.7	8.6	0.10	0.41	0.32	0.038	8.3	32.3	33.5	----
	60-72	7.7	8.8	0.06	0.42	0.08	0.016	5.3	46.3	19.5	----

Table 3. Particle size distribution of Avon, Manila, and Paradise profiles as determined by the hydrometer method

Profile	Depth (inches)	Sand 2 - .05 mm %	Silt 0.05 - 0.002 mm %	Clay <0.002 mm %	Clay <0.005 mm %	Textural class
	0-7	26	50	24	31	Loam
	7-17	26	46	28	37	Clay loam
	17-27	22	48	30	39	Clay loam
	28-35	20	47	33	42	Clay loam
Avon	35-38	26	43	31	38	Clay loam
	38-44	29	45	26	42	Loam
	44-60	38	46	16	16	Loam
	60-72	71	18	11	11	Sandy loam
	0-4	21	51	28	32	Clay loam
	4-11	22	47	31	42	Clay loam
	12-22	18	38	44	53	Clay
Manila	22-33	18	40	42	51	Clay
	36-45	40	25	35	42	Clay loam
	45-55	45	28	27	29	Clay loam
	60-100	59	30	11	14	Sandy loam
	0-1½	6	49	45	59	Silty clay
	1½-5½	8	42	50	60	Silty clay
	5½-19	12	33	55	65	Clay
Paradise	19-27	17	37	46	57	Clay
	27-28½	24	30	46	56	Clay
	28½-37	16	50	34	47	Silty clay
	60-72	24	46	30	42	Clay loam

Table 4. Mineral content, identified by use of the petrographic microscope, in the 0.1 - 0.05 mm. fraction of the surface soil and subsoil of the three profiles*

Profile	Depth (inches)	Mineral content: Quartz %	Altered feldspars %	Volcanic glass %	Horn-blende %	Andri-sine %	Oligo-clase %	Chlorite %	Plagio-clase %
Avon	0-7	40	55	5	--	--	--	trace	trace
	44-60	50	40	8	--	--	--	--	trace
Manila	0-4	50	20	15-20	trace	trace	--	--	--
	60-100	20	75	2	1	--	2	--	--
Paradise	0-1½	80-90	10-20	trace	--	--	--	--	--
	27-28½	50	49	--	--	--	--	--	1

*Performed by D. R. Olsen, Geology Department, Utah State University, Logan, Utah.

Table 5. The relative intensities of X-ray diffraction peaks of various Na-saturated silt (5 - 20μ) fractions of samples of Avon, Manila, and Paradise soil series

Sample depth (inches)	Relative peak heights[1]		
	Quartz	Feldspars	Micas
		Profile 1 - Avon	
0-7	23	12	4
17-27	18	13*	4
35-38	15	7*	tr.*
44-60	15	9	8
		Profile 2 - Manila	
0-4	33	18	4
4-11	40	21	8
22-33	19	6*	7
60-100	8	16	3*
		Profile 3 - Paradise	
0-1.5	34	14	0
1.5-5.5	26	10	0
19-27	24	12	0
27-28.5	22	4	tr.

[1] Relative peak heights in arbitrary units.
* Peak is broad.

Table 6. The relative intensities of X-ray diffraction peaks of various Ca-saturated and glycerol-solvated colloids in the fine clay (0 - 0.2 μ) fractions of samples of the Avon, Manila, and Paradise soil series

Sample depth (inches)	Peak heights1/			Peak height x av.peak width2/		
	Mont.3/	Illite	Interstr.4/	Mont.	Illite	Interstr.
			Profile 1 - Avon Series			
0-7	35*	8*	?	160*	25*	?
17-27	45*	4*	?	225*	4*	?
35-38	55	tr.*	0	220	tr.*	0
44-60	95	6	0	230	3	0
			Profile 2 - Manila Series			
0-4	30*	5	0	150*	10	0
4-11	25*	5	?	125*	10	?
22-33	35*	tr.	0	175*	tr.	0
60-100	90	tr.	30	310	tr.	100
			Profile 3 - Paradise Series			
0-1.5	55	tr.	0	250	tr.	0
1.5-5.5	70*	0	?	310*	0	?
19-27	70	0	0	290	0	0
27-28.5	95	0	0	250	0	0

1/ Relative peak heights to the closest multiple of 5, using the units of the recording graph paper.
2/ Relative peak area obtained by multiplying the peak height times the peak width at one-half its height.
3/ Montmorillonite
4/ Interstratified minerals with basal spacings between 25 and 35A.
* Peak is broad.

Table 7. The relative intensities of X-ray diffraction peaks of various Ca-saturated and glycerol-solvated colloids in the coarse clay (0.2 - 2.0 μ) fractions of samples of the Avon, Manila, and Paradise soil series

Sample depth (inches)	Relative peak heights[1]				
	Montmorillonite	Illite	Kaolinite	Interstratified minerals[2]	Quartz
	Profile 1 - Avon Series				
0-7	9*	7	0	0	5
17-27[3]	14	7	0	4*	6
35-38	47	10	0	0	6
44-60	56	5	0	0	4*
	Profile 2 - Manila Series				
0-4	9	8	5	3*	8
4-11	18*	9	2*	0	8
22-33	13	7	3	5	6
60-100	28	3	tr.[4]	0	tr.
	Profile 3 - Paradise Series				
0-1.5	21*	5*	6	0	7
1.5-5.5	13*	2*	5	0	11
19-27[3]	30	tr.	3	0	4*
27-28.5	61	0	0	0	4

[1] Relative peak heights in arbitrary units.
[2] Interstratified minerals with basal spacings between 20 and 35 A°.
[3] Had a trace of vermiculite.
[4] Trace.
* Peak is broad.

DISCUSSION

General soil characteristics

Soluble salts, pH, calcium carbonate, and exchange capacity. The data of table 2 indicate that all three soil series sampled are slightly acid to neutral in the surface soils. The subsoils of the Avon and Paradise are mildly alkaline. The Manila sample is the most acidic of the three profiles and has a pH low of 5.8 in the 22-33 inch horizon. It is somewhat surprising to find that the deeper Manila sample taken between 45 to 55 inches is also quite acid (pH 6.2), because the annual rainfall of the area is only about 18 inches. Such deep leaching of a clayey soil on a 32 per cent slope would not be expected in this rainfall belt.

In all soils the total soluble salt concentration is relatively low. It is lowest in the Manila soil and highest in the Paradise soil. From pH and salt content data, it would appear that the Manila soil is more highly leached than the Avon or Paradise soil. This result would not be expected under present conditions. The three soil sites are all within a half mile of each other and should have little or no macro climate differences. In addition, the Manila occurs on a steep slope relatively close to the hill summit. The Paradise and Avon sites, however, are on less steep slopes and are susceptible to water runoff from watersheds larger than the one which affects the Manila site. Logically, one would expect the leaching of the area to be greatest in the Avon and least in the Manila.

Both the Avon and the Paradise soils have marked carbonate accumulations at approximately 35 and 28 inches, respectively, whereas the Manila is completely leached to at least 8 feet. The accumulation of lime a few feet deep is expected in a "normal" soil of the area in the present environment. It is believed by the author that the upper 27-inch solum of the Paradise soil is similar to the Manila solum. It is quite obvious to the observer that this 27-inch solum of the Paradise soil has been layered onto the highly calcareous substratum beneath it. This latter material, buff in color, is markedly different in appearance and texture from the soil occurring above the 28-inch depth.

In contrast to this, the light-colored strata underlying the Manila soil is completely free of lime to at least 100 inches. It is possible that this white, ashy, sandy loam material underlying the soils of this area is not uniform. Portions ~~of it~~, especially on lower terraces, may be calcareous because of lime accumulations during the period of Lake Bonneville.

The values for the cation exchange capacity (CEC) of the samples is difficult to evaluate. All samples of the Paradise profile above the 28-inch depth have a considerably higher CEC than samples of the other two profiles. The fact that these samples of the Paradise soil have a higher percentage of clay than the other samples leaves the impression that a close relationship exists between CEC and clay content (see table 3). A comparison of individual values between and within profiles does not produce any obvious relationship between CEC and any of the other measured values.

Carbon, nitrogen and the C:N ratio. All three soils have large percentages of organic matter. All have Chernozem-like surface soils with gradually decreasing organic matter with increased depth. As expected, the total nitrogen content is directly proportional to the organic matter content.

In looking at the C:N ratios, however, the unexpected high values of 14.6, 14.6, and 14.3 were obtained for the surface soil of Avon, Manila, and Paradise, respectively. The present climate does not, in the opinion of local soil surveyors, favor such a high ratio.

Climatical data for the area are given in table 8, as prepared by Hutchings (14). The summers are quite warm and dry (average temperature for June through September is 67.8° F.), and the winters are cool and moist (average temperature for November through March is 30.4° F.). From November through March the precipitation exceeds the potential evapo-transpiration by the amount of snowfall because it occurs mostly as snow which does not melt. During the summer (June through September) the average monthly precipitation is reduced less than half that in the winter months and the potential evapo-transpiration exceeds it several times. In August and September the Manila and Paradise soils commonly dry to 2 or 3 feet in depth and shrink, to leave cracks one to several inches wide.

In the opinion of local survey authorities, the warm, dry summers should speed soil organic matter decomposition sufficiently to reduce the C:N ratio to eqilibrium levels which have commonly been assumed to be less than 13.5. However, in the past few years, as a result of development of soil criteria for soils of the forthcoming soil classification system, other soils have been found that have these wide ratios. Dryland loess soils of the Palouse soils in southeastern Washington also have similar high C:N ratios which have been reported by Moodie (22). In

Table 8. Climate of the Logan area at an elevation of 4,779 and latitude of 41°44'*

	Months												
	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Average
Average Temp. °F.	23.9	27.9	36.7	47.5	55.6	64.1	72.8	71.4	61.8	50.3	37.1	26.4	48.0
Potential evapo-transpiration	---	---	---	4.1	7.6	10.9	14.6	13.0	8.2	4.3	---	---	62.7
Precipitation (cm.)	4.0	3.8	4.9	4.6	5.2	2.2	1.5	1.7	3.3	4.1	3.1	3.1	41.5
Surplus or deficient moisture	4.0	3.8	4.9	0.4	-2.3	-8.7	-13.1	-11.3	-4.9	-0.2	3.1	3.1	-21.3

Years record: Precipitation 59; temperature 59; frost 39.
Frost-free period 5/7 - 10/11: 157 days.
*Modified from Hutchings (14)

Washington, two prairie soils have C:N ratios of 17.0 and 17.3; a Sierozem, a Red Desert, and a brown soil have C:N ratios of 15:8, 15:1, and 14:8, respectively. These last three soils are distributed in the center of the state of Washington and are under irrigation. Also, some other Cache Valley soils analyzed by the Soil Testing Laboratory at this institution have similar ratios.

No conclusion on soil differences can be drawn from these ratios. All soils are similar.

Mechanical analysis. Table 3 presents the mechanical analysis as obtained by the hydrometer method. The clay percentage, in the Manila soil, is relatively low in the surface, high in the B horizon, and low again in the C horizon. The wide-spread clay skins in the B horizon are a clear indication of clay migration in this profile. These facts indicate that this profile is considerably weathered.

The Paradise profile shows the same trend, but it occurs to lesser depth than the Manila and contains a relatively higher percentage of clay than the Manila. If the lithological makeup of these two profiles is the same, then the higher percentage of clay in the Paradise profile would indicate that this profile is even more weathered than the Manila.

The data of the Avon profile have a different trend from those of the Manila and Paradise. The percentage clay in the Avon profile as a whole is lower than that of either Manila or Paradise. The top 35 inches have a gradual increase in percentage clay with increased depth. This corresponds, but to a lesser degree, with that of the other two soils. Deeper than 35 inches the clay percentage becomes gradually lower.

The general percentage clay increase in the Manila and Paradise soils would indicate either longer or more intensive weathering. It is, however, of interest to note that only the Manila and the Avon "C" horizons have similar clay percentages. Since it is known that the complete Paradise profile was not formed in place from the substratum, no good estimation of the extent of weathering of this profile can be made from just these mechanical analysis data alone. The parent material must be known.

Mineralogical analysis. A brief study was made to determine the mineralogical composition of various selected horizons of the three profiles. A petrographic study on the surface sample of each profile and on the substratum material of the Avon and Manila revealed that the very fine sand fraction is predominantly quartz and feldspars. Small amounts of volcanic glass (5 and 8 per cent) were found in the Avon samples. In the Manila surface sample, 15 to 20 per cent of volcanic glass was found, but only 2 per cent was identified in the 60 to 100 inch level (see table 4).

Commonly feldspar weathers more rapidly than quartz or volcanic glass. Assuming that the sola of the three profiles sampled were derived from similar material, the greater the proportion of quartz and volcanic glass to the amount of feldspars, the greater the extent of weathering which has occurred. On this assumption the Avon surface soil is the least weathered (contains 40 per cent quartz and 55 per cent feldspars) and the Paradise surface soil is the most weathered (contains 85 per cent quartz and 15 per cent feldspars). Feldspars are known to weather to produce considerable clay. The low feldspar content and high clay content of the Paradise surface soil sample is, therefore, compatible.

The light-colored substratum of each of the Manila and Avon sites is not sharply separated from the solum above it and it is possible that these soils have developed in place. Assuming the soils are formed in place from the respective substratum, the following interpretation can be made. With increased weathering the percentage of quartz should increase and the percentage of feldspar should decrease as the C horizon weathers and becomes a part of the solum. The values obtained for Avon samples indicate a low degree of mineral weathering since there is no appreciable change in the percentages of quartz and of feldspars in the C and the surface horizons. In the Manila samples, though, quartz percentage increases from 20 per cent in the C horizon to 50 per cent in the surface soil. Feldspar content decreases from 75 per cent in the C horizon sample to 20 per cent in the surface sample. This would indicate that if the Avon and Manila soils are residual, the Manila soil is considerably more strongly-weathered. Also, the C horizon material in the two profiles is different. The C horizon of the Manila soil has a higher percentage of feldspars than the C horizon of the Avon.

The Paradise samples are somewhat unusual. The light olive gray clay sampled at a depth of 27-28.5 inches is probably a much more weakly-weathered sample than the rest of the solum above it. The surface sample has a high percentage of quartz (85 per cent) and a low feldspar content (15 per cent). This surface soil may be the most strongly-weathered sample of those studied.

Further mineralogical studies by X-ray diffraction were made on selected samples. The data are presented in tables 5, 6, and 7. In studying the X-ray data one should keep in mind that the peak heights are a function of: (1) the amount of sample on the slides; (2) orientation of the sample; (3) crystalinity of the particles; and (4) size of the particles. Interpretation of the data are necessarily somewhat general from the limited X-ray work done.

Table 5 contains X-ray diffraction on the medium silt (5 - 20μ) fraction. All samples are predominantly quartz and feldspars with smaller quantities of mica distinguishable in the Avon and Manila samples. The ratio of quartz to feldspars does not change appreciably in the Avon samples. This would indicate a low degree of weathering of the solum, assuming that the 44 to 60-inch depth is parent material.

In the Manila samples, however, the ratio of quartz to feldspars changes from about 1.8 in the surface sample to 0.5 in the sample from the 60 to 100-inch depth. Assuming that the Manila soil is formed in place from the substratum and that the latter horizon is the C horizon, the Manila soil has undergone quite extensive weathering. The presence of mica is evident but it is lower in amount than was expected. In a brief survey of the Manila site it was found that some deeper portions of the site hill have considerable quantities of biotite easily visible. This observation was made on a southern exposure of the same knoll on which the Manila occurs as an easternly exposure. The absence of strong mica or illite diffraction peaks was even more surprising in the clay fractions.

The data of the Paradise samples are not in good agreement with petrographic data given in table 4. The X-ray diffraction data of the 27-28.5 inch sample (the high quartz, low feldspar values) would indicate a strongly-weathered horizon. The petrographic study indicated the opposite. In contrast, the surface horizon is weakly-weathered according to X-ray data, but it is interpreted the opposite when studied petrographically. Amorphous material is not identified by X-ray diffraction methods and amorphous silica or altered feldspars may not show up on X-ray patterns, but it would be seen in a petrographic study. A more detailed study is needed before a conclusion would be made.

Table 6 presents X-ray diffraction data for the fine clay fractions (0 - 0.2 μ). In all samples montmorillonite is markedly dominant. This is surprising because of the mica found in samples near the Manila site in a brief survey of the area. In a previous study by Douglas* on Payson soil series, large proportions of illite were identified. This series lies east of the Great Salt Lake and west of the foot of the Wasatch Mountains. The Payson soil is calcareous and is an intrazonal degraded solonetz soil of brown and chestnut soil zones. Considerable interstratified montmorillonite-illite material was claimed to be present in the soil. Although the soils may be partially derived from the same mountain range material, the marked heterogeneity of the area makes it possible for the marked differences in clay types found in soils of the area.

As clays weather, they often become changed into less crystalline or into more amorphous material. X-ray diffraction peaks are more marked as crystallinity increases. It is not surprising, then, to observe larger (higher) peaks for the deeper samples.

It should be kept in mind that these values are on soil separates and not on the whole soil sample. The Manila sample taken at 22 to 33 inches has 33 per cent of fine clay, whereas the 60 to 100-inch sample has only 2.4 per cent. Thus, the marked montmorillonite peak in the lower horizon,

*Uncompleted M.S. thesis by Lowell Douglas, Utah State University.

when multiplied by the whole soil percentage made up by the fraction, only means that the small portion of the soil that is fine clay is very high in montmorillonite. In contrast to this, the 27 to 28.5 inch Paradise sample has 43 per cent fine clay, all of which is high in montmorillonite.

One unusual feature was found in the Manila 60 to 100-inch sample. For several reruns, a marked diffractions peak occurred which indicated an interlayer spacing (or more correctly, a repeating plane) of about 35 Angstroms. This is listed as interstratified material. It is common with mixed minerals where the mineral is made up of alternating layers of the components. Alternating mica and montmorillonite would have repeating planes of 20 to 28 Angstroms apart. Various other combinations (vermiculite plus montmorillonite, variable stacking of montmorillonite, others) will produce other spacings. It was found that after standing a few hours, the slide which had been prepared no longer produced a diffraction peak at the 35 Angstroms. The peak completely disappeared. Further work has not yet been done on this sample.

In the coarse clay samples (see table 7) montmorillonite again was the dominant mineral. As in the fine clay patterns, the peak intensities of the coarse clay samples increased as the samples from deeper depth in the profiles were analyzed. A small amount of illite was noted, mostly in the shallower soil samples. Quartz occurs in sufficient amounts to be identified in most samples.

For the first time in the samples analyzed kaolinite was identified. It was not found in large amounts. From experiences it is known that amounts as low as 20 per cent kaolinite will produce marked diffraction peaks. The Avon samples did not have any kaolinite identifiable. Because kaolinite is assumed to be the result of more acid or more intense weathering than either illite or montmorillonite, the conclusion is that the Avon soil is a younger soil (less weathered) than the other two. The 27 to 28.5 inch sample of the Paradise soil had no kaolinite identified. This would substantiate an earlier conclusion that this layer is less weathered than the rest of the solum above it.

The marked color difference between the solum and the 27 to 28.5 inch layer makes it impossible to assume the immediate source of each of these portions to be formed from the same material. The calcareousness and green color of the 27 to 28.5 inch layer could have formed from the white calcareous material below it. It is possible that this layer resulted from either weathering or from sedimentation during the period of the Bonneville lake. When the lake receded, the present solum was deposited on top of this material. It is possible that this solum was formed from material similar to the present substratum. But if so, it occurred at a different location and has been mixed with gravels during movement.

SUMMARY AND CONCLUSIONS

Three soil profiles were studied in this investigation. One of the profiles (the Manila) lies above the highest level of Lake Bonneville. The second soil profile represents the Avon soil series and lies below the Lake Bonneville shore line. The third profile, Paradise, occurs at about the highest level of the ancient lake.

Chemical, mechanical, and mineralogical analyses were made on the three profiles: (1) to characterize these soil samples, (2) to show the differences between them, and (3) to attempt to find out if the Manila and Paradise soil series are compatible with the present climatic conditions.

The Avon soils are well-drained, moderately fine-textured, zonal Chernozem-like soils. They are mostly dry-farmed. Wheat and alfalfa are the principal crops. The profile studied occurs on an east-facing slope of 5 per cent.

The Manila soils are well-drained, fine-textured soils. They occur mostly on steep slopes above the highest level of Lake Bonneville. The profile studied occurs on a slope of 32 per cent facing east. The present vegetation on this area is Artimisia tridentata (sagebrush) and Bromus tectorum (June grass). The B horizon of the Manila profile is strongly prismatic clay. It is characterized with wide cracks, some of them opening to the surface. The clay has a tendency to swell when wet and shrink when dry.

The Paradise soils are well-drained, fine-textured soils. The solum of which is quite similar to the Manila soil. The Paradise soils lie on about the Lake Bonneville shore line. The profile studied is in a northern exposure having 7 per cent slope. The present vegetation of this area is Artimisia tridentata(sagebrush), Balsomoriza sagittata (balsam weed), Rosa woodsie (wild rose), and Helianthella uniflora (little sunflower). The B horizon has very strongly prismatic structure and has even wider cracks than in the Manila, and some of them also open to the surface. The clay of this profile has a great tendency to swell when wet and to shrink when dry.

The following conclusions are drawn:

1. The data indicate that the Manila soil is more acidic than either of the Avon or Paradise soils and leached to a greater depth. Since the present climate results in no such excessive leaching, the explanation would be that either this soil is old or was influenced by other climatic conditions sometime during their formation.

2. The high content of clays and the wide extent of the clay skins in the B horizon and substratum of the Manila and Paradise soils are an indication that these soils are considerably weathered.

3. The silt and sand fractions of the three soils are predominantly feldspars and quartz with a small amount of mica present. Assuming that the sola of the three profiles sampled were derived from similar materials, it can be concluded that the Avon surface soil is the least weathered (contains 40 per cent quartz and 55 per cent feldspar) and the Paradise surface soil is the most highly weathered (contains 85 per cent quartz and only 15 per cent feldspar). Feldspars are known to weather to produce considerable clay. The low feldspar content and the high clay content of

the Paradise surface soil sample, is therefore, compatible.

4. The ratio of quartz to feldspar does not change appreciably in the various Avon horizon samples, which indicates a low degree of weathering of the solum. In the Manila, the ratio of quartz to feldspars changes from about 1.8 in the surface sample to 0.5 in the sample from the 60 to 100-inch depth. If it is assumed that the Manila soil is residual and that the latter horizon is the C horizon, the Manila soil has undergone quite extensive weathering.

5. The X-ray diffraction analysis indicates that all samples have predominantly montmorillonitic clays with a little illite in the Avon and Manila soils.

6. The data of the coarse clay fraction indicate that these samples also are predominantly montmorillonite, but do have small amounts of illite and quartz. The absence of kaolinite in the Avon samples and the presence of small amounts of it in the Manila and Paradise samples is another indication that the Avon soil has been less intensively weathered than the Manila and Paradise samples.

7. The deeply leached profile, high clay percentage, high quartz to feldspar ratio in the solum, and the presence of some kaolinite, lead the author to conclude, though not entirely certain, that the Manila soil has been developed partially under a climate (micro or macro) different than the present one. This climate would have been wetter than the present one.

8. The solum of the Paradise profile is so different from the layer below it that it is obvious to the observer that this solum has been layered onto the material beneath it. The boundary is abrupt. The solum contains about 10 per cent gravel, but the material beneath is free of gravel. The

solum is free of lime, but the material beneath is highly calcareous. These and other soil properties lead to the conclusion that the solum did not form from the material beneath it.

9. The Avon sample, leached to 35 inches, is considered to be younger morphologically than the Manila or Paradise soils. It is believed to be entirely compatible with the present climate, and to have developed under such a climate.

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