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Characteristic and Genesis of Some Soils of the Upper Terraces of Lake Bonneville

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CHARACTERISTICS AND GENESIS OF SOME SOILS OF THE UPPER TERRACES OF LAKE BONNEVILLE

by

Mohammad Ali Haji Mirsadeghi

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

of

MASTER OF SCIENCE

in

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(Soil Genesis and Classification)

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Mohammad Ali Haji Mirsadeghi

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ABSTRACT

Characteristics and Genesis of Some Soils on The Upper Terraces of Lake Bonneville

by

Mohammad Ali Haji Mirsadeghi, Master of Science
Utah State University, 1980

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Department: Soil Science and Biometeorology

The genesis and characteristics of the Timpanogos, Hillfield, and Sterling soils and an unnamed Mollisol (soil formed on north-slope) on the east part of Cache Valley were studied in order to determine (1) why the soil morphology is not chronologically related to the geomorphic surface and (2) why different soils have developed on these surfaces, even though the soil forming factors appear similar.

The particle size distribution of the upper horizons of the Timpanogos, Hillfield, and unnamed Mollisol pedons are relatively similar. These soils developed from stratified deposits with granulimetric composition in which 75 to 90 percent of the grains are less than 100 micrometers in diameter, characteristic of wind-blown material. Development of an incipient argillic horizon in Timpanogos pedon indicates this soil did not develop under the moist conditions of the Pleistocene and the geomorphic surface was not stable after deposition. The material was reworked by the wind. The Sterling soil formed on an alluvial fan which was deposited during Holocene time and its development is chronologically related to geomorphic surface.

The development of an incipient argillic horizon in the Timpanogos soil and a weak cambic horizon in the Hillfield soil and the unnamed Mollisol is due to topographic condition of the landscapes.

The thick and dark mollic epipedon in the unnamed Mollisol (north-slope) compared to the Hillfield soil (south-slope) which has an epipedon with color light to be mollic and a less thick A horizon is related to effect of microclimate.

(106 pages)

INTRODUCTION

Geomorphic surfaces are useful in the studies of soils, because they provide a chronological framework for the understanding of soil development. Terraces are prominent topographic features along the east side of Cache Valley extending south from Logan River to the town of Providence. The terraces represent different stages of Lake Bonneville which was a product of the glacial period and is believed to be Wisconsin age (about 70,000 YBP = years before present). Lake Bonneville deposits are divided into three different levels: 1) Alpine formation, up to 1554 meters altitute corresponding to Bull Lake glaciation (62,000-32,000 YBP), 2) Bonneville formation, up to 1565 meters altitute corresponding to Late Wisconsin age (interstade, about 20,000-18,000 YBP), 3) Provo formation, up to 1470 meters altitude corresponding to Pinedale glaciation (13,000-11,000 YBP) (Flint, 1971)

Assuming stability has prevailed, the soils present may be chronologically related (Gile and Hawley, 1972). Degree of soil development on the upper terraces of Lake Bonneville does not indicate that the terraces are old. Also, different soils with relatively different degrees of development are associated in the study area. In an effort to understand the reason for the differences in soil development four pedons were selected for this study.

Statement of the problem

The Hillfield, Timpanogos and Sterling soils are on the upper levels of Lake Bonneville terraces. It is necessary to study the genesis and characteristics of these soils on the east part of Cache Valley to determine, (1) Why the soil morphology is not chronologically related to geomorphic surface and (2) Why different soils have developed on these surfaces, even though the soil forming factors appear similar.

To answer these questions, the following objectives were chosen:

1. Determination of the characteristics and pedogenic processes of the Hillfield, Sterling and Timpanogos soils.

2. Determination of the relation of soil development to topographic position; i.e., the relation of soil horizon differentiation to Lake terrace level.

3. Determination of the differences between soils formed on different aspects (effect of microclimate on the formation of soil on north and south-facing slopes).

4. Verification of the classification of the soils.

To determine the origin(s) of the deposits on which the soils are formed, interpretation of particle size analysis and mineralogy of soil material were used. For mineralogical studies, clay and silt fractions were examined by X-ray diffraction analysis and sand fraction compositions were determined with the polarizing microscope. These studies also helped to determine the uniformity or lack of uniformity of the soil material. To establish the presence or absence of argillic horizons, thin sections were examined with the polarizing microscope. To acheive objectives 2 and 3, organic matter, calcium carbonate equivalent, free iron oxide and cation exchange capacity were determined.

LITERATURE REVIEW

Climatological review of Cache Valley

The climate in Cache Valley ranges from dry subhumid to moist subhumid. It is characterized by usually cold winters, wet springs, and dry and warm summers. Precipitation increases with increases in elevation. The average annual precipitation is 432 mm (Erickson, 1974), most of this is snowfall during October through April. The frost-free season on the floor of Cache Valley and on the Lake terraces is 120 to 160 days (Erickson, 1974). The climatic data at the Utah State University (USU) Station in Logan (Table 1, Richardson, 1974) shows that nearly 40 percent of the annual total precipitation falls in March, April and May. Precipitation decreases rather abruptly in July along with a rapid increase in temperature. The annual mean temperature during the period 1941 to 1970 was 8.3° C. Mean summer and mean winter temperatures are 20.8° C and -3.3° C, respectively.

Table 1. Mean monthly temperature and precipitation during 1941-1970 at the USU Station at Logan, Utah (elevation 1455 MSL)

Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov	Dec.
					Temperature (C)						
-4.4	-1.9	2.6	8.5	13.3	17.8	22.7	21.9	16.6	10.2	2.6	-3.0
					Precipitation (mm)						
40.7	37.6	47.0	49.5	48.8	30.0	12.7	18.3	28.2	38.6	36.1	35.8

Brief geological history of Cache Valley

Cache Valley is essentially Cache County and the drainage area surrounding it. Cache Valley, mapped as part of the middle Rocky Mountain Province by Fenneman (1928) and Hammond (1965) is located on the eastern edge of the Basin and Range Province.

Structurally, Cache Valley is a graben that is surrounded on both sides by north-south Tertiary Basin and Range faults (Williams, 1948), which are responsible for the major topographic features of Cache Valley. Cache Valley is elongated in a north-south direction, with generally parallel sides, and is delineated in the east and west by the Bear River Range and Western Rim (Wellsville Mountain, Junction Hills, Malad Range) respectively (Figure 1). The lowest part of Cache Valley, the west central part, is about 1346 meters above sea level, while Mount Noami is the highest point, at approximately 3040 m (Williams, 1948).

The geologic deposits that cover Cache Valley vary distinctly with elevation. In general, the Valley bottom is covered by Lake Bonneville group sediments; Tertiary rocks (Salt Lake formation) in the foothills, and Paleozoic rocks in the higher mountains bordering the valley (Williams, 1962). Paleozoic rocks were affected by the Laramide orogeny and Tertiary rocks by Basin and Range faults.

Thick, metamorphosed, fine-grained Precambrian clastics are overlain by hundreds of meters of quartzite of Early to Late Cambrian age. During Paleozoic time, a thick section of carbonate sediments was also deposited. The Laramide Orogeny (Late Cretaceous until Eocene time) produced folds and thrust-faulted mountains (Maw, 1968). The product of this activity is the eastern mountains in Cache Valley (formation of "broad anticlines and synclines") (Williams, 1962).

The foothills in Cache Valley are occupied predominantly by two Tertiary rock units, the Wasatch and the Salt Lake formations. The Wasatch formation, Paleocene and Eocene age, (Adamson, et al. 1955), consists of red conglomerate and sandstone. Its color reflects the warm humid climate of the subtropics which existed over the Piedmont area (Williams, 1958).

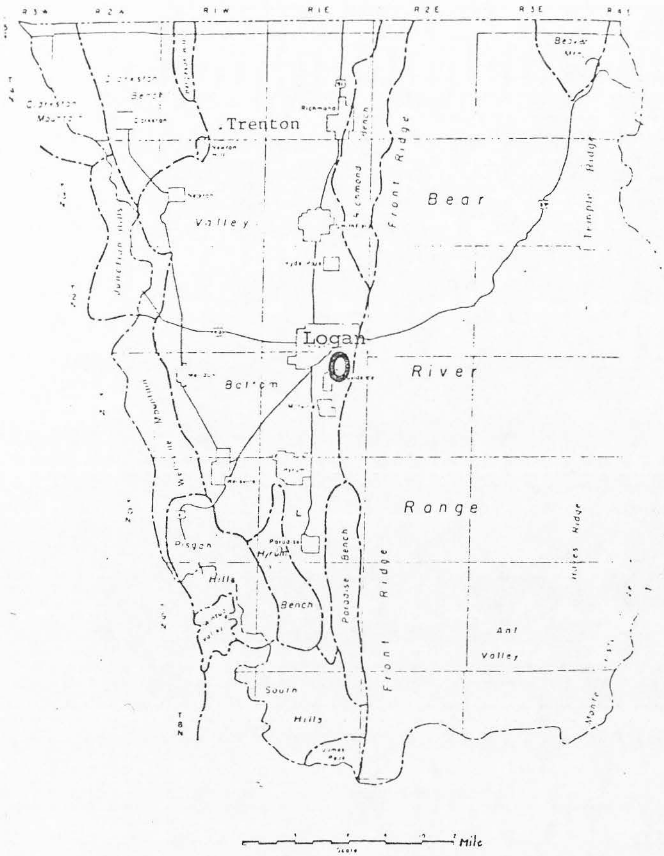
The Salt Lake formation was deposited later in the Tertiary period, during the Miocene and Pliocene epochs (Maw, 1968).

Williams (1962) classified the Salt Lake formation into three members:

1. Lower conglomerate unit: the oldest member, consisting of cobble and boulder conglomerate, in a white matrix exposed in the foothills near Wellsville and Mendon.

2. Tuff unit: consisting mostly of "soft earthy-gray tuff", also containing a minor amount of pebble conglomerate. Its distribution is restricted to Hyrum bench.

3. Upper conglomerate and sandstone unit: the



O-Location of the study area

Figure 1. Physiographic divisions of Cache Valley, showing the location of the study area. (adapted from J. Williams, 1948)

youngest unit, consisting of rounded pebbles and cobbles in a matrix of calcium carbonate and tuffaceous sand.

After deposition of the Salt Lake formation, subsequent faulting and tilting, and erosion created a varied topography. Then later, deposition of Lake Bonneville sediments occured (Maw, 1968).

Glacial processes are important in the Quaternary history of Cache Valley. It is estimated that at least 12 glaciers were active in the western ridges of mountains surrounding Cache Valley during the Pleistocene (Church, 1943). Young (1939) reported two epochs of glaciation separated by an interglacial period in Cache Valley. He also pointed out that the glaciers on the western and eastern ridges of the valley descended to elevations of 2130 and 1860 m., respectively. A pluvial climate during the Pleistocene was the main factor for the formation of Lake Bonneville. Lake Bonneville deposits cover most of the interior of Cache Valley (Williams, 1956, 1962). Lake Bonneville, in its last stages, corresponds to Wisconsin age. Lake Bonneville was the largest of the glacial lakes in western North America. Today, the highly saline Great Salt Lake, Utah, and Sevier Lakes are the remnants of the ancient Lake (Leopold, et al, 1964). Lake Bonneville was fed by streams from the Uinta and Wasatch mountains. Gilbert (1890) described some of the lake's remnant geomorphic features as deltas, shore embankments, and outlet channels. The elevation of the Lake shoreline is about 1565

m. above sea level (high stand at Bonneville level) and greatest depth about 320 m. It covered about 51,152 square kilometers. Gilbert also concluded that the Lake was created by glaciation and climatic changes, and the lacustrine epochs were epochs of relative cold. The four shoreline levels named by Gilbert, from oldest to youngest, are:

1. Alpine formation, proposed by Hunt et al. (1953), was considered the oldest deposit of Lake Bonneville, exposed above Provo shoreline and below Bonneville shoreline. It consists of lacustrine gravel, sand, silt and clay. The elevation extends to 1554 m. in southern Cache Valley (Williams, 1962). The Alpine formation was covered by the Bonneville formation and is not differentiated by Williams (1962).

2. Bonneville formation, younger than the Alpine formation, was deposited during the highest level of the Lake. It consists of silt and sand along the east side of the Valley. The elevation of the shoreline (at Bonneville level) is 1565 m. (Williams, 1962). The outstanding feature of Lake Bonneville deposits at levels between the Provo and Bonneville shorelines are current-built embankments of buff silt and fine sand (Williams, 1962). The embankments extend almost continuously along the east side of the Valley. These embankments have been severely dissected by closely spaced, generally parallel, gullies. Along the east side of

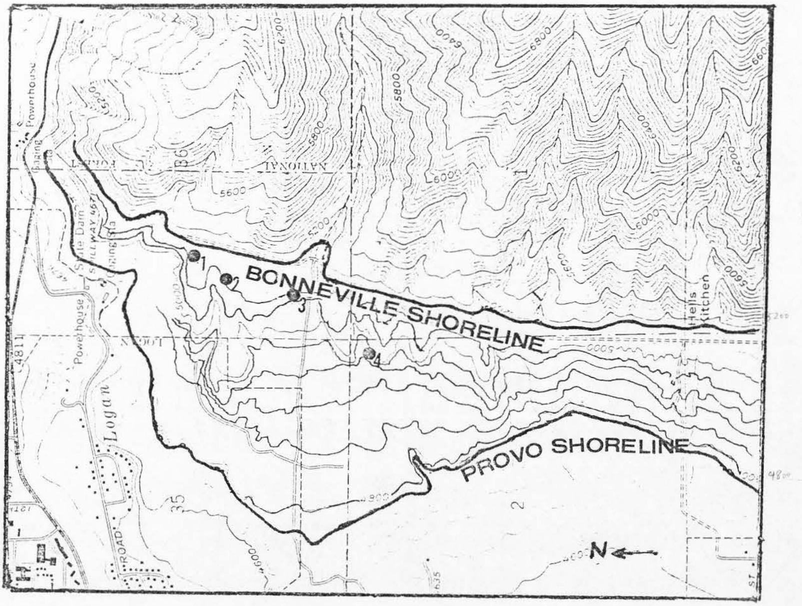
Cache Valley, the embankments that "once were continuous for kilometers, when first uncovered by the shrinking Lake" are now represented by scattered low mounds and parallel ridges, as a result of being eroded by streams from the mountains.

3. The Provo formation: an intermediate stage, with a maximum elevation of 1470 m., consists of boulders to fine sand and silt and clay, derived from Tertiary and Paleozoic rocks. This formation is extensively exposed in Cache Valley. Topographic expression and lithologic differences near the Provo shoreline are used to distinguish between the Provo and Bonneville formations (Maw, 1968). Most of the delta sediments were deposited during this stage (Williams, 1962).

4. The youngest stage is called the Stansbury, with an elevation of 1360 m. These deposits are not well exposed in Cache Valley.

It is believed that Lake Bonneville formed about 75,000 years ago, whereas the deposits of the Bonneville formation formed about 25,000 years ago (Morrison, 1966). The different shoreline levels of Lake Bonneville are due to the advances and retreats of glaciers in the Uinta and Wasatch mountains, and the corresponding fall and rise of lake level dependent on melt water from these glaciers.

Post Lake Bonneville deposits (11,000 years ago or Holocene), consist of coarse, angular, and poorly sorted fan gravel. Floodplain, slope wash, alluvial fan and eolian sands are the main features corresponding to the Altithermal



Scale 1:24,000

1: Timpanogos sample site

2: Hillfield sample site

3: Sterling sample site

4: Unnamed Mollisol sample site (north-facing slope)

Figure 2. Topographic map of study area, showing location of soils and the Provo and Bonneville shorelines (adapted from topographic map of Logan Quadrangle, 1961)

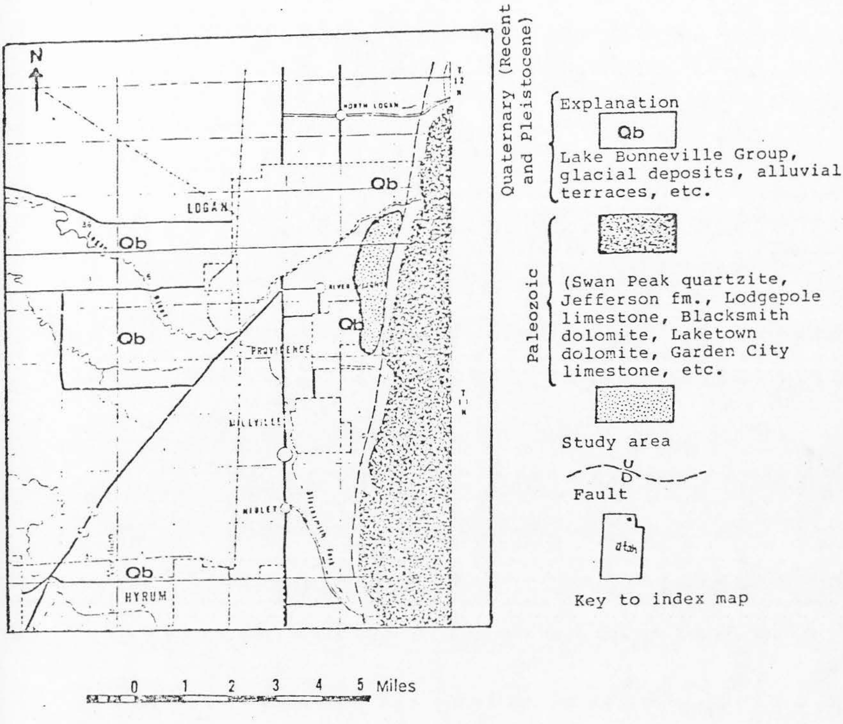


Figure 3. Geological map of the eastern part of Cache Valley, Utah, showing the location of study area (adapted from J. Williams, 1948)

age (7000-4500 years B.P.) of the Holocene epoch (Williams, 1956). Dominance of a much dryer and warmer climate during the Altithermal age has been postulated through studies of cycles of arroyo cutting (Leopold, et al., 1964), formation of alluvial fans (consisting largely of mud and rocks) in Logan Canyon and the mouths of other small canyons in Northern Utah, and the accumulation of salt and the decrease in water levels in Pleistocene Lakes (Gilbert, 1890, Russell, 1885). Core studies from the shores of the Great Salt Lake also show variations in carbonate, clay mineral content and buried soils. These are indications of several alterations of Pluvial (wet) and arid climates in the study area (Leopold, et al., 1964).

The location of the study area is shown in figure 1 and 2 and 3. The map, adapted from Williams (1958), shows that Hillfield, Timpanogos and unnamed Mollisols are formed on Lake Bonneville deposits. It was reported by Erickson et al. (1974) that these soils, with ranges in elevation from 1440 to 1530 m. above sea level, have been formed on medium-textured and moderately fine-textured materials on the intermediate or high Lake terraces. These terraces are the oldest deposits of Lake Bonneville. The pedons which were studied are located above the Provo shoreline (1470 m.) and below the Bonneville shoreline (1565 m.); therefore, it can be concluded that the soils were derived from undifferentiated Alpine and Bonneville formations.

The Sterling pedon, with an elevation of 1529 m. is located on the alluvial fan of Dry Canyon (coarse-textured, gravelly, and cobbly sediment), which transends the Lake Bonneville terraces.

The range of elevation of the Sterling soil is 1380 to 1650 m. Thus it has formed both above and below Lake Bonneville deposits.

Wind, wind erosion, transport, deposition and sorting

The wind is a result of interactions among the revolution of earth, the heating by the sun, land mass distribution and topographic influences. The landscape of Cache Valley, Utah, including high mountains and desert, with mountain valleys, canyons and basins in between, has a great effect on the formation of wind (Hubbard, 1978). Many factors affect wind in a given place and time. Change in atmospheric pressure patterns can modify wind strength and direction. A cold front moving through an area can drastically affect surface wind. Logan/USU has its strongest winds during the summer (Hubbard, 1978). In Cache Valley, winds generally are light, but winds from Logan and Blacksmith Fork Canyon sometimes reach a velocity of more than 80 miles per hour (Erickson, 1974). The direction of predominant wind is from the northwest during the winter in the Cache Valley area.

Leopold and Miller (1954), in a study of the alluvial valley of the Powder River Basin (Wyoming), considered the Altithermal to have had a climate more continental than the present, with strengthened anticyclones in both winter and summer. The winter anticyclone over the Rocky Mountain region would cause frequent storm passages with accompanying wind but only slight precipitation. Williams (1962) mapped some small patches of eolian sand north and east of Cornish. He believed that the sand was reworked from nearby sandy Post-Lake Bonneville levees of the Bear River and formed small dunes. Robertson (1978) reported an extensive cover of wind-blown sediments overlying the Bear Lake group in the Bear Lake Valley. The source of loess is believed to be Lacustrine sediments within the valley or the loess may have been derived from outside Bear Lake Valley. From the degree of soil development, he concluded that the loess was probably deposited several thousand years ago.

The number of dust storms estimated by Udden (1896) for the territory east of the Rocky Mountains and the Great Basin, ranged from four to twenty annually. They varied in length of time from one to 42 hours, although dust storms which continued for one week were not uncommon.

Wind erosion begins when the equilibrium of the system is disrupted by a change in one or more component variables (Cooke and Warren, 1973). Russell (1944) pointed out the sharp limitation in grain-size as being the most prominent single diagnostic characteristic of wind blown material. Bagnold (1954) showed that wind sorts the mineral grains because it transports them in three distinct ways: surface creep, saltation, and suspension. The threshold velocity is defined as the critical wind velocity at which particle movement is initiated without bombardment. Impact threshold is defined as the velocity required for particles to continue movement once dislodged by bombardment. The threshold value for fine sand of diameter 250 micrometer is 20 cm/sec (Bagnold, 1954). Bagnold found the minimum threshold velocities for quartz grains with a diameter of 84 micrometers. Chepil (1941) suggested minimum threshold velocities for aggregates with diameters between 50 and 150 micrometers. Due to differences in particle density as a result of aggregation, Chepil (1957a) defined the equivalent diameter as: Bd X D/2.65, where Bd is the bulk density and D is the actual diameter of the particle aggregate. Chepil (1941) showed that particles with diameters smaller than 50 micrometers always moved as aggregates, composed of sand, silt and/or clay. He pointed out that the largest dust particles were almost entirely composed of individual particles of fine and very fine sand. Gile and Grossman (1979), in their studies in New Mexico, found that only a small portion of dust exceeds 250 micrometers, despite particles appreciably greater than 250 micrometer in some of the nearby soils. Bagnold (1941) pointed out that particles larger than 200 micrometers are not moved by suspension but by saltation.

Gillette and Walker (1977) found wind-blown sand-sized particles to be almost exclusively quartz (a trace of calcite and feldspar were also present), while the fine fraction (less than 10 micrometers) was found to consist of a mixture of clay minerals. Although it is believed that clay minerals are transported as platlets coating sand grains (quartz) and as coarse aggregates of platlets, not as discrete particles in the clay-size range (Gillette and Goodwin, 1974). Gile and Grossman (1979) found dust storms in New Mexico to contain 20 to 40 percent clay. Krishna, et al. (1977), in India, related aggregate size to the dominant clay mineral present. Kaolinite results in aggregate diameters up to 50 micrometers, whereas smectite favors the formation of aggregates 250 to 1000 micrometers in diameter. Chepil (1957b) reported a high degree of aggregation for clay-sized particles, resulting in diameters between 20 and 100 micrometers.

Swineford and Frye (1945) found that the accumulation of wind-blown material is so homogeneous that at least 50 percent of its particles fall within the limited diameter range 10 to 50 micrometer. Gillette and Walker (1977) reported that, during dust storms in West Texas, most of the particulate matter moved in the height interval 0-1.3 centimeters above ground surface. For dust trapped by ground samplers, Gillette et al. (1978) found a bimodal distribution, with large concentrations in the 40 to 100 micrometer range and in the 1 to 30 micrometer range. Particle-size distribution of aerosol dust obtained by aircraft sampling was mainly in 1 to 30 micrometer range. It was concluded that movement of particles with diameters larger than 30 micrometers was restricted to a height close to the ground and resulted in short distance of transport (few kilometers). Chepil (1957b) found that particles moving 60 centimeters above the ground had an average equivalent diameter of 60 micrometers. Bagnold stated that, as grain size is reduced from 150 to 70 micrometers, it passes the critical diameter at which it is maintained aloft. Chepil (1957a) pointed out that the removal of 31 to 78 percent of the particles smaller than 1000 micrometers occured during a single wind storm in western Kansas. This sorting added considerably to the sandiness of the area. Movement of erodible material ceases as soon as the surface becomes protected by the smallest non-erodible particle at the specific wind speed.

Bagnold (1954) defined three modes of deposition: accretion, true sedimentation and encroachment. Accretion occurs on smooth continuous surfaces as the wind fails to carry away from a point as much sand as it brings. True sedimentation is the precipitaiton of grains (very fine grains) from suspension from slow moving air, causing encroachment on the lee sides of dunes and other obstructions. In encroachment, the coarser grain sizes move slowly by surface creep, while the finer grain sizes move more quickly by saltation. This results in a relatively coarse lag deposit of medium-sized sand. Armbrust, et al. (1964) studied in the laboratory the effect of ridges on erosion of soil by wind. They reported the removal of soil by deflation from the windward side and deposition on the lee side. White (1973) indicated that the influence of wind on soil genesis in South Dakota is of preferential erosion on windward slopes.

Soil genesis in arid and semiarid regions and evaluation of some soil-forming factors

The factors of soil formation (Jenny, 1941) - time, parent material, topography, biota, climate - in arid and semiarid regions are the same as those in any other part of the world. The relative intensities of various soil-forming factors in arid and semiarid regions, however, result in some pedogenic processes that are quite characteristic of the regions. A relatively limited amount of water is available for pedogenic processes in these regions.

The clay mineralogy in arid and semiarid soil is probably controlled more by parent material than by clay weathering during pedogenesis (Buol, 1965). Southard and Miller (1966), in the study of soil formation from sandstone and limestone, found that the clay of the studied soils was inherited from parent material without appreciable change. The clay did not form by weathering of primary minerals during alteration of sedimentary rock. Anderson, et al. (1975) studied the effect of parent material on the soils which formed in the high elevations of New Mexico. Other soil forming factors were constant for the soils studied. They concluded that Borolls are forming in residuum from limestone, but Boralfs exist where parent material is residuum, from sandstone. The genesis of two soil series, Parley and Mendon in Cache Valley, Northern Utah, was studied by Al-Amin (1975). Both were derived from different parent materials, but the other soil forming factors were similar. The degree of variability of soil properties such as clay type, calcium carbonate and iron oxide in the soils, support the idea that their differences are attributable to their parent material. Rooyani (1976) studied the genesis of Nebeker and McMurdie soil series in Cache Valley. He indicated that the Nebeker soil was developed from a parent material rich in quartzite and sandstone with a matrix predominantly of shale. The McMurdie Pedon was formed from material of the Salt Lake formation deposited on Lake Bonneville sediments. He reported that clay mineralogy in both series have properties of the parent material rather than the influence of weathering.

The relationships between parent material, geomorphic surfaces (age), and soil characteristics are emphasized in this part because of nature of the thesis problem. These relationships have been the subject of many studies during recent years.

The effect of age and parent materials on the soil boundaries in an arid region were studied by Gile (1975). He reported that the major cause of difference in age was episodic sedimentation at various times and places. He also indicated that important changes in soil occur across the boundary between Holocene and Pleistocene ages; whereas, the boundaries caused by changes in parent materials are due to differences in the amount of carbonate and coarse fragments.

Buol, et al (1973) pointed out that "time, like space, is continuous," yet recognize a "time zero" for a given soil." The time zero is a "point at which a pedologically catastrophic event is completed, initiating a new cycle of soil development."

The relation of soil to time may be discussed with regard to: 1) relative stage of development, 2) absolute dating of horizons, 3) rate of formation, 4) relation to age of slope and landform and associated weathering complex.

Dating of soils has been accomplished by tree-ring counts and by ^{14}C method (Buol, et al. 1973). Robinson (1950) used depth of leaching of carbonate to estimate age of loess derived soils in Southwestern Wisconsin. Horizon differentiation is one of the factors which governs the age of soil (Simonson, 1959). It is ascribed to additions, removals, transfers, and transformation within the soil system. Harper (1957) pointed out that the development of a calcic horizon at some depth below surface is one of the most important pedogenic processes of soils in arid and semi-arid regions. Gile, et al. (1966) stated that the characteristic morpholgy of the calcic horizon depends on the age and geomorphic history of the soil. They, also, pointed out that carbonate horizons formed in gravelly sediment display a different morphological sequence when compared with carbonate horizons formed in nongravelly sediment. Gile, et al. (1966) concluded that the developmental sequence of carbonate accumulation is related to time, and the amount of accumulated carbonate increases markedly with increasing age of soil. Gile and Hawley (1968) pointed out that with increasing soil age during recent time, the progression of soil development has been marked by the development of an A horizon, destruction of thin sedimentary strata, slight accumulation of carbonate, and the development of structure in material of sufficiently fine texture. The continued carbonate accumulation leads to the development of a weak calcic horizon.

Presence or absence of an argillic horizon is an important difference between many contiguons polypedons of arid and semiarid regions. Formerly, it was thought that the clay accumulation in arid soils was due to in-place weathering (Nikiforoff, 1937). However, later work indicates an illuvial origin for much of the clay despite the absence of clay skins on peds and in pores (Gile and Grossman, 1968, Smith and Boul, 1968, Nettelton, et al, 1975). Some of the clay in the argillic horizon must be illuvial and it must also have more clay than overlying eluvial horizons, depending upon clay content of the latter (Soil Survey Staff, 1975). The major criterion for recognition of argillic horizon in arid regions is the presence of oriented clay on sand grains (and on pebbles if present), and maximum expression of oriented clay in the horizon of maximum clay (Gile and Grossman, 1968). In studies of the morphology of argillic horizons in soils of southern New Mexico, it was observed that prominent argillic horizon occur only in soils that formed during the Pleistocene which indicates that accumulations of clay in argillic horizon are at least in part a result of translacation of clay. Nettelton, et al. (1975), in their studies of soil in desert areas of the southwestern United States found that the older Argids are probably products of the more moist Pleistocene climate. Also, they reported that clay skins are mostly lacking in the fine-textured soils with argillic horizons, Haplargids and Paleargids, formed in sandy alluvium.

In New Mexico, Gile (1975) has found that carbonate accumulation in the subsoil of recent alluvial soils is a youthful feature, while clay illuviation and argillic horizon formation require longer periods of time. Hawley (1968) and Gile and Grossman (1968) concluded that in arid regions of the southwestern United States argillic horzons appear to require more than 5,000 years to form.

In Oregon, Blaster and Parsons (1968) and Parsons and Herriman (1975) have observed argillic horizons developed in recent alluviam with ages of 2,350 to more than 5,250 years. Blaster and Parsons also noted that cambic horizons are found in recent alluvial soils with an age of approximately 550 years. While in Pennsylvania, Cunningham, et al. (1971)

have observed cambic horizon development and minimal clay illuviation in a recent alluvial soil with an age of approximately 450 years. In Iowa, Fenton, et al, (1974) reported that alluvial soils approximately 6,600 years old had argillic horizons while those 2,000 years in age did not. Ryan and Paeth (1977) in their studies on three soil series, representing a chronosequence from the Punjab River Plain of Pakistan, observed that with increasing soil age horizon differentiation and solum thickness increased, while cutans (which indicate the illuviation of clay) and CaCo3 concretions occured in the oldest soil. Also, some chemical and mineralogical properties of soil changed with age, and were mainly attributed to processes of soil formation. Brewer and Walker (1969) studied five soil profiles on alluvial terraces in Macleay River Valley N. S. W. in order to determine changes in soil development with increasing time. They concluded that the older soil which formed on older terraces represents, to a greater extent, formation of a horizon of illuviated clay.

Topography, which modifies the water relationships in soils, and to a considerable extent influences soil erosion, is usually treated as a soil forming factor (Jenny, 1941). Landscape position is significant, since it determines whether the soil is subject to runoff or run-in. Run-in can increase the number of moist days up to 2-fold in the soil. Glinka (1927) and Marbut (1927) have recognized slope of the land surface as an environmental factor influencing soil characteristics. King (1901) stated that the degree of inclination of the land surface and the direction of slope exert a marked influence upon the temperature of the soil, particularly its diurnal range. As temperature is one of the important factors in the environment of soil development, temperature variations produced by differences in slope would be expected to affect the development of some soil characteristics. Norton and Smith (1929) pointed out that, as slope increases the development of soil decreases.

In the northern hemisphere, south-facing slopes tend to be warmer and more droughty than north-facing slopes. Cooper (1960) compared north-and south-facing slopes in Michigan. The soils on the south-facing slope were found to have a lighter brown-colored A1 horizon and a redder B horizon than those on the north-facing slope. Also, the north-facing soils had both deeper solums and thicker A horizons, compared to south-facing soils. Shulgin (1957) reported that similar north-south relationships were found in Russia and that the soils on west-facing slopes were warmer than those on east-facing slopes.

Finney, et al. (1962) studied the influence of microclimate on the morphology of some soils of the Allegheny Plateau of Ohio. They concluded that the soil occurring on southwest-facing slopes has an appreciably thinner A1 horizon and more strongly developed A2 and B horizons than the soil on the northeast facing slopes. The differences in the soils appear to be closely related to different microclimatic regimes. The effect of aspect on soil development was studied on a small hill on the south side of the Snake River in an arid region of south central Idaho (Klemmedson, 1964). He concluded that the organic matter content of the top 10 cm. of soil is greater on the north slope than on the south slope. This is generally considered to be the result of higher soil temperature on south-facing slopes causing more rapid organic mineralization. Southard and Dirmhirn (1972) studied the relationship between direction of exposure, or slope aspect, and soil properties in north central Utah, along the western Wasatch mountains on rolling foothills below the upper shoreline of Lake Bonneville. They pointed out that pronounced differences in the upper 50 cm. soil layer on south and north slopes in the E-W trending foothills of western mountains are due to the constant influence of a pronounced difference in microclimate. Soil and climatic factors in combination provide the environment for different vegetation on the two slopes, which in turn influences the soil and climate conditions. The soils on the north slopes were classified as coarse-loamy members of the family of Typic Calcixerolls, and on the south slopes as a member of the coarse-loamy family of Calcixerollic Xerochrepts.

Erickson and Mortensen (1974) classified the Hillfield soil series as Calcixerollic Xerochrepts, coarse-silty, mixed, mesic (an Inceptisol). The Sterling and Timpanogos soils are classified as Typic Calcixerolls, loamy-skeletal, mixed, mesic and Calcic Argixerolls, fine-loamy, mixed, mesic, respectively.

METHODS AND PROCEDURES

Field procedures

In an effort to find sites near the modal concept of the associated soils on the upper level of Lake Bonneville on the east side of Cache Valley, many excavations on these geomorphic surfaces were examined. In choosing the representative pedon, the relation between topography and soil was considered. Three pedons which belong to the Hillfield, Timpanogos and Sterling soil series were described and sampled by genetic horizons. In order to determine the effect of microclimate or aspect, one pedon, representative of the soils on north-facing slopes in the study area, was described and sampled by genetic horizons. Dimensions of the pedons were 100 cm. wide, 150 cm. long and 150 to 170 cm. deep. The sampling was done by working upward from the lowest horizon to avoid contamination. If a horizon was more than 30 cm. thick, it was subdivided into two subhorizons for sampling and analysis.

Clods from each horizon were selected for thin section studies and determination of bulk density.

Laboratory procedures

The following laboratory methods were used to determine the chemical, physical, and mineralogical characteristics for the four pedons.

Particle-size distribution. The procedure used was that proposed by Kittrick and Hope (1963). The fine clay (0.2 micrometer), coarse clay (0.2 - 2 micrometer), silt and sand fractions were separated. Carbonate and soluble salts were removed using a sodium acetate solution and heating to 80 degrees C. for at least a half hour then repeating the procedure with an overnight digestion because of presence of carbonates in the soil sample. Samples were treated with hydrogen peroxide (30 percent by volume) in order to remove organic matter. Iron oxide coatings were removed by citrate buffer and dithionite. Clay and silt fractions (fine silt) were separated by centrifuge, and coarse silt and sand fractions by sieving.

Bulk density. Bulk density was determined using the paraffin coating method of Black (1965). The oven-dried clods were immersed in paraffin. Upon drying, the clods were suspended in water and bulk density values were calculated by dividing the value of dry weight by grams of water displaced. The figures were corrected for horizons that had some material coarser than 2 mm.

Organic matter. The procedure used was that proposed by Black (1965). Organic carbon was digested by potassium dichromate and concentrated sulfuric acid. After swirling and filtering, the color intensity was read at 610 nm (blue phototube in spectronic 20) using three organic matter standards (1.4, 1.6, 4.8 % om). The organic matter was calculated by multiplying the organic carbon by the factor 1.72.

Calcium carbonate equivalent. Calcium carbonate was determined by the titrimetric method as proposed by Richards et al. (1969). The procedure involves treating finely ground samples (less than 60 mesh) with an excess of 0.5N HCl. After the carbonate was decomposed, the excess acid was titrated with 0.25 N NaOH.

Cation-exchange capacity. Cation-exchange capacity was determined by the modified procedure of Brower et al. (1952) as described by Black, et al. (1965). The samples were saturated with sodium acetate (NaOAc pH=8.2), then washed with isopropyalcohol. The absorbed sodium from the sample was extracted with ammonium acetate solution (NH_4 OAc).

Water retention. Water retention at 15 atmospheres was determined using the pressure membrane apparatus method proposed by Richards et al. (1969). The samples were placed on a porous plate. The required pressure was applied after removing excess water. Moisture content was determined as percentage of oven-dry weight.

Extractable cations. Extractable bases-- sodium, calcium, potassium and magnesium-- were extracted by washing the sample with ammonium acetate (pH=7.0). The amount of cations in the extract was measured by using an atomic absorption spectrophotometer.

Soil reaction. The pH value was determined on a saturated paste with a Beckman model H-2 glass electrode pH meter.

Free iron. The method proposed by Kittrick (1963) was used for iron determination. Carbonate and soluble salts were removed by sodium acetate solution. Organic matter was removed by oxidizing with hydrogen peroxide. The samples were treated with citrate buffer and sodium dithionite ($Na_2 S_2O_4$). The samples were again washed with citrate buffer and centrifuged. The solution was diluted with water and free iron was determined by an atomic absorption spectrophotometer.

Mineralogy. Preparation of the samples for X-ray diffraction was done by the method proposed by Kittrick and Hope (1963), which was used for the determination of particle size distribution. The mineralogical composition of the clay (fine and coarse) and silt (fine 2-5 and coarse 5-50 micrometer) fractions were determined with a Siemens X-ray diffractometer equipped with a copper tube operated at 35 KV and 16 Ma and a nickle filter. Oriented slides of clay fractions were obtained by allowing a small amount of the clay suspension obtained during separation to evaporate at room temperature on the slides. The oriented slides were X-rayed, were saturated with elthylene glycol and run a second time then heated to 600 degrees C for 1 hour and run a third time.

Micromorphology. Thin sections were prepared from undisturbed soil clods, using the modified procedure of Bourbeau (1947). Clods were dried at room temperature. The clods were impregnated under suction with a mixture of one part castolite, two parts of styrene, and 0.5 percent by volume of hardner. After impregnation, they were allowed to harden at room temperature and were then placed in an oven at 60 degrees C. overnight. The hardened samples were cut, polished smooth on one side, and cemented with optical grade epoxy to a microscope slide, and ground to thickness of about 30 micrometers on a rotating lap with finer grades of grit.

The very fine sand fractions were observed under the microscope as grain mounts in oil.

RESULTS AND DISCUSSIONS

Field morphology and distribution of soils

On upper terraces of Lake Bonneville on the east side of Cache Valley, four soils were found to occupy the landscape. Three of these soils formed directly on Lake Bonneville deposits at elevations between 1440 to 1560 m. MSL. The main difference between them is the topographic position of landscape; other soil forming factors appear similar. The Timpanogos soil occurs on the nearly level sites, but the Hillfield and an unnamed Mollisol occupy the south-and north-facing slopes, respectively (Figure 4). The other soil found at the mouth of Dry Canyon is the Sterling soil which formed on alluvial fan deposits that transcend the lake deposits in the study area. Soil boundaries are not usually abrupt, except for the Sterling soil, which contains coarse fragments throughout the pedon and on the soil surface.

The parent materials of the soils under study are derived dominantly from limestone, sandstone and quartzite (Erickson, 1974). The vegetation which covers the study area is: <u>Agropyron</u> <u>Ierme</u> (bluebunch wheatgrass), <u>Agropyron smithi</u>, (western wheatgrass), <u>Artemisia</u> <u>tridentata</u> (big sagebrush), <u>Achillea</u> spp. (yarrow), <u>Balsamorhiza</u> <u>spp</u>., (Balsam root), and <u>Bromus</u> <u>tectorum</u> (Cheatgrass) (Erickson and Mortensen, 1974).

Figure 4. View of Lake Bonneville terraces in the east side of Cache Valley

Timpanogo pedon

The Timpanogos soil is a deep, well-drained soil, on nearly level lake terraces. These soils formed on medium-textured lake deposits. Timpanogos silt loam is associated with the Hillfield series in the Cache Valley area. This pedon is located in a pasture area 750 meters north and 380 meters east of the southwest corner of the southwest quarter of sec. 36, T12N, R1E, with an elevation of 1538 m.MSL. The landscape is exposed toward the west, with a 5 percent slope (Figure 5 and 6).

A detailed descripton of the Pedon is as follows:

A11--0 to 8 cm; very dark grayish-brown (10YR 3/2) moist, loam, brown (10YR 5/3) dry; weak, thin, platy structure that parts to moderate, medium and fine granular structure; slightly hard, friable, slightly sticky and slightly plastic; many fine roots; common fine pores; noncalcareous; mildly alkaline (pH 7.4 paste); clear smooth boundary.

A12--8 to 20 cm; dark brown (10YR 3.5/3 moist, loam; brown (10YR 5/3) dry; weak medium subangular blocky structure that parts to moderate, medium granular structure; slightly hard, friable, slightly plastic; many fine roots; common fine pores; noncalcareous; mildly alkaline (pH 7.4 paste); clear, wavy boundary.

B21t--20 to 35 cm. dark-yellowish brown (10YR 4/4) moist; loam, yellowish brown (10YR 5/4) dry; moderate medium subangular blocky structure; hard, friable, sticky and plastic; common fine roots; many fine pores; common thin clay film (sand bridges); noncalcareous; mildly alkaline (pH 7.6 paste); gradual wavy boundary.

B3ca--35 to 50 cm. yellowish brown (10YR 5/4) moist; loam; light yellowish-brown (10YR 6/4) dry; moderate, medium, and fine subangular blocky structure; hard, friable, sticky and plastic; common fine roots; many medium pores; very few thin clay film; slightly calcareous; mildly alkaline (pH 7.8 paste); clear smooth boundary.

IIC1ca--50 to 73 cm. yellowish brown (10YR 5/4) moist; loam; very pale brown (10YR 7/3) dry; moderate, medium subangular blocky structure; very hard, friable, slightly sticky and plastic; few fine roots; common fine pores; moderately calcareous; moderately alkaline (pH 8 paste); gradual wavy boundary.

IIIC2ca--73 to 91 cm. light yellowish brown (10YR 6/4) moist; loam; very pale brown (10YR 7/3) dry; massive; slightly hard, friable, slightly sticky and slightly plastic; few fine roots; common fine pores; strongly calcareous; moderately alkaline (pH 8.1 paste) clear smooth boundary.

IIIC3ca--91 to 120 cm. light yellowish brown (10YR 6/4) moist; loam, very pale brown (10YR 7/4) dry; massive, slightly hard, friable, slightly sticky and slightly plastic; few fine roots; common fine pores; strongly calcareous; moderately alkaline (pH 8.0 paste); clear wavy boundary.

IV C4ca--120 to 170 cm. light yellowish brown (10YR 6/4) moist; very fine sandy loam; very pale brown (10YR 7/4) dry; single grain; soft, friable, slightly sticky and slightly plastic; strongly calcareous; moderately alkaline (pH 8.1 paste).

The Timpanogos pedon exhibits a pronounced horizon differentiation. There are differentiations in color between the horizons. The color ranges from very dark grayish brown in the A11 horizon, to dark brown in the A12 and B21t horizons, yellowish brown in the IIC1ca and light yellowish brown in the IIIC3ca and IVC4 horizons. There is no indication of a change of the hue between the horizons.

Structures are platy to granular in the A11 and A12, subangular blocky in the B21t, B3ca and IIC1ca, massive in the IIIC2ca and IIIC3ca and single grain in the IVC4$_{ca}$ horizon.

Thickness of the solum is 73 cm. Dry and moist color, thickness and organic matter content of A11 and A12 horizons meet the requirements for the mollic epipedon.

Figure 5. Landscape of the Timpanogos pedon.

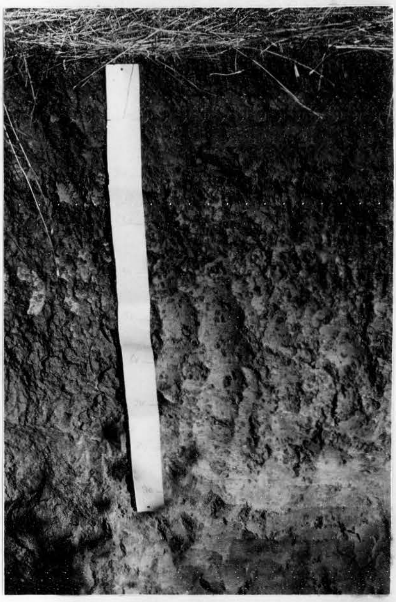


Figure 6. Profile of the Timpanogos pedon.

The development of subangular blocky structure, presence of clay films, and increase of the clay content from the A to the B horizons is sufficient to meet the requirements for an argillic horizon.

The noncalcareous nature of the surface and the presence of a prominent calcic horizon suggests of a high degree of leaching.

Particle-size distribution. The results of particle-size analysis for the Timpanogos pedon are presented in table 2 and illustrated in figures 7 and 8. It is assumed that differences in a particle size class with depth will be expressed as percent of the higher of two values. Differences between horizons of about 30 percent in two or more particle size classes are considered adequate indicators of discontinuities. Also, a sharp limitation in grain-size distribution is considered characteristic of wind-blown material.

The Timpanogos soil is characterised by an abrupt change in granulometric composition at 50 centimeters. At the depth of 50-73 cm, very fine sand increases nearly 30 percent and the medium-sand and silt fractions decrease 46 and 17 percent, respectively, compared to the 35-50 cm. depth. This indicates the presence of a depositional discontinuty, thus, the designation of the horizon as IIClca. The silt fraction increases 31 percent and fine sand decreases 25 percent at the depth of 73-91 cm in com-

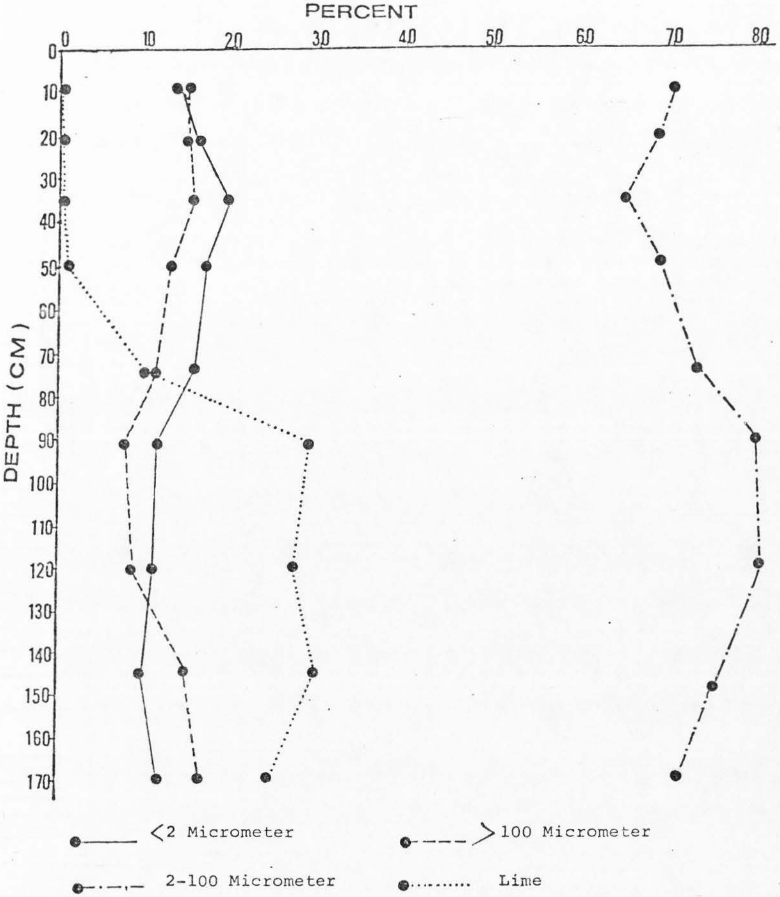


Figure 7. Calcium carbonate and particle size distribution with depth of Timpanogos pedon.

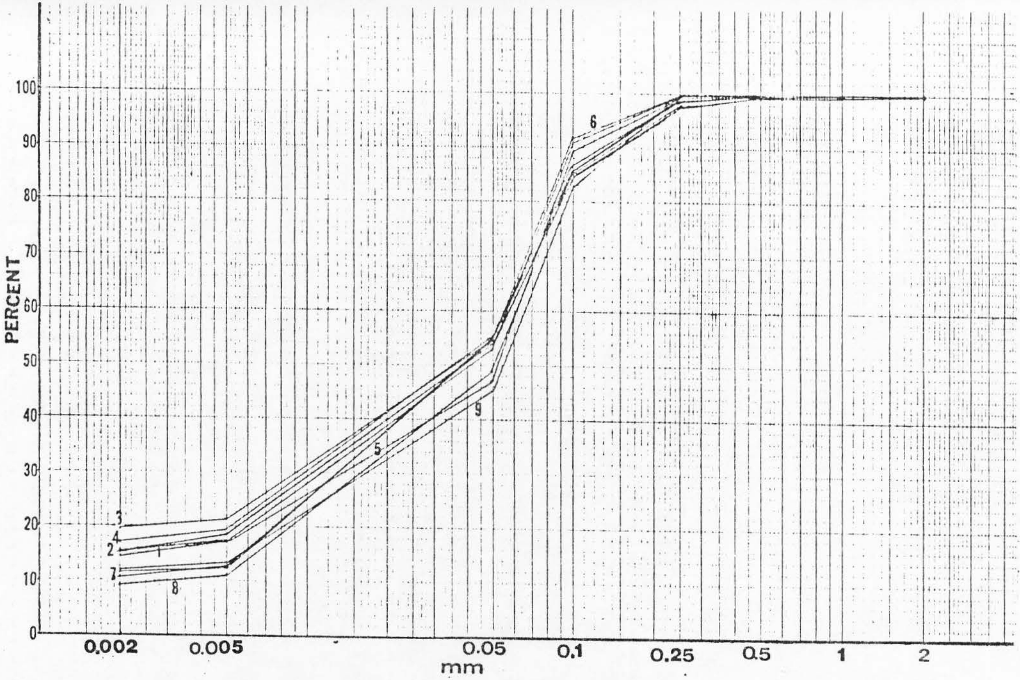


Figure 8 . Cumulative particle size curves for <2mm material of the Timanogos Pedon. horizons; the horizon depths are: 1=0-8 cm ; 2=8-20 cm; 3=20-35 cm; 4=35-50 cm; 5=50-73 cm; 6=73-91 cm; 7=91-120 cm; 8-120-145 cm; 9=145-170 cm.

Table 2. Particle size distribution * (in micrometers, percent) for the Timpanogos pedon.

		Total Fraction			Sand					Silt		Clay		Fine clay/
Horizon	Depth	sand	silt	clay	very coarse	coarse	medium	fine	very fine	coarse	fine	coarse	fine	Total Clay
	(cm)	50-2000	2-50	<2	1000-2000	500-1000	250-500	100-250	50-100	5-50	2-5	2-0.02	<0.02	ratio
A_{11}	0-8	46.97	38.39	14.62	0.22	0.59	1.18	12.71	32.26	35.70	2.69	12.6	2.02	0.13
A_{12}	8-20	46.09	38.29	15.62	0.22	0.59	1.18	13.41	30.69	35.60	2.69	14.0	1.62	0.11
B_{21t}	20-35	45.76	34.63	19.63	0.10	0.52	1.04	13.67	30.43	32.74	1.89	12.83	6.80	0.35
B_{3ca}	35-50	45.39	37.37	17.24	0.10	0.43	0.97	12.17	31.72	35.06	2.31	11.85	5.39	0.31
IIC_{1ca}	50-73	52.33	31.81	15.85	-	0.17	0.52	10.32	41.32	30.62	1.19	10.35	5.50	0.33
IIIC_{2ca}	73-91	46.47	41.73	11.79	-	0.18	0.18	7.7	38.41	40.45	1.28	8.06	3.73	0.31
IIIC_{3ca}	91-120	46.18	43.05	10.77	-	0.06	0.06	8.56	37.52	41.77	1.28	7.78	2.99	0.27
IVC_{4ca}^{**}	120-145	50.97	39.11	9.92	-	0.06	0.59	14.25	36.07	37.84	1.27	6.65	3.27	0.30
IVC_{4ca}^{**}	145-170	54.25	33.81	11.94	-	0.06	0.72	16.21	37.26	32.59	1.22	11.94	-	-

* Particle size distribution of carbonate-free material.

** Sampled at 120-145 cm. and 145-170 depth for lab analysis.

parison with the 50-73 cm. depth, indicating another deposition, thus, the designation of IIIC2ca and IIIC3ca horizon. In the substratum, 120-170 cm., the fine sand particle size increases between 65 and 89 percent and the silt fraction decreases 21 percent; therefore, this horizon is designated as IVC4ca.

Figure 8 shows the cumulative particle size distribution of the different horizons of the Timpanogos soil. Eighty four to 92 percent of the soil materials are less than 100 micrometers in diameter, almost 75 percent has a range of 5 to 100 micrometers and less than 5 percent of the materials exceed 250 micrometers in diameter. These indicate that the soil materials were probably sorted by wind.

The distribution of clay percentage in the solum of the Timpanogos pedon reflects the occurrence of pedogenic processes. The noncalcareous A11, A12 and B21t horizons of this soil show an increase in clay in carbonate-free material. This may indicate that this soil has reached a stage where silicate clay minerals start to translocate and accumulate in the horizon above the calcareous horizon. The results of carbonate-free clay distribution indicate that the clay at the 20-35 cm. depth, compared to that at the 0-20 cm. depth, increases more than 1.2 times. The maximum clay percentage occurs at the 20-35 cm. depth. An increase in fine-clay: total clay ratio from the A horizon to the B21t horizon is evident from Table 2, which suggests the occurrence of illuviation. Thus the characteristics of the

B21t horizon meet the requirements of an argillic horizon.

If it is assumed that this soil formed on deposits of the Bonneville level, it might also be assumed that after deposition, stabilization of the geomorphic surface occurred and soil formation started at about the same general period of time (Late Pleistocene epoch). Under the conditions of the greater effective moisture of that period of time, all of the carbonate would have been leached from the horizons and a well-developed argillic horizon would have been formed. The morphology of this soil however, showed that the incipient argillic horizon formed during the period of soil formation (pedogenesis). Thus, the Timpanogos soil probably formed under less effective moisture of Holocene time, because the moisture was clearly insufficient to remove carbonate from the solum and to translocate silicate clay minerals within the pedon to form a well-developed argillic horizon. It can be concluded that the geomorphic surface was not stable after deposition by Lake Bonneville and the lake deposit was probably reworked by wind during the Altithermal (7000-4500 YBP) which was dryer and warmer, with more intense wind activity than the present time. The particle size distribution of the soils material shows that the materials are either sorted by the wind in-place or, more probably, brought from the exposed lake bottom after the lake receded.

The soils which formed on the truncated spur (40 per cent slope) 20 meters above the landscape of the Timpanogos pedon were sampled. The particle-size distribution of carbonate-free material of this soil is noticeably different from that of Timpanogos soil. More than 30 percent of the soil material is greater than 0.25 mm in diameter and the soil also has 50 to 75 percent coarse fragments. However, in the Timpanogos soil only 2 percent of the material is greater than 0.25 mm. The mineralogical composition of this soil is different from the Timpanogos. The abundant clay mineral is illite with traces of kaolinite, whereas the clay minerals of the Timpanogos soil are a mixture of illite, montmorillonite, kaolinite and mixed-layer expanding clay. Thus, it can be concluded that the material of the soils which formed on the terraces is not slopewash from the truncated spur.

Calcium-carbonate equivalent. The distribution of calcium carbonate equivalent for the Timpanogos pedon is presented in table 3 and figure 7. It ranges from 0.1 to 29.6 percent. The minimum percentage is found in the surface horizons at the 0-35 cm. depth, whereas the maximum value is found at the 73-145 cm. depth, decreasing below this zone. The calcium carbonate equivalent at the depth below 73 cm. exceeds 15 percent. The 5 percent drop-off in underlying material qualifies these horizons as calcic (Soil Survey Staff, 1975). The high calcium carbonate content in the lower horizons suggests that there has been an eluviation of carbonate in the highly calcareous parent material. The leaching has probably taken place since stabilization of

Table 3. Selected chemical analysis and physical properties of the Timpanogos pedon.

Horizon	Depth (cm)	pH (paste)	Organic matter %	$CaCO_3$ equivalent %	CEC meg/100g soil	Calculated CEC meg/100g clay	Extractable Cations				Free Iron-Oxide %	Physical properties	
							Ca (NH4OAc	Mg	Na meg/100	K g)		Bulk density g/cm^3	Water rentention at 15 atm. %
A_{11}	0-8	7.4	1.98	0.2	13.5	65.25	14.4	4.3	0.2	1.0	0.35	-	8.8
A_{12}	8-20	7.4	1.68	0.1	14.0	68.1	13.8	4.2	0.2	0.8	0.36	1.36	8.7
B_{21t}	20-35	7.6	1.39	0.1	13.8	56.2	12.8	4.3	0.2	0.7	0.43	1.47	9.1
B_{3ca}	35-50	7.8	1.29	1.3	12.8	59.28	14.5	4.7	0.2	0.6	0.37	1.60	8.7
IIC_{1ca}	50-73	8.0	0.95	10.8	9.7	49.2	41.1	4.0	0.2	0.4	0.34	1.62	6.9
$IIIC_{2ca}$	73-91	8.1	0.69	28.8	6.0	39.2	43.8	3.2	0.2	0.2	0.25	1.70	5.0
$IIIC_{3ca}$	91-120	8.1	0.50	27.1	6.0	46.4	43.8	3.7	0.2	0.2	0.26	1.67	4.9
IVC_{4ca}	120-145	8.1	0.48	29.6	5.1	40.32	41.3	4.0	0.2	0.1	0.25	1.64	4.3
IVC_{4ca}	145-170	8.2	0.38	24.2	5.0	36.3	36.7	3.8	0.1	0.1	0.26	1.64	3.8

the geomorphic surface. The sequence of calcium-carbonate accumulation has been divided into four stages culminating with the development of a laminar horizon overlying a petrocalcic horizon (Gile et al., 1966). The calcic horizon of this soil is coincident with stage I or possibly II. The youngest geomorphic surface that is related to stage I or II is greater than 2600 and less than 5000 years, or late Pleistocene (especially stage II) (Gile et al., 1966). Thus, it can be concluded that the Timpanogos soil started to form during Altithermal time (7000-4500 YBP).

Organic matter. The distribution of organic matter is represented in table 3 and figure 17. The highest values were obtained for the upper layers (epipedon) of the soil. Values decrease uniformly with depth. Dark colors and low chroma that extend to a 20 cm. depth, more than 1 percent organic matter (more than 0.6 percent organic carbon) and, finally, higher than 50 percent base saturation firmly establish the presence of a mollic epipedon.

Free iron oxide. The data for free iron oxide is represented in table 3. The results show slight variation below 20 cm. depth. The amount of iron oxide is slightly greater at 20-50 cm. depth. This is probably related to the translocation of clay or weathering in place of primary minerals.

Cation exchange capacity, extractable cations and pH

Table 3 represents the data of cation exchange capacity. The range in CEC in the Timpanogos pedon is from 5.0 to 14.0

meg/100 grams soil. The range of CEC is related to the percentage and kind of clay, except in the upper horizons which are probably influenced by organic matter content.

Cation exchange capacities as shown in table 3 are calculated based on meg/100 grams clay. The values for this pedon range between 36.3 to 65.25 meg/100 grams clay which suggests a mixture of layer silicates. These data have been confirmed by the results from X-ray analysis which will be discussed later in this chapter.

The predominant extractable cation, as shown in table 3, is calcium. The amount of extractable calcium ranges from 12.8 to 43.8 meg/100 grams soil. The maximum extractable calcium is below 50 centimeters depth. Extractable magnesium decreases with depth. The presence of more magnesium at the upper horizons probably is a result of weathering of dolomite at the surface, and the presence of dolomite below 50 cm. was confirmed by X-ray analysis of the silt fraction. The extractable sodium is low (0.2 meg/100 gr. soil) and uniform throughout the pedon.

Extractable potassium is greater at the 0-50 cm. depth than at the 50-170 cm. depth of the Timpanogos soil. This can be explained by several possible mechanisms. Recycling of potassium by plants occurs as the roots absorb potassium from lower horizons and add it to the surface by the sloughing of leaves. Another explanation is that wind transported the dust from the Great Salt Lake Desert. Such dust, high in illite and contains larger amounts of potassium

(Hart, et al., 1973).

The pH values range from pH 7.4 at the 0-20 cm. depth to pH 8.2 at the 145 to 170 cm. depth. These relatively high values are considered typical in arid and semi-arid soils. The data in table 3, indicate that the calcium carbonate percent and the extent of the leaching depth of the pedon correlate highly with pH values.

Hillfield Pedon

The Hillfield pedon is a well drained soil with a loam to very fine sandy loam texture. The Hillfield soil is derived from calcareous parent material of the Lake Bonneville deposits, on the Bonneville level. It occurs at a maximum elevation of 1545 m MSL, and slopes range from 10 to 30 percent. The Hillfield Polypedon covers an area of about 635 hectares, which includes about 0.4 percent of the total area of Cache Valley. This pedon with an elevation of 1534 m. MSL, is located in a pasture area 590 meters north and 290 meters east of the southwest corner of the southwest quarter of Sec. 36, T12N, R1E. The landscape is exposed toward the south, with a 26 percent slope (figure 9, and 10).

A detailed description of the pedon is as follows:

A1--0-19 cm.; dark brown (10YR 4/3) moist, loam; brown (10YR 5/3) dry; weak, fine granular structure; soft, friable, slightly sticky, slightly plastic; common fine and few medium roots, common fine and few medium pores; moderately calcareous; mildly alkaline (pH 7.8 paste); abrupt, smooth boundary.

C1ca--19 to 32 cm. brown (10YR 5/3) moist; loam; pale brown (10YR 6/3) dry; weak, medium, subangular blocky structure that parts to moderate, fine subangular blocky structure; slightly hard, friable, slightly plastic and slightly sticky; common fine and few medium roots; common fine and few medium pores; strongly calcareous; mildly alkaline (pH 8.0 paste); clear smooth boundary.

C2ca--32 to 62 cm brown (10YR 5/3) moist; loam; pale brown (10YR 6/3) dry; weak, medium, subangular blocky structure that parts to weak, fine, subangular blocky structure; slightly hard, very friable, slightly plastic and slightly sticky; few fine roots; common fine pores; strongly calcareous; mildly alkaline (pH 8.0 paste); clear, wavy boundary.

IIC2ca--62 to 100 cm. pale brown (10YR 6/3) moist; silt loam; very pale brown (10YR 7/3) dry; massive, slightly hard, friable, slightly plastic and slightly sticky; few fine roots; many fine and few medium pores; strongly calcareous; moderately alkaline (pH 8.2 paste).

IIIC4--100 to 150 cm.; pale brown (10YR 6/3) moist, very fine sandy loam; very pale brown (10YR 7/3) dry; single grain; soft, very friable, nonsticky and nonplastic; strongly calcareous; moderately alkaline (pH 8.4 paste).

The Hillfield pedon does not exhibit a pronounced horizon differentiation. There are differentiations in color value between the horizons, but the hue is the same throughout the pedon. The color ranges from dark brown in the A1 horizons, to brown in the C1ca and C2ca horizons and pale brown in the IIC3ca and IIIC4 horizons. Structures range from granular in the A1, subangular blocky in the C1ca and C2ca, massive in the IIC2ca and single grain (structureless) in the IIIC4.

There is no evidence of eluviation of clay in the A1 horizon. A sharp variation in textural class between the 62-100 cm. and 100-150 cm. depths, indicates that a discontinuity occurred during deposition of soil material. The soil is strongly calcareous throughout. This probably indicates

Figure 9. Landscape of the Hillfield pedon (S-slope)

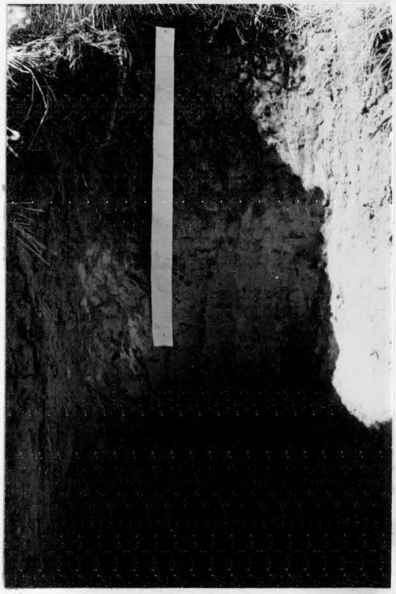


Figure 10. Profile of the Hillfield pedon.

that the rate of leaching has been low during the pedogenesis period.

The dry and moist colors of the A1 horizon do not meet the requirements for a mollic epipedon.

Particle-size distribution. Figure 11 and 12 and table 4 show the particle size distribution throughout the pedon. The clay fraction is almost uniform (12-14%). The silt fraction and the different sand fractions do not vary between the A1, C1ca and C2ca horizons. Also, the sum of the silt fraction and the very fine sand fraction is more than 60 percent, at the 0-62 cm. depth.

A 60 percent decrease in fine sand and a 60 percent increase in the silt fraction, coupled with a 65 percent decrease of medium sand from the C2ca to the IIC3ca horizon suggests a discontinuity. Also, a sharp decrease in the silt fraction (65% decrease) and an increase in the fine sand percentage, from 8.22 percent in the 62-100 cm. depth to 44.50 percent in the 100-150 cm. depth shows another discontinuity as suggested by the description. Thus, the 100-150 cm. depth is designated as IIIC4.

The cumulative particle size curve of the soil material of the Hillfield pedon is presented in figure 12. This figure shows that about 76 percent of the soil material in the 0-62 cm. depth is less than 100 micrometers in diameter. Also, at the depth of 62-100 cm. the soil material contains about 91 percent of the particles less than 100 micrometers.

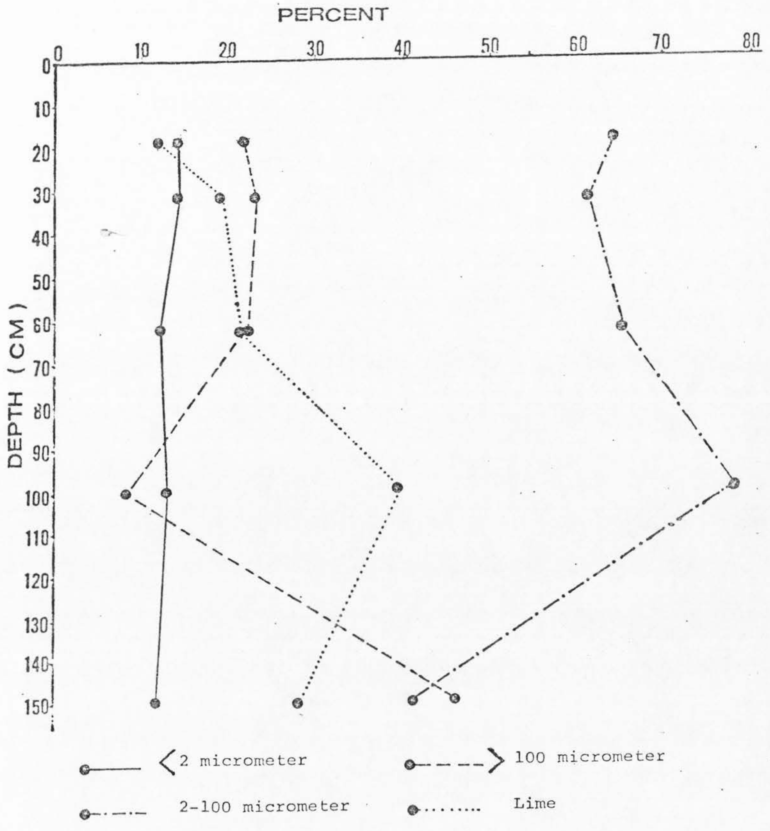


Figure 11. Calcium carbonate and particle size distribution with depth of Hillfield pedon (south) facing slope)

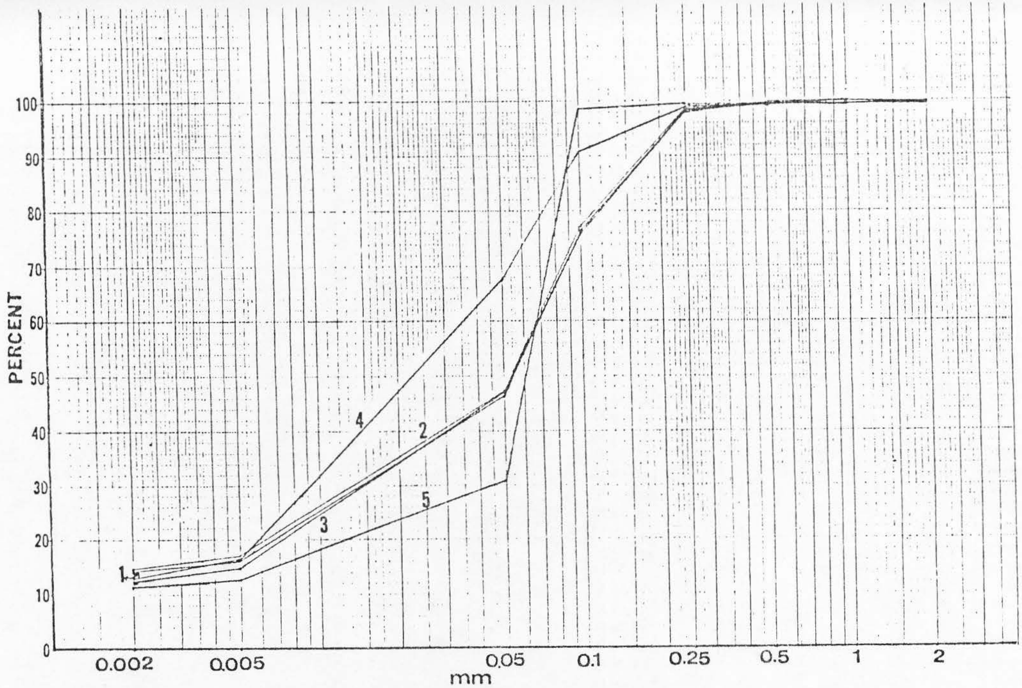


Figure 12 . Cumulative particle size curves for <2 mm material of the horizon of the Hillfield Pedon; The horizon depths are: 1 = 0-13 cm; 2 = 19-32 cm; 3 = 32-62 cm; 4 = 62-100 cm; 5 = 100-150 cm depth.

These data suggest wind deposition, but the deposition probably took place at two different times. Chepil (1957a) reported deflation of particles with a diameter less than 100 micrometers in Kansas.

A large concentration of material greater than 50 micrometers in diameter at the 100-150 cm. depth probably suggests this material was deposited by Lake Bonneville at the Bonneville stage. The wind-blown material was probably deposited on the lake deposits during Altithermal time. After deposition, the material was affected by soil-forming factors and soil began to develop.

Calcium-carbonate equivalent. Distribution of calcium-carbonate equivalent for the Hillfield soil is presented in table 5 and figure 11. It ranges from 12.1 to 40.2 percent. The presence of a relatively high amount of calcium carbonate in the upper layer (epipedon) of the soil indicates that the rate of leaching was low. The amount of calcium carbonate increases with depth from 0 to 100 cm., and decreases below that depth. The high amount of calcium carbonate at the 62-100 cm. depth meets the requirements of a calcic horizon. The south-facing slope of the landscape probaly has an influence on the rate of leaching because the effective moisture is not sufficient to weather and remove calcium carbonate.

Organic matter. The distribution of organic matter with depth in the Hillfield pedon is shown in table 5 and figure 17. It decreases uniformly with depth. The thickness of the Al horizon and the amount of organic matter meet the requirements of a mollic epipedon, but, despite the presence of 2.39 percent organic matter, the color of the Al horizon is not dark enough to be mollic. The reason for the light color is probably related to the high amount of calcium carbonate (12.1 percent), "because finely divided lime acts as a white pigment (Soil Survey Staff, 1975)."

Free iron oxide

The data for free iron oxide is presented in table 5. The results are quite similar throughout the pedon.

Cation exchange capacity, extractable cations and pH. The chemical analysis of the Hillfield Pedon is presented in table 5. The range of CEC is from 3.6 to 10.9 meg/100 gr. soil. The high CEC in the surface horizon is related to the presence of organic matter.

The calculated cation exchange capacities presented in table 5 are obtained based on meg/100 g clay. The range of values is between 22.1 to 44.1 meg/100 g clay, which suggests that a mixture of layer silicate is present in the soil material, but that illite is dominant, particularly at the depth below 62 cm. These data have been confirmed by X-ray analysis.

The predominant extractable cation is calcium, which probably is the result of weathering of calcium bearing

Table 4. Particle size distribution * (in micrometer, percent) of Hillfield and unnamed Mollisol pedons

Horizon	Depth (cm)	Total fraction Sand 50-2000	Total fraction silt 2-50	Total fraction clay <2	Sand very coarse 1000-2000	Sand coarse 500-1000	Sand medium 250-500	Sand fine 100-250	Sand very fine 50-100	Silt coarse 5-50	Silt fine 2-5	clay <2
Hillfield												
A_1	0-19	52.21	33.64	14.15	-	0.27	1.6	20.02	30.32	31.34	2.3	14.15
C_{1ca}	19-32	52.82	32.63	14.54	0.11	0.16	1.29	22.24	29.02	30.21	2.42	14.54
C_{2ca}	32-62	53.03	34.48	12.48	0.17	0.23	1.30	20.87	30.46	31.93	2.55	12.48
IIC_{3ca}	62-100	32.02	55.12	12.86	0.05	0.16	0.45	8.22	23.14	51.54	3.58	12.86
$IIIC_4$	100-150	68.87	19.25	11.89	0.16	0.16	1.48	44.50	22.57	18.50	0.75	11.89
Unnamed Mollisol												
A_{11}	0-13	54.53	25.76	19.7	0.27	0.7	2.46	22.42	28.68	24.23	1.53	19.7
A_{12} **	13-35	53.0	27.60	19.41	0.21	0.67	3.48	22.32	26.32	26.08	1.52	19.41
A_{12}	35-57	52.05	28.43	19.52	0.16	0.54	2.40	22.25	26.70	25.73	2.70	19.52
IIC_{1ca}	55-77	63.17	20.86	15.98	0.28	0.79	3.27	24.22	34.61	19.65	1.21	15.98
$IIIC2_{ca}$	77-110	66.49	17.91	15.60	0.57	1.49	4.97	25.96	33.50	16.7	1.21	15.60
IVC_3 ***	110-130	67.69	18.88	13.43	0.87	0.87	3.05	23.95	38.95	18.05	0.83	13.43
IVC_3	130-150	68.36	21.15	10.50	0.62	1.07	2.86	20.62	43.19	20.34	0.81	10.50

* Particle size distribution of carbonate free material.

** Sampled from 13-35 cm. and 35-57 cm. depth for lab analysis.

*** Sampled from 110-130 cm. and 130-150 cm. depth for lab analysis.

Table 5. Selected chemical analysis and physical properties of the Hillfield and unnamed Mollisol (North-facing slope) pedons.

Horizon	Depth cm	pH (paste)	Organic matter %	CaC03 equivalent %	CEC meg/100g soil	Calculated CEC meg/100g clay	Extractable Cations (NH4 0Ac meg/100gr)				Free Iron Oxide %	Physical properties	
							Ca	Mg	Na	K		Bulk density g/cm^3	Water rention at 15 atm. %
Hillfield													
A_1	0-19	7.8	2.39	12.1	10.9	42.25	25.5	2.8	0.2	0.9	0.25	-	7.0
C_{1ca}	19-32	8.0	1.14	19.2	8.4	42.1	43.0	2.4	0.2	0.5	0.24	1.57	6.4
C_{2ca}	32.62	8.0	1.05	22.1	7.6	44.1	45.3	2.6	0.1	0.4	0.21	1.59	7.4
IIC_{3ca}	62-100	8.2	0.88	40.2	6.5	36.9	45.6	4.9	0.2	0.3	0.25	1.70	6.7
$IIIC_4$	100-150	8.4	0.48	28.2	3.6	22.1	39.5	6.4	0.2	0.2	0.21	-	3.4
Unnamed Mollisol													
A_{11}	0-13	7.7	7.40	2.1	20.4	28.8	30.5	5.5	0.2	1.4	0.43	1.36	14.8
A_{12}	13-35	7.9	3.61	7.7	13.3	31.32	40.8	4.0	0.2	0.4	0.32	1.36	9.3
A_{12}	35-57	7.9	5.42	5.2	14.3	17.72	35.5	4.7	0.2	0.7	0.36	1.31	10.2
IIC_{1ca}	57-77	8.2	2.24	21.3	9.7	32.66	46.1	3.4	0.3	0.4	0.30	1.44	9.0
$IIIC_{2ca}$	77-110	8.5	1.26	40.4	4.3	16.15	45.8	2.8	0.2	0.1	0.17	1.32	8.1
IVC_3	110-130	8.6	1.08	36.9	4.5	17.42	40.9	7.3	0.2	0.1	0.18	1.37	6.1
IVC_3	130-150	8.7	0.69	34.4	3.6	21.2	38.6	7.2	0.2	0.1	0.21	1.41	4.6

minerals such as calcite and dolomite. The extractable magnesium is uniform in the upper 0-62 cms., but increases below 62 cm. which is probably related to the soil material and confirms the depositional discontinuity.

Despite the uniformity of extractable sodium throughout the pedon, the extractable potassium is greater at the 0-32 cm. depth. The reason for the higher amount of potassium at the surface as explained for the Timpanogos soil probably is applicable to this soil. The pH values range from pH 7.8 at the 0-19 cm. depth to pH 8.4 at the 145-170 cm. depth.

Unnamed Mollisol Pedon

This pedon is a well drained soil with a medium-textured subsoil. The soils which this pedon represents are derived from calcareous parent material of Lake Bonneville deposits. They were developed on north-facing slopes in the E-W trending foothills in the east part of Cache Valley. The pedon is located in a pasture area 90 meters south of the northeast corner of the northeast quarter of Sec. 2, T11N, R1E, with an elevation of 1490 m. MSL. The area is exposed toward the north, with a 32 percent slope (figure 13 and 14).

The Pedon is described as follows:

A11--0 to 13 cm.; very dark brown (10YR 2/2) moist; loam, very dark grayish brown (10YR 3/2) dry; weak, medium granular structure; common fine and few medium roots; many

Figure 13. Landscape of unnamed Mollisol (N-Slope)

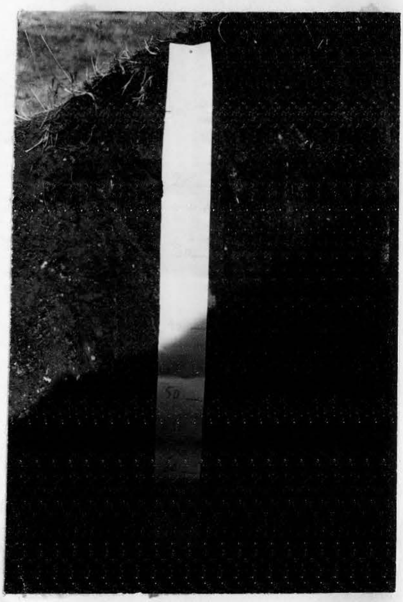


Figure 14. Profile Of unnamed Mollisol

fine pores; slightly hard, very friable, slightly sticky and slightly plastic; slightly calcareous; mildly alkaline (pH 7.7 paste); clear smooth boundary.

A12--13-57 cm. very dark grayish-brown (10YR 3/2) mosit; loam, dark brown (10YR 3/3) dry; moderate medium subangular blocky structure that parts, to weak, medium granular structure; slightly hard, friable, slightly sticky and slightly plastic; many fine, few medium roots; common fine and medium pores; moderately calcareous; moderately alkaline (pH 7.9 paste); clear smooth boundary.

IIClca--57 to 77 cm.; brown (10YR 5/3) moist, sandy loam; light brownish-gray (10yr 6/2) dry; massive; slightly hard; friable, slightly sticky an slightly plastic; common fine and few medium roots; common fine and medium pores; stongly calcareous; moderately alkaline (pH 8.2); clear wavy boundary.

IIIC2ca--77 to 110 cm.; very pale brown (10YR 7/4) moist; very fine sandy loam; very pale brown (10YR 8/3) dry; massive, slightly hard, friable, slightly sticky and slightly plastic; common fine, few medium roots; common fine pores; strongly calcareous; strongly alkaline (pH 8.5 paste); clear smooth boundary.

IV C3--110 to 150 cm.; very pale brown (10YR 7/3) moist; very fine sandy loam; very pale brown (10YR 8/3) dry; single grain, soft, very friable, nonsticky and nonplastic; few fine roots; few fine pores; strongly calcareous; strongly alkaline (pH 8.7 paste).

This Pedon (unnamed Mollisol) does not show, strong horizonation. There is differentiation in color betwen A and C horizon, but the hue is uniform. The color varies from very dark brown in the A11 and A12 horizon to very pale brown in the IIIClca and IVC3 horizons. The structure ranges from granular in the A11 and subangular blocky in the A12, massive in IIClca, IIIC2ca and single grain (structureless) in the IVC3 horizon.

The abrupt change in textural class indicates a depositional discontinuity in this soil. The soil is calcareous throughout. The lighter color and strongly effervescence in the IIClca and IIIC2ca horizon confirm the accumulation of calcium carbonate and suggests the presence of calcic horizon.

Particle-size distribution. The distribution of particle size is presented in table 6 and illustrated in figure 15 and 16. There is no evidence of eluviation of silicate clay in the upper surface of the pedon. The soil particles are relatively uniform at the 0-57 cm. depth. An abrupt change in texture occurs at 57 cm. At the depth of 57-77 cm., IIClca, the silt fraction decreases about 27 percent, whereas very fine sand particles increase 30 percent, compared with A12 horizon. This indicates a depositional discontinuity. A larger amount of coarse sand (88 percent increase), medium sand (increase of 51 percent) and a smaller amount of silt (decrease of 14 percent) in the IIIClca horizon by comparison with IIClca shows another depositional discontinuity. At the substratum the coarse sand and medium sand decrease 41 and 38 percent, respectively. Also, the silt fraction increases 16 percent; thus, this horizon is designated as IV C3.

The cumulative particle-size curve of the materials of the horizons of the unnamed Mollisol, as shown in figure 16, indicates that between 66 and 75 percent of the soil materials have diameters less than 100 micrometers. A small portion of the material is greater than 250 micrometer. The data show that the soil material has the characteristics of wind-

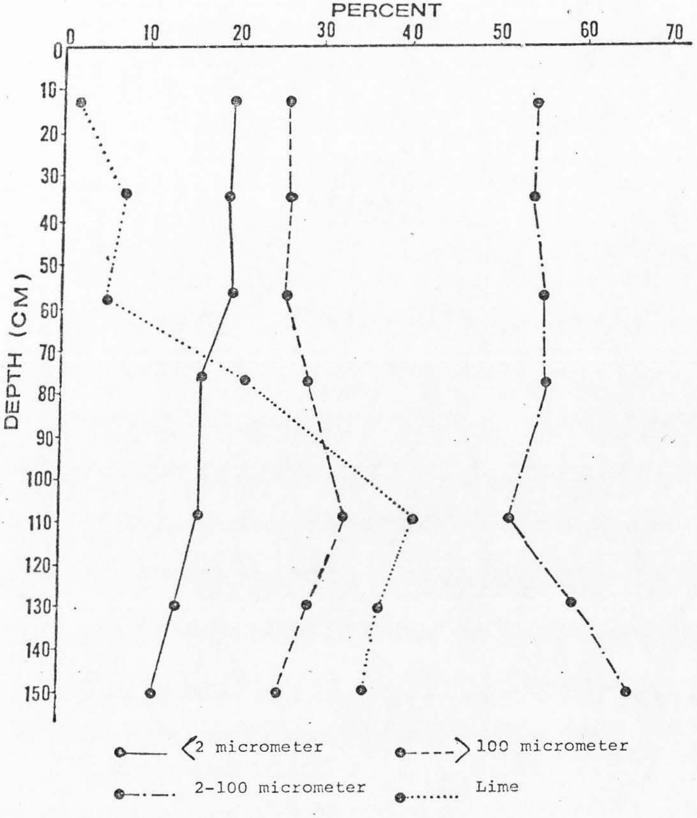


Figure 15. Calcium carbonate and particle size distribution with depth of unnamed Mollisol pedon (North-facing slope)

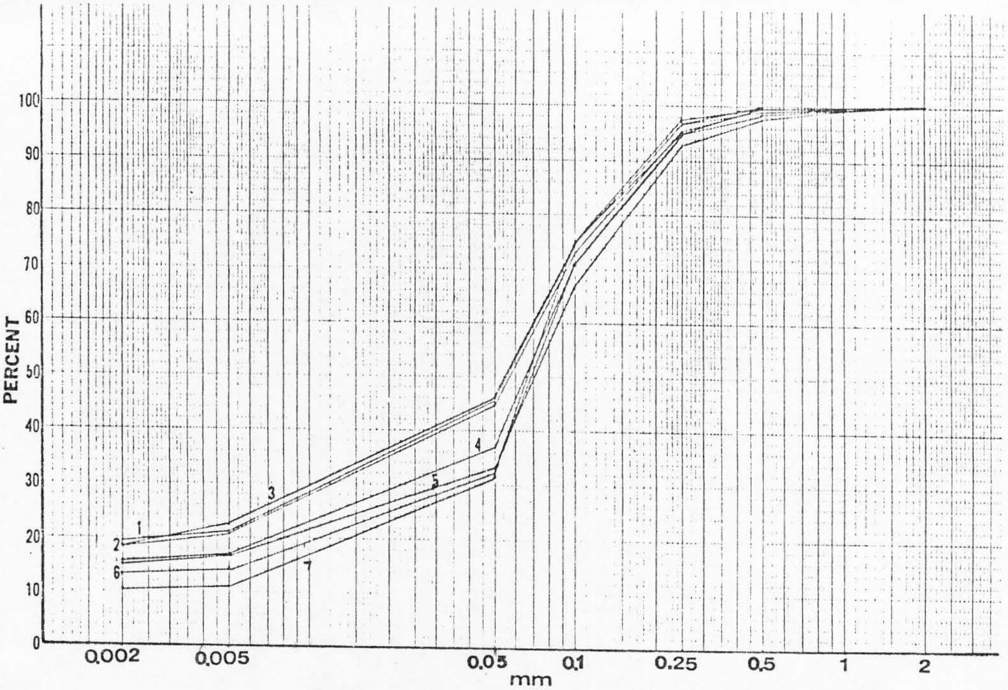


Figure 16 . Cumulative particle size curves for the <2 mm material of the unnamed Mollisol Pedon horizons. The horizons are: 1 = 0-13 cm; 2 = 13-35 cm; 3 = 35-57 cm; 4 = 57-77 cm; 5 = 77-110 cm; 6 = 110-130 cm; 7 = 130-150 cm.

blown materials. The shape of cumulative curves of materials of Timpanogos and unnamed Mollisol and upper part of the Hillfield pedons are quite similar to that Swineford and Frye (1945) obtained by the analysis of wind-blown material. The higher amount of effective moisture, as a result of exposure, in this soil compared to the Hillfield soil, probably has not affected particle-size distribution. The greater amount of clay in the epipedon is not related to clay formation in place, but is probably a result of the delivery of clay from upslope to downslope by erosion. The overthickened A horizon (pachic) resulted from the accumulation of eroded material on the downslope. Nikiforoff (1949) named this type of soil "cumulative". He believed that "the soil receives influxes of parent material at the same time that the soil formation is going on; that is soil formation and deposition are concomitant at the same site."

Calcium carbonate equivalent. Table 5 and figure 15 show the distribution of calcium carbonate equivalent for the unnamed Mollisol. The minimum (2.1 percent) occurs at the 0-13 cm. depth, whereas the maximum calcium carbonate (40.4 percent) accumulated at the 77-110 cm. depth, the IIIC2ca horizon. The low amount of carbonate in the upper part of the soil and the large amount below 57 cm., indicate a moderate rate of leaching took place during pedogenesis. At the 62 cm. depth in the Hillfield soil and the 77 cm. depth in the unnamed Mollisol the percentage of calcium carbonate is equal. The greater depth of accumulated calcium carbonate in the unnamed Mollisol is probably due to a microclimate effect which this soil experiences by being located on a north facing slope. Southard and Dirmhirn (1972) stated that "the total amount of carbonate apparently differs between the different exposures and the average carbonate content (weighted on a thickness of layer basis) is higher on the south slope than on the north slope". However, they believed these apparent differences in distribution of carbonates can not be fully explained by the higher effective moisture relations on the north slope. They also concluded that the sharp break in the particle size distribution at 55 cm. on the south slope and at 50 cm on the north slope tends to interfere with moisture movement across this interface and carbonate tends to accumulate there. These explanations are probably applicable for the Hillfield (south-slope) and the unnamed Mollisol (north-slope) because the particle size distribution changes at 62 cm. on the south-slope and 57 cm on the north-slope.

The higher amount of carbonate at the 13-35 cm. depth compared to the 35-57 cm. depth probably is due to accumulation of eroded material with a greater amount of carbonate on the soil surface during pedogenesis.

The calcium carbonate equivalent at the depth from 57 to 110 cm. exceeds 15 percent. The 5 percent drop-off in the underlying material qualified these horizons as calcic (Soil

Survey Staff, 1975).

Organic matter. Table 5 and Figure 17 present the distribution of organic matter with depth of the unnamed Mollisol which formed on North-facing slopes. It decreases uniformly with depth, except at the 13-35 cm. depth, which has less organic matter than the horizon below. The nonuniform distribution of organic matter is probably related to the deposition of material rich in organic matter which was eroded from upslope. The high amount of organic matter in the A11 horizon is due to its location on a north-facing slope with a greater amount of ground cover, as compared with the soil found on south-facing slopes (Hillfield). Southard and Dirmhirn (1972) found a larger quantity of organic matter, darker colors and a thick mollic epipedon on the North-slope. They also estimated the ground cover was 90 percent on the North-slope and 10 percent on the South-slope, which is a result of different microclimates. They concluded that the pronounced difference in microclimate of the south and north slopes in the E-W trending foothills of the western mountains can be related to the differences in the solar radiation, which persists throughout the year, together with the earlier snowmelt on the south slope. The result is a lower soil moisture percentage and higher soil temperature on the South-slope.

The moist and dry colors of 0-57 cm., and the amount of organic matter (greater than 1 percent) is sufficient to meet the requirements of thick, or pachic mollic epipedon. On the south-slope the color of the Hillfield epipedon however, is not dark enough to be mollic.

Free-iron oxide. The data for free iron oxide of the unnamed Mollisol is presented in table 5. The free iron oxide decreases with depth. It does not appear to have been translocated. The higher amount of iron oxide in the horizon probably related to the soil material or weathering of primary mineral in place.

Cation exchange capacity, extractable cations and pH. The results of chemical analysis of the unnamed Mollisol are presented in table 5. The CEC range in this pedon is from 3.6 to 20.4 meg/100g. soil. The high value of CEC in the upper layer (epipedon) of the soil is related to the presence of high amount of organic matter.

The calculated cation exchange capacities, based on meg/100 grams clay, are presented in the table 5. The range of CEC values is between 16.5 to 32.66 which suggests that illite is dominant in the clay fraction with lesser amounts of kaolinite and montmorillonite. These data have been confirmed by X-ray analysis.

Calcium is the dominant extractable cation throughout the pedon and is a weathering product of calcite and dolomite.

The extractable magnesium decreases from the surface to a depth of 110 cm. A greater amount of magnesium at the surface is probably due to the higher rate of weathering of dolomite at the surface horizons. Also, the large amount of magnesium in the substratum (110-150 cm.) is probably related to soil material origin and confirms the depositional discontinuity.

Extractable sodium is uniform through the pedon, but the amount of extractable potassium is high at the surface, and very low below 77 cm. The reason for this variation, as explained for the Timpanogos soil, is true for this soil as well.

The pH values range from pH 7.7 at the 0-13 cm. depth to pH 8.7 at the 130-150 cm. depth.

Sterling Pedon

The Sterling soils are somewhat excessively drained with a very gravelly sandy loam substrata formed on material derived from alluvium and lake deposits. It occurs at elevations from 1380 to 1650 m MSL and on slopes between 20 to 50 percent. The Sterling Polypedon covers an area of about 261 hectares, which includes about 0.1 percent of total area of Cache Valley.

This pedon formed on the alluvial fan of Dry Canyon and is located in a pasture area 250 meters north and 265 meters east of the southwest corner of the southwest quarter of Sec. 36 T12N, R1E, at an elevation of 1529 m MSL. The area is exposed toward the west, with a 9 percent slope (figure 18 and 19). A description of the pedon follows:

All--0 to 11 cm.; very dark-grayish-brown (10YR 3/2) moist; gravelly loam; dark brown (10YR 4/3) dry; moderate, medium, granular structure; slightly hard, friable, slightly sticky and slightly plastic; many very fine and fine, few medium roots; common fine pores; 30 percent gravel; slightly calcareous; moderately alkaline (pH 7.9 paste); clear smooth boundary.

A12--11 to 30 cm.; brown to dark brown (10YR 3/3) moist, gravelly loam; dark brown (10YR 4/3) dry; moderate, medium, subangular blocky structure; slightly hard, friable, slightly sticky and slightly plastic; common fine, few medium roots; common fine pores; 35 percent gravel; slightly calcareous; pebbles and gravels have thin discontinuous carbonate coatings; moderately alkaline (pH 7.9 paste); clear smooth boundary.

C1--30 to 98 cm.; dark brown (10YR 4/3) moist; gravelly loam; yellowish brown (10YR 5/4) dry; massive; hard, friable, slightly sticky and slightly plastic; common fine and few medium roots; common fine pores; 45 percent gravel; moderately calcareous, coarse fragments have thin discontinuous carbonate coatings; moderately alkaline (pH 8.1 paste); abrupt smooth boundary.

C2--98 to 125 cm.; yellowish brown (10YR 5/4) moist; very gravelly sandy loam; light yellowish brown (10YR 6/4) dry; massive, hard, friable, slightly sticky and slightly plastic; few fine roots; 65 percent gravel; strongly calcareous; relatively thin discontinuous carbonate coating on coarse fragments; moderately alkaline (pH 8.2 paste) clear smooth boundary.

IIC3--125-155 cm.; light yellowish brown (10YR 6/4) moist; very gravelly sandy loam; very pale brown (10YR 7/3) dry; single grain; loose, nonsticky and nonplastic; 75 percent gravel; strongly calcareous; gravels have thin discontuous carbonate coatings; moderately alkaline (pH 8.2 paste).

Sterling pedon does not show strong horizonation. The colors vary from dark brown in the A11 and A12 horizons to yellowish in the C2 horizon and light yellowish brown in the IIC3 horizon.

Structures range from granular in the A horizon to massive in the C horizon. The substratum (125-155 cm.) is strongly calcareous which shows the leaching of carbonates during pedonenesis. The abrupt change in texture class probably is

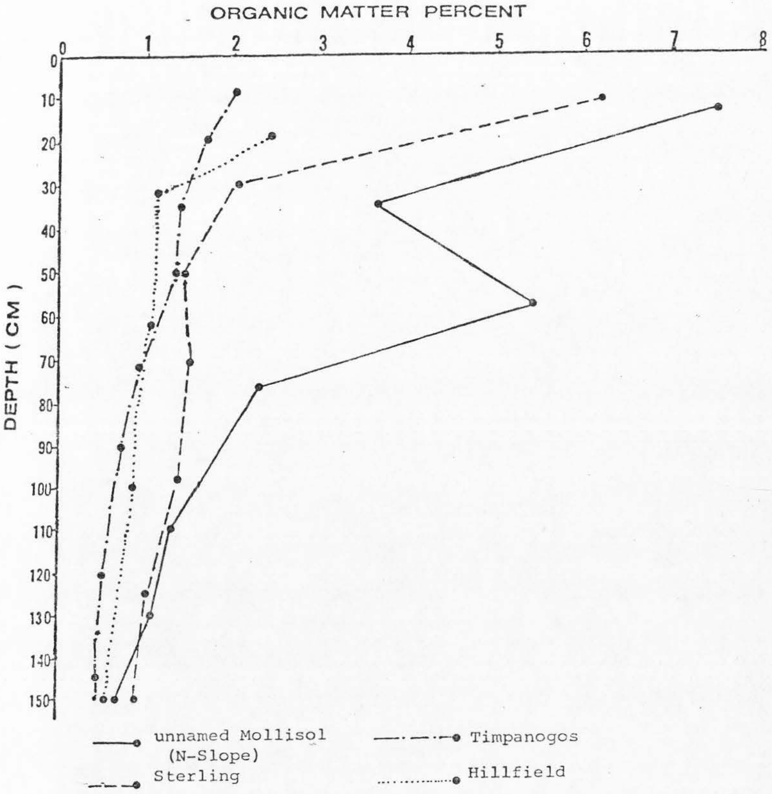


Figure 17. Distribution of organic matter with depth.

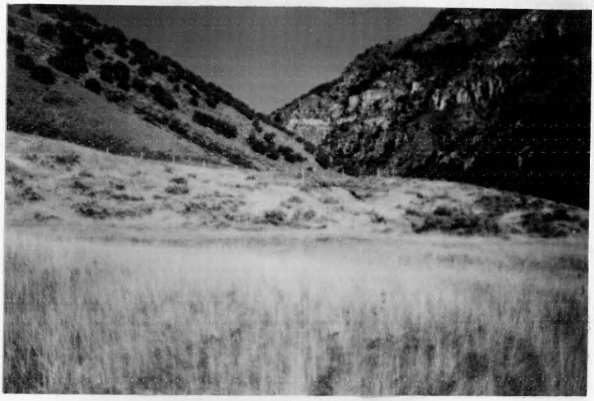


Figure 18. Landscape of the Sterling pedon.

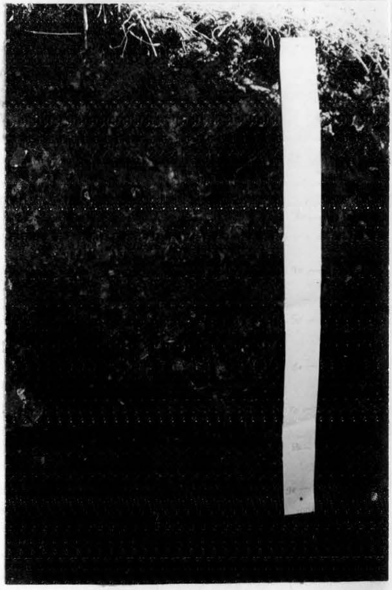


Figure 19. Profile of the Sterling pedon.

related to a depositional discontinuity. The dry and moist colors and thickness of the A11 and A12 horizon meet the requirements of mollic epipedon. The soil is calcareous throughout.

Particle-size distribution. The particle-size distribution of the soil material is represented in table 6, and illustrated in figure 20. There is no evidence of eluviation of silicate clay in the A horizon. The distribution of clay is relatively uniform for the 0 to 125 cm. depth.

A sharp break occurs at the depth of 125 cm. in the particle size distribution. An increase in the very coarse and coarse sand, together with a 32 percent decrease in the silt fraction from the C2 to the IIC3 horizon suggests a depositional discontinuity. The C2 horizon probably has the characteristics of a transitional zone, because there are some changes in particle-size distribution between the C1 and C2 horizons.

The pedon formed on the alluvial fan of Dry Canyon, which consists of large quantities of poorly sorted debris that was transported down the steep slope during Altithermal time (7000-4500 YBP). The fan transcends the Provo level of Lake Bonneville, hence the wide range in elevation of the Sterling soils.

Calcium carbonate equivalent. Distribution of calcium-carbonate equivalent for the Sterling soil is presented in table 7 and figure 20. It ranges from 2.8 to 35.6 percent.

Table 6. Particle size distribution * of Sterling Soil.

Horizon	Depth (cm)	Total Fraction			Sand					Silt		Clay	Fine earth***	coarse fragments	
		Sand 50-2000	silt 2-50	clay <2	very coarse 1000-2000	coarse 500-1000	medium 250-500	fine 100-250	very fine 50-100	coarse 5-50	fine 2-5	<2	<2mm	>2 mm	2-19 mm
		← in micrometer, percent →											← mm, percent →		
A_{11}	0-11	48.54	33.17	18.29	1.7	3.2	5.26	15.45	22.93	30.23	2.94	18.29	70	30	18.5
A_{12}	11-30	48.2	33.95	17.84	1.52	3.38	5.1	15.26	22.94	31.02	2.93	17.84	75	25	12.4
C_1**	30-50	51.3	31.13	17.65	1.75	2.67	4.47	15.40	26.92	28.15	2.98	17.65	77	23	11.0
C_1 **	50-70	51.99	30.32	17.68	2.07	3.23	4.75	15.16	26.78	27.44	2.88	17.68	66	34	19.4
C_1 **	70-98	51.22	30.91	17.87	1.99	3.36	5.04	14.81	26.02	27.29	3.62	17.87	70	30	13.4
C_2	98-125	57.14	25.56	17.31	3.36	5.45	6.98	16.40	24.95	23.37	2.19	17.31	63	37	21.1
IIC_3	125-155	69.06	17.3	13.63	7.97	12.06	10.85	20.35	17.83	15.78	1.52	13.63	35	65	53

* Particle size distribution of carbonate free material.

** Sampled from 30-50cm, 50-70cm and 70-98cm depth for lab analysis.

*** Fine material separated from coarse fragment without any prior treatment. Visual estimate during field description shows more coarse fragments at the control section (25-100 cm.). Because there are many cobblestone at the 30-98 cm. depth which was not sampled for lab analysis.

Table 7. Selected chemical analysis and physical properties of the Sterling pedon.

Horizon	Depth (cm)	pH paste	Organic Matter %	$CaCO_3$ equivalent %	CEC meg/100g soil	Calculated CEC meg/100g Clay	Extractable Cations				Free Iron-Oxide %	Physical Properties	
							Ca (NH4 OAc,.	Mg	Na meg/100g)	K		Bulk density g/cm^3	Water retention at 15 atm. %
A_{11}	0-11	7.9	6.16	3	17.3	25.8	19.2	6.1	0.2	1.2	0.43	-	11.2
A_{12}	11-30	8.0	2.06	2.8	12.8	48.65	14.1	5.5	0.2	1.1	0.54	-	7.8
C_1	30-50	8.0	1.39	4.9	11.4	48.83	12.7	5.1	0.2	0.9	0.56	-	7.2
C_1	50-70	8.1	1.51	6.8	11.5	48.5	15.5	5.0	0.2	0.8	0.45	-	7.1
C_1	70-98	8.1	1.41	8.0	11.3	47.5	15.0	5.1	0.2	0.8	0.45	-	7.1
C_2	98-125	8.2	1.0	12.2	9.6	42.0	16.7	4.3	0.2	0.5	0.47	-	6.7
IIC_3	125-155	8.2	0.83	35.6	4.3	31.32	40.8	3.1	0.2	0.2	0.39	-	4.6

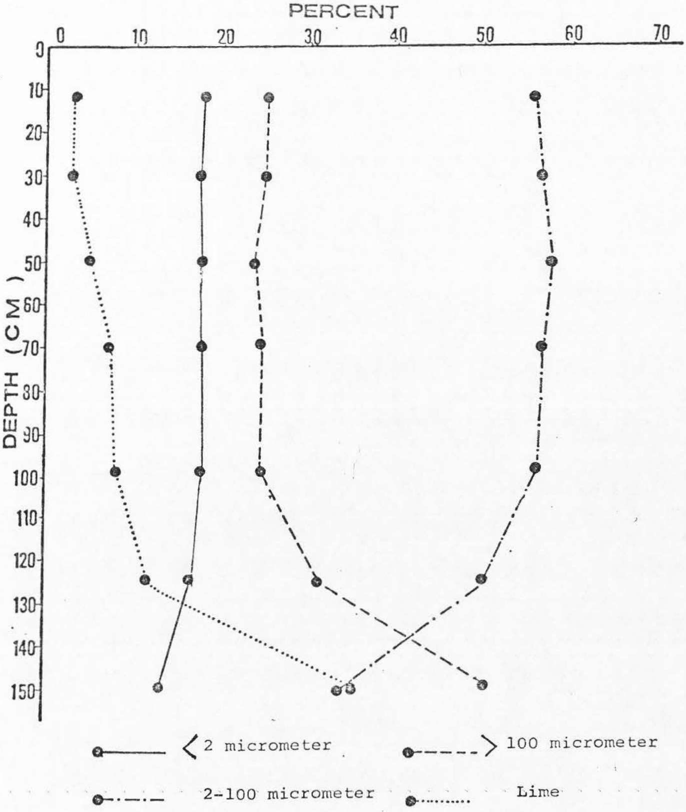


Figure 20. Calcium carbonate and particle size distribution with depth of the Sterling pedon.

The rate of leaching is relatively low. The cobblestones and gravels have a thin discontinuous carbonate coating. The gravels are not cemented by carbonate. This soil has the diagnostic carbonate morphology of stage I of a gravelly soil in New Mexico which has been estimated to have required 2600-5000 years to form (Gile et al., 1966). The zone of accumulation of carbonate between 0-100 cm. does not have the characteristics of a calcic horizon.

Organic matter. The distribution of organic matter with depth of the pedon is shown in table 7 and figure 17. Organic matter decreases uniformly with depth. The percentage of organic matter of the Sterling soil is higher than that of the Hillfield and Timpanogos soils and is similar to that of the unnamed Mollisol, which formed on a north-facing slope. The higher amount of organic matter of this pedon is probably due to coarse fragment and/or clay content. Gile and Grossman (1979) reported that pedons with greater coarse fragment volumes have a higher percentage of organic carbon in the fine earth. They also noted that organic carbon generally increases as clay content increases. The dry and moist colors, amount of organic matter and thickness of A11 and A12 horizons meet the requirements of a mollic epipedon.

Free iron oxide. Free iron oxide values for the Sterling soil are presented in table 7. The distribution of free iron oxide is relatively uniform through.

Cation exchange capacity, extractable cations and pH. Results of chemical analysis of Sterling Pedon are presented in table 7. The range of CEC in the pedon is from 4.3 to 17.3 meg/100g soil. The high CEC in the upper layer (epipedon) is related to the presence of a greater amount of organic matter.

Calculated cation exchange capacities as presented in table 7 are between 25.8 and 48.83 meg/100 gr. clay, which suggests a mixture of layer silicate. These data have been confirmed by X-ray analysis .

The predominant extractable cation is calcium, followed by magnesium. These are probably weathering products of calcite and dolomite.

The extractable sodium is distributed uniformly throughout the pedon, but extractable potassium is greater in the upper layer of the soil. The reason for the greater amount of potassium in the upper layer has been explained previously (page 47) and is applicable here.

The pH values range from pH 7.9 at the 0-11 cm. depth to pH 8.4 at the 125-155 cm. depth.

Mineralogy

Semiquantitative estimates were made of minerals occurring in the clay fraction of the soils which have been studied. The predominant clay mineral is illite (d=10Å) in the clay and fine silt (2-5 micrometer) fractions. Lesser amounts of kaolinite (d=7.2 A° which disappeared on heating at 575° C for two hours), mixed layer expandable clay, montmorillonite and quartz (d=3.32 A°) also, are present in the clay fraction of soil samples from different horizons.

X-ray diffraction patterns of the clay and fine silt fractions of the horizons showed little variation in mineralogy between pedons. This is not uncommon because the clay minerals of soils in arid and semiarid regions are controlled by parent material (Buol et al. 1973), and rate of weathering is slow. Southard and Miller (1966) showed the negligible effect of weathering on inherited clay in soils of northern Utah.

In Timpanogos soil which were formed on a nearly level geomorphic surface, montmorillonite (d=14 A° shifts d=17 A° by saturating with ethyleneglycol and heating to 60° C) is present at depths below 50 cm. and mixed-layer expanding minerals are not present below 91 cm. Birkland (1969), Barshad (1966), Jackson et al., (1948), and Jackson (1964) concluded that the diversity of clay minerals within any one soil or soil horizon is a result of inheritance and/or the formation of some of the clay minerals under different environmental conditions in the past. Also, Birkland (1974) believes that montmorillonite in the surface becomes desilicated and alters to kaolinite with time. But Buol, et al. (1973) stated that "it does not seem likely that montmorillonite has weathered to kaolinite or some other more resistant mineral in soils of arid and semiarid regions when such easily weathered minerals as gypsum and calcite remain in the soil profile." Whatever the cause of this diversity, the abrupt change of the kind of the clay in Timpanogos soil is coincident with the depositional discontinuity. So it seems that the changing of the kind of clay is related to soil material or probably the montmorillonite degraded to poorly crystaline mixed-layer expanding clay in the horizon above 50 cm. depth in the presence of potassium. Gile and Grossman (1979) reported that in New Mexico, Holocene soil developed in alluvium derived from high biotite monzonite contains small amounts of kaolinite and mica and small or moderate amounts of poorly ordered montmorillonite throughout the soil. Also, soils developed in Pleistocene alluvium have a similar distribution of kaolinite and mica, but the montmorillonite increases in abundance and degree of ordering within and below the K horizon (calcic horizon). Buol and Yesilsoy (1964) found an increase in montmorillonite in the K horizon. The change may not have a pedogenic origin; there is evidence of lithological change at the top of the K horizon. An explanation for the more ordered montmorillonite within and below the K horizon is that it was largely implaced in Pleistocene pluvials and during subsequent drier periods has not been subjected to appreciable pedogenesis. In the shallower horizon pedogenesis has reduced the crystalline quality of montmorillonite. An alternative explanation is that alteration from poorly ordered to well-ordered montmorillonite occurred after the lower material was insulated from surficial weathering by formation of K horizon. Upper horizons are subject to greater return of potassium by vegetation, a manifestation of which is higher extractable potassium in the soil surface. The increase in montmorillonite with depth may be in part a reflection of reduced potassium in the soil solution. The above explanations probably are true for the Timpanogos soil. The well-ordered montmorillonite is in horizons with a high amount of calcium carbonate and the extractable potassium is less than 0.4 meg/100g below the 73 cm. depth. The well-crystalized montmorillonite is present below 73 cm.

In the coarse silt fraction of the Timpanogos soil, the dominant mineral is quartz, followed closely by feldspar. But below the depth of 50 cm. the diffraction patterns of the coarse silt fraction show the presence of dolomite. The carbonates were theoretically removed prior to X-ray analysis. There are two possibilities for the absence of dolomite at the surface (above 50cm). First, weathering of dolomite above 50 centimeters has occurred because these horizons are within the zone of wetting; second, dolomite-free material was deposited on the surface of this soil. Also, the particle-size distributions of the horizons below 50 cm are not the same as above 50 cm.

In the Hillfield soils which were formed on calcareous Lake Bonneville deposits (same as Timpanogos) on south-facing slopes, illite (d=10 A°) is dominant in the clay fraction. Kaolinite, montmorillonite and mixed-layer expanding clay are also present in the clay fraction. Montmorillonite is not present above a depth of 32 cm. Poorly ordered montimorillonite (mixed-layer expanding clay) is formed above 32 cm. The explanation for the change of clay mineralogy probably is the same as Timpanogos. Clay-sized quartz is present in all horizons. In the fine silt fraction quartz is abundant, followed closely by illite. Small amounts of kaolinite and feldspar also are present. In the coarse silt fraction the predominant minerals are quartz and dolomite, which were present throughout the soil. If the lack of dolomite at the surface of the Timpanogos soils is a result of weathering, then the presence of dolomite in the Hillfield soil might suggest that the environmental conditions were not sufficient for weathering of dolomite.

In the unnamed Mollisols which formed on the same parent material but on the north-facing slope geomorphic surfaces, the diversity of clay minerals is the same as in the Timpanogos and Hillfield soils. Montmorillonite is present at a depth below 57 cm. This depth is the zone of accumulation of calcium carbonate and has an extractable potassium content of less than 0.2 meg/100g soil. Thus, it can be concluded that the explanation used for Timpanogos soil's change from well-crystalized montmorillonite to a mixed-layer expanding clay is applicable to the unnamed

Table 8. Mineral estimates from X-ray diffraction patterns from horizons of Timpanogos and Hillfield pedons.

Depth cm.	Size of Fraction (micron)	Quartz	Feldspar	Dolomite	Calcite	Mica Illite	Montmorillonite	Mixed layer expanding	Kaolinite
Timpanogos									
0-8	<0.2					+		tr	
	0.2-2					+		tr	++
	2-5	++++	+			+++		tr	++
	5-50	++++	+++			tr			
8-20	<0.2					+		tr	
	0.2-2					+		tr	+
	2-5	++++	+			++		+	++
	5-50	++++	+			tr			
20-35	<0.2					+		+	
	0.2-2	+				+		+	+
	2-5	++++	+			+++		+	++
	5-50	++++	++			tr			
35-50	<0.2					tr		+	tr
	0.2-2	tr	tr			+		+	+
	2-5	++++	++			++++		+	+++
	5-50	++++	+			tr			
50-73	<0.2					tr		+	
	0.2-2	tr	tr			++	+	+	+
	2-5	+++		tr		++++		+	+++
	5-50	++++	+++	++++		tr			
73-91	<0.2					tr	+		tr
	0.2-2	tr	tr			++	++	tr	++
	2-5	++++	tr	tr		++++	++	+	+++
	5-50	++++	++	++++					
91-120	<0.2					tr	+		
	0.2-2					++	++		++
	2-5	+++	tr			++++	++		+++
	5-50	++++	++	++++		tr			
120-145	<0.2						+		
	0.2-2					++	++		++
	2-5	+++		++++		+++	++		++
	5-50	++++	++	++++					
145-170	<0.2						+		
	0.2-2					tr	+		tr
	2-5	++++	+	+		++++	++		+++
	5-50	++++	+++	++++					
Hillfield									
0-19	<2	tr				+		tr	tr
	2-5	+++				++		+	++
	5-50	++++		++++					
19-32	<2					+		+	+
	2-5	+++				++++		+	+++
	5-50	++++	++	++++					
32-62	<2	tr				+		+	+
	2-5	++++	+	++		++++	++	tr	+++
	5-50	++++	+	++++					
62-100	<2					+		+	+
	2-5	+++		+	+++	++	+	tr	++
	5-50	++++	++	++++					
100-160	<2	tr				+	tr	tr	+
	2-5	+++				+++	+		
	5-50	++++	++	++++					

Table 9. Mineral estimates from X-ray diffraction patterns from horizons of Sterling and unnamed Mollisol pedons.

Depth cm.	Size of Fraction (micron)	Quartz	Feldspar	Dolomite	Calcite	Mica Illite	Montmorill-onite	Mixed layer expanding	Kaolinite
Unnamed Mollisol									
0-13	<2	tr				++		+	++
	2-5	+++	+			+++			++
	5-50	++++	++			++			
13-35	<2	tr				++		+	++
	2-5	+++	++			+++		tr	++
	5-50	++++	++++			+			
35-57	<2	tr				++		+	+
	2-5	++++	++			++++	tr	+	++
	5-50	++++	+			+			
57-77	<2	tr				+		+	+
	2-5	+++	+			+++	+	+	++
	5-50	++++	+++			tr			
77-110	<2	tr			tr	tr	+		
	2-5	++	tr		++	++	+	tr	+
	5-50	++++	tr	++++	+++				
110-130	<2	tr			tr	tr	+		
	2-5	+++			++	+	tr	+	
	5-50	++++	++	++++	+++				tr
130-150	<2	tr				+	+		tr
	2-5	+++	tr	+		+++	++		++
	5-50	++++	++	++++	++	tr			
Sterling									
0-11	<2	tr				+		tr	+
	2-5	++++	tr			+++		+	++
	5-50	++++	+			+			
11-30	<2	tr	tr			+		+	+
	2-5	+++	+			++		+	++
	5-50	++++	+++			+			tr
30-50	<2	+				+		+	+
	2-5	++++	+			+++		+	++
	5-50	++++	++	+		tr			
50-70	<2	+				+		+	+
	2-5	+++	tr			+++		+	++
	5-50	++++	+	+		tr			
70-98	<2	+	tr			+		+	++
	2-5	++++	+			+++		+	++
	5-50	++++	+++	++		tr			
98-125	<2	+	tr			+		+	+
	2-5	++++	tr			++++		tr	+++
	5-50	++++	+	++++					
125-150	<2	+				++	tr	+	++
	2-5	++++	tr			++++	++		+++
	5-50	++++	+	++++	+++	tr			

Explanation

1. The X-ray apparatus was used with a copper K_{α} radiation and a nickle filter having a current of 18 ma. at the 35 Kv., scanning speed 2θ/min. and beginning value was 4 deg.
2. Trace = less than 1 cm. peak height
   Low = 1 to 2 cm. peak height
   Medium = 2 to 4 cm. peak height
   High = 4 to 8 cm. peak height
   Dominant = more than 8 cm. peak height

* Dominant = ++++; High = +++; Low = +; Trace = tr (detetable)

Mollisol. Dolomite was present below 77 centimeters depth. The period of time during which moisture is present in this soil is greater than for the soil that formed on the south-facing slopes, which are also warmer. In addition to the microclimatic conditions, the existence of more vegetation on north-facing slopes and hence more organic acides might be concidered the cause of the weathering of dolomite at the depth above 77 cm. for these soils. The X-ray diffraction pattern of the silt fraction (fine and coarse) of the horizon below 77 cm. shows the presence of calcite (d= 3.04 A°).

In the Sterling soils which were formed on the alluvial fan of Dry Canyon, illite is the dominant clay mineral. kaolinite and a mixed-layer expanding clay mineral are also present throughout the soils. The montmorillonite peak is present in the X-ray diffraction pattern of the clay and fine silt fractions at the depth of 125-150 cm. This is coincident with the boundary of the depositional discontinuity. Quartz and feldspar are the dominant minerals of the coarse silt fraction. Dolomite is absent above 30 cm. and calcite is present at depths of 125-150 cm. Tables 8 and 9 show mineral estimates from X-ray diffraction patterns from the different horizons of the Hillfield, Timpanogos, unnamed Mollisols and Sterling pedons.

Micromorphology

Thin sections were prepared from selected horizons of the Timpanogos, Hillfield and the unnamed Mollisol pedons and were studied with a petrographic microscope in order to determine the illuviation of clay in the soil profile. The peds were also observed with a hand lens. No oriented clay in the form of sand grain coatings or skins was identified in the Hillfield or the unnamed Mollisol samples. The distribution of clay in these pedons does not show any zone of accumulated clay. A relatively moderate amount of oriented clay in the form of sand grain coatings (sandbridges) was observed in the samples of the B21t and B_3Ca horizons of the Timpanogos soil. The presence of oriented clay and the higher amount of clay fraction in the B21t horizon as compared to the A horizon, suggests clay illuviation and the formation of an incipient argillic horizon. The most reasonable explanation for the lack of good clay film is the presence of high calcium carbonate content and a small amount of sodium. Sodium may cause dispersion of clay fractions and enhance the clay movement with percolating water. Roots and fauna were recognized as disruptive factors for clay skins (Gile and Grossman, 1979).

Grain mounts of the very fine sand fraction from selected horizons were observed in oil under the petrographic microscope.

Quartz grains are the most abundant mineral, with small amounts of feldspar, and mica in all of the samples. Dolomite was presented in the samples and increased with depth in each pedon.

Comparison of the studied soils

The particle size distribution of the upper horizons of the Timpanogos, Hillfield, and unnamed Mollisol pedons are relatively similar. In the Timpanogos soil an abrupt change in granulometric composition occurs at 50 centimeters. The variations of particle size below 50 cm. indicates three depositional discontinuities. The materials of the soil have the characteristics of wind-blown material. In the Hillfield pedon, the particle size distribution of the surface horizon, 0-62 cm. is quite uniform and has the characteristics of wind blown deposits. The 62-100 cm. depth is a depositional discontinuity with about 78 percent silt and very fine sand, exhibiting the properties of wind-blown material. Below 100 cm., the materials have noticeably different characteristics. The particle size of the surface horizons of the unnamed Mollisol are uniform, however, below 57 cm. three depositional discontinuities occur. The materials of this soil also have the characteristics of wind-blown deposits. The Sterling soil, derived from alluvial deposits, has between 23 and 65 percent coarse fragments. In the depth 0-98 cm., the particle size distibution of carbonate-free material is uniform, but below 125 cm. a depositional discontinuity occurs and the C2 horizon, 92-125 cm. depth, is probably a transitional zone.

In the Timpanogos pedon, the upper horizons (0-35 cm.) are noncalcareous and there are indications of a high degree of leaching of carbonates. The maximum amount of calcium carbonate is accumulated at the 73-145 cm. depth. In the Hillfield pedon relatively high amounts of calcium carbonate are present in the upper horizons, which indicates the rate of leaching was low. The highest amount of calcium carbonate was measured in the 62-100 cm. depth, but in the unnamed Mollisol the maximum calcium carbonate accumulated in the 77-110 cm. depth. Also, the amount of the calcium carbonate in the surface horizons is lower in the unnamed Mollisol than in the Hillfield pedon. This indicates the rate of leaching of carbonate in the unnamed Mollisol is more than in the Hillfield soil. In the Sterling pedon, the rate of leaching is relatively low. This is confirmed by the presence of thin, discontinuous carbonate coatings on the coarse fragments, and relatively uniform distribution of calcium carbonate.

The highest amount of organic matter, 7.40 percent, was measured in the surface horizon of the unnamed Mollisol, which formed on the north-facing slope whereas it is 2.39 percent in the Al horizon of the Hillfield pedon (south-facing slopes); and 1.98 percent in the All horizon of the Timpanogos pedon. The All horizon of the Sterling soil has 6.16 percent organic matter, which is probably due to coarse fragments. The mineralogical compositions of the clay and silt fractions of the studied soils are quite similar. The dominant clay mineral is illite with lesser amounts of kaolinite, mixed-layer expanding clay and montmorillonite.

Table 10. Selected physical, chemical and mineralogical data for the studied soils.

Horizon	Depth	Particle-size distribution, mm				Ca Co3 equivalent	Organic matter	Mineralogical Composition						
	cm.	sand% 2-0.05	Silt% 0.05-0.002	Clay% 0.002	2mm	%	%	Q	F	D	I	MO	MI	K
Timpanogos Pedon: Calcic Argixeroll, fine loamy, mixed, mesic (formed on lake terraces, nearly level).														
A_{11}	0-8	46.97	38.39	14.62	-	0.2	1.98	X	X		X		X	X
A_{12}	8-20	46.09	38.29	15.62	-	0.1	1.68	X	X		X		X	X
B_{21t}	20-35	45.76	34.63	19.63	-	0.1	1.39	X	X		X		X	X
B_{3Ca}	35-50	45.39	37.37	17.24	-	1.3	1.29	X	X		X		X	X
IIC_{1ca}	50-73	52.33	31.81	15.58	-	10.8	0.95	X	X	X	X	X	X	X
$IIIC_{2ca}$	73-91	46.47	41.73	11.79	-	28.8	0.69	X	X	X	X	X	X	X
$IIIC_{3ca}$	91-120	46.18	43.05	10.77	-	27.1	0.50	X	X	X	X	X		X
IVC_{4ca}	120-145	50.97	39.11	9.92	-	29.6	0.48	X	X	X	X	X		X
IVC_{4ca}	145-170	54.25	33.81	11.94	-	24.2	0.38	X	X	X	X	X		X
Hillfield Pedon: Calcixerollic Xerochrept, coarse loamy, mixed, mesic (formed on lake terraces, S-slope)														
A_1	0-19	52.21	33.64	14.15	-	12.1	2.39	X		X	X		X	X
C_{1ca}	19-32	52.82	32.63	14.54	-	19.2	1.14	X	X	X	X		X	X
C_{2ca}	32-62	53.03	34.48	12.48	-	22.1	1.05	X	X	X	X	X	X	X
IIC_{3ca}	62-100	32.02	55.12	12.66	-	40.02	0.88	X	X	X	X	X	X	X
$IIIC_4$	100-150	68.87	19.25	11.89	-	28.2	0.48	X	X	X	X	X		X
Unnamed Mollisol: Pachic Haploxeroll, coarse loamy, mixed, mesic (formed on lake terraces (N-slope)														
A_{11}	0-13	54.53	25.76	19.7	-	2.1	7.40	X	X		X		X	X
A_{12}	13-35	53.0	27.60	19.41	-	7.7	3.61	X	X		X		X	X
A_{12}	35-57	52.05	28.43	19.52	-	5.2	5.42	X	X		X	X	X	X
IIC_{1ca}	57-77	63,17	20.86	15.98	-	21.3	2.24	X	X		X	X	X	X
$IIIC_{2ca}$	77-110	66.49	17.91	15.60	-	40.4	1.26	X	X	X	X	X	X	X
IVC_3	110-130	67.69	18.88	13.43	-	36.9	1.08	X	X	X	X	X	X	X
IVC_3	130-150	68.36	21.15	10.50	-	34.4	0.69	X	X	X	X	X		X
Sterling Pedon: Typic Haploxerall, loamy skeletal, mixed mesic (formed on alluvial fan)														
A_{11}	0-11	48.54	33.17	18.29	30	3.0	5.16	X	X		X		X	X
A_{12}	11-30	48.2	33.95	17.84	25	2.8	2.06	X	X		X		X	X
C_1	30-50	51.30	31.13	17.65	23	4.9	1.39	X	X	X	X		X	X
C_1	50-70	51.99	30.32	17.68	34	6.8	1.51	X	X	X	X		X	X
C_1	70-98	51.22	30.91	17.87	30	8.0	1.41	X	X	X	X		X	X
C_2	98-125	57.14	25.56	17.31	37	12.2	1.6	X	X	X	X		X	X
IIC_3	125-155	69.06	17.3	13.63	55	35.6	0.83	X	X	X	X	X	X	X

Q = Quartz, F = Feldspar, D = Dolomite, I = Illite, Mo = Montmorillonite,
MI = Mixed layer expanding, K = Kaolinite, X = Mineral present.

In the Timpanogos, Hillfield and unnamed Mollisol well-crystalized montmorillonite is present in the subsoil, but in the upper horizons the montmorillonite is degraded to a poorly crystaline expanding clay mineral in the presence of potassium. In the Sterling soil, the distribution of clay minerals is the same as for other studied soils. The most abundant mineral in the silt and very fine sand fractions of the studied soils is quartz, followed by feldspar and dolomite. Dolomite is present in the silt and sand fractions of the samples and increases with depth in each pedon. The absence of dolomite in the surface horizons (which are of different thicknesses for the different soils) is related to weathering processes and is probably due to the existence of those horizons within the zone of the wetting. Table 10 shows selected physical, chemical and mineralogical data for the studied soils.

SOIL CLASSIFICATION

Timpanogos Pedon.

The epipedon has a color value less than 5.5 when dry and 3.5 when moist, and chroma is less than 3.5 when moist to the 20 cm. depth. Average organic matter content is more than 1 percent. Base saturation is more than 50 percent because of calcareous nature of the soil. All characteristics above are enough to meet the requirements for a mollic epipedon.

The ratio of clay at the 20-35 cm. to that at the 0-20 cm. depth is more than 1.2 (table 2). The fine clay to total clay ratio is also a higher actual value at 20-35 cm. to that at 0-20 cm. depth. These characteristics together with presence of oriented clay in the form of sand coatings (Sandbridges) meet the requirements of the argillic horizon. The value of calcium carbonate at the 73-91 cm. depth is sufficiently high to qualify as a calcic horizon. The textural class of the control section at the 20-35 cm. depth is fine loamy because it has more than 18 percent clay. The mineralogy classifies as mixed because the particle-size class is fine loamy and has less than 40 percent of any one mineral other than quartz or feldspar, even though the dominant clay mineral is illite. It has a xeric moisture regime and mesic temperature regime. According to these properties, the Timpanogos pedon is classified as a member of fine-loamy, mixed, mesic, family of Calcic Argixerolls.

Hillfield pedon

The amount of organic matter, thickness and base saturation of the surface horizons of the Hillfield polypedon are sufficient to meet the requirement for a mollic epipedon, but the moist color value is more than 3.5 at th 0-18 cm. depth; thus, the epipedon is not mollic. The characteristic of horizon at 19-62 cm. depth meet the requirement of a very weak cambic horizon. Calcium carbonate in the 62-100 cm. zone is sufficiently high to qualify as a calcic horizon (table 5). The textural class of of the control section at the 25-100 cm. is coarse loamy, because it has less than 18 percent clay (table 4). The mineralogy class of the pedon is mixed because the particle-size class at the control section is coarse loamy and has less than 40 percent of any mineral other than quartz or feldspar, even though the dominant clay mineral is illite. It has xeric moisture regime and mesic temperature regime because the mean annual precipitation is about 432 mm.

According to these characteristics the Hillfield Pedon meets the requirement for the Xerochrept at the great group level. The complete classification name for the pedon is coarse-loamy, mixed, mesic Calcixerollic Xerochrept.

Unnamed mollisol pedon

The epipedon of this soil is mollic. The moist and dry color values are less than 3.5 and 5.5 to 57 cm. depth, respectively. The chroma is less than 3. The organic matter is more than 1 percent, also, the base saturation is greater than 50 percent. The mollic epipedon is pachic because it is more than 50 cm. thick. This pedon does not have good horizonation or well express development of horizons. The amount of calcium at the 77-110cm. depth, IIIC2ca horizon, and thickness of that horizon (more than 15 cm.) and at least 5 percent more CaCO3 than underlying horizon meet the requirements of calcic horizon.

The textural class of the control section (25-100 cm.) is coarse loamy because the average weight percentage of clay is less than 18 (table 4). The mineralogy class of the pedon is mixed because particle size class of the soil is coarse loamy and has less than 40 percent of minerals other than quartz or feldspar, even though the dominant clay mineral of the control section is illite. The moisture regime is xeric and temperature regime is mesic.

The above mentioned characteristics of unnamed Mollisol pedon meet the requirements for the Pachic Haploxeroll at the subgroup level. The complete classification name for the pedon is coarse loamy, mixed, mesic, Pachic Haploxeroll.

Sterling pedon.

The epipedon of this soil is also mollic. The dry and moist color values are less than 5.5 and 3.5 to the 30 cm. depth. The chroma is equal 3 to this depth. Average organic carbon content is more than 0.6 percent in the 0-30 cm. depth and base saturation is more than 50 percent. The subsoil does not have the characteristic of a well-developed cambic horizon. The pedon does not have well expressed development of horizons.

The textural class of the control section (25-100 cm.) is loamy-skeletal because it has less than 18 percent clay and rock fragment make up more than 35 percent by volume of soil mineral (table 6). The mineralogy class of pedon is Mixed ~~illitic~~, because, the particle size class is loamy-skeletal and has less than 40 percent any one mineral other than quartz or feldspar, eventhough the abundant clay mineral in the clay fraction of control section is illite. The moisture regime is xeric with a mesic temperature regime.

According to the above properties, the Sterling pedon is classified as a member of a loamy-skeletal, mixed, mesic family of Typic Haploxerolls.

SUMMARY AND CONCLUSIONS

In an effort to achieve the objectives of this study, four soils on upper-level terraces of Lake Bonneville (above Provo shoreline, 1470 m. MSL) on the east side of Cache Valley, Utah, were studied. Representative pedons were described and sampled by genetic horizon to determine the nature and arrangement of these horizons. Particle-size distribution, calcium carbonate equivalent, organic matter, cation exchange capacity, extractable cations, PH, free iron oxide and mineralogy of the clay and silt fraction were determined. Thin sections and grain mounts of selected horizons were observed with a petrographic microscope.

The first objective of this study was to determine the characteristics and pedogenic processes of the Timpanogos, Hillfield and Sterling soil series in order to learn why the soil morphology is not chronologically related to geomorphic surface. The Timpanogos and Hillfield soils and the unnamed Mollisol formed on the presumeably undifferentiated Alpine and Bonneville formations which were deposited during the Pleistocene. But horizon development of these soils and the rate of weathering do not show the soils to be old, nor do they indicate they formed under the more effective moisture of Pleistocene time. Development of an incipient argillic horizon in the Timpanogos pedon, which formed on the nearly level surfaces that have been less affected by erosion than the landscapes of the Hillfield soil and the unnamed Mollisol, indicate these soils did not develop under the moist conditions of the Pleistocene. The rate of weathering of primary minerals is low. X-ray analysis shows the presence of dolomite below the 50 cm. depth. Clay minerals are inherited from the parent material, although, there are some differences in clay minerals between the horizons of studied pedons. The presence of mixed-layer expanding clay in the surfaces horizons and montmorillonite in the subsoil probably relates to the soil material or degradation of montmorillonite in the presence of more potassium; however, X-ray diffraction analysis cannot be used to determine adequately the weathering processes.

The particle size distribution of the studied soils suggests heterogeneity of their parent material. These soils developed from stratified deposits with granulimetric composition in which 75 to 90 percent of the grains are less than 100 micrometers in diameter, characteristic of wind blown material. It can be concluded that the geomorphic surfaces (Lake terraces) were not stable after deposition and that the soils formed on the material which was reworked by the wind during Altithermal time (7000-4500 YBP), which was warmer and dryer and had more intense wind activity than today, or possibly was brought by the wind from the Lake bottom after the Lake receded.

The Sterling soil formed on the alluvial fan of Dry Canyon which was deposited during Holocene time. Little horizon development and low degree of carbonate leaching, confirmed by the presence of discontinuous coatings of carbonate on the surfaces of pebbles and cobbles, indicate this soil started to form during Holocene time. Therefore, the development of the soil is chronologically related to its geomorphic surface.

The second objective of this study was to determine the relation of soil development to topographic position. The important acquired (developed) properties of the studied soils are the color and thickness of the epipedon, the illuvial clay of the argillic horizon, and depth of the zone of accumulated carbonate. The studied soils show different degrees of horizonation as well as different acquired properties. This dissimilarity could reinforce the presumption in this study that these soils developed under different topographic conditions. The Timpanogos soil with an incipient argillic horizon formed on nearly level surfaces, but the Hillfield soil and the unnamed Mollisol with weak cambic horizons formed on sloping sites. The upper boundary of the calcic horizon in the Timpanogos soil is 73 cm. and is noncalcareous about this. In the Hillfield soil and the unnamed Mollisol the depth of calcic horizon is 62 cm. and 77 cm., respectively, but they are calcareous above this. The amount of iron oxide is quite similar in these pedons. Difference in color of the epipedons of these soils is directly related to organic matter content. Also the amount of calcium carbonate has an effect on the color because fine powdery calcium carbonate acts as a pigment. The color differences are pedogenic (acquired) properties.

The third objective of the study was to test the effect of microclimate on the formation of soil on north-and south-facing slopes.

The unnamed Mollisol which formed on a north-facing slope was chosen for comparison with the Hillfield Pedon that formed on the south-facing slopes.

The other soil forming factors were presumed to be similar. At the 62 cm. depth in the Hillfield soil and the 77 cm. depth in the unnamed Mollisol the percentage of carbonate is equal. The greater depth of accumulated calcium carbonate in the latter is probably due to microclimate effect. Also, the epipedon of the unnamed Mollisol is dark and thick (57 cm.) but in the Hillfield soil the epipedon is not dark and has a thickness of 19 cm. It is related to a greater amount of ground cover on the north-facing slope as compared to south-facing slope, which is due to higher soil moisture percentage and lower soil temperature on the north-facing slopes.

The fourth objective of the study was the verification of the classification of the soils. These soils show some similarity in more than one of the diagnostic properties. In the Timpanogos and Sterling soils and the unnamed Mollisol, the color, depth, and organic matter percentage of each pedon coincide with the concept of the mollic epipedon. The color of the epipedon of the Hillfield soil, however, is not dark enough for it to qualify as mollic. The thickness of the mollic epipedon in the unnamed Mollisol qualifies it as Pachic. These soils classify as follows:

1. Timpanogos pedon; fine-loamy, mixed, mesic, Calcic Argixerolls.

2. Hillfield pedon; coarse-loamy, mixed, mesic, Caleixerollic Xerochrepts.

3. Unnamed Mollisol pedon; coarse-loamy, mixed, mesic, Pachic Haploxerolls.

4. Sterling pedon; loamy-skeletal, mixed, mesic, Typic Haploxerolls.

The changes in classification of the pedons in this study are 1) The Timpanogos remains the same 2) Hillfield is reclassified as coarse-loamy rather than coarse-silty, the great group remain the same and 3) Sterling is reclassified as a Typic Haploxeroll because it lacked a calcic horizon necessary for Calcixerolls. The family remained the same.

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