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Comparison of the Mineralogy and Morphology of Some Cambic and Argillic Horizons in Soils of Northern Utah

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COMPARISON OF THE MINERALOGY AND MORPHOLOGY OF SOME CAMBIC AND ARGILLIC HORIZONS IN SOILS OF NORTHERN UTAH

by

Randal Jay Southard

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

of

MASTER OF SCIENCE

in

Soil Science and Biometeorology

with emphasis in

Soil Genesis and Classification

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1980

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Randal J. Southard

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ABSTRACT

Comparison of the Mineralogy and Morphology of Some Cambic and Argillic Horizons in Soils of Northern Utah

by

Randal Jay Southard, Master of Science

Utah State University, 1980

Major Professor: Dr. Jerome J. Jurinak
Department: Soil Science and Biometeorology

The mineralogy and morphology of a soil with a cambic horizon (Stingal) and a soil with an argillic horizon (Hansel), occurring in northern Utah, were studied. Pedons representing the central concept of each of the soils were sampled by genetic horizon for laboratory analyses. Particle-size distribution, calcium carbonate equivalent, cation-exchange capacity, organic carbon, and the mineralogy of the silt, coarse clay, and fine clay fractions were determined. Thin sections of the soils were examined with a petrographic microscope. Selected peds were observed using a scanning electron microscope, and elemental analyses were made with an x-ray analyzer.

The two soils were found to be similar in many respects. The particle-size distribution and mineralogy were essentially the same, indicating the similarities of parent materials and the nature of pedogenic processes. As expected, the argillic horizon contained more fine and total clay than did the cambic horizon, and the Hansel soil showed signs of more intense weathering. Both factors are related to the greater age of the Hansel soils.

The clay increase in both the cambic and the argillic horizons was attributed to a combination of *in situ* clay formation and illuviation. This conclusion was based on the lack of depositional discontinuities, greater ratios of fine to total clay in the B horizons, and the electron microscopic observation of discontinuous clay films in pores of the Hansel soil. The lack of visible clay films in thin section is probably the result of soil mixing by cicada and/or the prevention of translocation by carbonates.

The scanning electron microscope proved to be useful in the investigation of the two soils. The similarities of the two soils were apparent from laboratory analyses and scanning microscope observations. Evidence of illuviation, which was lacking in thin section, was visible with the scanning electron microscope, thus demonstrating the potential of the microscope in classifying and interpreting soils in future investigations.

(50 pages)

INTRODUCTION

The identification of cambic and argillic horizons is fundamental in the classification of soils, particularly those of the Aridisol order. The presence of an argillic horizon affects the classification at the suborder level, distinguishing Argids from Orthids. Positive field identification of argillic horizons in soils of arid and semi-arid regions is often difficult because the horizons have marginal development and the argillic characteristics are not strongly expressed. Laboratory analysis is often necessary to differentiate between cambic and argillic horizons.

In an attempt to demonstrate the differences in mineralogy and morphology between cambic and argillic horizons, two soils occurring in Blue Creek Valley, Box Elder County, Utah, were chosen. Figures 1 and 2 show the location of Box Elder County and Blue Creek Valley, respectively. One of the soils has a cambic horizon, the other has an argillic horizon. In order to show that any differences are due to pedogenic processes, the soils chosen had to have been developed from similar parent materials. The two soils are located close to each other and were developed from Lake Bonneville sediments.

To make a comparison of cambic and argillic horizons, the following objectives were proposed:

1. To determine the mineralogical and morphological differences between cambic and argillic horizons.

2. To determine whether the existence of the cambic and argillic horizons is the result of pedogenic processes or the result of various depositional events.

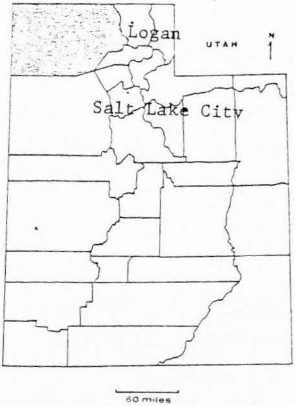

Figure 1. Location of Box Elder County, Utah. (Shaded portion).

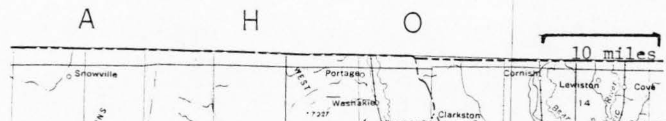

Figure 2. Approximate location of the study area in Blue Creek Valley, Box Elder County, Utah. (Shaded portion).

3. To correlate observations made using the scanning electron microscope with field observations and other laboratory analyses to determine the feasibility of using the scanning electron microscope as an aid in identifying argillic and cambic horizons.

REVIEW OF LITERATURE

Geology

The most prominent geologic features in Blue Creek Valley are remnant shore lines of Lake Bonneville. Morrison (1966) and others have studied the history, hydrology, and sedimentary deposits of the lake. Three still-stands of the lake produced shore lines which are evident in the study. The highest is the Bonneville shore line (elevation 1565 meters), which resulted from the highest stand of the lake about 13,000 to 15,000 years ago. Below this level are the Provo level (1470 meters) and the Stansbury level (1360 meters), resulting from still-stands during the recession of the lake, approximately 10,000 and 8,000 years ago, respectively. Soils occurring at the various levels of the lake show increasing development with increasing age of the sediments (Morrison, 1966).

The major sources of lake sediment parent materials are limestone, quartzite, dolomite, and conglomerate rocks of Tertiary to Paleozoic ages. These materials were transported mainly by the two major rivers in the area--the Bear and the Malad, and by other local streams (Chadwick et al., 1975).

Argillic Horizons

According to the Soil Survey Staff (1975), an argillic horizon is an illuvial horizon in which layer-lattice silicate clays have accumulated to a significant extent. The accumulation of clay must be sufficient to satisfy one of the following requirements: (1) a 3%

increase if the overlying horizon contains less than 15% clay, (2) an increase of 1.2 times if the overlying horizon contains from 15 to 40% clay, (3) an 8% increase if the overlying horizon contains more than 40% clay. Orientation of clay on ped surfaces and in pores and a greater ratio of fine to total clays in the B horizon compared to adjacent horizons are considered to be evidence that illuviation has occurred.

Gile and Grossman (1968) studied argillic horizon morphology in southern New Mexico. Soils formed on 5000-year-old geomorphic surfaces had developed weak argillic horizons, but ped surfaces lacked oriented clay films. They thought that carbonates and biological mixing may have prevented oriented clay films from forming, and suggested that the requirement of clay films in the soils of this area should be waived. Argillic horizons formed during the Pleistocene showed stronger development and had clay films on ped surfaces. It is believed that the greater development was the result of wetter climates associated with Pleistocene pluvials (Gile and Hawley, 1968, 1972; Nettleton et al., 1975).

Nikiforoff (1937) proposed that the clay found in B horizons in soils of desert areas of the western United States formed in place by mineral hydrolysis. Brown and Drosdoff (1938) found evidence to support Nikiforoff's proposal in soils of the Mojave Desert, and concluded that the B horizon was more weathered than the surface horizon. Buol (1965) hypothesized that clay might be forming in situ due to a wetter condition in the B horizon position. Smith and Buol (1968) demonstrated that the soil surface was more weathered than the subsoil and that weathering decreased regularly with depth in three soils in Arizona. They concluded that the clay increase in B horizons was the result of translocation combined with in situ clay formation. Clay skins are not well developed in argillic horizons of Aridisols (Smith and Buol, 1968; Buol et al., 1973), presumably because wetting and drying cycles destroy this evidence of illuviation.

Nettleton et al. (1975) studied the genesis of argillic horizons in desert regions of the southwestern United States. The volume of clay skins in the B horizon of a sandy soil with an argillic horizon was found to be approximately equal to the clay increase in the B horizon. Analyses of finer-textured soils with argillic horizons showed the A horizons to be as weathered as, or more weathered than, the B horizons. These facts indicated that illuviation had occurred to produce the argillic horizons. This and other studies by Nettleton et al. (1969) also led these researchers to believe that clay skins are often absent in argillic horizons with high shrink-swell potentials. Repeated cycles of wetting and drying probably disrupt ped surfaces and destroy clay films that may have formed.

McKeague and St. Arnaud (1969) suggested that translocation may or may not be a factor in argillic horizon formation.

Brewer and Haldane (1957) conducted laboratory experiments on the development of oriented clay in soils. They found that silt-sized particles disrupted the orientation of clay-sized material because of the reduced available pore size in the silty sediment compared to sandy sediments.

Southard and Miller (1966) demonstrated that most of the clay found in well-developed A and B horizons in sedimentary-derived northern Utah soils was inherited from the parent materials and was not greatly altered by weathering.

Cambic Horizons

A cambic horizon is an altered soil horizon that has a texture finer than loamy fine sand (Soil Survey Staff, 1975). Physical alteration by roots and animals and aggregation of soil particles into peds have destroyed much of the original rock structure as well as fine stratifications of parent material sediments. Other alterations include redistribution of carbonates, liberation of free iron oxides (often producing a somewhat reddened horizon), decomposition of inherited organic matter, and hydrolysis of primary mineral to form clays. A cambic horizon which meets these requirements may have an increase in silicate clay content as long as the increase does not exceed the limits for an argillic horizon.

Gile (1966) studied cambic horizons in southern New Mexico in relation to the age of the deposits in which the soil developed and established a sequence of horizon development. Horizons in the B position showed increased development with age. Cambic horizons in older soils were better developed than those in younger soils. As soil age increased further, argillic horizons were found to occur in the B position. This sequence fits well in the U. S. Soil Taxonomy model of horizon genesis (Soil Survey Staff, 1975).

Gile (1975) observed that reddish-brown, non-calcareous horizons (cambics) formed in low-carbonate (less than 2% $CaCO_3$ equivalent) parent materials were about 4000 years old. Soils of the Holocene (as old as 7500 years) which developed in high-carbonate (more than 15% $CaCO_3$ equivalent) parent materials did not have carbonate-free cambic horizons.

Cambic horizons of soils in arid and semi-arid regions are usually underlain by a horizon of carbonate accumulation (Soil Survey Staff, 1975).

Scanning Electron Microscopy

Extensive work has been conducted using the scanning electron microscope to study clay minerals. Micrographs of silicate clay minerals show great differences in the appearance of the various clay minerals (Brady, 1974). The use of the scanning electron microscope in studying whole soil has been quite limited. Lynn and Grossman (1970) observed soil fabrics from several diagnostic soil horizons. Their observations of a well-developed argillic horizon clearly showed the presence of clay films on ped surfaces.

DESCRIPTION OF STUDY AREA

Location

The soils chosen for this study occur in Blue Creek Valley, in eastern Box Elder County, Utah (Figures 1 and 2, page 2). Blue Creek Valley is a north-south trending valley approximately 40 kilometers long and 10 kilometers wide, located between $41^{0}40'$ and $41^{0}55'$ north latitude and $112^{0}25'$ and $112^{0}30'$ west longitude. The elevation ranges from 1560 meters in the north end to 1300 meters in the south end.

Climate

The climate of this region is dry subhumid continental (Chadwick et al., 1975). Table 1 contains temperature and precipitation data from Thiokol Plant No. 78, located about 10 kilometers south of Howell at an elevation of 1400 meters. Most of the precipitation comes as winter snow and early spring rain and snow. Little precipitation occurs during the summer growing season. Summers are warm, winters are cold.

Geology

The land forms of the study area are dominated by remnant features of Lake Bonneville. The three major stands of Lake Bonneville evident in Blue Creek Valley are the Bonneville (elevation 1565 meters), the Provo (1470 meters), and the Stansbury (1360 meters) (Morrison, 1966). Minor lake terraces, resulting from shorter periods of lake level stability, are evident between these major stands.

Table 1. Mean monthly and annual temperature and precipitation for the period 1963-1975 at Thiokol Plant No. 78 near Howell, Utah.

	J	F	M	A	M	J	J	A	S	O	N	D	ANN. AVE.
TEMP. (°C)	-5.4	-2.5	1.9	6.4	12.7	17.1	22.4	21.3	15.1	8.8	-2.5	-4.4	7.6
PPT (mm)	25.4	19.3	23.6	40.9	25.1	54.1	14.7	19.3	23.4	36.3	31.2	26.4	339.2

Elevation: 1400 meters.

Sec. 9 T. 11 N. R. 5W.

The parent materials, from which the soils developed, are derived mainly from limestone, dolomite, and quartzite rocks (Chadwick et al., 1975). These lake-bottom sediments are dominated by silt-sized particles and are calcareous.

Soils

Two major soil associations were mapped in Blue Creek Valley by Chadwick et al. (1975). The Kearns-Parleys association was mapped on low lake terraces and alluvial fans. The Sanpete-Stingal-Hansel association was mapped on intermediate and high lake terraces and steep valley-side escarpments. The classifications of these soils are contained in Table 2. The soils chosen for study are of the Hansel and Stingal series.

Table 2. Classification of the major soils mapped in Blue Creek Valley, Box Elder County, Utah. (After Chadwick et al., 1975).

Association	Series	Suborder	Family
Kearns-Parleys	Kearns	Calcic Haploxerolls	Fine-silty, mixed, mesic
	Parleys	Calcic Argixerolls	Fine-silty, mixed, mesic
Sanpete-Stingal-Hansel	Sanpete	Xerollic Calciorthids	Loamy-skeletal, carbonatic, mesic
	Stingal	Xerollic Camborthids	Coarse-silty, mixed, mesic
	Hansel	Xerollic Haplargids	Fine-silty, mixed, mesic

METHODS

Field Study

Several pits were excavated in each of the soil types. Three pits in the Hansel soil and two pits in the Stingal soil were described and sampled for laboratory analysis. Bulk samples of argillic and cambic horizons were collected for morphological studies. The selection of pit locations was made with the aid of the Soil Survey of Box Elder County, Utah, Eastern Part (Chadwick et al., 1975).

Laboratory Studies

Particle-size distribution

The particle-size distribution of selected horizons from the two soils was determined by the method of Kittrick and Hope (1963). Eight fractions were collected.

Mineralogy

Samples were prepared for x-ray diffraction studies using the method of Kittrick and Hope (1963). Oriented mounts of the fine and coarse clay fractions were prepared by allowing a few drops of suspension to evaporate on a glass slide. These fractions were solvated with ethylene glycol for one hour at $60^{\circ}C$ and heated to $500^{\circ}C$. Oriented mounts of magnesium-saturated clays were prepared by making a slurry of the clay with acetone and applying a few drops to a glass slide. All other fractions were prepared as powder mounts by sprinkling the sample on a Vaseline-coated glass slide.

Mineralogy of the fractions was determined using a Siemens diffractometer with a nickel-filtered copper tube operated at 35 kV and 16 mA.

Thin section

Thin sections of selected clods from argillic and cambic horizons were made. Clods were dried at 110°C overnight and placed in paper cups. The clods were impregnated under vacuum with a 1:1 mix of Castolite and thinner, with 15 drops of hardener per 50 milliliters of the mixture. The plastic was cured overnight at 60°C. From the hardened plastic blocks, sections 1 centimeter thick were cut, polished with 600-grit silicon carbide on glass, and attached to glass microscope slides with optical grade epoxy. These sections were machine- and hand-ground to a thickness of 0.03 millimeters.

Calcium carbonate equivalent

Calcium carbonate equivalent was determined by the Utah State University Soil Testing Laboratory, using a manometric technique developed by Williams (1948).

Organic carbon

Organic carbon was determined by the Utah State University Soil Testing Laboratory, using a colorimetric acid-dichromate digestion technique proposed by Black (1965).

Cation-exchange capacity

Cation-exchange capacity was determined by the Utah State University Soil Testing Laboratory, using the procedure proposed by Richards (1954). This procedure uses NaOAc at pH 8.2.

Scanning electron microscopy

Peds selected from cambic and argillic horizons were observed with a binocular light microscope to isolate areas of interest for scanning electron microscopic observation. The peds were trimmed with a razor blade so they would fit on the aluminum specimen stubs. The pieces of soil were glued to the stubs with Duco cement and coated with a gold-palladium alloy, using a Polaron E 5000 sputter coater. Specimens were observed, using an AMR 1000 B scanning electron microscope operated at 20 kV. Stereo pairs were made by tilting the specimen 7 degrees for the second photo. A Princeton Gamma Tech x-ray analyzer was used for elemental analysis of selected areas of the peds.

RESULTS AND DISCUSSION

Field Study

Several pedons of each of the soils were described. From these pedons two were chosen which represent the central concept of soils with an argillic and a cambic horizon--one from the Hansel series and one from the Stingal series.

Field morphology of the Hansel soil

A description of the Hansel soil follows. The pedon is located in a fallow field, 350 meters west, 75 meters south of the northeast corner of Section 30, T. 13 N., R. 5 W., on a 2% east-facing slope, at an elevation of 1430 meters, about 5 kilometers northwest of Howell, Utah.

Figures 3 and 4 are photographs of the Hansel landscape and the profile, respectively.

Horizon	Depth (cm)	
A1p	0- 13	Light brownish gray (10YR 6/2) silt loam; very dark grayish brown (10YR 3/2) moist, weak coarse platy, breaking to moderate medium subangular blocky; hard, friable, slightly sticky, slightly plastic; few fine and very fine roots; pH 8.2 (T.B.); abrupt smooth boundary.
A12	13- 32	Light brownish gray (10YR 6/2) silt loam; very dark grayish brown (10YR 3/2) moist; moderate medium subangular blocky; hard, friable, sticky, plastic; common fine and very fine roots; pH 8.2 (T.B.); clear wavy boundary.
B2t	32- 52	Brown (10YR 5/3) silty clay loam; dark brown (10YR 3/3) moist; strong medium and fine subangular blocky; very hard, firm, sticky,

Figure 3. Photograph of the Hansel landscape.

Figure 4. Photograph of the Hansel profile.

Horizon	Depth (cm)	
		plastic; common fine and very fine roots; strongly calcareous; pH 8.4 (T.B.); common hard cicada casts; clear wavy boundary.
C1ca	52- 94	Very pale brown (10YR 7/3) silt loam; pale brown (10YR 6/3) moist; moderate medium subangular blocky; very hard, firm, slightly sticky, plastic; few fine and very fine roots; strongly calcareous, many fine lime veins; pH 8.8 (T.B.); many extremely hard cicada casts; abrupt wavy boundary.
IIC2ca	94-150	Light yellowish brown (10YR 6/4) silt loam; yellowish brown (10YR 5/4) moist; massive; hard, firm, slightly sticky, slightly plastic; strongly calcareous; pH 8.8 (T.B.); interbedded with light gray (2.5Y 7/2) silty clay; light brownish gray (2.5Y 6/2) moist; common medium prominent brownish yellow (10YR 6/6) and brown (7.5YR 4/4) mottles; massive; very hard, firm, sticky, plastic; strongly calcareous; pH 9.0 (T.B.).

The soil to a depth of 32 centimeters is quite dark, but is not mollic because it is too light when dry. The platy structure is typical of cultivated soils. Free carbonates are leached to a depth of 32 centimeters. The B horizon has an increase in clay, is browner than the surface soil, and shows strong structural development. Clay films in the B horizon were not observed with a 20X hand lens. Cicada casts are present below 32 centimeters, and are most abundant between 52 and 94 centimeters. Such extensive occurrence of these cicada casts suggests that mixing of the subsoil has taken place. The interbedded material of the IIC2ca is probably the result of a fluctuating lake level, and indicates different depositional events. Mottling is caused by a reducing environment, and indicates that at times free water is present below 94 centimeters.

Field morphology of the Stingal soil

A description of the Stingal soil follows. The pedon is located 480 meters east, 790 meters south of the northwest corner of Section 29, T. 11 N., R. 5 W., on a 2% west-facing slope, at an elevation of 1310 meters, one kilometer southwest of the Thiokol industrial area. Figures 5 and 6 are photographs of the Stingal landscape and the profile, respectively.

Horizon	Depth (cm)	
Alp	0- 8	Light brownish gray (10YR 6/2) silt loam; very dark grayish brown (10YR 3/2) moist; moderate medium and fine platy; slightly hard, friable, non-sticky, slightly plastic; common fine, few very fine and medium roots; strongly calcareous; pH 8.2 (T.B.); clear smooth boundary.
A12	8- 17	Pale brown (10YR 6/3) silt loam; dark brown (10YR 3/3) moist; weak coarse platy breaking to moderate medium blocky; slightly hard, friable, non-sticky, plastic; common fine and few very fine roots; moderately calcareous; pH 8.2 (T.B.); clear smooth boundary.
B21	17- 30	Pale brown (10YR 6/3) silt loam; dark brown (10YR 3/3) moist; moderate medium subangular blocky; hard, firm, slightly sticky, plastic; common fine and very fine roots; moderately calcareous; pH 8.4 (T.B.); gradual wavy boundary.
B22	30- 47	Light yellowish brown (10YR 6/4) silt loam; dark yellowish brown (10YR 4/4) moist; moderate medium subangular blocky; slightly hard, firm, slightly sticky, plastic; many fine and very fine, few medium roots; moderately calcareous; pH 8.4 (T.B.); common very hard cicada casts; clear wavy boundary.
Clca	47- 76	Pale brown (10YR 6/3) silt loam; brown (10YR 4/3) moist; moderate medium subangular blocky; hard, firm, slightly sticky, plastic; common fine and very fine roots; strongly calcareous, many fine lime veins; pH 8.8 (T.B.); many extremely hard cicada casts; gradual wavy boundary.

Figure 5. Photograph of the Stingal landscape.

Figure 6. Photograph of the Stingal profile.

Horizon	Depth (cm)	
C2ca	76-110	Pale brown (10YR 6/3) silt loam; brown (10YR 4/3) moist; weak medium subangular blocky; hard, firm, slightly sticky, plastic; few fine and very fine roots; strongly calcareous, common fine lime veins; pH 8.8 (T.B.); common extremely hard cicada casts; gradual wavy boundary.
C3ca	110-140	Light gray (10YR 7/2) loam; grayish brown (10YR 5/2) moist; massive; slightly hard, friable, non-sticky, non-plastic; strongly calcareous; pH 9.2 (T.B.); few cicada casts; gradual wavy boundary.
C4ca	140-162	Light gray (10YR 7/2) loam; grayish brown (10YR 5/2) moist; massive; slightly hard, friable, non-sticky, non-plastic; strongly calcareous; pH 9.2 (T.B.).

The epipedon is not dark enough when dry to meet mollic requirements. The platy surface is indicative of cultivation. Unlike the Hansel soil, this soil is calcareous to the surface. There is an accumulation of carbonates below 47 centimeters. The B horizon has moderate structure, is yellower than the overlying horizons, and contains more clay. Clay films were not observed with a 20X hand lens. Evidence of cicada activity is present below 30 centimeters, and is most prevalent between 47 and 76 centimeters, again suggesting mixing of the subsoil.

Morphologically, the Hansel and Stingal soils are quite similar. The major differences are the leaching of carbonates from the surface of the Hansel soil, the slightly greater structural development, and increase in clay in the Hansel B horizon. The depths of carbonate accumulation and cicada activity are nearly the same in the two soils, suggesting that the environments under which the soils developed were similar.

The Hansel pedon was described at an elevation slightly lower than the Provo level of Lake Bonneville. The Stingal pedon was described at an elevation slightly lower than the Stansbury level. The leaching of carbonates from the surface of the Hansel soil, as well as the stronger development of the B horizon, may be attributed to the fact that the Hansel soil is estimated to be about 3000 years older than the Stingal soil.

Laboratory Studies

Particle-size distribution

The particle-size distribution of the Hansel soil is presented in Table 3 and Figure 7. The dominance of silt is attributable to the fact that the soils developed in lake-bottom sediments. The uniform distribution of silt and sand with depth suggests a relatively constant depositional environment. The increase in clay in the B horizon is probably not a result of a depositional discontinuity.

According to the Soil Survey Staff (1975), a horizon must have an increase in clay of 3% absolute if the overlying horizon contains less than 15% clay to be classified as an argillic horizon. The weighted average clay content of the A1p and A12 horizons is 13%. The increase of 3.7% clay to 16.7% is sufficient to consider the B horizon an argillic horizon. Examination of the fine clay (less than 0.2 micron) percentages reveals a six-fold increase in the argillic horizon. The ratio of fine clay to total clay in the B horizon is four times greater than the same ratio in the A horizons. Since fine clay-sized material is the most easily transported soil component,

Table 3. Physical and chemical properties of the Hansel soil.

		Particle Diameter (micrometers) %*										
Horizon	Depth (cm)	2000-1000	1000-500	500-250	250-100	100-61	61-2	2-0.2	<0.2	% O.C.**	$CaCO_3$ equiv. %	CEC me/100 g soil
A1p	0-13	0.0	0.0	0.0	1.8	10.2	76.7	10.1	1.1	1.54	0.1	23.4
A12	13-32	0.0	0.0	0.0	1.9	8.6	75.1	13.4	0.9	1.26	0.4	24.1
B2t	32-52	0.0	0.0	0.0	0.6	7.6	75.2	11.1	5.6	0.65	7.5	19.8
C1ca	52-94	0.0	0.0	0.0	1.0	10.6	77.4	7.6	3.4	0.43	31.9	11.2

* carbonate-free.

** organic carbon.

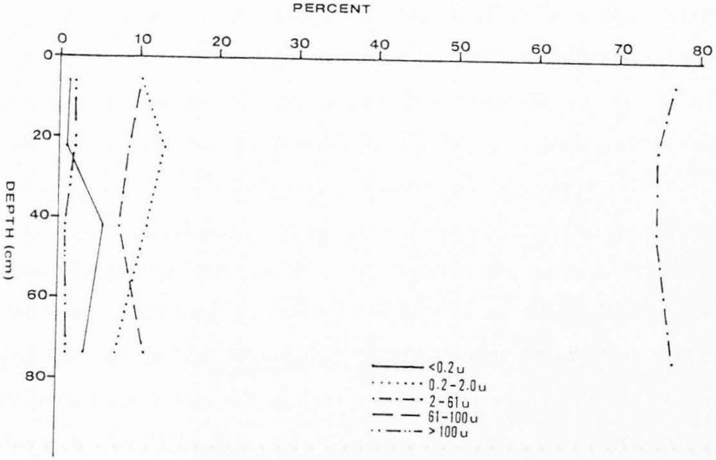

Figure 7. Particle-size distribution with depth of the Hansel soil.

the increase in the ratio of fine to total clay is evidence that translocation of the fine clay from overlying horizons to the B horizon has probably occurred. The decrease of fine and total clay in the C horizon indicates that clay accumulation has occurred in the B horizon.

Table 4 and Figure 8 contain the particle-size distribution of the Stingal soil. Again, silt is the dominant size class. No depositional discontinuities are evident in the Stingal soil. The similarities between the particle-size distributions of the two soils substantiate the initial assumption that the depositional environments of the soils were the same.

The increase in clay content (2.3%) of the B horizon is not enough for the horizon to be an argillic horizon. It is, therefore, a cambic horizon. The ratio of fine to total clay increases from 0.1 to 0.29 in the B horizon. Illuviation of fine clay has probably occurred in this soil, but not to as great an extent as in the Hansel soil. This evidence suggests that continued weathering of the Stingal soil will ultimately produce sufficient clay movement and accumulation for the development of an argillic horizon.

Mineralogy

To determine whether soil-forming processes resulted in mineralogical differences between these cambic and argillic horizons, it was necessary to choose soils formed from similar parent materials.

The mineralogies of the silt, coarse clay, and fine clay fractions of selected horizons from the two soils are presented in Table 5 in the order of decreasing peak intensity. The x-ray diffraction analyses reveal few differences between the two pedons. Illite and

Table 4. Physical and chemical properties of the Stingal soil.

Horizon	Depth (cm)	Particle Diameter (micrometers) %*								% O.C.**	$CaCO_3$ equiv. %	CEC me/100 g soil
		2000-1000	1000-500	500-250	250-100	100-61	61-2	2-0.2	<0.2			
A1p	0- 8	0.0	0.0	0.4	4.1	11.8	72.8	9.3	1.6	1.56	5.0	14.3
A12	8-17	0.0	0.0	0.6	3.0	9.5	76.5	9.9	0.6	1.09	4.1	15.7
B21	17-30	0.0	0.3	0.4	4.0	12.4	69.0	10.7	3.1	0.82	3.8	16.4
B22	30-47	0.0	0.3	0.4	6.7	11.7	68.5	8.1	4.2	0.70	8.2	14.7
C1ca	47-76	0.3	0.4	0.4	5.4	11.5	69.0	6.1	7.0	0.52	19.7	12.2

* carbonate-free.

** organic carbon.

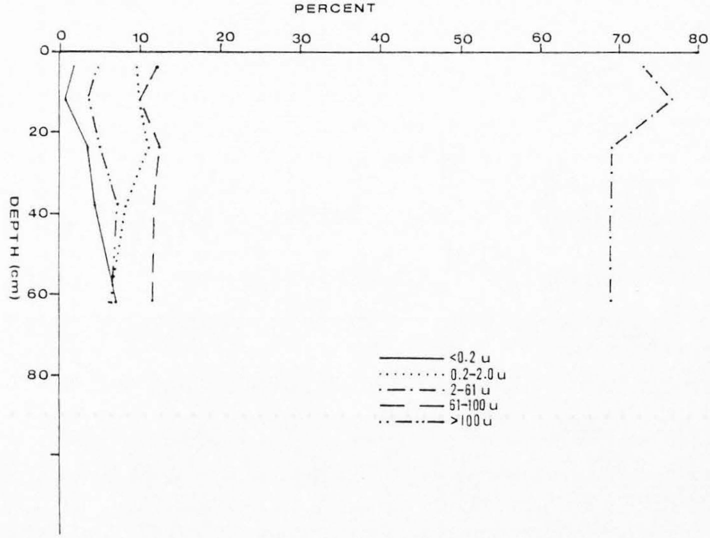

Figure 8. Particle-size distribution with depth of the Stingal soil.

Table 5. Mineralogy of the silt, coarse clay, and fine clay fractions of the Hansel and Stingal soils.

Horizon	Depth (cm)	Silt (61-2μ)	Coarse clay (2.0-0.2μ)	Fine clay (<0.2μ)
		Hansel		
A1p	0- 13	Q,F,M,K*	I,K*	I
A12	13- 32	Q,F,M,K*	I,K,E	I,E
B2t	32- 52	Q,F,M	I,K,E	I,E
C1ca	52- 94	Q,F,M	I,E,K*	I,E
C2ca	94-107	Q,F,M	---	I,E*
		Stingal		
A1p	0- 8	Q,F,M,K*	I,K	I
A12	8- 17	Q,F,M,K*	I,K	I
B21	17- 30	Q,F,M,K*	I,K,E*	I,E*
B22	30- 47	Q,F,M,K*	I,K,E*	I,E*
C1ca	47- 76	Q,F,M,K*	I,K,E	I,E
C2ca	76-110	Q,F,M	---	I

Q - quartz

F - feldspar

M - mica

K - kaolinite

I - illite

E - expandable, interlayered clay

* - trace

the micas yielded similar x-ray diffraction patterns. Therefore, the peak at 8.9 degrees 2θ was arbitrarily designated as an illite peak in the two clay fractions and as a mica peak in the silt fraction, although silt-sized illite and clay-sized mica may exist.

The silt fraction of all horizons of both soils is dominated by quartz, feldspar, and mica. Minor amounts of kaolinite are present in most of the horizons. The procedure used in the particle-size separation destroyed most carbonates (Kittrick and Hope, 1963), so diffraction peaks characteristic of calcite were not present. When samples of the C2ca horizons from both soils were prepared without destroying carbonates, the x-ray diffraction analyses revealed the presence of calcite, a result to be expected in a highly calcareous system.

The sand fractions of the two soils are similar in that quartz and feldspar are the dominant minerals. This fact, together with the constancy of the composition of the silt fractions, suggests uniformity of the depositional environment of the parent materials.

The coarse clay fractions all contain illite and kaolinite. Another clay component present produced a broad peak between 5 and 7 degrees 2θ. Upon glycolation, this peak shifted to between 4 and 6 degrees 2θ, indicating expansion of the clay's structure. This clay could not be identified specifically as montmorillonite because the peak is so broad. Instead, it is considered to be an interlayered, 2:1 clay, that probably contains some montmorillonite.

The expandable clay occurs in the Hansel soil below a depth of 13 centimeters. Increased mineral hydrolysis (possibly due to wetter conditions) below the surface can account for the presence of the more highly weathered expanding clay in subsurface horizons and the lack of it in the surface. Or, this clay may be accumulating by illuviation from above. The surface horizons of the Stingal soil do not contain the expanding clay. Small amounts of the clay were found in horizons below 17 centimeters. The apparently lesser amounts of expandable clay in the Stingal soil compared to the Hansel soil suggest less extensive weathering of the Stingal parent materials, or that less illuviation has occurred.

The mineralogy of the fine clay fraction is similar to that of the coarse clay fraction. Illite and an expandable clay are the dominant minerals. Fine clay-sized kaolinite was not detected in either the Stingal or the Hansel soil. The x-ray diffraction tracings of the fine clay fraction from a Stingal B (cambic) horizon and a Hansel B (argillic) horizon are shown in Figure 9. The illite peak (8.9^{o} 2θ) is higher and sharper in the cambic horizon. This can be construed to mean that the illite is better crystallized, and therefore less weathered, than in the argillic horizon. Magnesium-saturation of the two fractions enhanced a broad peak between 5 and 7 degrees. Relative peak height, together with particle-size distribution data, suggest that there is more of this clay in the argillic horizon than in the cambic horizon. Glycolation of these fractions caused the broad peak to shift to between 4 and 6 degrees, and heating to 500^{o}C caused the peak to collapse, suggesting that this fine clay mineral is expandable.

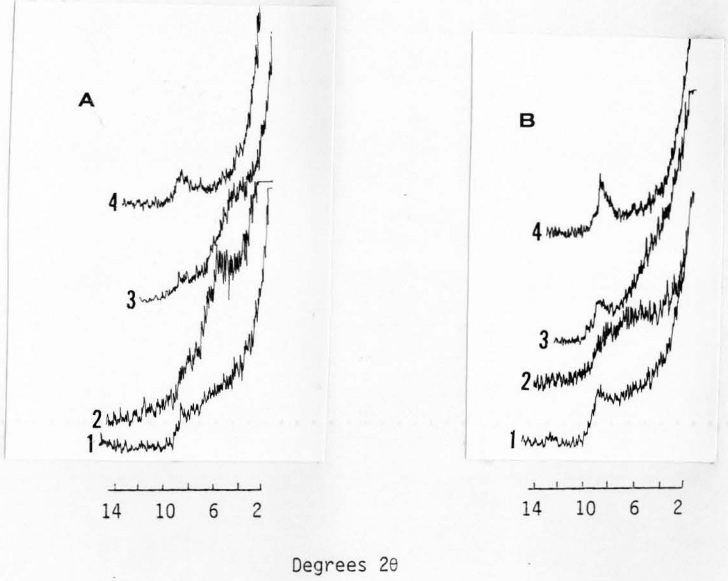

Figure 9. X-ray diffraction tracings of the less-than-0.2 micron fraction from (A) a Hansel argillic horizon and (B) a Stingal cambic horizon. Treatments were: 1) Na-saturated, 2) Mg-saturated, 3) glycolated, 4) heated to 500°C.

All of the horizons analyzed by x-ray diffraction also contain amorphous material. These amorphous components produce high background noise on the x-ray tracing, as well as occasional erratic peaks. This x-ray diffraction evidence is supported by cation-exchange capacity data (discussed later), which suggest that the soils contain amorphous material. The Salt Lake Formation, which occurs extensively in and around the study area, contains much volcanic glass and is the likely source of the amorphous material.

On the whole, the mineralogies of the two soils are similar. The Hansel soil shows signs of greater weathering as evidenced by the presence of more expanding clay and less crystalline illite. The presence of kaolinite in soils with high base status which are subject to slow weathering suggests that the kaolinite was inherited from the parent material, and is not a product of weathering in the soil.

Thin section

Observation of thin sections of soil from the argillic and cambic horizons revealed that neither contained oriented clay in pores or on ped faces. Peds of each of the horizons were also observed by reflected light. Again, neither had any evidence of clay translocation, either as clay coatings on ped faces or as clay bridges between sand and silt grains. By contrast, peds from the argillic horizon of a Cluff soil had thick clay coatings on ped faces and clay flows in the pores. The Cluff soil occurs in the Bear River Range of northern Utah at elevations around 2400 meters. Cluff soils are classified as clayey-skeletal, montmorillonitic, Mollic Cryoboralfs. A description of this soil is provided in the Appendix.

The lack of evidence of clay translocation may be the result of several factors. First, as reported in the field study section, the subsoil below 32 centimeters in the Hansel soil is permeated with cicada casts. Biological activity, such as cicada burrowing, mixes the soil and can disrupt the peds, thus destroying argillans that may occur on ped faces. Second, as a result of cicada activity, carbonates from greater depths may be mixed into the B horizon. The divalent cations flocculate clay, preventing its dispersion, suspension, and translocation by ground water. Third, argillans may be too thin to be discernible in thin section. Slow weathering, due to the cold, dry climate of the area, may not produce enough clay to form thick argillans. Finally, the increase in clay in the argillic horizon may be due solely to in situ weathering in the B horizon. Previous examination of fine to total clay ratios, however, indicates that some translocation of clay from the A horizon to the B horizon may have occurred.

Calcium carbonate equivalent

Calcium carbonate equivalent distribution data presented in tables 3 and 4 (pages 23 and 26) substantiate the field observations made, namely, that the Hansel soil is leached of free carbonates to a depth of 32 centimeters, and that the Stingal soil is calcareous to the surface.

Calculation of the weighted average carbonate content reveals that both pedons contain nearly the same amount of carbonates. The fact that the surface of the Hansel soil is leached of carbonates, plus the strong accumulation of carbonates in the Clca, clearly show that this soil has been more strongly affected by pedogenic processes, and evidence of weathering is expected to be better expressed in the Hansel soil than in the Stingal soil.

The A1p and A12 horizons of the Stingal soil contain more carbonates than the B21, yet the accumulation of carbonates in the C1ca horizon indicates a downward movement of carbonates in the soil. Addition of carbonates from an external source must be occurring to increase the carbonate content of the surface. This recharging of the solum may be the result of addition of windblown carbonates or of carbonates in runoff water from higher terrain.

Organic carbon

The regular decrease of organic carbon with depth in both soils (tables 3 and 4, pages 23 and 26) precludes the presence of buried A1 horizons, which indicate various cycles of soil development. Although both epipedons exceed the organic carbon requirements for a mollic epipedon, neither is dark enough to meet the color requirement.

Cation-exchange capacity

The cation-exchange capacities of the various horizons are contained in tables 3 and 4 (pages 23 and 26). Some inferences as to the type of clay in the horizons may be drawn from CEC data. Assuming a contribution of 4 meq/100 g soil exchange capacity for each percent of organic carbon, and that the cation-exchange capacity of the sand and silt fractions is negligible, the CEC per 100 grams of clay can be calculated. In all of the horizons the exchange capacity due to clay exceeds 80 me and is 154 me/100 g clay in the Hansel A1p.

These cation-exchange capacities are greater than those expected for soils whose clay fractions contain mostly illite, and even exceed the upper limit of the CEC of pure montmorillonite (Nelson and Nettleton, 1975). X-ray data show that the clay mineralogy is not dominantly montmorillonitic. It is therefore concluded that the high CEC values for clay are due to amorphous material in the clay fractions.

The exchange capacities of the clay in the Hansel soil are higher than those in the Stingàl soil. Both soils are influenced by Salt Lake Formation materials, which contain much volcanic ash. According to the Soil Survey Staff (1975), amorphous materials are often early weathering products of volcanic ash and other pyroclastics. Considering the fact that the mineralogies of the parent materials of the two soils were shown to be similar, the higher CEC values of the Hansel soil are probably the result of a greater proportion of amorphous material. The presence of more amorphous material suggests that more weathering has occurred in the Hansel soil than in the Stingal soil.

Scanning electron microscopy

Figure 10 is a stereo pair of micrographs of soil from the Hansel argillic horizon. The large pore is lined with clay which forms a reticulate pattern, unlike the soil fabric outside the pore which is not coated with clay. Figure 11 shows the clay at higher magnification. The particle in the lower left foreground is a silt grain, which may have been transported with the clay. The presence of clay only in the pore suggests that the clay has been deposited by water moving through the pore. It is probable that the discontinuous, network-like pattern of the clay along the wall of the pore is the initial stage in the

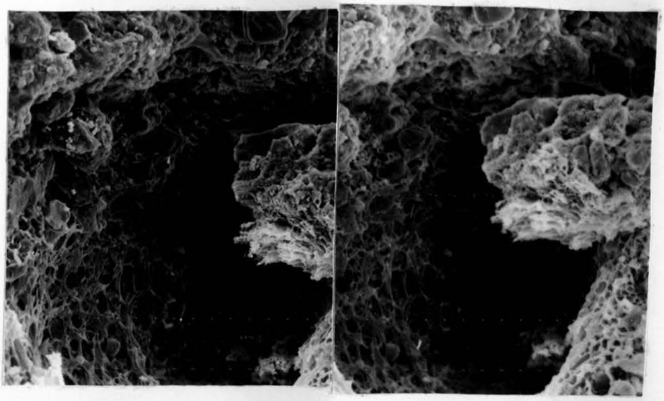

Figure 10. Stereo pair of soil fabric from a Hansel argillic horizon (1200X).

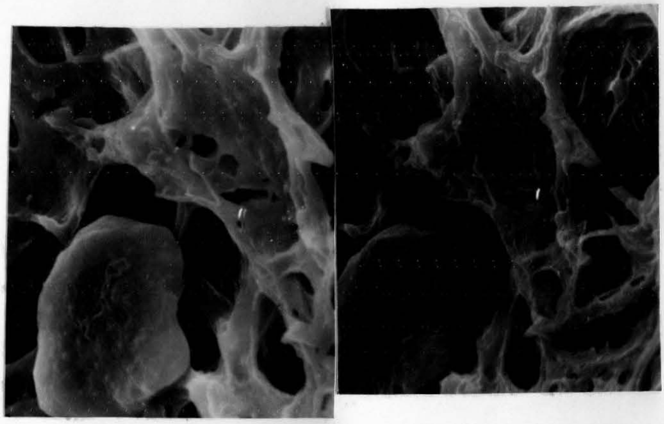

Figure 11. Stereo pair of clay in a pore of a Hansel argillic horizon (12,400X).

development of a continuous clay film. As more clay is translocated, the gaps in the network, as well as individual silt particles, may be covered to produce a smooth clay film.

Elemental analysis of the clay reveals that it is composed mainly of silica and alumina, as expected. A stereo pair of micrographs of Wyoming bentonite (Figure 12) shows similarities between montmorillonite and the clay in the pore of the Hansel soil. This correlates well with the particle-size distribution and mineralogical data which indicate that an accumulation of fine, expandable clay has occurred in the argillic horizon. The thinness and irregular orientation of the clay deposit can account for the lack of visible clay films in thin section.

Figure 13 shows soil from the Stingal cambic horizon. There is no evidence of clay movement similar to that found in the Hansel soil.

In contrast to the minimal evidence of clay translocation in the Hansel soil, Figure 14 shows smooth, continuous clay coatings in a Cluff argillic horizon. The argillic horizon of Cluff soils is well developed, and clay films are visible with a 20X hand lens. Silt grains (in the right foreground) appear to be embedded in the clay. These particles were probably transported with the clay and have been partially covered by subsequent clay deposits.

The use of the scanning electron microscope in the study of these soil fabrics allows three important observations. First, the Stingal cambic and the Hansel argillic horizon fabrics are very similar. This study and other laboratory analyses revealed that this argillic horizon is only slightly more developed than is the cambic horizon. Second, evidence of clay movement was observed in the Hansel soil, which was

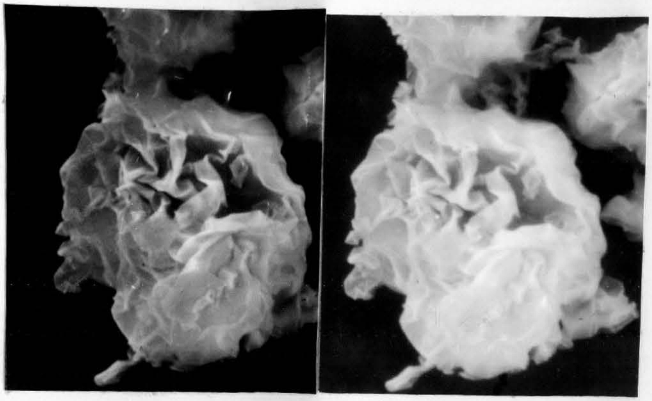

Figure 12. Stereo pair of Wyoming bentonite (12,500X).

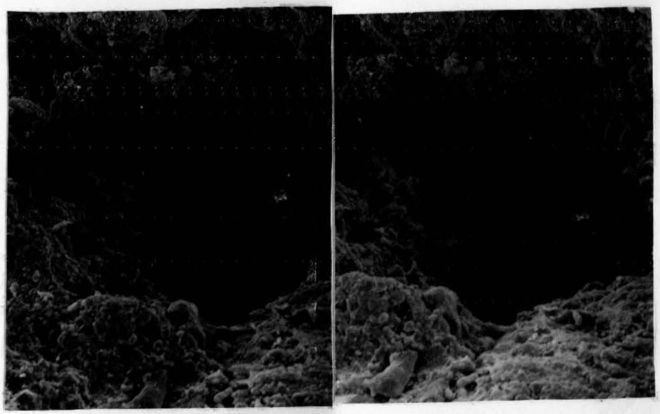

Figure 13. Stereo pair of soil fabric from a Stingal cambic horizon (1200X).

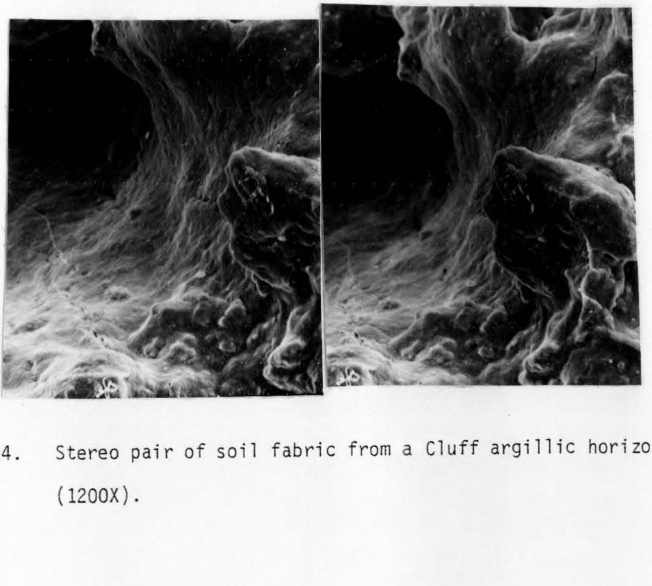

Figure 14. Stereo pair of soil fabric from a Cluff argillic horizon (1200X).

not observed in the thin section study. The resolving power of the scanning electron microscope provided opportunity for refined surface study, allowing observation of translocation of clay in the Hansel soil. Finally, because evidence of translocated clay is seen so infrequently in the argillic fabric, and not at all in the cambic fabric, it is likely that the increase in fine and total clay in the B horizons of the two soils is mainly the result of _in situ_ weathering of minerals to produce clay. Clay illuviation evidently is occurring, at least in the Hansel soil, but it contributes to the clay increase to a lesser extent than does weathering.

SUMMARY AND CONCLUSIONS

In an effort to compare cambic and argillic horizons in northern Utah, two soils occurring in Blue Creek Valley, Box Elder County, were selected for study. The Hansel soil, a Haplargid, and the Stingal soil, a Camborthid, were described and sampled for laboratory analyses, which included particle-size distribution, calcium carbonate equivalent, organic carbon content, and cation-exchange capacity. The mineralogies of the silt, coarse clay, and fine clay fractions were determined by x-ray diffractometry. Thin sections of clods from the cambic and argillic horizons were made and studied with a petrographic microscope. Micro-morphological observations and elemental analyses were made using the scanning electron microscope.

The first objective of this study was to compare the mineralogy and morphology of the cambic and argillic horizons. X-ray diffractometry revealed that the soils developed from similar parent materials; however, minor differences in the mineralogies were detected. The Hansel soil contains more expanding clay, and illite appears to be less well crystallized than in the Stingal soil. Cation-exchange capacity values for the clay components of both soils are higher than those expected for the clays which are present. The high CEC values are attributed to amorphous materials derived from the Salt Lake Formation. The Hansel soil is leached of carbonates to a depth of 32 centimeters, whereas the Stingal soil is calcareous to the surface. The Hansel soil was sampled at an elevation (Provo level of Lake Bonneville) about 120 meters higher than the elevation at which the Stingal soil was sampled

(Stansbury level of Lake Bonneville). Assuming soil development began after the lake receded, the Hansel soil must be 2000 to 3000 years older than the Stingal. The age difference, leaching of carbonates from the surface of the Hansel soil, greater amounts of amorphous material in the Hansel soil, plus less expanding clay and better crystallized illite in the Stingal soil all indicate that more weathering has taken place to produce an argillic horizon in the Hansel soil.

Morphologically, the soils are similar. Both the cambic and the argillic horizons occur at about the same depth in the soils and are underlain by horizons of carbonate accumulation. Cicada activity is evident between about 30 and 100 centimeters. These similarities suggest that the development of the two soils has been similarly influenced by four of the soil-forming factors: parent material, climate, relief, and biological activity. The other factor, time, is responsible for the leaching of carbonates from the Hansel surface, as well as for the greater clay accumulation and structural development of the B horizon.

The second objective of this study was to determine whether the cambic and argillic horizons were formed pedogenically or if they were the result of various depositional events. Depositional discontinuities are not indicated by the particle-size distribution of either soil. Mineralogical analyses reveal no evidence of deposition of dissimilar parent materials. The existence of a buried A horizon, which would indicate a period of soil stability followed by a second depositional event, is precluded by the regular decrease of organic carbon with depth.

Increases in the percentage of fine clay, as well as larger ratios of fine to total clay in the cambic and argillic horizons, suggest that both the cambic and the argillic horizons are forming, at least in part, by the illuviation of clay from overlying horizons. Mineralogical data show that these horizons contain more expanding clay than overlying horizons. If this clay is like montmorillonite, which usually occurs as fine clay-sized particles, it would be most easily moved by ground water and could be accumulating in the B horizons by translocation.

Evidence of translocation could not be substantiated by thin section studies. However, mixing of the soil by cicada and the resultant redistribution of carbonates could destroy oriented clay films that may have formed by illuviation. Observation of peds with the scanning electron microscope revealed that some of the pores in the Hansel soil were lined with clay, indicating that this material had been moved and deposited in the pores. Too few of the pores had coatings of clay to account for the increase in fine clay in the argillic horizon by illuviation alone. Visible evidence of translocation was not found in the Stingal cambic horizon, yet there is a significant increase in the fine clay content. The clay increase in the B horizons of the two soils is probably due to both illuviation and *in situ* clay formation. Most of the evidence of illuviation probably has been destroyed by biological mixing and carbonates.

The third objective of the study was to correlate scanning electron microscope observations with field observations and other laboratory analyses. Preliminary laboratory analyses showed that the soils have similar particle-size distributions and mineralogies, properties inherited from similar parent materials. The main differences between the two soils are a slightly greater accumulation of clay in the argillic horizon and stronger weathering of the Hansel soil in general. These differences are the result of the age difference of the soils. Pedogenic processes have been occurring for a longer period of time in the Hansel soil. The similar morphologies of the two soils were substantiated by electron microscopic observations.

Clay films were not visible in thin sections of the two soils. Using the scanning electron microscope, illuvial clay was identified as thin, discontinuous clay films in some pores of the Hansel argillic horizon. These clay films probably represent the initial stages in the development of continuous, smooth clay films like those seen in the well-developed argillic horizon of the Cluff soil. The observation of these clay films correlates well with the particle-size distribution data which indicated that the increase in fine clay of both B horizons is due, in part, to illuvial processes.

The scanning electron microscope is very useful for observing and characterizing whole soil fabrics. The potential for its use is great, and it should be exploited in future soil studies.

RECOMMENDATIONS

In order to understand the genesis of cambic and argillic horizons better, more extensive examination of closely related soils with these horizons is warranted. Further correlation of soil development with geomorphic surfaces would be instructive in demonstrating the sequential evolution of diagnostic soil horizons in semi-arid regions.

This study used somewhat indirect evidence in demonstrating greater weathering of the Hansel soil than the Stingal soil. A quantitative, complete chemical analysis would further elucidate the degree of weathering of the two soils.

Portions of the subsoil affected by cicada are found extensively in the study area and throughout much of the arid and semi-arid western United States. Studies of the habits of these insects are necessary for determining the chronological relationship between the hard layers they produce and the development of other soil characteristics, how they may affect further soil development, and how they affect the classification and interpretation of the soils.

The scanning electron microscope has proved to be a very useful tool in the study of whole soil. It should be used for characterization of soils to facilitate the identification of diagnostic soil horizons and to aid in the classification and interpretation of soils for soil surveys.

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APPENDIX

Description of a Cluff soil

This description is the Cluff series description from the Soil Survey of the Cache Valley Area, Utah (Erickson and Mortensen, 1974). Samples from the argillic horizon were provided by Ahmad Jalalian.

Horizon	Depth (cm)	
01	6 - 5	Fir needles.
02	5 - 0	Partly decomposed litter that is mostly fir needles.
A11	0 - 10	Dark brown to brown (7.5YR 4/2) silt loam, dark brown (7.5YR 3/2) when moist; weak, fine, granular structure; soft, friable, nonsticky and nonplastic; many fine, medium, and large roots; medium acid; clear, wavy boundary.
A12	10 - 22	Brown (7.5YR 5/3) silt loam, dark brown (7.5YR 3/3) when moist; weak, coarse, subangular blocky structure that parts to fine granular structure; slightly hard, friable, slightly sticky and slightly plastic; many fine, medium, and large roots; common, very fine, discontinuous, random and inped interstitial pores; thick, continuous, light-colored coatings; slightly acid; clear, wavy boundary.
A22	22 - 60	Light brown (7.5YR 6/3) very gravelly loam, brown (7.5YR 4/3) when moist; weak, coarse, subangular blocky structure that parts to medium granular structure; slightly hard, friable, slightly sticky and slightly plastic; common, fine and medium roots and few large roots; common, very fine, discontinuous, random and inped interstitial pores; 65% gravel; medium acid; diffuse, wavy boundary.
A2 & B2t	60 - 78	About 60% of this horizon is similar to the A22 horizon and the 40% B2t part is light reddish brown (5YR 6/4) very gravelly clay loam, light reddish brown (5YR 6/4) when moist; moderate, coarse, fine and medium subangular blocky structure; hard, firm, sticky and plastic; common, fine and medium roots and few large roots; common, very fine, discontinuous, random inped and interstitial pores; common thin clay films in pores; thick, light-colored coatings on peds; 60% gravel; strongly acid; clear, wavy boundary.

Horizon	Depth (cm)	
B2t	78 - 155	Reddish yellow (5YR 6/6) very gravelly light clay, yellowish red (5YR 4/6) when moist; moderate, coarse to fine, subangular blocky structure; very hard, very firm, sticky and very plastic; few fine, medium, and large roots; common, very fine, discontinuous, random inped, interstitial, and tubular pores; common,moderately thick clay films; moderate, patchy, light-colored coatings; 50% gravel; strongly acid.