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Chronosequence of Terrace Soils in Western South Dakota

by
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A thesis submitted
in partial fulfillment of the requirements for the
degree of Master of Science
Major in Agronomy

Chronosequence of Terrace Soils
in Western South Dakota

This thesis is approved as ceditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable for meeting the thesis requirements for the degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Gary D. Lemme Date
Major Advisor

Maurice L. Horton Date
Head, Plant Science Department

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One of my most pleasurable experiences at S.D.S.U. was coming to know Dr. K.P. Sharma, his wife Anju, and daughters Sinju and Ekata of Nepal. I want to acknowledge the contribution of each of these people to my well being while in Brookings, South Dakota. The many meals they so willing shared with me and their undemanding friendship is something I will never forget.

I dedicate this work to my daughter, Heidi.

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INTRODUCTION

Soils on the high terraces of the Cheyenne River in Haakon County, South Dakota have long been recognized as important to the agriculture of the area. Data from this study as well as Haakon County Extension Service and Soil Conservaton Service knowledge of the area will complement the soil survey in progress and provide a broader base of information for the future management of this important agricultural resource. This study will also help to quantify some of the properties that set the high terrace series apart from the surrounding shale uplands.

Similar sets of high terrace systems along other major east flowing tributaries to the Missouri River have been studied by Warren (1952), Crandell (1953), Flint (1955), and White (1964). Agreement as to the glacial period that caused their isolation has not been reached. Soil morphology of the Cheyenne river terraces will supplement the accumulated data leading toward the resolution of this question.

The objectives of this study were: (1) to characterize the morphological, mineralogical, edaphic, physical, and selected chemical properties of the terrace soils; (2) examine the impact of time upon the genesis of these soils; (3) classify and identify soil series on the various terrace levels; (4) apply the characterization to land use interpretation.

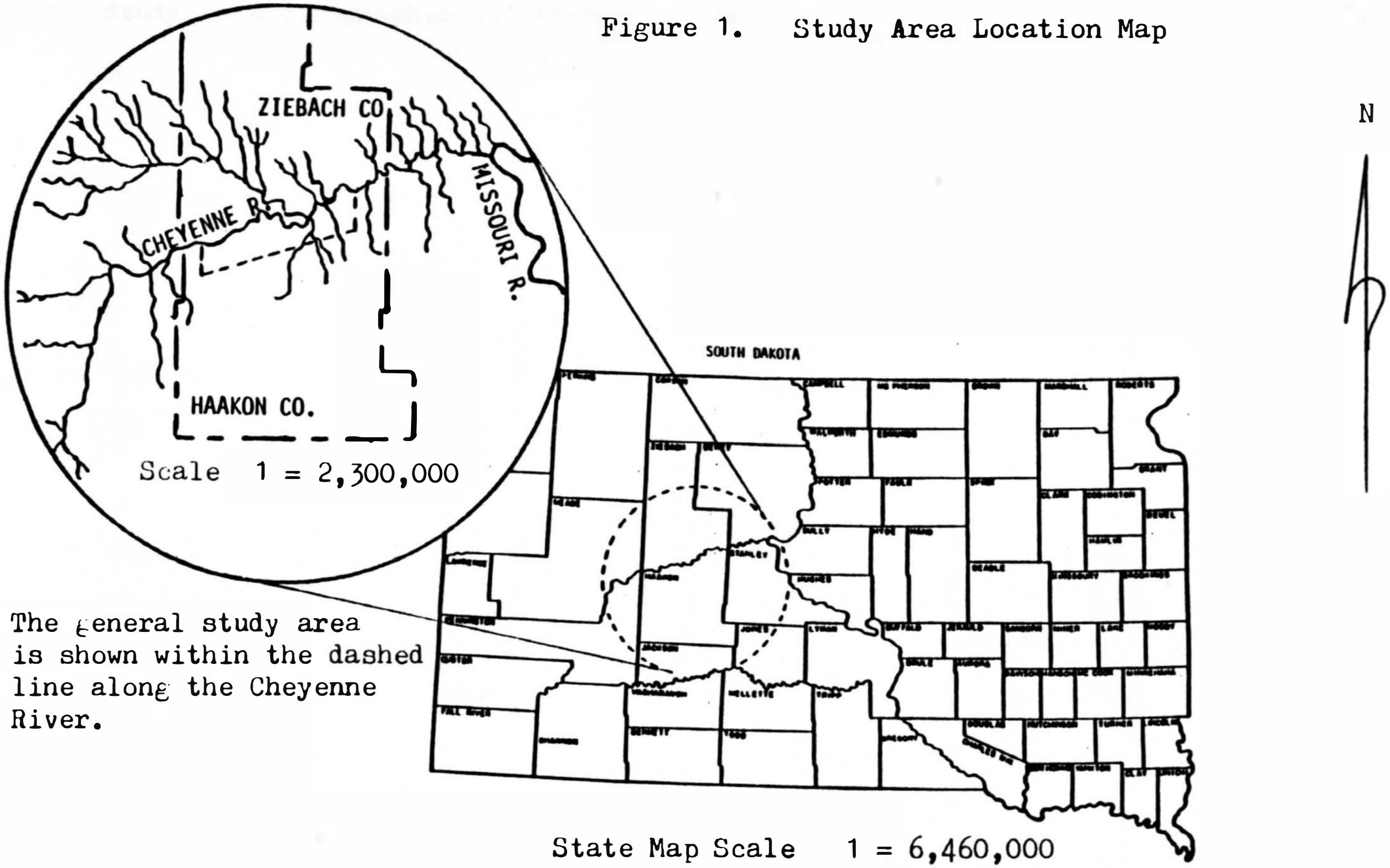
STUDY AREA DESCRIPTION

Location and Climate

The study area was located within Haakon County in west central South Dakota, between 101° 15' west to 102° 0' west longetude and 44° 25' to 44° 41' north latitude, on a series of five terraces now isolated from the present day Cheyenne River flood plain (Figure 1 and 2). The present day flood plain on the west end of the study area is at an elevation of 570 m above mean sea level while along the down stream eastern boundary it is at 497 m. On the western boundary of the study area, the high terrace series is between 655.3 m above mean sea level for the lower terrace, and 725.4 m for the upper terrace. The lower terrace on the eastern boundary of the study area is at 579 m and the upper terrace along this boundary is at 680 m above mean sea level (USGS 1955).

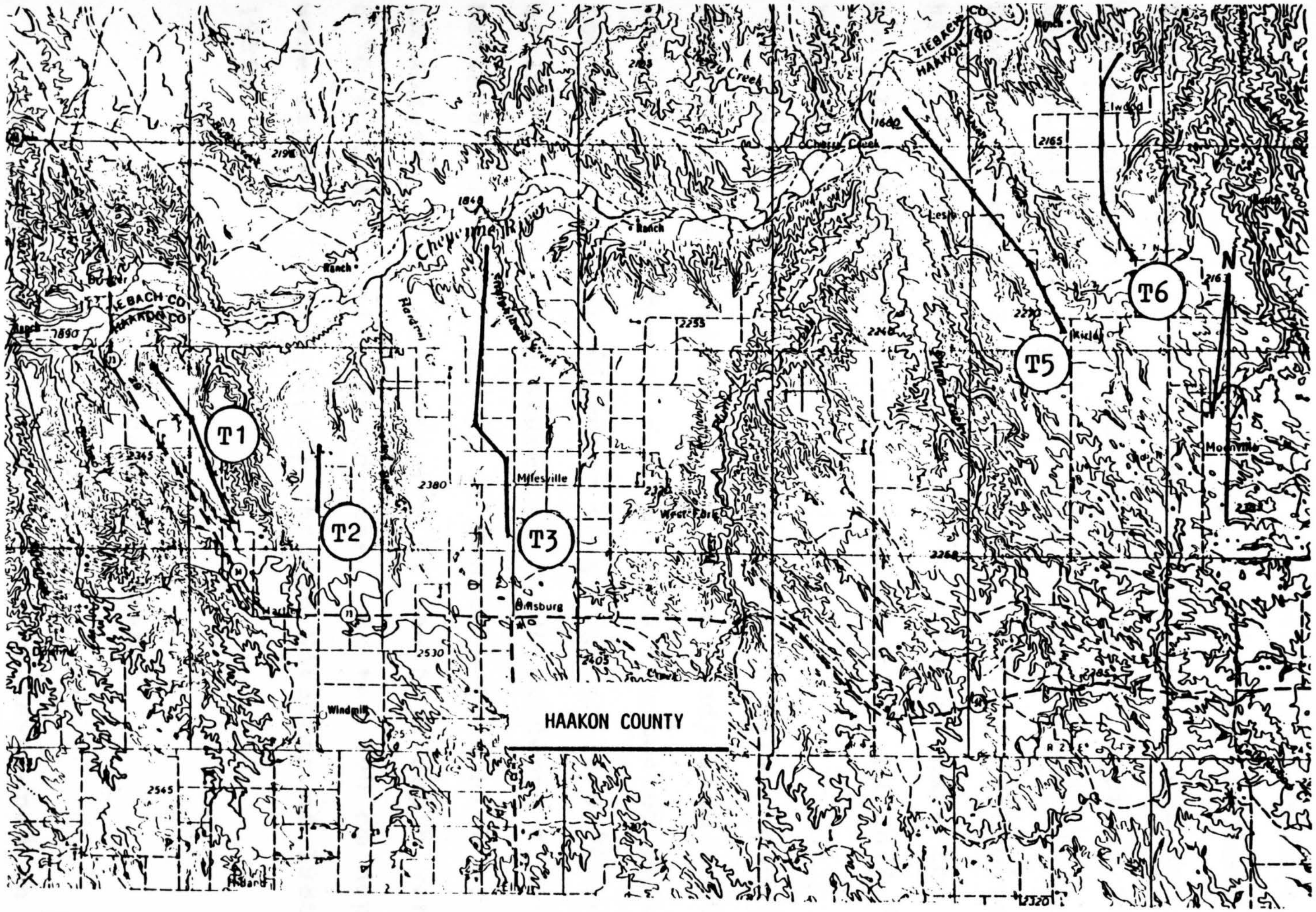
The climate is semi arid continental. Mean annual climatological data have been recorded for the area at the Milesville, South Dakota weather station of the National Oceanic and Atmospheric Administration and are based on a 54 year record history. The Milesville station is located at 44° 32' north latitude and 101° 34' west longitude at an elevation of 676.6 m above sea level.

Figure 1. Study Area Location Map



The general study area is shown within the dashed line along the Cheyenne River.

Figure 2. Study area topographic and transect location map



○ = Transect

Approximate Scale 1 : 320,000

Annual precipitation is approximately 42.5 cm. Mean annual precipitation for the six month period from April to September is approximately 33.35 cm and accounts for 76 % of the annual total. May and June are the months of highest precipitation and account for 16.1 cm or 37 % of the annual total. Mean monthly temperatures fluctuate from a low of -8.9 degrees Celsius (°C) in February to a high of 23.7 °C in July. July and August have the highest monthly temperatures and average 26.7 °C and 30.6 °C respectively (NOAA 1985).

The soil temperatures are based on data recorded in 1985 at the Milesville station in a sandy loam textured soil. Temperatures at a 5 cm depth fluctuated between a low of - 7.9 °C in February to a high of 18.9 °C in July of 1985. Soil temperatures at a 100 cm depth fluctuated between a low of - 1.5 °C in February to a high of 17.7 °C in August. Soil temperatures at the 5 cm depth were above 5 °C from April through October. At the 100 cm depth they were above 5 °C from April through November of 1985 (NOAA 1985).

Geomorphic Area

The soils in the study area have developed on stream terraces of the Cheyenne River which is an east flowing tributary to the Missouri River. The lowest terrace of the high terrace system is now isolated from the present day Cheyenne River flood plain by approximately 93 m. Soils on the upland landscape above the terrace system have developed on one of the upper members of the Cretaceous age, 145 to 65 million years before present (ybp), Pierre shale. By extrapolating data from a related terrace level 51.4 km east of the eastern boundary of the study area it is assumed that the upper member of the Pierre Shale in the study area is the Virgin Creek Member. The Virgin Creek member includes all beds between the Sully Member below and the highly calcareous beds of the Mobridge Member of the Pierre Shale above. The Virgin Creek Member has been separated into two zones based on lithology. The lower zone is light to medium gray shale which contains a number of bentonite beds. The upper zone, especially the base of this zone, is what Searight (1937) described as a "lead gray-gumbo, in many places tinged rusty-brown". The upper member also contains small fossiliferous concretions in the lower portion and a bed containing large limestone concretions (Agnew and Tychsen 1965).

Deposits Associated with the High Terrace System

Alluvial sediments near the outlet of the Cheyenne River and along other east flowing tributaries to the Missouri River that have been investigated by Crandell (1953), White (1964), Bluemel (1977), and Christiansen (1979) help to bracket the period in which the soils of the study area developed.

Deposits that cap Standing Buttes, 19.3 km south and 9.7 km west of the present Cheyenne River outlet, cover land areas in sections 1, 2, 3, 11 and 12 of T7N, R27E (Warren 1952). Alluvial deposits capping Standing Buttes antedate the deposits on the terraces in this study. Antedating was based on the higher elevation of the Standing Buttes alluvial deposits versus the lower elevation of the Cheyenne River terraces of this study. The Standing Buttes deposits are the oldest stream deposits associated with a possible ancestral Cheyenne River near the present outlet. These deposits have also been correlated with similar sediments that cap Sully Buttes located east of the Missouri River. The mineralogy of these sediments has identified them as originating from non-glacial formations west of the Missouri River. The fact that these alluvial deposits now occupy the highest landscape position in their area indicates topographic inversion since their deposition. Fossil remains indicate that deposition could have taken place 1.7 to 3 million ybp. A fossil tooth found in these deposits from a subgenera of zebra has been found in deposits from three million ybp to approximately 900,000 ybp. This fossil, however, was to abraded to date these sediments with reasonable assurance. The abrasion was taken as an indication that the tooth could have been transported from older sediments than the Standing Buttes sediments in which it was found. Pebbles studied from these deposits indicate a lack of a distinctive green quartzite found in other deposits of lower elevation, namely those capping Willow Creek Butte and the Stroup Deposit. Since these lower deposits have been dated with greater assurance as having occurred sometime between 550,00 to 150,000 ybp, late Yarmouth to Wisconsin age, the inferred age of the Standing Buttes deposit is greater than 550,000 ybp. Willow Creek Butte in the SW 1/4 of Section 15, T5N, R29E and the Stroup deposit in section 26 are part of a collective body of northeast trending alluvial remnants. They have been organized into three very general groups based on elevation and are part of a high, now isolated, terrace system of the Bad River which is directly south of the Cheyenne River. The lower terrace in this system was isolated from the present day Bad River floodplain as a result of the down cutting of the Missouri River trench. The high terrace system itself is believed to have developed as a result of lateral corrasion of the Bad River during a period of general down cutting. This system now ranges between 90 and 180 m above the present floodplain. Willow Creek Butte and the Stroup deposit all have the same general range in grain size and lithology. Well preserved unabraded fossils in these deposits have been identified as horse teeth from Equus niobrarensis and Equus excelsus and have been found elsewhere in deposits dating from early Yarmouth to Wisconsin age (Crandell 1953).

A similar set of high terraces on the White River, also an east flowing tributary to the Missouri, ranges between 60 m to 105 m above the present day White River flood plain. White (1964) suggested that these terraces were isolated from the present day flood plain as a result of down cutting of the Missouri River trench and proposed that this event occurred during the maximum western extension of Wisconsin age ice. Radiocarbon dates indicate that this maximum extension of Wisconsin age ice occurred sometime between 38,000 to 27,900 ybp (Wright and Frey 1965). White (1964) also indicated that soil development on the lower terrace of the high terrace system of the White River was not different than known

Wisconsin age soils in the area. He traced the lower terrace to a hanging channel in the east wall of the Missouri River trench identified by Warren (1952). White (1964) concluded that soil development on the lower terrace alluvium could not antedate the down cutting of the Missouri River trench by an appreciable interval. If the diversion of the White River that caused the high terraces to become isolated had occurred during an earlier glaciation, Illinoian 390,000 to 550,000 ybp for example, he assumed that the soils on the lower terrace would have been better developed than Wisconsin age soils. White also examined work by Warren (1952) in which Warren stated that the Missouri River trench could not have formed during Wisconsin age glaciation because the erosion and aggradation of the channel required a longer period of time. White concluded that his proposed Wisconsin age of the Missouri River trench was reasonable based on the relatively soft Pierre Shale bedrock of the area and the fact that the erosional period required for the 60 m lowering of the White River base level was not a factor in the time analysis by Warren (1952).

Christiansen (1979) determined that large quantities of melt water were being channeled down the Missouri River 17,000 ybp during a Wisconsin glacial phase that represented a readvance glacial position to what is now the border between North Dakota to the south and Saskatchewan and Manitoba to the north. His assessment of meltwater volume was based on the enormous size of Frenchman Valley and the numerous large valleys that enter it in extreme southwest Saskatchewan. These valleys, 17,000 ybp, were part of the headwaters of the Missouri River because water flow to the north and east was blocked by the glacier. Meltwater channeling to the Missouri River continued until approximately 15,000 ybp but several changes in the drainage system of the headwaters region, near the glacier, resulted as the ice sheet began to retreat north. By 14,000 ybp the southern margin of the Wisconsin ice sheet had retreated far enough north into Canada that drainages were opened to the east. This resulted in abandonment and/or redirection to the east, of the channels that once carried glacial meltwater to the Missouri River.

Bluemle (1980) determined that the Cannonball, Heart, Knife, and Little Missouri Rivers of North Dakota had been diverted as a result of the Missouri River trench development by 25,000 ybp, but during Wisconsin age glaciation.

Sections of the Missouri River trench have been shown to be older than Wisconsin age. These sections have been identified as remnants of older stream valleys that once continued east of the Missouri River (Bluemle 1977), (Crandell 1953).

LITERATURE REVIEW

Time as part of the Soil Forming Process.

Many early soil scientists reported that soil was not a static body, they preceived it as evolving. Evolution requires that the soil not only exist in space but also in time. The primary state factors influencing soil formation were determined to be: climate, parent material, biological influences, topography, and the passing of time (Dokuchaev 1883, Hilgard 1921, Jenney 1961).

Soil Formation Factors as Chronosequence Components.

Time in a monogenetic system of soil development involves the passing of time while the intensity of the other factors in the functional relationship remains essentially constant. Time modifies the expression of soil characteristics by adding its dimension to the combined constant influence of the other soil forming factors (Vreeken 1975, Stevens and Walker 1970).

Climate and Vegetation

Short periods of variation in biological and climatic factors generally do not require polygenetic explanations for soil development (Vreeken 1975). This is especially true if the profile characteristics being described require long periods of development such as subsoil clay accumulation through translocation versus carbonate redistribution in the profile (Birkland 1974, Torrent and Nettleton 1978, Alexander and Holowaychuk 1983).

The assumption of monogenesis can also be loosely extended to essentially constant macro-environmental conditions or to soil development that has taken place during a single geological period. Researchers evaluating the climatic factor over time warn however, that accepting the premise that soil history has repeated itself is difficult to prove (Vreeken 1975, Yaalon 1975).

Birkland (1974) in a review of Jenney's (1941) definition of the climate factor states that climate should be considered the regional climate and because temperature and precipitation are not necessarily interdependent they should be treated as separate subfactors of climate. Birkland (1984) further indicates that different combinations of precipitation and temperature result in varied leaching regimes.

This explains why similar soils are produced over a range of individual precipitation and temperature variations (Arkley 1967). Birkland (1974) suggests that a threshold concept should be used to explain the influence of climate where gradual changes in climate may not show a response in terms of soil development until a level is reached where the system changes quickly and dramatically.

The leaching regime or effective precipitation of the mesic temperature area in the north central region of the United States is directly controlled by the hot summer. In the south central thermic temperature area of the United States the leaching regime is controlled by the cool season (Ruhe 1984).

Research in New Zealand on eight soils of similar aeolian parent material and separated by 60 to 480 m in altitude demonstrates the effect of more effective precipitation resulting in increased leaching at higher altitude within essentially the same latitude. The soils formed a developmental sequence related primarily to altitude. The soils at higher altitudes were classified as Typic Dystrochrepts with an iron pan, while the dryer lower altitude soils had fragipan development and were classified as Aeric Fragiaquepts. The leaching regime increased with increasing altitude because of increased precipitation and decreased evapotranspiration.

Higher altitude soils with more effective leaching differed from lower altitude soils by having a lower pH and increased leaching of sesquioxides. Phosphorous levels were also lower in surface horizons that had experienced a loss of sesquioxides. The mechanism increasing iron and aluminum mobility and subsequent translocation was hypothesized to be solubilization via metallo-organic chelating complexes. Precipitation of these complexes occurred in subsoil zones as a result of an increase in calcium and magnesium or through the decomposition of the chelating organic matter which left the metal ions free to precipitate as oxides or hydroxides (McIntosh 1984). Subsoil precipitation of chelated complexes was reported by Wright and Schnitzer (1963) indicating that metallo-organic chelating complexes of iron precipitated when soil solution calcium reached 0.13 parts per million (ppm) and magnesium reached 4.5 ppm. Alumninum metallo-organic complexes precipitated at 10 ppm calcium and 45 ppm magnesium.

Wilding and Westin (1961) in a characterization study of the Sinai Series, an Udertic Haploboroll on the Prairie Coteau of eastern South Dakota, discovered differences in profile morphology within 43.5 to 45.7° N latitude. The development of soil structure to greater depths, browner colored A and B horizons, a trend toward more extensive leaching of extractable bases, and lower organic matter levels in the southern Sinai soils was attributed to warmer more moist conditions. This study shows that small differences in climate are influential in soil profile development. The temperature and precipitation from north to south along the Coteau vary from 6 °C and 52 cm to 7.7 °C and 62.5 cm respectively.

Bruce (1983) determined that the variation in moisture from 55 cm to 115 cm under similar mean annual temperature of 9.7 to 11.1 °C, produced strikingly different morphological characteristics over similar time periods of genesis. Soils of similar parent material exhibited thicker A horizons and no fragipan to thick fragipan across a moisture continuum from perudic to a ustic moisture regime.

Wisconsin to Holocene Paleoclimate.

Throughout the Wisconsin glacial age, 10,000 to 150,000 (ybp), summers over the non-glaciated midcontinent region of the United States were generally more cool and moist than today but warm dry periods are known to have occurred. The best documented shifts in climate cover what is referred to as late Wisconsin time, 10,000 to 25,000 ybp. The coldest temperatures during late

Wisconsin time occurred 17,000 ybp. At this time the mean July temperatures in central Iowa were about 10 °C. This is comparable to temperatures at the tree line in Canada today. Central Iowa now has mean July temperatures of 23 °C. By 13,000 ybp mean annual temperatures in North Dakota were between 1 to 2 °C which is comparable to those in Canada in the mid-Boreal Forests of today. From approximately 13,000 to 9,000 ybp mean annual temperatures in North Dakota increased from 1 to 5 °C. By the end of this period mean summer temperatures in North Dakota were comparable to those today in southern Manatoba at the southern edge of the Boreal Forest. During 10,000 to about 9,500 ybp temperatures began to increase and as conditions also became drier, prairie replaced much of the woodland in North Dakota. This occurred first in the western part of the state and progessed eastward (Bluemule and Clayton 1982).

Ruhe (1984) indicates that prairie was established and extended into Illinois at least 8,000 ybp and that the border of the prairie extended 120 km farther northeast between 7,000 to 2,000 ybp than it does today. During this time of maximum extension of the prairie the climate was much drier than the present climate. The Upper Mississippi Valley moisture regime was more like the ustic moisture regime in west central South Dakota of today than the present day wetter udic moisture regime. Paleoclimate reconstruction indicates that conditions across the upper Great Plains were like present day drought periods during this maximum extension of the prairie. Climates generally cooled 2,000 ybp to our present climate but have included some short shifts in mean annual temperature and precipitation. As a result of this cooling the prairie receded south westward from the Upper Mississippi River Valley in Minnesota to its present position. Bluemle and Clayton (1982) suggest that warming and drying conditions in North Dakota reached a maximum between 7,000 to 5,000 ybp and that climatic patterns shifted toward conditions more representative of conditions today at approximately 3,500 ybp. They agree with Ruhe (1984) in that short variations in climate have occurred and may have lasted several hundred years during this most recent period within the last 3,500 years.

Sangamon to Wisconsin Age Paleoclimate

Based on megafauna and pollen in Sangamon age deposits the climate shifted from a cool moist climate at the end of Illinoian glaciation, followed by warm generally dry periods, and back to cool climates as the Wisconsin age approached. Sangamon deposits from several locations, including southeastern Montana and central Illinois, provide evidence of the vegetational changes. The vegetational history is initially dominated by pollen from coniferous trees followed by deciduous trees as the Sangamon climate began to turn warmer. The deciduous tree pollen and megafauna then changed to pollen dominated by grasses as the Sangamon went through a drier, warmer period. As the Wisconsin age ice approached the pollen history again shows deciduous tree, followed by coniferous tree pollen dominance (Gruger 1972, Bernabo and Webb 1977, VanZant 1979, King and Sanders 1986).

Parent Material

Uniformity of parent material can be established by examining the more resistant elements of the soil profile i.e. resistant weatherable mineral ratios as well as clay free silt and clay free sand distribution throughout the profile and their correspondence with other profiles (Jackson 1953, Birkland 1974, Chittleborough and Oades 1980, White 1981).

Topography

The topographic component can usually be held constant on terrace systems by sampling from a single landscape position. However, Vreeken (1975) points out that the development of internal drainage by lowering of the groundwater table during landscape evolution can be responsible for differences in soil morphology on similar landscapes positions of different age.

Non-Strict Post-Incisive Chronosequences

The term "non-strict" is applied to a chronoseguence in which the age of the members and the magnitude of soil forming factors are not quantitatively known (Jenney 1941). Many of the inferences derived from non-strict chronosequences are supported by studies of quantitative chronofunction.

Stream terraces, as a rule, are separated in time in an inherent post-incisive sequence. Older terraces occupy higher landscape positions. Each successively younger terrace is separated from other older sequence members by an inception period post dating the older members (Ruhe 1956). A second relationship to time can be introduced if exposed surfaces become buried at different intervals thus having different lengths of genesis time, not totally related to initial exposure of the terrace surface (Stevens and Walker 1970, Vreeken 1975, Muhs 1982).

Soil Morphology and Time

Jenney (1961) defines the soil forming factors as "state factors". They describe the state of the soil system. Their relationship to pedogenesis is through the types of processes that exist as a result of their interaction. These processes include but are not limited to; melanization, lessivage, decalcification, and pedoturbation. The state factors of time, biological influences, climate, parent material, and topography should not be confused with steady state conditions. The stability of the state factors does however, have a great deal to do with the particular steady state of a soil system (Crooker 1952). A steady state is used to refer to a soil system in which processes are ongoing but increases or decreases in their expression as soil profile characteristics remains constant (Laukulich 1969). Leaching of carbonates and the organic matter content of surface horizons are examples of characteristics that reach steady state conditions in relatively short periods of time while development of maximum redness or increases in hue take much longer (Birkland 1974, Abtahi 1980).

The length of time required for a soil profile characteristic to reach a steady state is important when applying that characteristic to a chronosequence. Characteristics that reach a steady state rapidly such as surface horizon pH and organic matter content are usually not as usefull in separating chronosequence members as degrees of clay translocation and changes in clay mineralogy are when long periods of pedogenesis are involved.

Organic Matter.

Birkland (1974) states that "organic matter probably reaches a steady state more rapidly than any other property of the soil". He also suggests that data over many locations and different parent materials leads to a range of 200 to 3000 years for organic matter to reach a steady state.

Calculated turn over rates of organic matter have shown that levels of organic matter are inter-related to vegetation, parent material, and climate. Equilibrium conditions on the northern Great Plains over at least the past 400 years are known to have been relatively constant (VanVeen and Paul 1981).

Research in the southern Great Plains by Nichols (1984) establishes a linear relationship between soil clay content, mean annual precipitation, and organic carbon with a coefficient of determination (R^2) for multipal linear regression of 0.90 at the 1 % level of significance for the relationship. All soils in the study were on uplands, not excessively wet, and did not have a high shrink-swell potential. This study indicates that within a precipitation range of 33 to 114 cm, a mean annual temperature from 14 to 23.3 °C, and a clay content between 0.3 to 60.7 %, percent clay is positively correlated with organic carbon content. The percent clay was the primary independent variable for the prediction of organic carbon in the surface horizon of undisturbed pedons.

Sondheim and Standish (1983) determined that organic carbon and nitrogen levels of surface horizons reached a steady state in less than 200 years after deglaciation in Canada at 53° N latitude and 119° W longitude. This study includes the period in time required for vegetational succession to the present spruce forest.

In the Willamette Valley of Oregon, a series of seven successively older surfaces from middle Pliesticene to the present had similar levels of surface organic matter.

Subsurface horizons however decreased in organic matter content with increasing age (Parsons, Balster, and Ness 1970).

Parsons, Scholtes, and Riecken (1962) evaluated soils formed on indian mounds in northeastern Iowa. They concluded that organic matter accumulated in the A horizon under deciduous forest reached a maximum expression in a period of 1000 years based on similar levels in 14,000 year old adjacent soils.

Soil Color

A highly significant coefficient of determination (r^2)of 0.89 has been reported by Kemp (1985) for the degree of redness of argillic horizons in several soils of eastern England and their pedogenic hematite iron content. Pedogenic goethite and iron oxide contents were not highly correlated with profile redness. After eliminating inherited parent material affects, red argillic horizons were determined to be a product of extensive periods of weathering under a cool moist paleo-climate that promoted the accumulation of hemitite. Paleo-argillic horizons could be separated from younger argillic horizons in that the older argillic horizons tended to have redder matrix hues of 7.5YR or redder, chromas of more than four, and values of four or more, when comparing fine-textured materials. Non-inherited red colors particularly within 5YR and possibly 7.5YR hues were not considered conclusive evidence for paleo-argillic horizons and stratigraphic and/or micromorphological data were required to substantiate the interpretations.

In the Willamette Valley of Oregon subsurface soil color is one of the factors that separates surfaces of different age. Soils of middle Pleistocene age generally have hues of 7.5YR while soils younger than late Pleistocene have hues of 10YR (Parsons, Balster, and Ness 1970). Many determinations of soil color have been made to evaluate age relationships in Wisconsin age loess in the midwest. In general, loess younger than 28,000 years at nearly all locations is no redder than 7.5YR with the exception of soil developed in red parent material and usually fall within the 10YR hue (Nickerson 1941).

Lessig (1961) examined several glacial outwash terraces of similar parent material in northeastern Ohio. The gravelly loam material of Wisconsin age had soil colors of 7.5YR hue which were similar to the colors found in the B horizons of profiles developed on Illinoian age outwash terraces. The primary difference between the Wisconsin and Illinoian age profiles was in the depth to which a 7.5YR hue occurred. The mean depth for 7.5YR hue in Wisconsin age soil was 147.5 cm and 225 cm in the Illinoian age soil. Other soils in the region which are believed to have developed in pre-Illinoian outwash had 5YR hue soil colors.

Research in west central Idaho by Colman and Pierce (1984) using the Harden index of rubification (Harden 1982), on soils 14,000 to 150,000 years old, agrees with progressive reddening of the subsoil with age.

Clay Enrichment of the B Horizon

Lessivage involves the mechanical migration of small minerial particles from the A horizon to the B horizon. These mineral particles can be clay constituents in suspension and/or in collodial form. They are normally illuviated to the upper Bt but can extend to the lower Bt following heavy rainfalls (Mermut and Acton 1984, Protz et al. 1984, Howitt and Pawluk 1985).

St. Arnaud and Mortland (1963) determined that expanding types of clay minerals are more readily dispersed and translocated in preference to non-expanding clays. These findings support later research in the Glacial Lake Edmonton Basin of Alberta, Canada by Arshad and Pawluk (1966). Chemical analysis and surface area determinations for clays in Bn horizons indicated that montmorillonite was being preferentially translocated over illite type clays.

A graph of clay content against depth usually shows an increase in the amount of clay and thickness of the B horizon as progressively older soils are compared (Birkland 1974). In a comparison of 32 chronosequences from 27 areas between 66° N and 78° S latitude and over a wide range of parent materials, Bockheim (1980) determined that the rates of increase in clay content and B horizon thickness were positively correlated with clay content of the parent material. Soils in this study ranged in clay content from 2 to 38 %. This relationship was refered to as a multivariate function of time and parent material in which climate was not found to be as significant as parent material. Low clay content soils developed argillic horizons slowly because of the lack of inherited clay available for translocation. Clay size particles generally took longer to accumulate in subsurface horizons because they had to first weather from coarse parent material. Soils with higher initial clay contents had an immediate source of translocateable material.

Barshad (1957) investigated the rate of clay formation from mineral constituents as affected by the major state factors of climate, topography, parent material, vegetation, and time. He concluded that an increase in the age of soil is expressed in an increase in clay formation. Rates of clay formation were based on the amount of clay formed from 100 g of the non-clay fraction, using unweathered parent material as the initial state. Formation rates ranged from 272 g to 55 kg of clay per 30 cm of soil per year. Each of the soil forming factors were considered significant. Clay formation from mineral constituents translocated to the B horizon was greatest for parent material from basic rocks and those having high contents of alumino-silicates. Grassland vegetation resulted in high levels of clay constituents because nutrient cycles were short. Carbon dioxide evolving from fiberous root systems also aided in the chemical weathering of primary minerals by creating a more acid environment through the increase in carbonic acid. Topography was a factor in that clay formation was inhanced in profiles as drainage decreased. Both the illuviation of discrete clay particles and downward movement of molecular constituents were hypothesized as being responsible for Bt horizon development.

Morphological differences in four soils of recent alluvial parent material indicate that it takes more than 2,000 years to form an argillic horizon in central Pennsylvania. The soils studied were derived from red shale alluvium, brown acid shale alluvium, limestone influenced alluvium, and gray acid sandstone alluvium. Radiocarbon dating placed the soils from less than 205 years old, to approximately 320, 470, and 1,955 years old respectively. The oldest soil profile, which had developed in acid sandstone and shale alluvium, had a well developed cambic horizon grading into an argillic horizon. The three younger soils had only weakly developed cambic horizons and could not be separated from each other based on this morphologic charateristic. The three younger soils also had very little clay formed from weathering of particles in place. The oldest soil, a fine-loamy, mixed, mesic, Fluvaquentic Dystrochrept, had significant amounts of clay forming by weathering of particles in place compared to the three younger soils. The three younger soils had less than 0.1 % illuvial clay by volume in cross section compared to 0.6 % for the 1,955 year old soil. The thickness of illuvial clay films was not significantly different at the 0.05 level among the three younger soils but was significant for the comparison of the younger soils to the oldest soil (Bilzi and Ciolkosy 1977).

Northeastern Iowa indian mounds built 2,500 ybp had clay distributions very similar to adjacent 14,000 year old soils. Further comparisons between younger mounds indicated that 1,000 year old mounds contained only two-thirds the amount of translocated clay as the 2,500 year old mounds (Parsons, Scholtes, and Riecken 1962).

Wisconsin and Illinoian age terraces formed in glacial outwash indicate a similar trend. Wisconsin age soils had clay coats on sand and gravel to a depth of 147.5 cm while Illinoian age soils had clay coats to a depth of 225 cm. Illinoian age soils also had deeper B horizons and with clay bulges to 152 cm where as clay bulges in Wisconsin age soils averaged 107 cm in depth (Lessig 1961).

Genesis of an argillic horizon in a Xerollic Haplargid, Fine-silty, mixed, mesic east facing lake terrace soil in northern Utah was estimated at 9,000 years. The influence of at least two pluvial periods between 6,000 and 9,000 ybp was suggested as a major contributing factor in the argillic horizon development. There was no argillic horizon development in a soil located in the same area on a 6,000 year old west facing lake terrace. The west terrace Xerollic Camborthid, Coarse-silty, mixed, mesic soil did have some removal of carbonates from the upper profile. The B horizon did meet the clay percentage for an argillic horizon but no evidence of translocation was evident in the profile morphology. The climate in this area 6,000 ybp to present was characterized as being at least as dry as the present climate (Southland and Southland 1985).

Investigations of a Typic Haplargid by Gile and Grossman (1968) in southern New Mexico show weak argillic horizon development in 2,000 to 5,000 years. Subsequent investigations of soils developed in highly calcareous material did not show argillic horizon development over the past 5,000 years. The primary factor was considered to be the lack of clay dispersion as a result of almost negligible carbonate leaching. The development of argillic horizons in paleosols found in this area has been attributed to soil formation during more moist periods of the Pleistocene (Gile and Hawley 1968).

High correlations between the age of glacial deposits relative to thickness of the B horizon, depth of oxidation, and percent clay in the B horizon were obtained by Colman and Pierce (1984) in west central Idaho. Initial parent materials with 5 to 40 % clay varied in inferred age from 14,000 to 150,000 years old. Development of a Bt horizon was not noted in 14,000 year old soils but was clearly evident after 20,000 years in soils with less than 10 % clay. None of the properties measured were determined to have reached steady state conditions.

Carbonates and Soil pH

If we move across a gradient from humid to arid conditions, horizons of salt accumulation begin to develop at higher positions in the soil profile. The solubility of the salts present as well as the moisture regime, determines the position of the salt precipitate in the profile (Gardner and Brooks 1957). The depth of the upper surface of soil horizons with carbonate salt accumulations has been shown to be related to mean annual precipitation and soil texture in the western Great Plains and in California. The equation $D = 8.28 + (1.62\ maP) - (0.45\ ME)$ where D = the depth to the upper surface of carbonate salt accumulation, maP = mean annual precipitation, and ME = moisture equivalent of the A horizon on a percent volume basis as a term used to quanitify soil texture, produced a r^2 of 0.75. This r^2 was improved to 0.92 when the range in soil textures used to compute the value for D was narrowed to a ME of 8 to 17 %. The negative value for ME indicates that as the clay content increases more water is held in the profile which allows for less leaching of carbonates. When this expression is applied to soils of the Great Plains as compared to soils of Nevada and California the slope of the line for the expression over a range in soil textures is steeper for the far west soils. This is due to the fact that cold California winter rains are more effective in leaching soluble salts from the soil profile than warm summer rains on the western Great Plains (Arkley 1963, Jenny 1980).

A sequence of progressively higher and older land surfaces, along the Rio Grand Valley in New Mexico, dating from present time to middle Pleistocene time was studied to determine the development of carbonate horizons. The climate in the study area was arid with a present day annual precipitation of 20.0 to 30.0 cm. The development of thicker and more continous coatings of calcium carbonate on pebbles and increased filling of interpebble spaces were major charactertistics associated with carbonate morphology over time. Geomorphic surfaces less than 2,600 years old to 5,000 years old exhibited thin discontinous calcium carbonate coatings on pebbles at 15 cm to 45 cm below the soil surface if the parent material was gravelly. Non-gravelly sediments of the same age contained fine fillamentous carbonates. Non-gravelly soils greater than 5,000 years old but less than late Pleistocene in age contained few to common nodules. Non-gravelly soils of middle Pleistocene to late Pleistocene developed many carbonate nodules and internodular fillings (Gile, Peterson, and Grossman 1966).

Arkley (1967) applied his formula for calcium carbonate movement in soils to the calculation of the minimum age of certain soils located in the Great Plains. The correlation to age was made through the solubility of calcium carbonate and the time required to form horizons of calcium carbonate accumulation. No corrections to the formula were made for; heterogenity in the profile, surface runoff, carbonates added to the soil surface, mineral weathering, and redistribution of carbonates to the surface by plant roots. It was determined that the effect of these factors would tend to slow down the process of carbonate accumulation thereby adding to the minimum developmental time required. Weathered till and loess soils studied from South Dakota to Kansas, gave calculated minimum ages of less than 15,000 years old using just the solubility of pure calcium carbonate. Minimum ages of less than 13,000 years old were obtained when using the solubilities of calcium and magnesium carbonate combined. In South Dakota the minimum average age for the site on a Agar series, a (Fine-silty, mixed, mesic Typic Argiustoll) developed in deep loess, was estimated at 12,300 years. The minimum average age of the Houdek series, (Fine-loamy, mixed, mesic, Typic Argiustoll) was estimated at 10,450 years.

Both ages represent the minimum average age based on the solubility of calcium carbonate. When the formula was considered over a range of soils from late Wisconsin to Yarmouthian and Illinoian age, a period from 14,000 to 900,000 ybp, it was determined that the calculated ages were at least within the same order of magnitude as the geologic evidence.

Several moderately well-drained soils in eastern North Dakota with calcium carbonate accumulations indicate that finely divided lime of secondary origin is precipitating out of capillary water that is rising or moving laterally from a zone of water saturation. The micromorphology of profiles examined showed an increase in calcium carbonate, in the form of finely divided lime, for the horizon of lime accumulation when compared to unaltered parent material. Parent material examined contained 10 to 15 % calcium carbonate with an average of 35 % of the total within less than 2 microns in size. Total calcium carbonate in the zone of maximum accumulation increased to approximately 35 % with 50 to 69 % of the total calciun carbonate less than 2 microns in size (Redmond and McClelland 1959).

Well-drained loam to clay loam soils in central and west central North Dakota examined by Morgen et al. (1959) had maximum zones of calcium carbonate accumulation between 65 and 100 cm. In profiles that had gypsum, the zone of calcium sulfate accumulation was below that of calcium carbonate because of the higher solubility of the calcium sulfate. The soil pH was related to the calcium carbonate distribution only in that it tended to increase with increasing calcium carbonate percent. The zone of maximum accumulation did not however, have the highest pH. In most cases the C horizons with 7 to 17 % calcium carbonate equivalent values had higher pH values by 0.7 to 0.3 units. This was true even for the profile with the maximum percent calcium carbonate euivalent of 29 % in the horizon of accumulation. The pH in surface soils ranged from 6.5 to 7.2 with less than 1 % by weight of calcium carbonate present.

Data from a study conducted in Ohio on seven Wisconsin glacial age soils, 150,000 to 10,000 ybp, and seven Illinoian age soils, 550,000 to 390,000 ybp, indicates that the pH and depth to carbonates decreases with soil age. Average morphological properties of the two soil age groups on gravelly glacial outwash terraces indicated that carbonates had leached to approximately 210 cm in the Wisconsin age material and 525 cm in the Illinoian age material. Measurements of surface horizon pH indicated a drop from 5.2 to 4.6 from the younger to the older material. The average pH throughout the profile for the Illinoian age outwash terraces was below 6 to a depth of 350 cm whereas the Wisconsin age material was still above a pH of 6 at 112 cm (Lessig 1961).

Interpedal Soil Structure Development

Interpedal soil structure defines how soil peds are organized in the soil profile. The morphology of this level of organization is expressed by the size, shape, and arrangement of peds and interpedal voids. Primary structure is the first level of organization for peds occurring in a soil material. Primary peds can not be divided into smaller pedal units. Secondary structure refers to the manner in which primary units are organized and tertiary structure identifies the organization of structural units using secondary units as building blocks. In many soils the primary structural units are angular or subangular blocks. Secondary structure expressed as prisms is common if a geographical region is characterized by wet and dry cycles that promote vertical soil cracking. These secondary prismatic structural units normally are grouped into larger prisms which form tertiary units. The boundaries of the secondary units within a tertiary unit can be horizontal cracks that divide long prisms and/or vertical cracks that separate associated groups of prisms (Brewer 1964).

Changes in moisture content within a soil body cause the soil to expand and contract. This has been proposed as the causal agent in the development of subsoil structure. Shear and tension fracture planes which develop during soil volume changes form the boundaries of structural units (White 1967).

Tension joints caused by a decrease in material volume commonly appear as polygonal patterns when viewed in horizontal cross section. Rupture that takes place within the horizontal plane radiates out from each ped center creating vertical cracks that form polygonal prisms. Tension is also set up in the vertical direction but because of gravity the soil material can shrink more easily without rupturing in the vertical plane. As a result horizontal cracking occurrs to a lesser degree in secondary structure (Billings 1965).

The development of blocky peds, which are commonly the primary structural units, is probably due to the intersection of shear planes formed as the soil material swells. Uneven wetting of the soil as water moves into the profile causes areas of the soil to swell faster than others. To release tension the soil is broken into peds that slide past one another producing shear planes which become the ped surfaces. Primary peds can be broken from dried blocks of soil but they are usually more discrete in the profile when the soil moisture content is at or slightly less than field capacity. This is an indication that shearing has occurred during swelling and has separated the peds forming the primary structural units. Once shear planes have developed, the tendency for the profile to wet along cracks and shear planes perpetuates the previously formed peds (White 1966).

Increased clay content is a major contributing factor to the size of soil peds in that clays generally increase the amount of swelling and contraction which causes tension to develop. As the clay content increases the ped size tends to decrease. The stability of the ped faces and their orientation in the profile depends on both the clay content and the number of wetting and drying cycles a particular portion of the profile is subjected to. Normally, clay zones closer to the surface exhibit the greatest degree of pedoturbation because the upper part of the profile is more subject to changes in moisture content (White 1967).

Czeratzki and Frese (1958) determined that the surface conformation of natural planar voids is controlled by the clay mineralogy and the type of exchangeable cations. Calcium-saturated clays tended to develop wide continuous cracks with smooth vertical surfaces. Prismatic structural units of calcium saturated clays were also larger than the structural units of sodium and hydrogen saturated clays. Sodium and hydrogen saturated clays tended to develop narrower more irregular vertical cracks with irregular surfaces.

A study of 25 Mollisol soils located in Texas, Kansas, and Oklahoma related the size of prismatic structural units to soil texture. The largest diameter prismatic structural units formed in soils with the lowest clay content. Prisms with diameters larger than 22.5 cm were found in fine sandy loam or silt loam textured soils. Smaller 10 cm diameter prisms were more common in clay loam textured soils. Prism size was also affected by clay mineralogy which was correlated with prism size through cation exchange capacity (CEC) per 100 g of clay. Higher CEC were associated with an increase in expanding 2:1 clay minerals. Soils with similar percent clay content but higher CEC produced smaller prisms (Stirk 1954).

Differences in spacing between vertical cracks of soils with similar clay contents were also reported by Sleeman (1962). The largest diameter prisms were found in soils with 37 meq/100 g of clay. The soil with the highest CEC, 63 meq/100 g of clay, had the smallest diameter prismatic structural units. More hetergeneous soil material also produced more irregular drying patterns and less continous vertical cracks as well as a less regular horizontal surface pattern of polygonal cracking. A general trend throughout all the soils in the study was toward the dominance of vertical cracks near the upper portion of clay zones. Horizontal cracks increased in abundance with increasing profile depth. The tendency for horizontal cracking to increase with depth was associated with more uniform drying at increasing depth. Horizontal cracking was also associated with changes in soil texture within the profile. These changes were from sources such as bedding planes of aeolian and fluvial deposits as well as changes in parent material relative to texture.

Mineral Weathering

Weathering of minerals refers to both the chemical and physical decomposition and disintegration of minerals. Minerals weather when they are not in equilibrium with temperature, pressure, and moisture conditions. The environmental factors and the composition of a particular mineral gives rise to weathering reactions that dominate the state of weathering at any one time but not necessarily throughout the total weathering process. These reactions can be grouped into categories based on their mode of action. They are oxidation-reduction, hydration, hydrolysis, and solution (Jackson 1968).

Goldich (1938) proposed a "stability series" for the weathering of primary minerals. Generally the least stable minerals at the atmosphere-lithosphere interface were those that originally crystallized from a molten mass at the highest temperatures. The stability series also revealed an order that pertained to the number of silica tetrahedral linkages. The least stable minerals were also the minerals with silica tetrahedral units held together by easily hydrolyzable and or easily oxidizable bonds. Olivine which was one of the most easily weathered minerals had tetrahedral units that were linked by hydrolyzable magnesium and readily oxidizable ferrous iron. The feldspars were separated and organized as a second branch in the stability series because it was noted that the degree to which divalent calcium substituted into the crystal structure caused increasing distortion of the crystal and partially accounted for the increased ease of weathering within the feldspar group. Substitution of monovalent sodium increased the stability of the plagioclase feldspars but as a group they were more easily weathered than the orthoclase feldspars. This was due to the fact that potassium fits into the crystal structure with less distortion and still satisfied the charge imbalance created by aluminum substitution for silicon in the tetrahedral units.

A second weathering series proposed by Jackson (1968) follows a similar order of weathering for the same reasons but it introduces the factor of particle size. The primary difference between the two series is that quartz and muscovite switch positions. Clay size particles of quartz were more easily weathered than muscovite of the same particle size. This was due to an increase in the solubility of quartz once a threshold minimum particle size was reached. Jackson added halite, gypsum, and calcite as easily weatherable minerals because of their relative high solubilities vermiculite, montmorillonite, and kaolinite were added to the some what harder to weather minerals. Vermiculite was however, more easily weathered than kaolinite because of the decreased amount of substitution within the Kaolinite crystal structure. The more diffuse nature of the lattice charge imbalance was also a factor in weatherablity. Vermiculite with more substitution in the tetrahedral layers had a more concentrated charge imbalance which caused it to be more easily weathered than montmorillonite which had less tetrahedral substitution and more octahedral substitution.

The importance of the silicon to oxygen bond ratio and mineral weatherability was pointed out by (Keller 1968). The energy of formation of several bonds was calculated and the composition of various minerals was examined. Silicon to oxygen bond energy was 3,110 kg cal. per mole, aluminum to oxygen 1,800, ferrous iron to oxygen 919, and calcium to oxygen 839. It was determined that the weathering of silicate minerals was inversly proportional to the total for their energies of formation. As the energy of formation decreased the ease of weathering increased in the following order of most easily weathered to least easily weathered: Nesosilicates, Sorosilcates, Inosilcates, Phyllosilicates, and Tectosilicates.

Goldich (1938) examined several fresh and weathered samples of minerals from Minnesota and South Dakota. One sample was taken from an outcrop in the Black Hills northeast of Lead, South Dakota. The fresh rock was determined to be amphibolite. Its composition was approximately 75 % hornblend with the remaining 25 % made up of garnet, titanite, quartz, chlorite, calcite, pyrite, and a black opaque mineral identified as possibly being ilmenite. Conclusions drawn from the amphibolite examination indicated that oxidation, hydration, and solution were the active agents of weathering for this material. These conclusions were supported by several differences in the fresh unweathered material and residual material. These included the complete removal of calcite and severe alteration of hornblend to beidellite and related clay minerals as well as a 13 % increase in water content in the residual material, of which half could be driven off at 110 °C. Secondary iron oxide coatings were also noted on the mineral grains of the weathered phase. The weathered phase also had gained ferric oxide and potassium oxide.

The majority of soils on St.Vincent Island, west of Barbados, have developed from parent material of porphyritic pumiceous andesite. The relative degree of weathering of these soils increases as the anorthite content of the parent material increases. Several late Pleistocene ash deposites over a period of 11,000 years were also compared to determine relative degrees of weathering since deposition. Fine virtic ash was the first material to be altered followed by plagioclase primarily composed of anorthite. The olivines and pyroxenes also weathered at a rapid rate followed by hornblend. Alteration of these minerals was also accelerated if they were deposited in clay layers. The increased weathering was due to an increase in moisture content of the weathering environment.

Even crystals partially embeded in clay rich zones, which had higher moisture holding capacities, were more highly weathered on that portion embeded in the clay than the portion protruding into the surrounding coarser material. This was attributed to the increase in moisture content of the clay which accelerated the weathering processes (Hay 1959).

METHODS AND MATERIALS

Site Selection and Site Sampling Procedure

Geomorphic features associated with a high terrace system were identified on 7.5 minute series (topographic) U.S. Geological Survey quadrangle maps of the study area. Random transects were then drawn perpendicular to the west-east parallel orientation of the terrace system. In the field the upper most terrace was located on any particular transect line. Sites were sampled along the transect line based on one site per intersected terrace level.

All sites sampled were located on the flat upper surface of the terraces. Slight depressions or areas of unusual vegetation were avoided. Sites were also located greater than 100 m from the toeslope of higher terraces and greater than 30 m from a terrace shoulder.

Two profiles approximately three to five meters apart were sampled per site. The two samples were then combined into one composite sample for laboratory analysis because of uniform sample morphology within a site and to reduce the number of samples requiring laboratory analysis. Profile descriptions were prepared in the field with the help of Richard Schlepp, Soil Conservation Service, Soil

Scientist and Dr. G.D.Lemme of the South Dakota State University, Plant Science Department. Correlation trays of each horizon were prepared for each site at the time of sampling.

Sample Preparation

Samples were air dried and passed through a 2 millimeter (mm) sieve. All soil aggregates not passing the initial 2 mm sieve size were crushed with a wooden roller and resieved until all the soil material, other than pebbles greater than two mm passed through the screen. Laboratory analysis was run on the fraction less than 2 mm in diameter (Methods of Soil Analysis 1965, Soil Survey Investigations 1982).

Particle Size Analysis

Particle size analysis was completed for all sites by the pipet method for the silt and clay fractions and by sieving the sand fractions. This was completed after carbonates had been removed with 1 N sodium acetate adjusted to a pH of 5, and after organic matter was destroyed with 30 % hydrogen peroxide (Soil Survey Staff 1972). Reproduciblity of the particle size analysis procedure was checked by comparing histograms from duplicate samples (Longohr et al. 1976). Duplicate particle size analysis sample data was averaged only after a minimum histogram overlap of 75 % for 11 sand fractions and three silt fractions was reached. No sample required more than three replications. Replications not meeting the histogram overlap criteria were considered to be laboratory error and not included in the average of the sample for a particular site.

The fine clay percent ($\leq$ 0.21 microns) was determined by centrifuging 250 ml of suspension which was decanted from the original suspension after the total clay pipet sample had been taken. After centrifuging, a 25 ml sample was pipeted at three cm below the surface of the liguid for determination of the fine clay fraction (Tanner and Jackson 1947).

Organic Matter

A modified Walkley-Black method was used to determine readily oxidizable organic matter (Jackson 1958, Carson and Gelderman 1980).

Calcium Carbonate and pH

Percent calcium carbonate equivalent was determined by titration (Bundy and Bremner 1972). A 1:1 suspension using deionized water was prepared to determine soil pH. The actual measurement was made potentiometrically using a hydrogen-ion-indicating glass electrode assembly referenced against a saturated calomel electrode. The meter used was a Hach, Soil Test Laboratory Model A 17000 (Mc Lean 1982).

Mineralogy

Mineralogical composition was determined by examination of coarse sands and medium sands for each individual horizon. Minimum grain counts of 600 grains were made along a 13.75 cm transect using a petrographic microscope to establish the percent quartz, feldspar and dark minerals for selected profiles. Once percentages were established further semi-quanitative sample compositions were determined by comparison. The comparison procedure was assumed valid because of the uniform dominant single mineralogical composition of the samples (Brewer 1964).

Soil Fabric Analysis

Thin sections were prepared by Cal Brea Geol. Services, Anaheim, Ca. from peds selected from the upper and lower terrace levels. The upper terrace level peds were selected from the Bt1, Bt2, and Bk horizons of Level 5, transect 3. The lower terrace peds were selected from the Level 1, transect 3 site and represented the Bt1 and Bt2 horizons of that profile. The fabric of the soil was examined for evidence of clay illuviation and the relationship of skeletal grains, voids, and plasmic structure (Brewer 1964, McKeague 1983).

Data Analysis

Data analysis was completed by using analysis of variance with the terrace levels and transects as class variables. Significant differences among class variables were indicated by a preplanned probability value of a significant F of 15 % or less. The level effects were interpreted as being caused in part by soil genesis over time. Sampling from a uniform landscape position and determining parent material uniformity helped to strengthen inferences to soil genesis for the time factor. This assumption was based on the generally accepted formula for soil formation in which the influential variables came from the major state factors of time; parent material; biological activity; climate; and topography (Dokuchaev 1883). By determining the uniformity of parent material and holding topography constant through sampling procedures, the contribution of time to soil genesis could be isolated with greater confidence. Since climate and vegetation were interrelated, the influence of these factors on soil genesis was examined by investigating paleoclimate.

The data set used in analysis of variance contained 19 of the 21 possible sites. The two sites of transect 2 were dropped from the analysis of variance portion of data analysis because their inclusion would have required the analysis to function with four missing cells. Only two terrace levels out of five were identified on transect 2. The remaining 19 sites were analysed with level 4 of transect 1 as the only missing cell. The Proc General Linear Models (GLM) procedure of Statistical Analysis Systems (SAS) was used for analysis of variance of this unbalanced design (Statistical Analysis System 1985).

Univariate analysis of variance was preformed to determine which measured properties had significantly different means on the basis of their expression on the class variables which were the terrace levels and transects. The F-test statistic was taken as indicating a significant difference if the probability level was equal to or less than 0.15 % for rejecting a true null hypothesis.

Multivariate analysis of variance was performed using selected dependent variables that related to soil genesis over time. This type of analysis deals with the simultaneous variation of two or more dependent variables. Roy's maximum root criterion, which is an F test statistic, was used to test the null hypotheses concerning the class variables which were terrace levels and transects. Terrace levels were separated based on the value of the discriminant function when the means for the dependent variables, by individual terrace level, were substituted into the equation.

RESULTS AND DISCUSSION

Location Characterization

The soils in this study were comprised of a group of alluvial deposits that have been separated into five terrace levels. Within the study area, these levels extend approximately 51 km west to east between T6N to T8N and 16 km south from the Cheyenne River between R18E to R23E of Haakon County, South Dakota (Figure 1). The lowest terrace level, from west to east, ranged from 85 m to 100 m above the present day Cheyenne River floodplain. The upper most terrace level, west to east, ranged from 155 m to 218 m above the present day floodplain. The highest point sampled within the study area (level 5 of transect 1) was 725 m above mean sea level. The lowest point sampled (level 1 of transect 6) was 597 m above mean sea level (Table 1). Missing values for level 4 transect 1 and level 5 transect 2 were probably a result of stream meandering followed by undercutting and removal of a higher terrace section by erosion. As a result of dissection of the high terrace system by water erosion during the development of upland drainage, sites for level 1 and 2 of transect 2 were also missing. This upland drainage developed perpendicular to the direction of

Table 1. Terrace Site Sampling Schematic

(Elevations in meters above mean sea level)

west ——— to ——— east

570 m ~~~ Cheyenne River Floodplain ~~~ 497 m

North to south across study area Levels					
1	655 m		645 m	603 m	597 m
2	672 m		658 m	655 m	643 m
3	708 m	704 m	689 m	658 m	652 m
4		716 m	708 m	670 m	668 m
5	725 m		719 m	683 m	679 m
	1	2	3	5	6

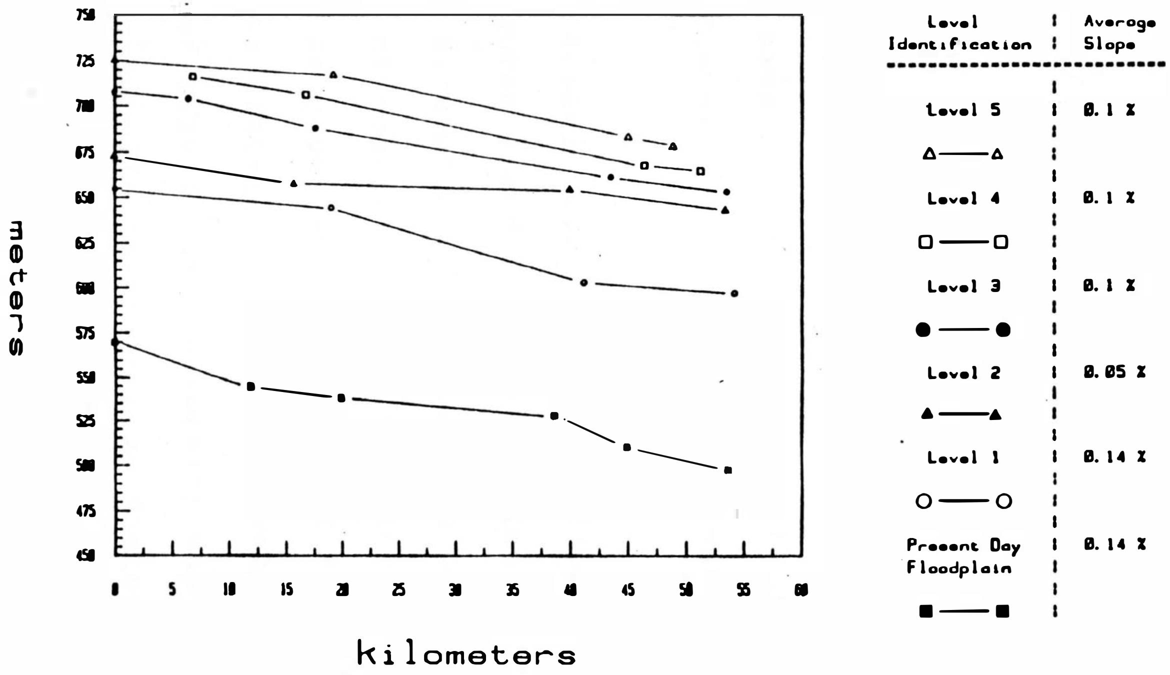
Transects, west to east across study area stream flow as stream entrenchment exposed the terraces.

The approximate west to east grade for the terrace levels was between a low of 0.05 % for level 2 to a high of 0.14 % for level 1 (Figure 3). The west to east grade on the present day floodplain was 0.14 %. This low gradient, which varied little from the present day stable channel grade, indicated that downward cutting of the stream bed during the period of landscape evolution that produced the terraces may have reached a stable period for each terrace level. The upper set of three terraces included levels 3 to 5. These terraces formed a closer group than the total series of terraces with respect to south to north and west to east drop in elevation (Figure 3). Levels 1 and 2 were slightly more eradic and contained sections of somewhat greater stream entrenchment which produced greater separation of individual levels within short 5 to 20 km reaches. Each site sampled did appear to represent a major level change from other sites on the same transect. Relatively complete and obvious separation of levels and lack of major zones of close transition indicated that no more than five major terrace levels probably existed in the study area. One or two minor benches were observed within the lower two terraces, but at slightly higher or lower elevations than the major level being sampled. It was assumed that these minor

Figure 3.

West to East Grade on Individual Terrace Levels

(Points plotted for terrace levels = site elevations)



benches typified the stage of genesis for the major terrace level to which they belonged. Locating the major levels was done by sighting upstream and downstream and also observing significant drops in elevation along the individual transects.

Analysis of Clay Free Silt and Sand

Analysis of clay free silt and sand indicated that 17 of the 21 sites sampled contained a profile discontinuity (Appendix A). The mean depth of the discontinuity was 94.1 cm.

The modal particle size above the discontinuity was coarse silt (Figures 4 and 5). The portion of the pedons above the major discontinuity was assumed to be uniform for the purpose of comparing means of selected genetic properties such as depth and thickness of the argillic, pH, and carbonate distributions among levels or transects. The assumption of significant uniformity was based upon the unimodal coarse silt particle size distribution for all horizons above the discontinuity. Analysis of variance also indicated no significant differences among levels or transects for the clay free silt of the argillic horizons. Clay free silt content of the argillic horizons had an overall mean of 68.9 %, a standard error of 13.2

Figure 4.

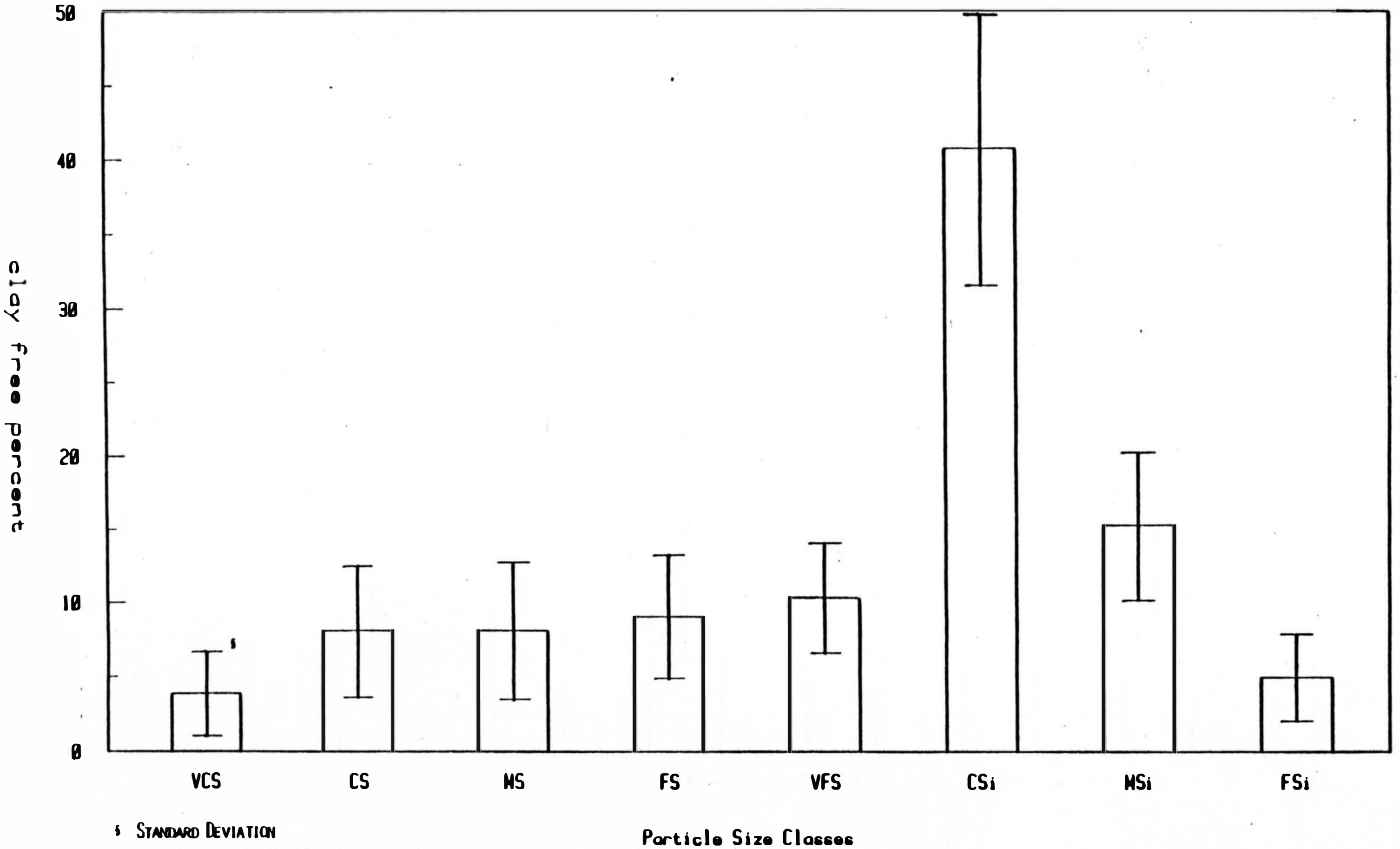

Particle Size Means over Study Area
All horizons within 0-50 cm from the soil surface
clay free percent
50
40
30
20
10
0
VCS
CS
MS
FS
VFS
CSi
MSi
FSi
s
s STANDARD DEVIATION
Particle Size Classes

Figure 5. Particle Size Means over Study Area

All horizons >50 cm from the soil surface
but above the profile discontinuity

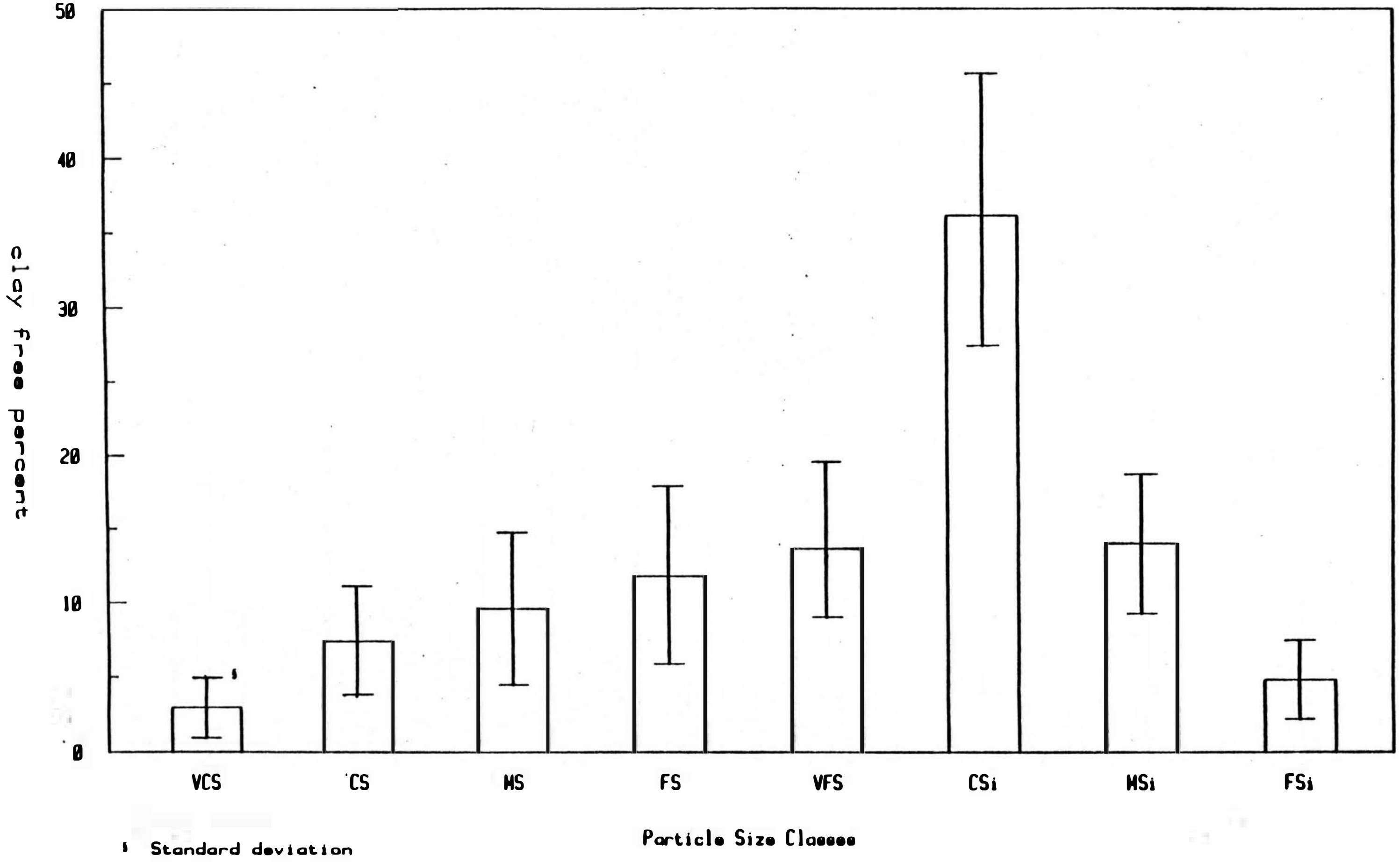
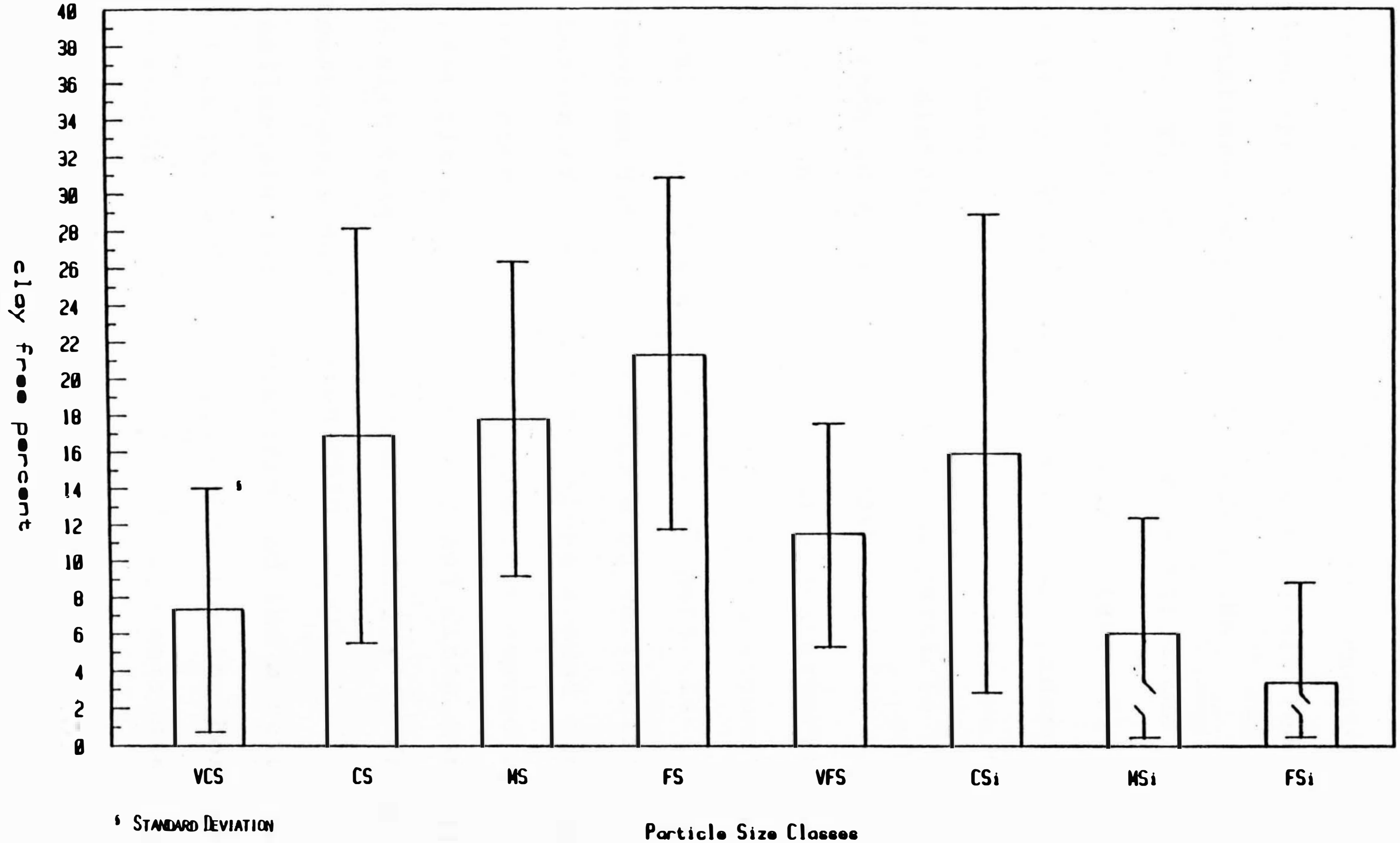


Figure 6. Particle Size Means over Study Area

All horizons below the discontinuity



and a coeffiecent of variation of 9.7.

Clay free silt and sand particle size fractions of horizons below the profile discontinuity exhibited larger standard deviations than fractions above the discontinuity. The modal particle size below the discontinuity trended toward fine sand (Figure 6). Data compiled by Allen (1970) showed that water transported and deposited sediments became more variable relative to particle size distribution as the modal particle size went from a silt mode to a sand mode. Sediments with a modal particle size in the silt fraction were characterized by a normal distribution of other particle sizes around the silt mode, while sediments with a modal particle size in the sand fraction had a higher degree of variability in the distribution of other particle sizes around the sand mode. If the water velocity was such that coarse silt was the modal particle size, then coarser and finer particles than coarse silt tended to decrease gradually in frequency from the coarse silt mode (Allen 1970).

The smaller standard deviations and the more uniform transition from the modal particle size for the horizons above the discontinuity (Figure 4 and 5), contrasted with the less distinct mode and larger standard deviations for horizons below the discontinuity (Figures 6) followed Allens conclusions on sorting.

Figure 7. By Level Differences in Fine Sand

Means for 3 depth separations on each level

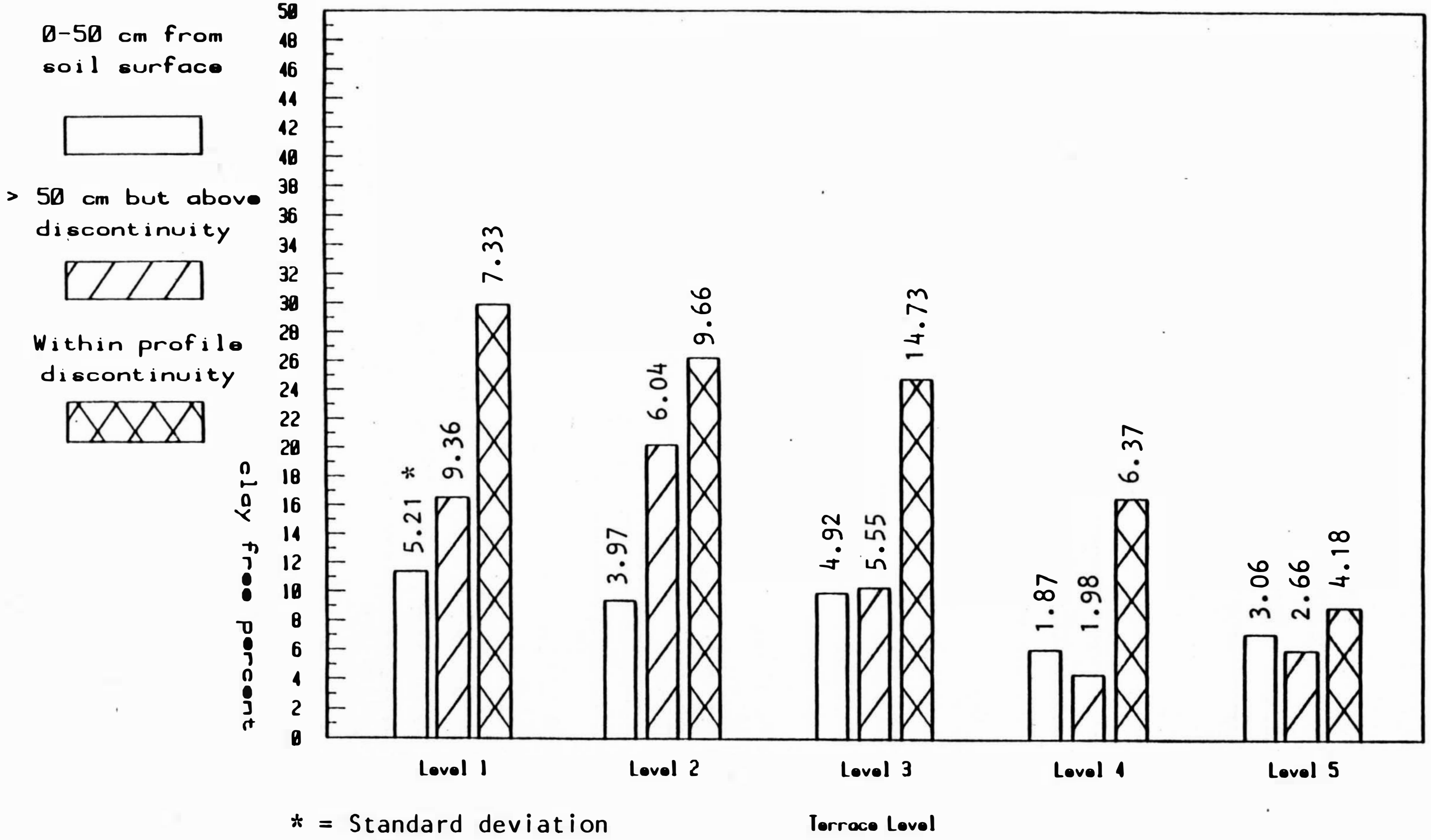


Figure 8.

By Level Differences in Coarse Silt

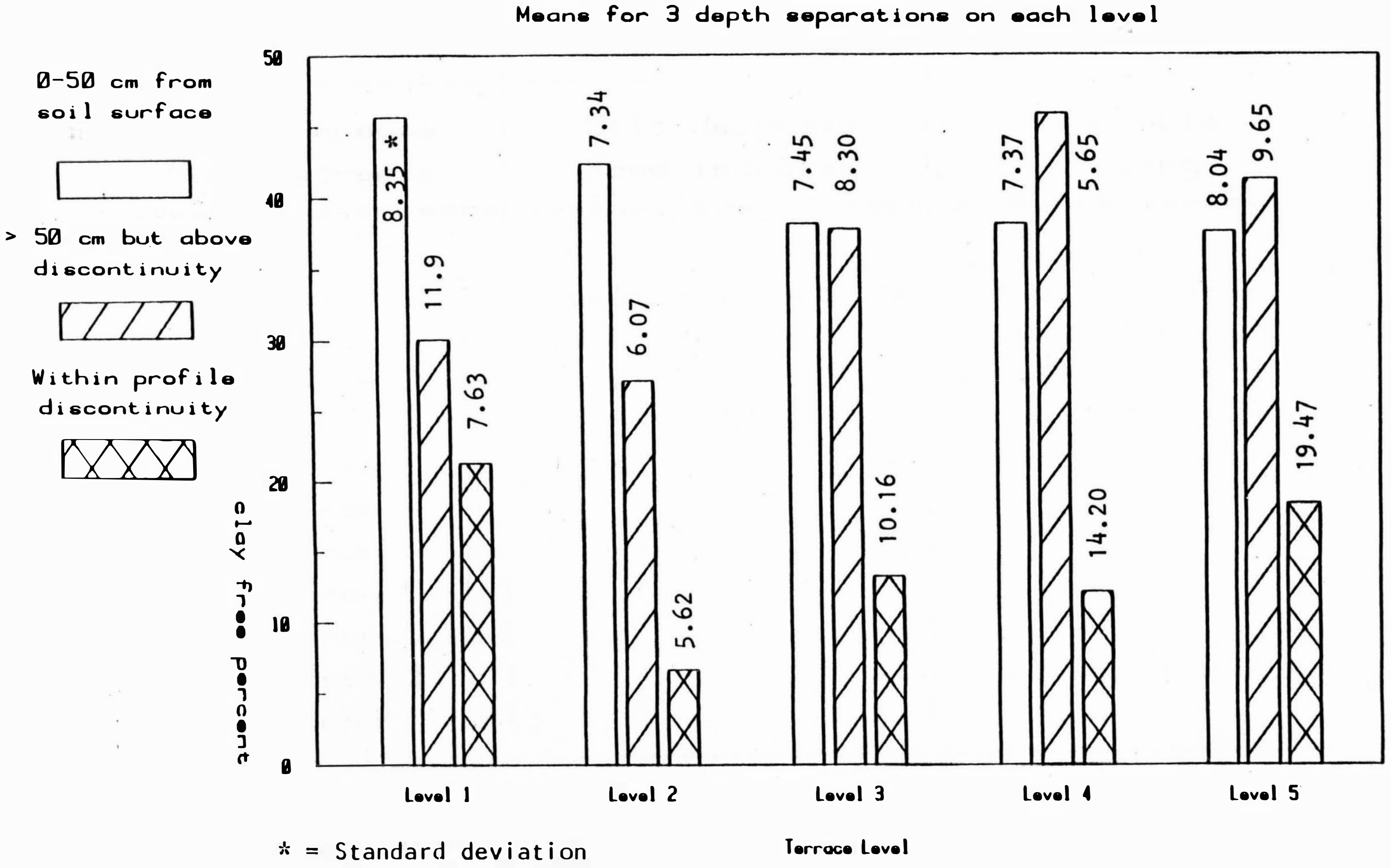


Table 2. Sand and Silt Sorting within a Profile

Type of Sorting from Discontinuity to Soil Surface		
Silt increase Sand decrease	Silt decrease Sand increase	Variable Sorting
Level 1 Tran 1 a	Level 3 Tran 6 b	Level 3 Tran 2 a
Level 1 Tran 3 b	Level 4 Tran 5 ba	Level 3 Tran 3 ba
Level 1 Tran 5 b	Level 4 Tran 6 b	Level 4 Tran 2 a
Level 1 Tran 6 a	Level 5 Tran 5 ba	Level 4 Tran 3 a
Level 2 Tran 1 b	Level 5 Tran 6 b	Level 5 Tran 3 a
Level 2 Tran 3 b		
Level 2 Tran 5 ba		
Level 2 Tran 6 b		
Level 3 Tran 1 b		
Level 3 Tran 5 a		
Level 5 Tran 1 b		

a = Fine-silty control sections
b = Fine-loamy control sections
ba = Fine-loamy control sections but > 26 % clay, > 52 % silt, and < 22 % sand which makes these pedons border line to Fine-silty control sections.

Within Profile Sorting

A comparison of sorting within pedons on the basis of coarse silt and fine sand indicated a uniform decrease in coarse silt and increase in fine sand with increasing pedon depth for levels 1 and 2 (Figures 7 and 8, Table 2). Levels 3, 4, and 5 followed similar trends but with less uniformity (Figures 7 and 8, Table 2).

The upper three terrace levels were also charaterized by broader terrace surfaces such as the Milesville flat of transect 3 and Robbs Flat of transect 6. This was probably due to lateral planing of the Cheyenne River during periods of limited down cutting which served to introduce more variability in particle size through shifting zones of deposition and reworking of the floodplain surface. Flooding of subsidiary basins and their interconnection after submergence was probably common on all levels. The broad flats of the upper terrace levels provided these conditions on a larger scale. Sediments could have been reexposed or covered depending on the position of newly forming and old low relief alluvial ridges, meander channels, and micro relief lows and highs. This could have resulted in the differences in profile sorting that are indicated in Table

2 and given in more detail in Appendix A. Gradual northward lateral planing of the Cheyenne River during deposition of sediments was supported by the broad terrace flats and uniform depth of sediments above the coarser soil material discontinuity. The terrace system was also less defined north of the Cheyenne River on the bank opposite the study area. This may have occurred for two possible reasons. Northward lateral planing would have undercut and removed terrace sections on the north bank and opposite the study area. As a secondary result, runoff would have dissected the north bank terraces on a steeper less stable front slope. Secondly, the south facing slopes of the north bank would be less stable because of lower soil moisture conditions and plant cover making them more susceptible to soil erosion.

In general most of the profiles show characteristics of material deposition in an alluvial environment of decreasing stream velocity (Appendix A).

Parent Material Mineralogy

The dominant mineral in the 1000 to 500 micron particle size range (coarse sand and medium sand) for all horizons was quartz which comprised, on average, 90.4 % of the total. Feldspars made up approximately 3 % of the total (Appendix B).

Argillic Horizon Characterization

Clay films on peds in the argillic horizon were identified as pressure faces based on thin section analysis. Thin films did however, permeate the soil matrix and coated coarse grains viewed under a petrographic microscope.

Thin continuous pressure faces were present in the lower portion of Bt horizon. They were broken and less continuous in the upper portion of the argillic horizon because of destruction by pedoturbation due to the shrinking and swelling of clays with changing moisture conditions. The degree of ped face disruption was dependent upon the percent total clay and the distance of the argillic horizon from the soil surface. Argillic horizons closer to the soil surface underwent more frequent wetting and drying cycles. Clay content of the upper argillic horizon became an important factor in pedoturbation as a threshold value of 27 % clay on a weight basis was reached. This was indicated by the broken boundaries of pressure faces on peds and disruption of their vertical orientation.

Thin pressure faces in the Bt2 horizons indicated little pedoturbation and tended to be continous along prismatic structural unit ped faces.

Thin pressure faces in the Btk tended to be continuous along vertical ped faces and extended upward to the Bt2 along prismatic structural unit ped faces. This was especially true in profiles that had deep argillic horizons. Pressure faces in the Btk and deep Bt2 horizons also showed some orientation along horizontal ped faces with less clay coating of individual grains within the soil matrix (Appendix F).

Even though clay films were not prominent in the Bt horizons, the location of the zones of clay accumulation and carbonate accumulation within the pedons sampled served to identify the processes of accumulation as being genetic. The following simple correlations were used to characterize the development of the argillic horizon as a genetic process.

1. As the depth of the total clay bulge increased the pH of this zone also increased ($r = 0.60$), and the pH of the A horizon decreased ($r = - 0.43$).

2. The total percent clay of the clay bulge increased as the percent calcium carbonate in the zone of carbonate accumulation, below the clay, increased (r = 0.46).

These simple correlations indicated that translocated clay was moving in response to the redistribution of carbonates within the pedons sampled. Major zones of calcium carbonate accumulation were found below major zones of clay illuviation (Appendix D). This is supported by the general model of clay movement in soils in that a reduction of bases is first required for dispersion of clays and subsequent translocation to occur (Buol and Hole 1961).

Mollic Epipedon and Organic Carbon Values.

The mean depth for a moist soil color of 10YR 3/3 or darker was 37.7 cm with a minimum value of 12 cm and a maximum value of 82 cm. In general soil colors of 10YR 3/3 or darker corresponded to soil organic carbon values greater than 0.60 %. Organic carbon values, in the data summary Appendix G, of 0.56 % were essentialy considered as equal to 0.60 %. Only 5 % of the horizons had a soil color of greater than 10YR 3/3 with an organic carbon content lower than 0.60 %. Soil colors changed in chroma from 3 to 4 and 5 but stayed within the 10YR hue and color values of 3 or 4 when organic carbon values dropped below 0.60 %. A shift in the chroma from 3, to 4 or 5, was also influenced by the depth of the horizon from the soil surface. In other words when organic carbon values close to but less than 0.60 % were associated with deeper horizons the tendency was for chromas of 5 rather than 4 to dominate. Horizons closer to the surface with organic carbon values of less than 0.60 % tended toward chromas of 4. All pedons sampled, except for level 4 of transect 5 met the requirement for profile depth of 10YR 3/3 moist soil colors or darker and all pedons had organic carbon contents of 0.60 % or greater to meet mollic epipedon criteria.

Analysis of variance indicated that the terrace levels were not significantly different based on the maximum depth of organic carbon values of 1 % or greater ($F = 1.01$, $P \leq 0.44$, SE of the Mean = 16.2). This followed the expected trend in organic carbon values for soils with genesis periods greater than 200 to 3000 years. Organic carbon has been shown to reach a steady state within a relatively short time period (Parsons, Scholtes and Riecken 1962, Parsons Balaster and Ness 1970, Birkland 1974, VanVeen and Paul 1981, Sondheim and Standish 1983, Nichols 1984).

Moisture Holding Capacity

Regression analysis indicated that soil moisture held at 0.03 MPa, within the particle size range of the study area, was highly dependent on values for clay content and silt plus very fine sand. Soil moisture held at 1.5 MPa was highly dependent on values for clay content and organic matter. The actual values taken from pressure plate measurements were used in multiple linear regression analyses to generate equations 1 and 2. The equations were then used to develop predicted values for the horizons not measured with the pressure plate (Appendix C).

Moisture Content Equations
from Multiple Linear Regression

0.03 MPa Equation

$$0.03 \text{ MPa (mass basis)} = 0.032 + (\text{ Clay \%} * 0.336) + ((\text{ Silt + Very Fine Sand \%}) * 0.187)$$

$R^2 = 0.93$ (Equation 1)

1.5 MPa Equation

1.5 MPa (mass basis) = 1.02 + (Clay % * 0.339) + (Organic Carbon % * 1.37)

R^2 = 0.89 (Equation 2)

Organic carbon was considered more important than silt plus very fine sand in predicting moisture retained at 1.5 MPa. The smaller particle size of organic matter relative to silts and very fine sand produced more total pore space as well as smaller pores. The effect of smaller pores enabled organic matter to retain more moisture than silt plus very fine sand at equal soil matric potentials. This is especially true as the soil becomes dryer.

Silt plus very fine sand was slighty more important than organic matter in predicting the moisture content at 0.03 MPa than at 1.5 MPa.

Modal Pedon

The type of pedon horizonation and individual horizon properties such as thickness, depth, color, structure, texture, effervescence, and the kind of boundary between horizons were used to develop a modal pedon description. In terms of the kind of profile horizonation, all pedons sampled deviated little from the modal pedon. Recognized deviations in horizonation from the modal pedon included the combination of A horizons into an Ap horizon for cultivated pedons and a trend for the absence of a Btk horizon in those pedons from terrace levels 1 and 2 (Appendix F).

The horizon properties indicated in the modal pedon represent overall averages based on all pedons sampled. Some properties were represented equally by two values, in this case both values were indicated in the modal pedon description. For example, the texture of the A1 horizon was equally represented by loam or silt loam surface textures.

Thin clay films reported during sampling in the field were not supported by thin section analysis. It was assumed that pressure faces on peds were much more common than clay films caused by translocated clays. The upper portion of many Bt1 horizons showed signs of pedoturbation. Pressure faces in all Bt horizons below the Bt1 were continous on vertical ped faces.

A1 - 0 to 7 cm; dark gray brown 10YR 4/2 dry color; very dark gray brown 10YR 3/2 moist; loam or silt loam; moderate thin and medium platy structure parting to weak fine granular; no effervescence; clear smooth boundary.

A2 - 7 to 17 cm; dark gray brown 10YR 4/2 dry color; very dark gray brown 10YR 3/2 moist; loam or silt loam; weak medium prismatic structure parting to weak fine and medium subangular blocky; no effervescence; clear smooth boundary.

Bt1 - 17 to 39 cm; dark gray brown 10YR 4/2 dry color and very dark gray brown 10YR 3/2 moist; or brown 10YR 5/3 dry and dark brown 10YR 4/3 moist; loam; moderate medium prismatic structure parting to moderate fine and medium subangular blocky; no effervescence; clear wavy boundary.

Bt2 - 39 to 60 cm; brown 10YR 5/3 dry color; dark brown 10YR 4/3 or dark brown 10YR 3/3 moist; loam; moderate medium prismatic structure parting to moderate fine and medium subangular blocky; no effervescence; clear wavy boundary.

Btk - 60 to 91 cm; brown 10YR 5/3 dry color and dark brown 10YR 4/3 moist; or light brown 10YR 6/2 dry color and brown 10YR 5/3 moist; loam; weak medium prismatic structure parting to moderate fine and medium subangular blocky; violent effervescence; gradual wavy to clear wavy boundary; few to common fine and medium soft lime accumulations.

Bk - 91 to 119 cm; pale brown 10YR 6/3 dry color; 10YR 5/3 moist; loam; weak medium prismatic structure parting to weak medium subangular blocky; violent effervescence; gradual wavy boundary; few to common medium soft lime accumulations.

2C - 119 to 156 cm; very pale brown dry color and light gray moist; or pale brown 10YR 6/3 dry color and brown 10YR 5/3 moist; coarse sand; violent effervescence; few fine soft lime accumulations.

Soil Development Over Time

Calcium carbonate distribution and pH.

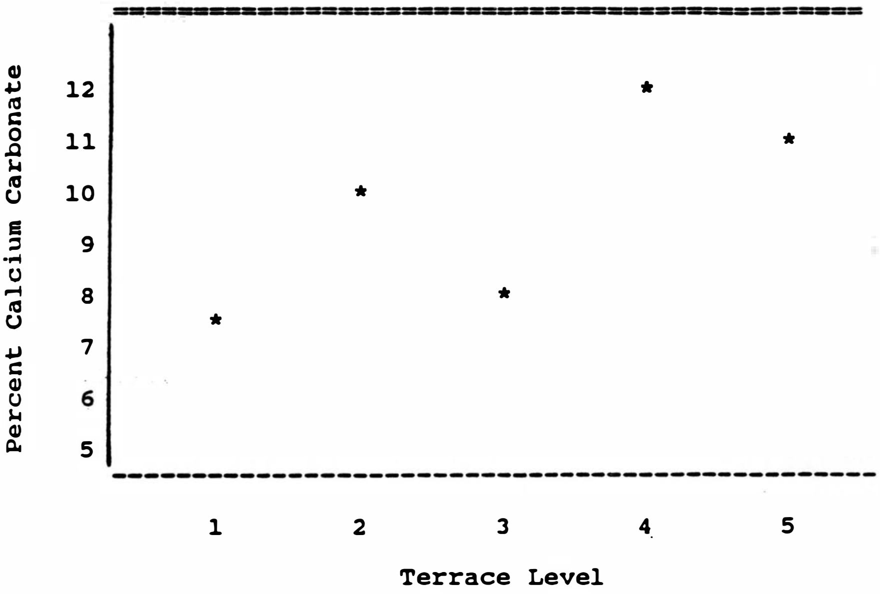
Differences among levels in the depth to the upper boundary and the depth to the lower boundary of the horizon of maximum calcium carbonate accumulation were not significant based on analysis of variance ($P \leq 0.48$ for upper boundary, $P \leq 0.21$ for lower boundary). Calcium carbonate distributions indicated that the depth to a coarser textured profile discontinuity was a primary factor in the establishment of the lower boundary of the horizon of maximum calcium carbonate accumulation (Appendix D). The upper boundary of the horizon of maximum calcium carbonate accumulation should be a more reliable indicator of differences over time than the lower boundary. This was based on the assumption that the upper boundary was not subject to restricted water movement due to changes in capillarity like the lower boundary. Because differences among terrace levels in the upper boundary of the horizon of maximum calcium carbonate accumulation were not significant, all levels were considered to be at similar states in the thickness and depth of the zone of maximum calcium carbonate accumulation.

The percent calcium carbonate in the horizon of maximum calcium carbonate accumulation was significantly different among terrace levels ($P \leq 0.09$). The trend in the percent calcium carbonate in this horizon indicated an increase in this property over time (Figure 9). Variation in the values from a more straight line relationship were probably due to slight differences in initial calcium carbonate content, soil texture, and the fact that this property during development moves toward a steady state condition. Even though clay free silt and sand content were not significantly different among terrace levels ($P \leq 0.77$) or transects ($P \leq 0.34$), it was believed that subtle differences in silt content affected the rate of calcium carbonate accumulation and the percent calcium carbonate in the horizon of maximum calcium carbonate accumulation. Clay free silt of the control section had a positive simple correlation with the percent calcium carbonate in the horizon of maximum calcium carbonate accumulation ($r = 0.56$).

The relationship of texture to calcium carbonate accumulation had at least two contributing factors.

1. Initial calcium carbonate values of the parent material could increase, during deposition, as parent material silt content and composition increased. Smith (1942) indicated that the calcium carbonate content of

Figure 9. PERCENT CALCIUM CARBONATE IN THE ZONE OF MAXIMUM ACCUMULATION



loess was correlated with the modal particle size of the loess. He hypothesized that finer size loess (fine silts and coarse clays) contained lower percentages of calcium carbonate than coarser loess (medium and coarse silt) due to the preferential deposition of calcium carbonate particles with coarse and medium silts. White (personal communication White 1986), based on Smith (1942), suggested that the calcium carbonate content of the terrace parent material could increase as the silt content increased because some of the terrace parent material has been derived from prior deposited starta within the Cheyenne River watershed that contained calcareous loess.

2. Calcium carbonate had a tendency to accumulate above the major profile discontinuity. As textures above and below the discontinuity became more contrasting, changes in capillarity restricted downward movement of soluble minerals favoring their precipitation due to their subsequent increased concentration. These textural differences (Table 2), would have affected the rate of carbonate movement over time but were probably not great enough to completely mask the overall trend for an increase in the percent calcium carbonate in the horizon of maximum accumulation (Figure 9).

Calcium carbonate morphology supported the trend for accumulation of carbonates in the form of soft lime accumulations over time. Profile descriptions indicated that soft lime accumulations separate the terrace levels into two groups. Levels 1 and 2 form the first group and levels 3, 4, and 5 form the second group (Appendix F). Soft lime accumulations tended to be few and fine, interconnected, thread like filaments oriented along vertical ped faces in the pedons of levels 1 and 2. The soft lime accumulations of the second group tended to develop zones of maximum morphological expression within the upper portion of the Bk and Btk horizons. The soft lime accumulations tended to be more common and larger in these zones. Orientation along horizontal ped faces was also more common in the older group made up of levels 3, 4, and 5. These differences in carbonate morphology indicated that the second terrace group developed over a longer period of time than the first group.

Similar changes, over time, in calcium carbonate morphology have been reported in research on desert soils (Gile, Peterson, and Grossman 1966).

Changes in pH over time.

Significant differences among terrace levels for the pH of the A horizon ($P \leq 0.01$) and pH of the horizon of maximum fine clay accumulation ($P \leq 0.005$) were found to exist.

Surface pH's decreased as terrace age increased (Figure 10). This same trend in pH values existed within the horizon of maximum fine clay accumulation (Figure 11). Both these trends followed logical directions relative to their development over time. The slight increase in the trend for the pH of the zone of maximum fine clay accumulation for level 5 is unaccounted for. The higher pH may be related to chemical weathering factors that reach expression as the reduction in pH of the A horizon reaches a threshold value. For example, it is known that calcium carbonate is mobile within a profile. The direction of movement is dependent on the moisture and temperature regime (Arkley 1963, Jenny 1980). Processes of depletion or accumulation occur rapidly relative to the rate of

Figure 10. A HORIZON pH BY TERRACE LEVEL

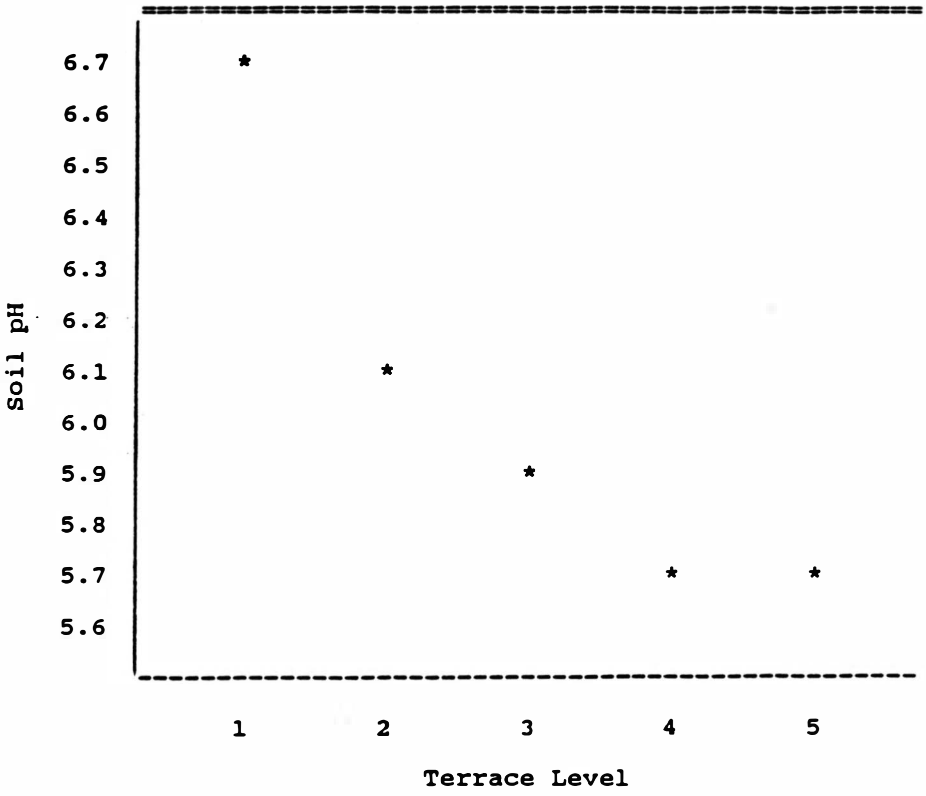
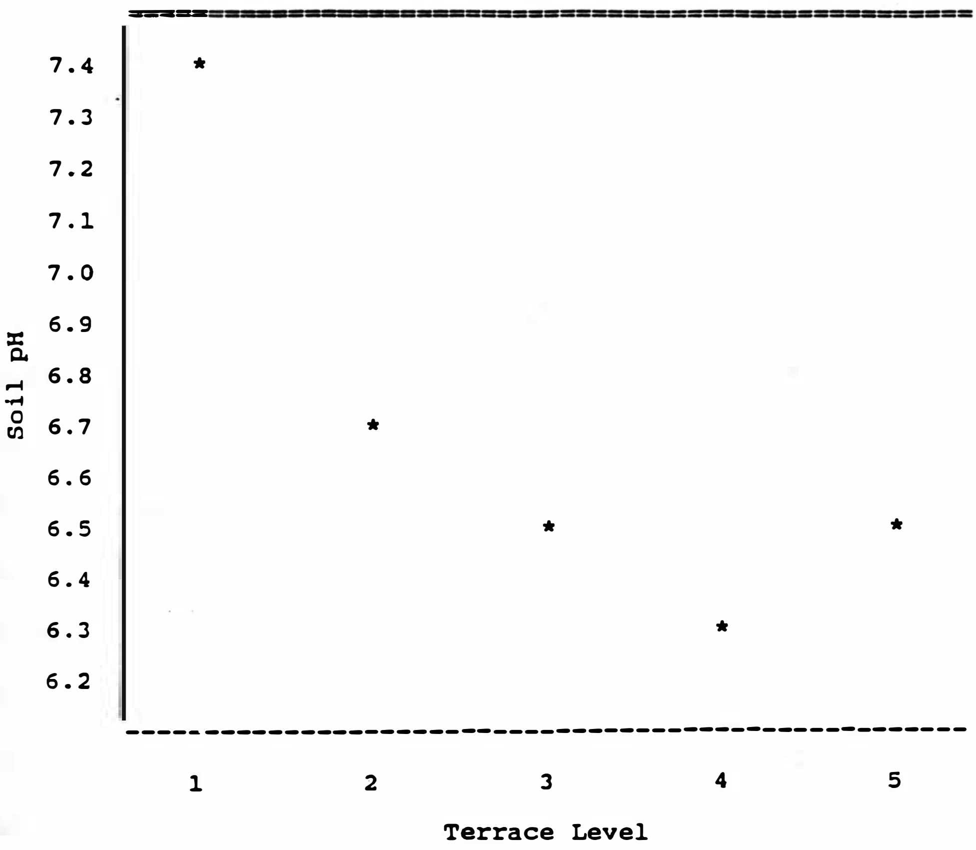


Figure 11. SOIL pH IN THE ZONE OF MAXIMUM FINE CLAY ACCUMULATION



other genetic properties. Thus, the increase in the pH value of the zone of maximum fine clay accumulation for level 5 could be due to a slight increase in bases and hydroxyaluminum ions produced by the weathering of clay minerals in the A horizon after initial parent material bases have been leached. Level 4 may be just reaching the threshold pH value in the A horizon for the chemical weathering of clays and the leaching of weathering products to become significant.

Level 5, being the oldest level, may be reflecting a response to the chemical weathering of clays in the A horizon. This would result in the substitution of translocated bases and hydroxyaluminum ion weathering products for hydrogen ions on the exchange complex of clays in the Bt horizon. Hydroxyaluminum ions may also be blocking exchange sites by forming amorphous coatings on clay particles and in so doing reducing the exchangable hydrogen related to the clay particle and soil solution hydrogen ion concentration balance (Seatz and Peterson 1964). Microscopic investigation of Bt horizons from all the pedons sampled indicated coatings suspected as being iron oxides on sand grains for all terrace levels. It follows that these coatings could also be associated with finer particles. No quantitative measure of oxides of aluminum or iron was made.

The slight increase in the pH of the zone of maximum fine clay accumulation for level 5 could also be related to weathering and accumulation of clay minerals from 2:1 montmorillonitic clay minerals to 1:1 kaolinitic clay minerals in the Bt horizon. Similar percent base saturations produce higher pH values in a kaolinitic clay mineral system than that of a montmorillonitic clay or organic system (Seatz and Peterson 1964). Lower exchange capacity systems require fewer bases in the soil solution to replace a larger amount of exchangable hydrogen, on a percent bases of the total exchange capacity. The balance between the inner layer and outer layer ions, of the clay particle and soil solution system, should then contain fewer hydrogen ions to be measured by potentiometric methods.

Argillic horizon development over time.

No significant differences among terrace levels were indicated by the depth to the horizon with the maximum total clay ($P \leq 0.93$) and the depth to the horizon of maximum fine clay ($P \leq 0.40$)(Table 3).

Significant differences among levels were indicated for the thickness of the argillic horizon ($P \leq 0.13$) and for the depth or maximum extension of the argillic horizon

Table 3. SELECTED ARGILLIC HORIZON PROPERTIES
ANALYSIS OF VARIANCE
TERRACE LEVEL COMPARISONS

PROPERTY and PROBABILITY	PROPERTY MEANS BY TERRACE LEVEL				
	1	2	3	4	5
Depth of total clay bulge. (CM) ($P \leq 0.93$)	61	55	53	59	60
Depth of fine clay bulge. (CM) ($P \leq 0.40$)	45	55	50	43	54
Thickness of the argillic horizon. (CM) ($P \leq 0.13$)	49	54	59	84	70
Depth of the argillic horizon. (CM) ($P \leq 0.07$)	65	72	80	106	90

A probabilty of ≤ 0.15 was considered as indicating a significant difference.

($P \leq 0.07$) (Table 3). A trend of increasing values in the thickness and depth of the argillic horizon from lower terrace levels to higher terrace levels indicated a logical direction of development of these properties over time (Table 3). A lower value for the argillic horizon thickness and depth on terrace level 5 relative to terrace level 4 was unaccounted for but the least square means table did indicate that level 4 and 5 were not significantly different (Bt thickness $P \leq 0.33$, Bt depth $P \leq 0.26$). Differences in capillarity in the horizons above the discontinuity could also, in part, be responsible for argillic horizon variations in thickness and depth due to restricted downward movement inhibiting the translocation of clay. This restricted development could be seen on the other terrace levels but because the argillic horizon had not moved deep enough into the profile on the other levels it was a more important factor in interpreting the depth and thickness of the argillic horizon on terrace levels 4 and 5. For properties that develop rapidly such as carbonate leaching, the depth to the major profile discontinuity affected all the pedons studied (Appendix D).

The trend for a decrease in the fine clay to total clay ratio in the A horizon and an increase in the difference between the argillic horizon fine clay to total clay ratio minus the A horizon fine clay to total clay ratio supported the assumption that the amount of translocated fine clay had increased over time (Table 4). The ratios were determined based on a weighted average for the clay content of the argillic horizon, which took into account the thickness of the argillic horizon as well as the percent total clay and fine clay. The A horizon and argillic horizon ratio differences were consistant with what would be expected as soils develop over time (Barshad 1957, Birkland 1974). The F tests however, indicated that the means for these properties were not significantly different (Table 4). A T test for the preplanned comparison of the means for the argillic horizon fine clay to total clay ratio minus the A horizon ratio was used to test differences between terrace level 1 and 5. Since only this preplanned pairwise comparison mentioned above was made, in an effort to bracket the genesis period, the lack of a significant F (Table 4) involving all means was not considered a critical prerequisit for the use of a least square means comparison (Steel and Torri 1980). Terrace level 5 was considered significantly different from level 1 based on this pairwise comparison ($P \leq 0.12$).

Multivariate analysis of variance supported the separation of the terraces over time by the use of selected genetic properties for among level comparisons.

TABLE 4. FINE CLAY TO TOTAL CLAY RATIOS BY LEVEL COMPARISON

PROPERTY and PROBABILITY (F)[&]	MEANS BY TERRACE LEVEL				
	1	2	3	4	5
A horizon fine clay to total clay ratio. (P $\leq$ 0.36)	0.58	0.59	0.51	0.55	0.51
Argillic horizon fine clay to total clay ratio. (P $\leq$ 0.48)	0.64	0.63	0.61	0.62	0.66
Argillic horizon ratio minus A horizon ratio. (P $\leq$ 0.35)	0.06[£]	0.04	0.10	0.07	0.15[£]

& = Probability values for a significant F shown above that are larger than (P = 0.15) were considered as indicating a non-significant difference.

£ = Pairwise means comparison of terrace level 1 and 5 argillic horizon fine clay to total clay ratio minus A horizon ratio had a T test value which indicated a significant difference in least square means (P $\leq$ 0.12).

This analysis provided a discriminate function multiplier for each genetic property in the model (Table 5). The value of the discriminate function, when solved for each terrace level, provided a logical trend from which separation of the terrace levels due to the genesis time factor was inferred (Table 6). The four variable multivariate model was considered more useful than than univariate analysis of variance because Roy's maximum root criterion (F = 10.7), the test statistic in multivariate analysis, was greater than the highest individual F value in univariate analysis of variance (F = 5.5). The lower F value applied to the by terrace level comparison of the pH of the A horizon. Terrace level 4 had a lower discriminate function value than terrace level 5, this was probably due to the influence of the shallower soil material discontinuity on terrace level 5 in limiting the extension of the argillic horizon.

Estimated Soil Age

Development of the Missouri River trench has been reported by Crandell (1953), Warren (1952), Flint (1955), and White (1964). White concluded that the Missouri River was created during the Wisconsin glacial period.

Table 5. MULTIVARIATE ANALYSIS OF VARIANCE DISCRIMINATE FUNCTION VALUES BY TERRACE LEVEL

Multivariate Model Variables	Function Multiplier	Genetic Property Means By Terrace Level				
		1	2	3	4	5
Upper Boundary of Calcium Carbonate Accumulation (cm)	0.01	72.2	77.2	63.7	74.2	66.2
Depth to Maximum Clay Accumulation (cm)	-0.005	61.0	55.3	53.5	59.5	59.8
Maximum depth of Argillic horizon (cm)	-0.1	64.5	72.5	80.0	106.8	90.0
The A Horizon pH	0.83	6.7	6.1	5.9	5.7	5.7

Table 6. MULTIVARIATE ANALYSIS OF VARIANCE
VALUE FOR
DISCRIMINATE FUNCTION SOLVED BY TERRACE LEVEL

Terrace Level	Discriminate Function	Function value
1	(0.01 * 72.2) + (-0.005 * 61.0) + (-0.01 * 64.5) + (0.83 * 6.7) =	5.4
2	(0.01 * 77.2) + (-0.005 * 55.3) + (-0.01 * 72.5) + (0.83 * 6.1) =	5.0
3	(0.01 * 63.7) + (-0.005 * 53.5) + (-0.01 * 80.0) + (0.83 * 5.9) =	4.6
4	(0.01 * 74.2) + (-0.005 * 59.5) + (-0.01 * 106.8) + (0.83 * 5.7) =	4.2
5	(0.01 * 66.2) + (-0.005 * 59.8) + (-0.01 * 90.0) + (0.83 * 5.7) =	4.3

Test statistic for the multivariate model was Roy's Maximum Root Criterion (F = 10.7).
The pH of the horizon with maximum fine clay accumulation was the genetic property used in the 5 variable multivariate model that had the highest F value in univariate analysis of variance (F = 7.03)

The other authors mentioned above considered the development of the trench to have occurred during the Illinoian glacial period. All these authors indicated that the Missouri River trench formed on the western margin of glacial ice.

The data in this study seem to support the conclusion of White (1964) that the terraces were isolated during Wisconsin glaciation. The following points, while by themselves not conclusive, contributed to this conclusion.

1. The order of terrace level separation based on the use of selected genetic properties in multivariate analysis of variance (Table 6).

2. Soil color, indicated that the terrace soils were probably not Illinoian in age. It seems likely that the soils would have developed slightly redder hues if they had been subjected to weathering during the Sangamon inter-glacial period. This inter-glacial period was characterized by warm-dry conditions throughout the Great Plains. Long cool-wet intervals occurred after the Illinoian glacial age ended and during the onset of the Wisconsin ice age (Bluemle and Clayton 1982).

3. The Sangamon period was also characterized by intervals of tens of thousands of years of aeolian activity on the Great Plains (Bluemle and Clayton 1982). The parent material of the terrace soils did not support a theory of deposition in an aeolian environment.

4. If the pedons sampled had developed since the end of Illinoian glaciation, which would roughly mean 300,000 to 390,000 ybp (Ericson and Wollin 1968), there would have been little or no distinction between terrace levels based on the depth and thickness of the argillic horizon. We could expect that the genesis of these properties over such a great time period would have reached a steady state well within 300,000 ybp. Secondly the effect of paleoclimate over such a long period would have provided sufficient periods of time for translocation of clays into the discontinuity or at the very least concentrate them directly above the discontinuity.

5. The difference in the argillic horizon fine clay to total clay ratio minus the A horizon fine clay to total clay ratio for the comparison of terrace level 1 to level 5 indicated differences in these levels that probably would not exist over genesis periods extending to Illinoian time.

6. The differences and the trends for by terrace level comparisons of the percent calcium carbonate in the zone of maximum accumulation, A horizon pH, and pH of the zone of maximum fine clay accumulation probably would not have persisted if the genesis period had exteded to Illinoian time. These properties have generally been considered to develop steady state conditions over short periods of time (Birkland 1974 and Bockheim 1980).

The reasoning in the preceding points does not completely preclude the development of the Missouri River trench during Illinoian time, but, it lends very little support and favors White's (1964) Wisconsin ice age conclusion. This reasoning almost eliminates the possibility that the terrace surfaces were stable over a 300,000 year period, since terrace levels could still be separated based on argillic horizon properties. The development of an argillic horizon did indicate that the landscape had been stable for a period greater than a few thousand years.

Large water channels in southern Saskatchewan, Canada and northern North Dakota that are tributaries to the Missouri River have been carbon dated as having existed 17,000 ybp (Christiansen 1979). Since these channels were created during a recessional phase in Wisconsin glaciation and drainage channels to the south had to be developed, or were developed by carrying northern melt water from these northern tributaries, it was assumed that the Missouri River was already deeply entrenched by 17,000 ybp. Bluemel and Clayton (1982) indicated that the Little Missouri River in western North Dakota was intercepted by the Missouri River about 25,000 ybp and Wright and Frey (1965) indicated that the maximum extension of Wisconsin age ice occurred between 27,900 to 38,000 ybp. The lowering of the base level of the Cheyenne River from terrace level 1 to its present floodplain position probably occurred as the Missouri River went through the entrenchment process along the western margin of this Wisconsin Glacial Age ice.

Because the terrace levels can be separated on the basis of Bt thickness and depth, and these properties reach steady state conditions in a matter of thousands of years or tens of thousands of years, it is believed that soil genesis on the lower terrace surface probably started less than 27,900 ybp using the upper limit estimate of Wright and Frey (1965). The value for the difference in the Bt horizon fine clay to total clay ratio minus the A horizon fine clay to total ratio indicated that terrace level 1 differed from terrace level 5 by a factor of 2.3. Since the slope of the line for accumulation of fine clay in the Bt horizon over time has been generally considered to be less steep as the soil ages, Birkland (1974), a direct age difference could not be calculated from the ratio differences. Speculation was that the ratio indicated a time period between terrace (level 1) and the oldest terrace (level 5), of not less than 2.3 times the age of the younger group if there was a straight line relationship between time and clay translocation. We knew that during early development of an argillic horizon this may be true but that the process of translocation decreases over time. If we gave the lower levels a minimum genesis period of 27,900 years then the older level could have started soil genesis 64,170 years ago. It was believed that 27,900 years was ample time for clay translocation to reach a point at which the rate of clay accumulation would have begun a progressive decrease (Barshad 1957, Lessig 1961, and Birkland 1974). This meant that the terrace levels older than level 1 could be older than a straight line relationship implied. Paliocliamate climate and vegetation producing a boreal forest condition, on the other hand, would have accelerated clay translocation on the older terraces. The estimated age bracket of 27,900 ybp to 64,000 ybp fits well into one of the major cold periods predicted to have occurred during the Wisconsin Ice Age. This period reached its coldest peaks between 25,000 to 90,000 ybp on a generalized climate curve (Ericson and Wollon 1968). Because the terrace levels indicated significant differences among each other, and logical trends for those differences existed in the thickness and depth of the argillic horizon, calcium carbonate accumulation in the Bk, pH in the A horizon, and pH in the zone of maximum fine clay accumulation it was believed that terrace levels 1 through 5 could not be older than 100,000 years. This assumption is based on the fact that Sangamon age soils and older are difficult to separate on the basis of argillic horizon thickness, depth, and the percent translocated clay (Birkeland 1974). In other words, a genesis period greater than 100,000 years would probably have brought these properties too close together morphologically to separate terrace levels by analysis of variance. Estimates for the origin of the Missouri River trench during the Illinoian ice age would mean that the soils would have to be 390,000 years old or older (Ericson and Wollin 1968).

Lateral corration and development of broad flats on terrace levels 3, 4, and 5 contrasted with the narrow surfaces of terraces 1 and 2 could have indicated that base level adjustments in the east flowing streams, that originated in western South Dakota, occurred in stages as Wisconsin ice approached its maximum westward extension.

Uniform particle sorting and the lack of broad flats on terrace levels 1 and 2 indicated that the residence time for the floodplain when at these lower levels was shorter than for the upper terrace levels. In other words down cutting was occurring at a faster rate than lateral corration when the lower two terraces were formed. The primary influences governing the rates of down cutting and corration were assumed to be related to the period of time it took glacial ice to reach a westward position and the type of bedrock control affecting entrenchment at that position.

Based on the preceding evaluation, a minimum age of 27,900 years ± 3,000 for terrace level 1 and a maximum age of 64,000 to 90,000 ybp for terrace level 5 seemed to be a reasonable estimate of genesis time. The 27,900 year limit being based on Wright and Frey's (1965) estimate for the maximum extension of Wisconsin age ice.. The 64,000 year limit was based on the fact that argillic horizon property separations could still be made statistically among terrace levels. This precluded an Illinoian age for the complete terrace series. If the terrace series had been isolated earlier then differences in argillic horizon properties would probably not have existed do to an extremely long genesis period. The pleistocene climatic record established by Ericson and Wollin (1968) indicated an early major Wisconsin ice phase at 150,000 ybp was followed by glacial retreat and a second later major phase which was used for the upper age limit in this study.

Land Use Relationships to Soil Genesis

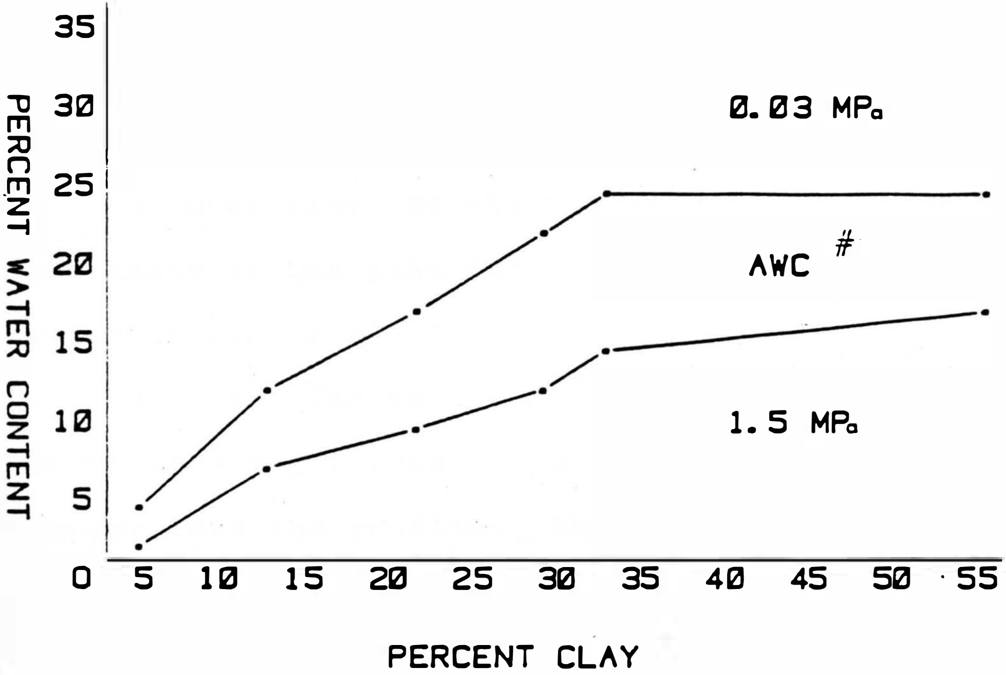
Agriculture comprised almost all of the present day land use within the study area. Crop production consisted of small grain dominated by winter wheat but included barley, oats, and some rye and spring wheat. Grain sorghum, sunflowers, corn, and introduced and native pasture were also found within the study area. The high terrace series is the only area on which non-irrigated corn has been cropped, within a large area including the surrounding shale uplands, with some assurance of a harvestable crop. The study area cropping patterns were in sharp contrast with the surrounding uplands on which soils had developed from Cretaceous shale and were dominated by native range land use.

Soil infiltration rate and available moisture holding capacity were the primary factors controlling the differences in cropping patterns.

The shale derived soils had higher moisture holding capacities because of their high clay content but their range in available moisture was lower than the alluvial terrace soils. The shale derived soils, as a result of their high clay content, also had much slower recharge rates because of their very slow infiltration rate. Readily soluble sodium salts in areas on the shale landscape also reduced available water through osmotic relationships between the plant and the soil solution.

The soils developed on the river terraces within the study area, on the other hand, had more rapid infiltration rates and a wider range in available moisture holding capacity. These properties were related to the texture of the parent material. The particle size and moisture holding capacity relationship was demonstrated by sorting the horizons by lower to higher clay content then silt content and observing the concurrent increase in water holding capacity at 0.03 and 1.5 MPa (Appendix G). Multiple linear regression also indicated a high correlation of moisture holding capacity at 0.03 MPa with clay content and silt + very fine sand content (Equation 1). The moisture holding capacity at 1.5 MPa was highly correlated with clay content and organic matter content (Equation 2). A graphic illustration of the moisture holding capacity and available water indicated that the highest available moisture capacity occurs at a clay content of approximately 34 % (Figure 12). The table in Appendix C also indicated that 41 % of the horizons above the C horizon contained from 25 to 44 % clay. Of the horizons above the C horizon that qualify for a Bt horizon, 72 % contained between 25 to 44 % clay.

Figure 12.
MOISTURE CONTENT ON A MASS BASIS



AWC = Available water holding capcity

The following points are supported by the information given in the table from Appendix C;

1. Horizons above the Bt horizon tended to be slighty coarser textured and subsequently had higher hydraulic conductivity rates.

2. Most of the Bt horizons shown in the table from Appendix C were within the highest available moisture range indicated by Figure 12.

3. Over time, as the Bt horizon has increased in thickness it has also increased the cummulative available water holding capacity of the soil profile.

4. Over time as the Bt horizon has increased in depth, the major zone of water holding capacity has moved deeper into the profile. This extends the period that moisture is available to the plant because the profile does not dry out as readily from evaporation compared to profiles that contain their major water reserves closer to the soil surface.

5. The majority of the C horizons, being coarser textured than overlying horizons, tended to promote the condition of a free drained profile more readily than on the surrounding clay soils of the shale uplands. This allows farmers to complete spring tillage and planting operations early enough for spring planted crops to take advantage of the early season optimum moisture and

temperature periods of the ustic moisture regime of the area. This is a major factor in spring planted small grain yields because high late season soil temperatures can be avoided when the grain heads are filling.

Soil Classification within the Study Area

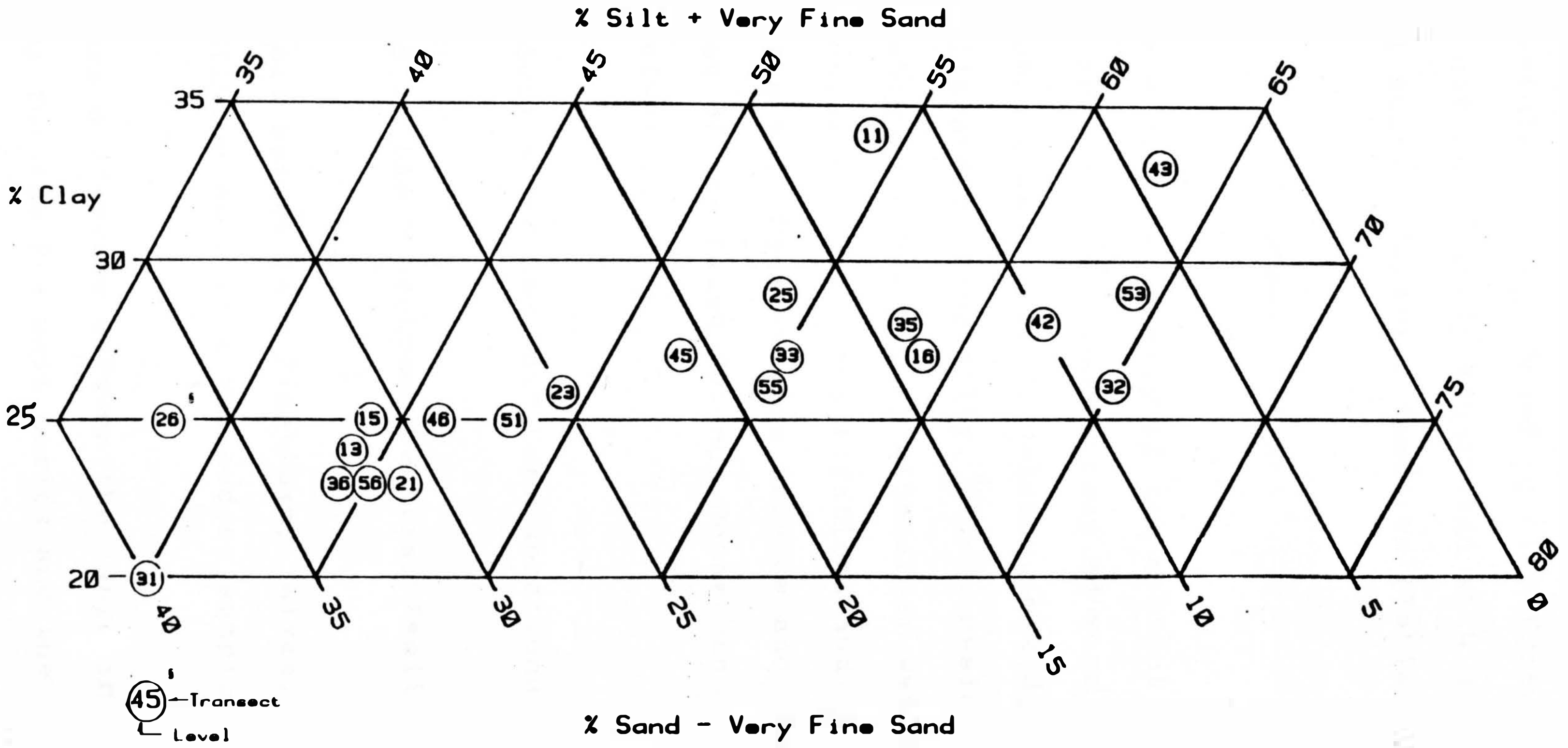
Particle Size Control Section

Textural Family

The pedons sampled in the study area were placed into the Mollisol soil order based on the percent organic carbon and the color and depth of the mollic epipedon. The particle size control section for the textural family was based on the texture of the argillic horizon (Soil Taxonomy 1975, Appendix F and G).

All the pedons sampled can be placed into two textural families. Of the total 21 pedons sampled, 14 fell within the fine-loamy textural family while the remaining seven pedons fell within the fine-silty textural family (Figure 13). The pedons could not be associated with terrace levels based on the control section textural family. The two control section textural families occurred on all terrace levels at random.

Figure 13. Particle Size Distribution of Control Sections



The type of particle sorting, based on clay free sand and silt, was also not exclusively associated with either of the two control section textural families (Table 2).

Taxonomic Class

Based on the textural family of the control section and laboratory analysis, the pedons sampled were placed into two taxonomic classes; 1. Fine-loamy, mixed, mesic, Typic Argiustolls and 2. Fine-silty, mixed, mesic, Typic Argiustolls (Table 7). Mixed clay mineralogy was assumed based on the review of prior investigations and laboratory analysis from the Soil Conservation Service and from the Pedology section of the Plant Science Department of South Dakota State University.

Soil Series and Map Unit Considerations

Pedons in the Fine-Loamy Textural Family

The Ree Soil Series is a Fine-loamy, mixed, mesic, Typic Argiustoll and best fits the pedons sampled in this study (Appendix H).

The primary difference between the range in characteristics for the Ree soil series and the pedons in

Table 7. TAXONOMIC CLASS GROUPS
and
RANGE IN PERCENT CLAY OF THE Bt

Taxonomic Class									
Fine-Loamy, Mixed, Mesic Typic Argiustall					Fine-Silty, Mixed, Mesic Typic Argiustall				
L[$]	T[$]	Argillic horizon clay content (%)			L[$]	T[$]	Argillic horizon clay content (%)		
		low[#]	high[#]	control[*] section			low[#]	high[#]	control[*] section
1	3	21.1	25.3	23.2	1	1	27.0	40.0	34.2
1	5	24.5	25.6	24.7	1	6	26.7	28.3	27.5
2	1	20.2	25.3	22.6	3	2	24.0	27.2	25.9
2	3	22.0	28.0	26.0	3	5	26.7	28.6	27.5
2	5	27.4	34.1	29.6	4	2	26.4	27.5	27.1
2	6	22.5	27.3	25.9	4	3	28.3	34.2	32.8
3	1	16.3	21.7	19.3	5	3	27.9	31.0	29.4
3	3	25.8	27.7	26.9					
3	6	21.0	24.8	22.4					
4	5	23.3	28.8	26.3					
4	6	26.5	27.0	25.9					
5	1	22.3	27.1	24.3					
5	5	25.5	26.6	26.0					
5	6	20.3	23.7	22.9					
Average		22.7	26.6	24.7	Average		27.6	31.0	29.3

$ = Site Identification (L = Level), (T = Transect)
# = The high and low percent clay content for all Bt horizons within a single pedon.
* = Textural family control section clay content.

this study with a fine-loamy control section was the average clay content of the Bt horizon. The present series description includes a range of 27 to 35 % clay for the argillic horizon. The fine-loamy textural family pedons sampled in this study had an average control section clay content of 24.7 % and a range of 19.3 to 29.6 % clay. The highest clay content for any Bt horizon in the fine-loamy textural family was 34.1 % and the lowest Bt horizon clay content was 16.3 % (Table 7). The average clay content for all Bt horizons in the fine-loamy textural family group was 24.8 %.

Expansion of the present series description to include a lower control section average clay content of 24 % but recognizing that some pedons within the Haakon County, South Dakota mapping area could have clay contents as low as 19 % would seem reasonable. These lower clay content pedons would be out of the expanded Ree soil series range but could be considered similar inclusions in a Ree map unit. Of the 14 pedons with fine-loamy control sections, five pedons contained control sections with from 19.3 % clay to less than 24 % clay. Only one pedon, level 3 of transect 1, did not have greater than 23 % clay in at least one of its Bt horizons (Table 7 and Appendix G).

The present Ree soil series description also states that the Bt horizon commonly has a texture of clay loam but sandy clay loam or silty clay loam textures occur in some pedons (Appendix E). The fine-loamy textural family pedons in this study contained Bt horizons dominated by a loam texture with some silt loam and clay loam textured Bt horizons. This information suggests that the present typical pedon may not be typical for the actual entire range of the Ree Series. However, this can only be conclusively determined by comparing Ree polypedons and their occurrence over the entire area that this soil is distributed. Within the study area and for the ongoing Haakon County soil survey it seems apparent that the Ree typical pedon will conform to the ranges for other properties outlined in this study.

Pedons in the Fine-Silty Textural Family

The seven pedons in this study that fell into the fine-silty textural family had a control section average clay content of 29.3 % and a control section range from 27.1 % to 34.2 %. The highest clay content for any Bt horizon in the fine-silty textural family was 40 % and the lowest Bt horizon clay content 24.0 % (Table 8).

Table 8 and Figure 2 both demonstrate that the average clay content of all the pedons sampled did not vary greatly and that this average did not differ greatly from that of the present Ree Soil Series description. The discussion and the graphs of the particle size mode for the 0 to 100 cm profile depth demonstrates that the variation from the modal particle size is gradual (Figure 7 and 8). Since the modal particle size was coarse silt, this indicated that the difference between control section particle size classes was a function of gradual shifts from the silts to the sands. The fine-silty pedons were fine-silty because of increases in coarse silt and very fine sand. The fine-loamy pedons were fine-loamy because of increases in fine sands primarily at the expense or loss of very fine sands and coarse silts. This gives reason to believe that the pedons grouped into the two textural families were closely related. In other words, the pedons are not polarized between the textural family groups but form a relatively close grouped transition from one textural family to the other.

The textural family of the control section was the only major difference between the pedons sampled and there was no recognized soil series that fit the fine-silty textural family pedons. The fine-silty pedons could be recognized as a taxadjunct of the Ree Series since textural family differences would not cause major changes in soil interpretations. This taxadjunct could then be an inclusion within the Ree mapping unit for two reasons.

1. On the basis of this study the fine-silty textural family control section did not appear to be dominant within the study area.

2. It would be difficult to separate these soils by control section in the field. This difference was not major and was difficult to recognize by field texturing due to the gradation from one textural family to another.

SUMMARY and CONCLUSIONS

The high terrace series along the Cheyenne River in Haakon County, South Dakota has long been recognized as an important agricultural area. The goals of this research were to; characterize and classify the terrace soils, examine the impact of time through the degree of genetic property expression, determine if the various terrace levels differed over time, and apply this information to landuse interpretation.

The 21 pedons sampled over the terrace system were very similar in morphology. The alluvial parent material was deposited in a fluvial environment of decreasing water velocity. A coarse textured discontinuity was found to underlie a surface mantle dominated by coarse silt. Sorting in the surface mantle above the discontinuity showed a continuing decrease in particle size from the discontinuity to the soil surface. This was supported by a very uniform increase in silt and decrease in sand above the discontinuity in 52 % of the pedons sampled. Another 24 % of the pedons continued this trend but with more variability in sorting. The remaining 24 % of the pedons sampled still had a particle size mode within the silt range but sorting, from the discontinuity to the surface, was typified by an increase in fine sands and a decrease in coarse silt.

Levels 1 and 2 showed the most uniform increases in coarse silt from the discontinuity to the soil surface. The fact that all horizons in the surface mantle also contained some coarse fragments greater than 2000 microns (3 % to 5 % by weight) supported deposition in a fluvial environment rather than aeolion deposition. Wind and water acting together were ruled out because of the combination of the three types of sorting found in the surface mantel. If wind had been the primary mode of material deposition individual terrace levels would have possessed the same sorting pattern. Coarse fragments greater than 2000 microns also would have been very rare in wind deposited parent material.

Quartz to feldspar ratios in the sand fraction indicated that there were no differences in the coarse particle mineralogies among any of the pedons sampled. Quartz comprised over 90 % of the total mineral composition of the sand fraction.

All the pedons sampled, except level 4 of transect 5, contained a mollic epipedon which placed the soils in the Mollisol soil order. The depth to less than 1 % organic carbon and moist soil colors brighter than 10YR 3/3 were not significantly different among terrace levels. This indicated that these properties were probably at steady state conditions.

Pedons over all levels contained Bt horizons, and Btk and/or Bk horizons. The Btk horizons were more common on the upper terrace levels. The presence of a mollic epipedon, an argillic horizon, and a ustic temperature regime identified the terrace soils as belonging to the Argiustoll great group.

Carbonate morphology centered around soft lime accumulation 5 to 10 mm in size on ped faces. Soft lime accumulations were evident in the Btk or Bk horizons of all pedons.

Surface horizon and subsoil colors were not significantly different.

The productivity of the terrace soils was noticeably better than that of the surrounding Cretaceous shale derived soils. Infiltration rates on the terrace soils were much higher than on the shale derived soils. This allowed the terrace soils to recharge lost moisture more efficiently. The available water holding capacity of the terrace soils was greater than that of the high clay content shale derived soils. Among pedons of the terrace soils those with the thickest mollic surfaces and thickest Bt horizons had the highest available water holding capacity because of their cumulative water storage. Available water holding capacity was also enhanced as these horizons moved deeper into the profile because the lower portions were less subject to drying cycles.

The primary time related significant differences among terrace levels included a decrease in the pH of the A horizon, increased argillic horizon thickness and depth, and increased accumulation of calcium carbonate below the argillic horizon accompanied by differences in calcium carbonate morphology.

Over time the A horizon pH tended to decrease. Differences in pH may have been, in part, reflecting the effect of paleoclimate on the older terrace levels. The upper terrace levels would have been subjected to more severe leaching regimes during a moist-cool climate shift that occurred at the onset of glaciation, prior to the deposition of material that formed the lower terrace levels.

As the thickness of the argillic horizon increased it also moved deeper into the profile. Horizonation within pedons also showed a trend toward the development of Btk horizons as the terraces aged.

The lower two terrace levels generally had zones of calcium carbonate accumulations that expressed themselves as few fine, interconnected filaments along vertical ped faces. The upper three terrace levels tended to have calcium carbonate accumulations oriented both horizontally and vertically on ped faces. Development of zones of few to common soft lime accumulations within the upper portion of the Btk horizon was evident in terrace levels 3, 4, and 5. Calcium carbonate accumulations present in profiles of terrace levels 1 and 2 were distributed more uniformly throughout the Bk horizons.

The trend for the A horizon fine clay to total clay ratio was for a decrease over time. Even though differences were not significant for analysis of variance, the trend direction was logical and supported by observed significant differences in the related genetic properties as mentioned above. The pairwise comparison of means for terrace level 1 and level 5 did however indicate a significant difference for the Bt horizon fine clay to total clay ratio minus the A horizon ratio. Development of an argillic horizon also indicated landscape stability for several thousand years.

The creation of the Missouri River as a drainage channel on the western margin of glacial ice lowered the base level of the Cheyenne River and thus isolated the terraces in this study. Broad flats of the upper three terrace levels contrasted with narrow benches on levels 1 and 2 could have indicated that not all the terraces evolved as a result of down cutting of the Missouri River in its present position. Broader flats suggested that the residence time for the floodplain at the upper levels was longer and down cutting was slower.

The degree of lateral corration and down cutting was assumed to be influenced by the position of the glaciers western edge, duration at that position, and the type of bedrock control affecting down cutting. A minimum age of 27,900 years was assigned to the lower terrace level based on the estimates of the maximum extension of Wisconsin ice by Wright and Frey (1965). A maximum age for the terrace system was, in part, based on the Bt horizon fine clay to total clay ratio minus the A horizon ratio. The maximum age was also based on Pleistocene climates determined from a chronology of deep-sea sediments (Ericson and Wollin 1968). The amount of fine clay translocation indicated by the comparison of ratios for terrace level 1 and 5 suggested a maximum age for terrace level 5 of approximately 64,000 to 90,000 years. An older genesis period for terrace level 5 was considered unlikely because the terrace levels could be separated on the basis of other genetic properties that reach steady state conditions over relatively short periods of time compared to fine clay translocation.

The data indicated that all but eight of the 21 pedons collected could fall within the series description range for the Ree soil series, a Fine-loamy, mixed, mesic, Typic Argiustoll, with only a slight expansion of the series description. Expansion would include changing the average clay content of the control section from the present 27 % to 35 % clay to a new range of 24 to 35 %. The texture of the Bt horizon would have to be expanded to include loam and silt loam with the present range of clay loam, sandy clay loam, and silty clay loam. Of the remaining eight pedons, seven differed only in control section textural family which was Fine-silty and the eighth fell within the fine-loamy textural family but had a control section clay content of 19.3 %. The fine-silty pedons did not fit into a presently established series. Because of the lack of differences that would significantly affect soil interpretations, the Fine-silty pedons could be classified as taxadjuncts to the Ree series. All of the remaining eight pedons could be considered as similar inclusions in a Ree map unit.

The fact that agricultural production on the terrace system was superior to adjacent upland soil was related to parent material and soil genesis over time. The parent material provided a free draining profile in which relatively deep profile development could take place. Development of a mollic epipedon and development of an argillic horizon which increased in depth and thickness over time added to the cumulative water holding capacity and availabilty. The mollic epidedon indicated a relatively high base status and the presence of organic matter contributed greatly to cation exchange capacity.

The terrace system formed islands of productive soils in an area that was dominated by soils developed in Cretaceous shales. Landsat photography revealed patterns of cultivated cropland that were in sharp contrast to the mono-tone pattern of the range land that surrounded the terraces. The terrace parent material and the influence time had on it, were the undisputable factors that set the terraces apart from the shale derived soils. Because of their evolution they provided a unique opportunity to study a chronosequence within the ustic moisture regime of western South Dakota.

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APPENDIX A

PARTICLE SORTING
WITHIN PEDONS SAMPLED

Particle Sorting within a Profile

Level 1, Transect 1

Percent									
			Overlap of Particle Size Distribution Histograms[†]						
Si	S[¶]	Hor.	Ap	Bt	Btk1	Btk2	Bk	C1	C2
80	20	Ap	–	88	69	58	65	74	54
77	23	Bt		–	72	61	68	78	57
74	26	Btk1			–	74	74	73	55
53	47	Btk2				–	82	78	74
57	43	Bk					–	85	76
62	38	C1						–	72
41	58	C2							–

[¶] Silt and sand on a clay free basis.

[†] Fractions include total clay, FSi, MSi, CSi, VCS, CS, MS, FS, VFS.

Particle Sorting within a Profile

Level 1, Transect 3

Percent

			Overlap of Particle Size Distribution Histograms[†]							
Si	S[1]	Hor.	A1	AB	Bt1	2Bt2	2Bk1	2Bk2	2Bk3	3C
67	33	A1	-	53	45	32	28	36	28	21
69	31	AB		-	72	47	45	58	45	31
52	47	Bt1			-	65	57	73	56	40
31	68	2Bt2				-	77	71	72	55
24	76	2Bk1					-	69	87	67
37	62	2Bk2						-	70	49
25	74	2Bk3							-	71
15	85	3C								-

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[1] Silt and Sand on a clay free basis.

[†] Fractions include total clay, FSi, MSi, CSi, VFS, FS, MS, CS, VCS.

Particle Sorting within a Profile

Level 1, Transect 5

Percent

			Overlap of Particle Size Distribution Histograms[†]							
Si	S[¶]	Hor.	Ap	A2	Bt1	Bt2	Bk1	Bk2	C1	C2
55	45	Ap	–	80	75	67	53	56	49	24
56	44	A2		–	87	76	65	66	60	31
48	52	Bt1			–	83	72	74	67	36
42	58	Bt2				–	72	71	66	35
32	68	Bk1					–	86	83	52
23	77	C1						–	86	47
22	78	C2							–	52

[¶] Silt and sand on a clay free basis.

[†] Fractions include total clay, FSi, MSi, CSi, VCS, CS, MS, FS, VFS.

Particle Sorting within a Profile

Level 1 Transect 6

Percent								
			Overlap of Particle Size Distribution Histograms †					
Si	S[1]	Hor.	Ap	Bt	Btk1	Btk2	2Bk	3C
71	29	Ap	-	81	72	71	52	68
70	30	Bt		-	88	87	50	68
62	38	Btk1			-	91	56	74
64	36	Btk2				-	54	72
30	70	2Bk					-	66
49	51	3C						-

[1] Silt and sand on a clay free basis.

† Fractions include total clay, FSi, MSi, CSi, VFS, FS, MS, CS, VCS.

Particle Sorting within a Profile

Level 2, Transect 1

Percent										
			Overlap of Particle Size Distribution Histograms[†]							
Si	S[¶]	Hor.	A1	A2	BA	Bt1	Bt2	Bk1	Bk2	2C
75	25	A1	-	80	75	67	53	56	49	24
65	35	A2		-	87	76	65	66	60	31
58	42	BA			-	83	72	74	67	36
54	46	Bt1				-	72	71	66	35
39	61	Bt2					-	86	83	52
40	60	Bk1						-	86	47
39	61	Bk2							-	52
11	89	2C								-

[¶] Silt and sand on a clay free basis.

[†] Fractions include total clay, FSi, MSi, CSi, VCS, CS, MS, FS, VFS.

Particle Sorting within a Profile

Level 2, Transect 3

Percent								
			Overlap of Particle Size Distribution Histograms[†]					
Si	S[1]	Hor.	Ap	Bt1	Bt2	Bk	2Bk	2C
64	36	Ap	-	90	68	73	42	52
65	35	Bt1		-	68	72	38	48
44	56	8t2			-	77	52	61
46	54	Bk				-	55	62
19	81	2Bk					-	75
28	72	2C						-

[1] Silt and sand on a clay free basis.

[†] Fractions include total clay, FSi, MSi, CSi, VFS, FS, MS, CS, VCS.

Particle Sorting within a Profile

Level 2 Transect 5

Si	S[1]	Hor.	Ap	Bt1	Bt2	Btk	Bk	2C
			Percent					
			Overlap of Particle Size Distribution Histograms †					
69	31	Ap	–	84	74	69	65	17
68	32	Bt1		–	86	78	63	17
70	30	Bt2			–	79	60	17
57	43	Btk				–	67	23
46	54	Bk					–	29
7	93	2C						–

[1] Silt and Sand on a clay free basis.

† Fractions include total clay, FSi, MSi, CSi, VFS, FS, MS, CS, VCS.

Particle Sorting within a Profile

Level 2, Transect 6

Percent							
			Overlap of Particle Size Distribution Histograms[†]				
Si	S[1]	Hor.	A1	A2	Bt1	Bt2	2C
63	37	A1	–	84	70	67	8
56	44	A2		–	80	73	10
47	53	Bt1			–	88	11
45	55	Bt2				–	10
3	97	2C					–

[1] Silt and sand on a clay free basis.

[†] Fractions include total clay, FSi, MSi, CSi, VFS, FS, MS, CS, VCS.

Particle Sorting within a Profile

Level 3, Transect 1

			Percent					
			Overlap of Particle Size Distribution Histograms[†]					
Si	S[1]	Hor.	Ap	BA	BT1	Bt2	Bk	2C
55	45	Ap	–	86	73	80	68	31
48	52	BA		–	83	84	72	35
40	60	Bt1			–	85	80	39
46	54	Bt2				–	81	37
34	66	Bk					–	44
4	96	2C						–

[1] Silt and sand on a clay free basis.

[†] Fractions include total clay, FSi, MSi, CSi, VCS, CS, MS, FS, VFS.

Particle Sorting within a Profile

Level 3, Transect 2

Percent								
			Overlap of Particle Size Distribution Histograms [†]					
Si	S[1]	Hor.	Ap	Bt1	Bt2	Bk	2Bk	2C
75	25	Ap	-	88	78	79	34	45
70	30	Bt1		-	82	82	41	50
64	36	Bt2			-	86	44	54
73	27	Bk				-	37	46
25	75	2Bk					-	79
34	66	2C						-

[1] Silt and sand on a clay free basis.

[†] Fractions include total clay, FSi, MSi, CSi, VFS, FS, MS, CS, VCS.

Particle Sorting within a Profile

Level 3, Transect 3

Si	S[1]	Hor.	Ap	Bt1	Bt2	Btk	2Bk	3C	4C
			Percent						
			Overlap of Particle Size Distribution Histograms [†]						
54	46	Ap	-	82	72	60	69	35	42
54	46	Bt1		-	79	68	73	43	40
67	33	Bt2			-	71	58	47	26
66	34	Btk				-	59	47	26
36	64	2Bk					-	34	47
77	23	3C						-	20
12	88	4C							-

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[1] Silt and sand on a clay free basis.

[†] Fractions include total clay, FSi, MSi, CSi, VFS, FS, MS, CS, VCS.

Particle Sorting within a Profile

Level 3, Transect 5

Percent

		Overlap of Particle Size Distribution Histograms[†]							
Si	S[1]	Hor.	Ap	BA	Bt1	Bt2	Bk1	Bk2	C
73	27	Ap	-	91	75	77	64	66	67
71	29	BA		-	82	84	70	70	72
66	34	Bt1			-	94	76	71	74
68	32	Bt2				-	76	70	72
59	41	Bk1					-	90	79
56	44	Bk2						-	81
51	49	C							-

[1] Silt and Sand on a clay free basis.

[†] Fractions include total clay, FSi, MSi, CSi, VFS, FS, MS, CS, VCS.

Particle Sorting within a Profile

Level 3, Transect 6

Percent								
			Overlap of Particle Size Distribution Histograms[†]					
Si	S[¶]	Hor.	Ap	Bt1	Bt2	Bt3	Btk	2C
49	51	Ap	–	83	83	65	67	39
47	53	Bt1		–	91	71	73	36
51	49	Bt2			–	72	75	33
64	36	8t3				–	91	22
62	38	Btk					–	22
8	92	2C						–

[¶] Silt and sand on a clay free basis.

[†] Fractions include total clay, FSi, MSi, CSi, VFS, FS, MS, CS, VCS.

Particle Sorting within a Profile

Level 4, Transect 2

Percent							
			Overlap of Particle Size Distribution Histograms[†]				
Si	S[1]	Hor.	Ap	Bt	Btk	2C	3C
60	40	Ap	-	80	76	61	19
70	30	Bt		-	85	54	14
76	24	Btk			-	49	10
38	62	2C				-	21
6	94	3C					-

[1] Silt and sand on a clay free basis.

[†] Fractions include total clay, FSi, MSi, CSi, VFS, FS, MS, CS, VCS.

Particle Sorting within a Profile

Level 4, Transect 3

Percent

			Overlap of Particle Size Distribution Histograms[†]						
Si	S[1]	Hor.	Ap	Bt1	Bt2	Btk1	Btk2	Bk	C
80	20	Ap	-	78	79	77	70	80	64
82	18	Bt1		-	86	87	73	74	61
83	17	Bt2			-	91	74	75	62
78	22	Btk1				-	76	80	65
62	38	Btk2					-	83	80
72	28	Bk						-	72
53	47	C							-

[1] Silt and sand on a clay free basis.

[†] Fractions include total clay, FSi, MSi, CSi, VCS, CS, MS, FS, VFS.

Particle Sorting within a Profile

Level 4, Transect 5

Percent

			Overlap of Particle Size Distribution Histograms †						
Si	S[1]	Hor.	Ap	A2	Bt1	Bt2	Bt3	Btk	2C
59	41	Ap	-	97	78	78	73	76	28
57	43	A2		-	78	77	72	75	29
56	44	Bt1			-	82	73	77	25
63	37	Bt2				-	84	91	23
70	30	Bt3					-	85	17
66	34	Btk						-	21
7	93	2C							-

[1] Silt and sand on a clay free basis.

† Fractions include total clay, FSi, MSi, CSi, VFS, FS, MS, CS, VCS.

Particle Sorting within a Profile

Level 4, Transect 6

Si	S[1]	Hor.	Ap	Bt1	Bt2	Btk	2C
			Overlap of Particle Size Distribution Histograms[†] (Percent)				
53	47	Ap	–	80	73	59	27
52	48	Bt1		–	87	68	24
60	40	Bt2			–	78	18
70	30	Btk				–	11
3	97	2C					–

[1] Silt and sand on a clay free basis.
[†] Fractions include total clay, FSi, MSi, CSi, VFS, FS, MS, CS, VCS.

Particle Sorting within a Profile

Level 5, Transect 1

Si	S[1]	Hor.	A1	A2	AB	Bt1	Bt2	Btk	2C	3C
			Percent							
			Overlap of Particle Size Distribution Histograms†							
64	36	A1	–	91	89	63	75	74	27	66
61	39	A2		–	92	68	81	71	30	72
61	39	AB			–	69	82	68	29	72
50	50	Bt1				–	80	60	33	74
50	50	Bt2					–	66	36	87
69	31	Btk						–	20	62
10	90	2C							–	39
43	57	3C								

[1] Silt and sand on a clay free basis.

† Fractions include total clay, FSi, MSi, CSi, VCS, CS, MS, FS, VFS.

Particle Sorting within a Profile

Level 5, Transect 3

Percent								
			Overlap of Particle Size Distribution Histograms[†]					
Si	S[¶]	Hor.	Ap	Bt1	Bt2	Btk	Bk	2C
72	28	Ap	-	78	76	71	72	20
78	22	Bt1		-	79	77	74	17
81	19	Bt2			-	87	72	12
79	21	Btk				-	77	12
63	37	Bk					-	17
9	91	2C						-

[¶] Silt and sand on a clay free basis.

[†] Fractions include total clay, FSi, MSi, CSi, VFS, FS, MS, CS, VCS.

Particle Sorting within a Profile

Level 5, Transect 5

Si	S[1]	Hor.	Ap	AB	Bt1	Bt2	2Btk	3Bk	4C
			Overlap of Particle Size Distribution Histograms[†]						
			Percent						
39	61	Ap	-	71	68	64	43	80	38
59	41	AB		-	80	85	60	77	28
57	43	Bt1			-	87	64	77	27
61	39	Bt2				-	66	74	25
82	18	2Btk					-	52	12
47	53	3Bk						-	36
6	94	4C							-

[1] Silt and sand on a clay free basis.

[†] Fractions include total clay, FSi, MSi, CSi, VFS, FS, MS, CS, VCS.

Particle Sorting within a Profile

Level 5, Transect 6

Percent

Si	S[¶]	Hor.	Ap	Bt1	Bt2	Btk	2C
			Overlap of Particle Size Distribution Histograms[†]				
48	52	Ap	–	83	69	78	40
46	54	Bt1		–	66	73	39
65	35	Bt2			–	83	24
55	45	Btk				–	32
7	93	2C					–

[¶] Silt and sand on a clay free basis.

[†] Fractions include total clay, FSi, MSi, CSi, VFS, FS, MS, CS, VCS.

APPENDIX B

QUARTZ TO FELDSPAR RATIO DATA
BASED ON THE
COARSE AND MEDIUM SAND PARTICLE SIZE CLASSES

Quartz Feldspar Ratio Data
Terrace Level 1

LEVEL 1
TRANSECT 5
ELEVATION 603 meters

HORIZON	HORIZON DEPTH (CM)	QUARTZ	DARK MINERALS	FELDSPAR
		---Percent of Grain Count---		
AP	0 - 14			
A2	14 - 24	92	7	1
Bt1	24 - 33	94	5	1
Bt2	33 - 59	96	3	1
Bk1	59 - 86	92	7	1
Bk2	86 - 107	97	2	1
C	107 - 138	94	5	1
2C	138 - 188	97	2	1

LEVEL 1
TRANSECT 6
ELEVATION 597 meters

HORIZON	HORIZON DEPTH (cm)	QUARTZ	DARK MINERALS	FELDSPAR
		---Percent of Grain Count---		
A1	0 - 7	89	9	2
Bt	7 - 22	90	7	3
Btk1	22 - 43	91	7	2
Btk2	43 - 79	90	8	2
2Bk	79 - 113	91	8	1
3C	113 - 200	93	6	1

Minimum of 600 grains counted per horizon

Quartz Feldspar Ratio Data
Terrace Level 2

LEVEL 2
TRANSECT 3
ELEVATION 658 meters

HORIZON	HORIZON DEPTH (CM)	---Percent of Grain Count--- QUARTZ	DARK MINERALS	FELDSPAR
Ap	0 - 15	91	6	3
Bt1	15 - 30	93	6	1
Bt2	30 - 62	93	6	1
Bk	62 - 87	89	9	2
2Bk	87 - 109	89	10	1
2C	109 - 210	92	7	1

LEVEL 2
TRANSECT 6
ELEVATION 643 meters

HORIZON	HORIZON DEPTH (cm)	---Percent of Grain Count--- QUARTZ	DARK MINERALS	FELDSPAR
A1	0 - 7	--	-	-
A2	7 - 22	89	8	3
Bt1	22 - 36	94	2	4
Bt2	36 - 71	92	6	2
2C	71 - 200	91	7	2

Minimum of 600 grains counted per horizon

Quartz Feldspar Ratio Data
Terrace Level 3

LEVEL 3
TRANSECT 1
ELEVATION 708 meters

HORIZON	HORIZON DEPTH (CM)	---Percent of Grain Count--- QUARTZ	DARK MINERALS	FELDSPAR
AP	0 - 10	93	6	1
BA	10 - 27	--	-	-
Bt1	27 - 51	95	5	0
Bt2	51 - 70	93	5	2
Bk	70 - 91	90	8	2
2C	91 +	93	6	1

LEVEL 3
TRANSECT 5
ELEVATION 658 meters

HORIZON	HORIZON DEPTH (cm)	---Percent of Grain Count--- QUARTZ	DARK MINERALS	FELDSPAR
Ap	0 - 5	--	-	-
BA	5 - 16	92	6	2
Bt1	16 - 34	93	4	3
Bt2	34 - 56	94	5	1
Bk1	56 - 83	--	-	-
Bk2	83 - 120	94	5	1
C	120 - 158	91	6	3

Minimum of 600 grains counted per horizon

Quartz Feldspar Ratio Data
Terrace Level 4

LEVEL 4
TRANSECT 3
ELEVATION 708 meters

		---Percent of Grain Count---		
HORIZON	HORIZON DEPTH (CM)	QUARTZ	DARK MINERALS	FELDSPAR
AP	0 - 29	91	8	1
Bt1	29 - 58	94	5	1
Bt2	58 - 82	95	4	1
Btk1	82 - 113	92	8	0
Btk2	113 - 142	92	7	1
Bk	142 - 162	90	9	1
C	162 - 200	--	-	-

LEVEL 4
TRANSECT 5
ELEVATION 670 meters

		---Percent of Grain Count---		
HORIZON	HORIZON DEPTH (cm)	QUARTZ	DARK MINERALS	FELDSPAR
Ap	0 - 5	92	6	2
A2	5 - 12	87	8	5
Bt1	12 - 28	84	7	9
Bt2	28 - 52	92	6	2
Bt3	52 - 66	92	7	1
Btk	66 - 91	94	6	0
2C	91 - 150	94	5	0

Minimum of 600 grains counted per horizon

Quartz Feldspar Ratio Data
Terrace Level 5

LEVEL 5
TRANSECT 3
ELEVATION 719 meters

HORIZON	HORIZON DEPTH (CM)	---Percent of Grain Count---		
		QUARTZ	DARK MINERALS	FELDSPAR
AP	0 - 14	93	6	1
Bt1	14 - 39	92	6	2
Bt2	39 - 59	92	7	1
Btk	59 - 106	94	6	0
Bk	106 - 144	91	8	1
2C	144 - 150	--	-	-

LEVEL 5
TRANSECT 6
ELEVATION 679 meters

HORIZON	HORIZON DEPTH (cm)	---Percent of Grain Count---		
		QUARTZ	DARK MINERALS	FELDSPAR
Ap	0 - 18	92	7	1
Bt1	18 - 52	89	9	2
Bt2	52 - 64	90	8	2
Btk	64 - 91	89	9	2
2C	91 - 120	92	6	2

Minimum of 600 grains counted per horizon

APPENDIX C

SUMMARY OF PARTICLE SIZE CLASS AND MOISTURE HOLDING CAPACITY RELATIONSHIP

PARTICLE SIZE AND WATER CONTENT RELATIONSHIPS BY HORIZON
HORIZON DATA SORTED BY CLAY CONTENT THEN SILT CONTENT

Particle Size Data in % of Total
(fraction separations in microns)

				Total			Sand Fraction					Silt Fraction							
LEVEL	TRANSECT	HORIZON	OC§ %	CLAY <2	SILT 2-50	SAND 50 -2000	VC 1000 -2000	C 500 -1000	M 250 -500	F 100 -250	VF 50 -100	C 20 -50	M 5 -20	F 2 -5	0.03 MPa θm %	¶	1.5 MPa θm %	¶	TEXTURAL CLASS
4	6	2C	0.08	1.7	3.0	95.4	8.8	23.9	45.0	16.8	1.0	2.2	0.5	0.3	1.34	P	1.71	P	CS
2	6	2C	0.24	2.4	2.5	95.1	19.7	22.2	29.0	22.3	2.1	0.8	0.0	1.7	1.69	P	2.16	P	CS
4	5	2C	0.08	3.4	6.4	90.3	12.3	29.9	27.3	15.4	5.4	4.9	0.3	1.2	3.36	P	2.27	P	CS
4	2	3C	0.16	3.9	5.7	90.4	7.3	24.4	44.4	11.1	3.3	4.0	1.2	0.6	3.02	P	2.56	P	CS
3	6	2C	0.16	4.4	7.9	87.8	9.3	36.1	28.2	11.3	3.0	5.0	1.9	1.1	3.20	A	2.00	A	CS
5	5	4C	0.16	4.6	5.9	89.6	20.2	43.5	7.1	11.8	7.1	4.0	1.0	0.9	3.98	P	2.78	P	CS
2	5	2C	0.16	4.6	7.2	88.3	11.9	29.5	27.9	15.2	3.9	4.1	2.1	1.0	3.63	P	2.78	P	LCS
3	1	2C	0.00	5.2	3.5	91.4	12.3	22.1	23.0	28.8	5.3	2.7	0.3	0.5	3.42	P	2.79	P	CS
5	3	2C	0.00	7.1	8.3	84.7	19.9	37.3	17.7	5.8	4.1	5.0	0.9	2.5	6.00	A	3.40	A	LCS
5	6	2C	0.00	8.1	6.8	85.2	7.4	31.7	27.9	14.0	4.3	3.2	2.3	1.4	4.80	P	3.75	P	CS
5	1	2C	0.16	8.2	9.6	82.3	25.5	30.4	16.2	7.5	2.8	6.5	2.5	0.6	6.20	A	3.20	A	LS
1	3	3C	0.00	8.7	13.6	77.8	0.6	6.0	20.0	39.7	11.6	9.7	2.6	1.3	7.65	P	3.97	P	FSL
2	1	2C	0.16	9.2	9.9	81.0	1.5	10.2	19.8	36.1	13.6	6.0	2.9	1.0	7.50	P	4.36	P	LS
2	3	2BK	0.24	10.9	17.4	71.8	1.6	11.0	18.1	23.5	17.7	13.0	2.7	1.7	10.24	P	5.05	P	SL
1	5	C2	0.00	11.6	12.3	76.1	1.6	8.8	22.4	29.3	14.0	8.7	2.6	1.1	8.85	P	4.96	P	SL
3	3	4C	0.00	12.6	10.8	76.6	1.7	3.0	14.7	48.4	8.9	6.8	2.9	1.2	7.50	A	4.70	A	CSL
2	3	2C	0.24	12.8	25.1	62.2	0.4	4.9	16.4	28.0	12.7	16.8	5.0	3.3	11.37	P	5.68	P	FSL
2	1	BK2	0.48	12.8	33.8	53.5	0.9	3.3	10.3	21.0	18.0	22.7	8.1	3.0	14.00	P	6.02	P	FSL
3	2	2BK	0.16	13.2	21.9	65.0	1.5	5.5	11.8	25.4	20.8	16.6	3.2	2.2	12.43	P	5.70	P	FSL
1	5	C1	0.08	13.3	18.7	68.1	3.6	9.9	17.0	24.6	13.1	13.1	4.2	1.5	10.43	P	5.63	P	SL
3	6	AP	1.36	13.4	42.3	44.4	6.4	18.1	10.9	5.2	3.8	27.6	10.9	3.8	14.10	A	7.10	A	L
1	3	2BK3	0.00	14.5	21.4	64.1	0.4	5.2	15.0	28.7	14.9	14.9	4.0	2.6	11.68	P	5.94	P	SL
4	6	AP	1.60	14.5	45.2	40.4	6.9	12.8	10.4	6.5	4.0	26.7	13.2	5.3	14.08	P	8.11	P	L
3	1	AP	2.08	15.0	46.4	38.6	3.1	8.4	10.3	10.3	6.7	31.7	12.1	2.7	15.00	P	8.95	P	L
1	3	AB	0.88	15.2	58.3	26.5	0.4	1.9	3.6	8.4	12.2	43.8	11.2	3.3	18.33	P	7.38	P	SIL
3	2	2C	0.24	15.5	28.6	56.0	0.3	1.8	6.2	24.0	23.8	22.3	3.5	2.8	15.02	P	6.59	P	FSL
2	6	A2	1.36	15.6	47.0	37.5	8.2	11.9	8.5	5.1	3.9	29.4	13.0	4.6	14.76	P	8.16	P	L
5	5	AP	2.48	15.7	33.1	51.3	4.0	15.6	14.0	10.9	6.9	20.9	9.2	3.0	12.76	P	9.72	P	L
1	5	BK2	0.32	16.0	19.1	64.9	4.8	9.9	16.4	22.5	11.4	13.7	4.5	1.0	11.11	P	6.89	P	SL
1	3	2BK1	0.32	16.0	20.1	64.0	2.2	8.8	14.8	24.9	13.4	14.4	3.2	2.6	11.66	P	6.87	P	SCL
3	1	BT2	0.56	16.3	38.5	44.8	2.9	8.0	13.2	14.1	6.8	24.6	8.1	5.9	13.98	P	7.32	P	L
5	6	AP	1.60	16.3	40.2	43.6	2.8	14.2	13.6	7.7	5.5	23.7	13.0	3.5	14.02	P	8.72	P	L
1	5	BK1	0.40	16.4	26.8	56.9	3.2	7.5	13.8	21.0	11.6	17.9	8.4	0.6	12.69	P	7.12	P	FSL
1	3	2BK2	0.24	16.4	31.2	52.5	0.9	3.7	9.2	20.1	18.7	20.1	6.3	4.8	14.86	P	6.92	P	SL

¶ A = Measured value from pressure plate.
P = Predicted value from regression analysis.

§ Organic Carbon

PARTICLE SIZE AND WATER CONTENT RELATIONSHIPS BY HORIZON
HORIZON DATA SORTED BY CLAY CONTENT THEN SILT CONTENT

Particle Size Data in % of Total
(fraction separations in microns)

				Total			Sand Fraction					Silt Fraction							
LEVEL	TRANSECT	HORIZON	OC[§] %	CLAY <2	SILT 2-50	SAND 50 -2000	VC 1000 -2000	C 500 -1000	M 250 -500	F 100 -250	VF 50 -100	C 20 -50	M 5 -20	F 2 -5	0.03 MPa θm %	¶	1.5 MPa θm %	¶	TEXTURAL CLASS
3	1	BK	0.56	16,5	28.5	55.1	2.7	8.0	19.2	15.7	9.5	18.9	6.5	3.1	12.67	P	7.39	P	FSL
4	2	2C	0.24	16.5	32.2	51.4	0.9	3.6	6.7	23.8	16.6	24.8	5.7	1.7	14.67	P	6.93	P	L
3	3	AP	0.88	16.7	45.2	38.2	1.4	5.6	10.8	13.4	7.2	25.8	15.2	4.2	13.10	A	7.70	A	L
4	5	AP	2.72	16.7	48.8	34.6	7.2	10.8	6.4	4.4	5.8	29.8	13.9	5.1	15.85	P	10.40	P	L
5	5	AB	1.60	16.7	49.1	34.3	4.0	11.1	6.7	6.8	5.7	29.6	14.0	5.6	15.88	P	8.87	P	L
3	5	AP	4.80	16.7	60.5	22.8	2.8	5.2	3.5	4.1	7.3	39.5	15.1	6.0	18.33	P	13.24	P	SIL
5	5	3BK	0.48	17.0	38.7	44.4	6.2	14.5	6.4	8.6	8.8	25.7	9.5	3.6	14.60	P	7.43	P	L
2	6	A1	2.80	17.0	52.1	31.0	5.6	9.4	7.2	4.4	4.4	34.9	14.0	3.2	16.30	P	10.60	P	SIL
1	5	AP	1.36	17.2	45.5	37.4	0.7	4.7	9.3	12.4	10.3	33.4	9.6	2.6	16.23	P	8.70	P	L
4	5	A2	2.88	17.3	47.4	35.4	7.5	11.1	6.6	4.7	5.6	28.9	13.8	4.8	15.75	P	10.83	P	L
3	1	BA	1.12	17.8	39.7	42.6	4.3	9.1	11.4	12.1	5.8	28.2	9.6	2.0	14.51	P	8.58	P	L
5	1	A1	2.40	18.0	52.9	29.2	5.8	7.1	5.4	4.8	6.1	34.7	15.4	2.8	16.90	A	10.40	A	SIL
2	5	BK	0.48	18.4	37.5	44.2	0.6	3.2	10.4	15.4	14.6	26.9	8.6	2.0	15.95	P	7.92	P	L
2	3	AP	2.00	18.8	52.3	29.0	0.4	4.1	6.0	9.5	9.1	37.2	11.8	3.3	17.81	P	10.12	P	SIL
2	1	A2	1.68	18.9	52.4	28.7	0.4	2.3	5.1	8.9	12.2	38.1	9.9	4.5	18.46	P	9.73	P	SIL
2	1	BK1	0.40	19.6	32.1	48.4	0.4	2.7	8.2	20.1	17.1	21.4	8.6	2.1	15.79	P	8.20	P	L
5	1	AB	1.04	19.7	49.1	31.3	6.5	7.6	6.0	4.9	6.3	36.5	9.9	2.8	14.90	A	9.20	A	L
3	5	BA	2.56	19.8	56.7	23.6	3.4	4.7	3.2	3.8	8.6	37.5	14.3	5.0	18.09	P	11.24	P	SIL
3	5	BK2	0.00	19.9	44.5	35.7	0.8	2.7	4.3	9.9	18.1	31.0	7.9	5.6	18.41	P	7.76	P	L
1	3	A1	1.12	19.9	53.5	26.7	0.6	1.9	3.6	8.9	11.7	42.8	9.0	1.7	18.91	P	9.31	P	SIL
5	1	A2	1.20	20.0	48.9	31.2	7.4	7.4	6.1	4.5	5.8	34.1	13.0	1.9	14.40	A	8.70	A	L
2	1	A1	3.12	20.0	60.0	20.0	0.2	1.3	3.0	5.7	9.9	42.2	15.6	2.3	19.83	P	12.07	P	SIL
2	1	BT2	0.40	20.2	30.9	49.0	0.8	4.4	10.4	21.2	12.3	19.2	8.3	3.4	14.88	P	8.42	P	L
2	3	BK	0.56	20.2	37.0	42.9	0.4	2.7	7.2	15.6	17.1	26.3	6.5	4.3	16.92	P	8.64	P	L
5	6	BTK	0.24	20.3	43.9	35.9	2.5	12.0	9.7	5.1	6.7	30.6	10.0	3.4	16.30	P	8.22	P	L
2	1	BA	1.20	20.3	45.9	33.8	0.6	2.8	6.4	11.7	12.4	33.1	10.2	2.7	17.76	P	9.55	P	L
5	3	AP	1.44	20.5	57.5	22.1	2.3	5.8	3.8	2.7	7.6	37.4	17.7	2.5	18.70	A	11.10	A	SIL
2	5	AP	2.08	20.6	54.5	24.9	1.8	4.1	4.3	4.0	10.8	37.8	12.0	4.8	19.17	P	10.85	P	SIL
1	6	2BK	0.16	20.7	24.0	55.4	0.6	3.3	9.5	25.7	16.4	17.8	4.9	1.4	12.30	A	7.40	A	SCL
3	5	C	0.00	20.7	40.9	38.5	2.9	7.5	5.8	7.3	15.0	26.8	9.2	4.9	17.42	P	8.03	P	L
1	5	A2	0.80	20.7	44.5	34.9	0.8	3.9	8.7	13.0	8.7	30.3	11.4	2.8	16.92	P	9.14	P	L
1	6	A1	3.68	20.7	56.0	23.4	0.3	0.8	1.8	5.2	15.4	40.8	13.5	1.8	22.80	A	15.60	A	SIL
1	3	BT1	0.88	21.1	41.8	37.1	1.3	3.7	6.3	12.4	13.6	27.6	11.3	3.0	17.46	P	9.37	P	L
1	6	3C	0.24	21.2	38.8	40.3	0.1	0.6	2.1	15.9	21.6	27.9	7.7	3.3	13.00	A	7.90	A	L

¶ A = Measured value from pressure plate.
P = Predicted value from regression analysis.

§ Organic Carbon

PARTICLE SIZE AND WATER CONTENT RELATIONSHIPS BY HORIZON
HORIZON DATA SORTED BY CLAY CONTENT THEN SILT CONTENT

Particle Size Data in % of Total
(fraction separations in microns)

				Total			Sand Fraction					Silt Fraction							
LEVEL	TRANSECT	HORIZON	OC§ %	CLAY <2	SILT 2-50	SAND 50 -2000	VC 1000 -2000	C 500 -1000	M 250 -500	F 100 -250	VF 50 -100	C 20 -50	M 5 -20	F 2 -5	0.03 MPa θm %	¶	1.5 MPa θm %	¶	TEXTURAL CLASS
3	6	BT2	0.48	21.3	40.4	38.4	4.6	14.8	10.8	4.5	3.8	27.9	12.1	0.5	17.30	A	9.80	A	L
4	2	AP	1.20	21.4	47.4	31.3	2.1	5.5	5.0	6.6	12.2	33.7	13.1	0.6	18.35	P	9.92	P	L
3	1	BT1	0.48	21.7	31.6	46.8	3.3	9.3	14.2	14.0	6.1	21.6	8.0	2.0	14.35	P	9.04	P	L
4	3	AP	1.68	21.7	62.3	16.1	0.9	1.8	1.8	2.3	9.4	39.3	16.4	6.7	20.71	P	10.66	P	SIL
5	6	BT2	0.32	21.8	50.9	27.4	1.9	7.9	6.8	3.8	7.2	31.8	12.5	6.7	18.20	P	8.84	P	SIL
2	3	BT1	0.96	22.0	50.8	27.3	0.6	2.9	6.3	9.3	8.2	34.2	12.2	4.5	18.44	P	9.78	P	SIL
5	1	BT2	0.56	22.3	39.1	38.6	7.0	10.4	8.5	6.8	6.0	29.2	8.5	1.5	15.10	A	9.40	A	L
3	6	BTK	0.56	22.3	48.5	29.3	4.3	9.0	5.9	2.4	7.8	34.8	11.0	2.7	19.20	A	9.90	A	L
3	6	BT1	0.48	22.4	36.4	41.3	5.6	16.0	11.2	4.7	3.9	26.4	8.9	1.1	16.40	A	9.80	A	L
2	6	BT1	0.64	22.5	36.8	40.8	8.4	11.8	10.7	6.8	3.2	22.0	10.6	4.2	15.06	P	9.53	P	L
3	3	2BK	0.08	22.6	27.8	49.7	1.5	5.9	9.5	18.0	14.8	20.2	6.2	1.5	15.58	P	8.78	P	SCL
5	1	3C	0.56	22.8	32.9	44.3	8.7	11.4	9.4	6.2	8.7	23.1	8.2	1.7	15.60	A	9.10	A	L
3	5	BK1	0.24	23.1	45.2	31.8	0.8	1.6	2.6	9.7	17.2	31.7	8.9	4.6	19.45	P	9.19	P	L
4	5	BTK	0.64	23.3	50.6	26.1	4.2	6.8	5.5	3.0	6.8	36.0	11.3	3.4	18.59	P	9.80	P	SIL
5	6	BT1	0.88	23.7	35.3	41.1	3.4	13.7	13.2	6.7	4.2	19.2	14.5	1.6	15.36	P	10.25	P	L
3	2	AP	1.28	23.8	57.3	18.9	0.5	1.4	2.0	5.0	10.1	38.8	15.3	3.3	20.64	P	10.85	P	SIL
5	3	BK	0.24	23.9	47.8	28.3	0.9	2.4	2.7	4.3	18.1	34.4	10.3	3.1	19.40	A	10.60	A	L
4	3	C	0.24	24.0	40.4	35.7	1.1	3.8	5.2	9.6	16.0	24.1	11.6	4.7	18.63	P	9.50	P	L
3	2	BT1	0.80	24.0	53.1	23.0	0.8	1.5	2.5	5.8	12.5	35.2	12.4	5.6	20.33	P	10.24	P	SIL
1	1	C2	0.56	24.2	31.4	44.5	5.0	8.4	9.6	8.7	12.9	20.7	9.1	1.7	16.41	P	9.98	P	L
1	5	BT1	0.80	24.5	36.3	39.2	0.7	2.4	6.3	14.1	15.8	23.3	8.7	4.4	18.01	P	10.43	P	L
5	1	BT1	0.64	24.9	37.3	37.8	7.2	10.2	7.6	6.3	6.7	28.1	0.0	9.2	16.50	A	4.40	A	L
3	6	BT3	0.56	24.9	48.4	26.8	2.7	8.9	6.3	2.5	6.4	34.6	9.6	4.3	19.10	A	11.00	A	L
5	5	BT2	0.56	25.0	46.0	29.1	3.8	10.4	4.8	5.6	4.6	28.8	13.4	3.9	17.87	P	10.26	P	L
4	5	BT3	0.80	25.0	52.4	22.7	3.2	4.7	3.3	2.3	9.3	33.8	14.0	4.7	19.96	P	10.58	P	SIL
4	5	BT2	0.80	25.2	47.2	27.7	5.3	8.0	5.4	3.4	5.7	33.7	10.1	3.4	18.37	P	10.67	P	L
1	3	2BT2	0.32	25.3	23.8	50.9	2.1	6.6	11.9	19.9	10.5	15.1	6.2	2.5	14.95	P	10.05	P	L
4	6	BT1	0.64	25.3	38.9	35.9	5.5	10.3	9.9	6.6	3.8	24.5	12.2	2.2	16.48	P	10.47	P	L
2	1	BT1	0.80	25.3	40.7	34.0	0.8	3.3	7.0	13.2	9.8	27.6	9.6	3.5	17.97	P	10.70	P	L
4	3	BK	0.24	25.4	53.6	21.1	0.2	0.9	1.3	4.2	14.5	36.9	9.7	7.0	21.29	P	9.95	P	SIL
1	1	A	2.32	25.6	59.8	14.6	0.5	1.1	1.5	2.3	9.3	42.1	12.6	5.2	21.56	P	12.88	P	SIL
1	5	BT2	0.56	25.7	31.4	43.1	1.6	5.2	11.0	16.0	9.5	20.5	7.4	3.6	16.28	P	10.49	P	L
3	3	BT1	0.64	25.9	39.9	34.3	1.2	3.9	8.5	13.9	6.9	25.0	12.4	2.6	17.20	A	11.20	A	L
5	5	2BTK	0.80	26.3	60.2	13.6	0.4	1.4	0.9	1.5	9.5	41.4	14.3	4.5	21.88	P	11.02	P	SIL

¶ A = Measured value from pressure plate.
P = Predicted value from regression analysis.

§ Organic Carbon

PARTICLE SIZE AND WATER CONTENT RELATIONSHIPS BY HORIZON
HORIZON DATA SORTED BY CLAY CONTENT THEN SILT CONTENT

Particle Size Data in % of Total
(fraction separations in microns)

				Total			Sand Fraction					Silt Fraction							
LEVEL	TRANSECT	HORIZON	OC§ %	CLAY <2	SILT 2-50	SAND 50 -2000	VC 1000 -2000	C 500 -1000	M 250 -500	F 100 -250	VF 50 -100	C 20 -50	M 5 -20	F 2 -5	0.03 MPa θm %	¶	1.5 MPa θm %	¶	TEXTURAL CLASS
4	2	BTK	0.32	26.4	56.2	17.5	0.4	1.2	1.5	2.7	11.8	40.6	13.7	1.9	21.59	P	10.40	P	SIL
4	6	BT2	0.56	26.5	43.8	29.8	4.3	8.0	8.1	4.8	4.8	29.4	12.2	2.3	18.01	P	10.78	P	L
5	5	BT1	0.96	26.6	41.5	31.9	3.2	9.5	5.3	7.5	6.4	25.0	12.1	4.5	17.93	P	11.36	P	L
1	1	C1	0.64	26.6	45.5	28.0	1.9	5.4	5.6	6.1	9.1	31.1	11.3	3.1	19.16	P	10.92	P	L
3	5	BT2	0.72	26.7	50.2	23.2	3.2	4.0	2.7	4.1	9.4	34.3	12.3	3.6	20.11	P	11.05	P	SIL
1	6	BT	1.20	26.7	51.6	21.8	0.2	0.8	2.6	7.1	11.2	35.7	12.1	3.8	19.80	A	12.00	A	SIL
1	1	BT1	2.16	27.0	56.2	16.9	0.4	1.7	1.8	2.5	10.5	35.7	14.4	6.1	21.56	P	13.12	P	SIL
3	3	BIK	0.24	27.1	48.3	24.6	0.3	1.1	2.4	5.0	15.9	30.3	12.4	5.7	19.60	A	10.90	A	CL
5	1	BTK	0.56	27.1	50.5	22.4	2.7	4.0	2.8	2.7	10.2	30.5	16.8	3.3	18.60	A	9.80	A	CL
4	6	BIK	0.48	27.1	50.9	22.2	1.9	3.7	4.7	3.8	8.3	36.0	11.1	3.8	20.17	P	10.86	P	SIL
3	2	BI2	0.56	27.2	46.5	26.4	0.2	1.0	1.8	4.5	19.0	31.5	12.3	2.7	21.39	P	11.00	P	CL
2	6	BI2	0.56	27.3	32.4	40.3	7.3	11.7	9.9	7.3	4.2	19.3	10.4	2.8	16.04	P	11.05	P	CL
2	5	BT1	1.44	27.4	49.6	23.1	1.5	3.9	4.0	4.1	9.7	31.5	13.3	4.9	20.30	P	12.27	P	CL
4	2	BT	0.56	27.5	50.8	21.8	1.1	2.3	3.0	4.6	10.9	35.5	11.5	3.9	20.79	P	11.10	P	CL
1	6	BTK1	0.56	27.6	45.0	27.5	0.1	1.0	3.7	10.7	12.0	31.6	10.3	3.2	20.00	A	12.00	A	CL
3	3	BT2	0.56	27.7	48.1	24.2	0.6	2.4	5.4	10.0	6.0	27.5	17.4	3.2	20.20	A	13.00	A	CL
5	3	BTK	0.24	27.9	56.7	15.5	0.2	0.5	0.5	1.5	12.9	39.8	12.8	4.2	23.60	A	12.00	A	SICL
2	3	BT2	0.64	28.0	32.1	40.0	0.5	3.1	8.9	15.1	12.5	21.2	9.4	1.5	17.74	P	11.38	P	CL
1	1	BK	0.64	28.1	40.7	31.2	3.9	7.3	6.9	7.0	6.3	25.9	10.5	4.4	18.26	P	11.43	P	CL
4	3	BTK2	0.24	28.3	44.5	27.3	0.9	2.1	2.1	6.5	15.9	31.2	9.2	4.2	20.82	P	10.96	P	CL
1	6	BTK2	0.88	28.3	46.2	25.6	0.2	0.9	3.2	9.8	11.6	29.0	12.1	5.2	20.70	A	13.40	A	Cl
5	3	BT1	0.64	28.4	56.0	15.7	1.5	3.9	2.8	2.0	5.6	34.1	15.2	6.8	24.30	A	14.10	A	SICL
3	5	BT1	0.80	28.6	47.3	24.2	3.3	4.4	3.0	4.4	9.2	32.5	10.6	4.3	20.19	P	11.80	P	CL
4	5	BT1	0.80	28.8	39.8	31.4	6.0	9.0	6.3	3.9	6.3	23.7	12.8	3.4	18.33	P	11.89	P	CL
2	5	BTK	0.64	30.4	39.6	30.1	1.4	4.8	7.4	8.6	8.0	23.4	11.0	5.2	19.12	P	12.20	P	CI
3	2	BK	0.32	30.7	50.3	19.1	0.2	0.6	0.9	2.2	15.3	35.4	12.6	2.3	22.59	P	11.86	P	SICL
4	3	BT2	0.72	30.9	57.3	11.9	0.2	0.7	0.6	1.7	8.8	31.7	16.2	9.4	22.75	P	12.48	P	SICL
5	3	BT2	0.64	31.0	56.0	13.0	0.4	1.1	0.9	0.8	9.9	38.2	14.5	3.4	25.50	A	15.00	A	SICL
4	3	BTK1	0.40	32.1	53.3	14.7	0.2	0.5	0.6	2.0	11.5	32.5	13.9	7.0	22.92	P	12.46	P	SICL
2	5	BT2	0.88	34.1	46.4	19.6	0.9	3.1	4.3	4.8	6.7	29.7	13.0	3.8	21.38	P	13.78	P	CI
4	3	BT1	0.72	34.2	54.2	11.7	0.4	1.3	1.5	2.0	6.5	33.9	15.3	5.1	22.87	P	13.61	P	SICL
1	1	BTK2	0.80	35.7	34.2	30.2	3.8	5.6	6.2	6.3	8.5	20.1	10.4	3.7	19.97	P	14.22	P	CL
1	1	BTK1	0.96	40.0	44.6	15.5	0.6	2.2	3.2	3.5	6.2	27.9	12.3	4.4	22.93	P	15.89	P	SICL
3	3	3C	0.16	55.3	34.3	10.5	0.3	1.2	1.9	3.9	3.4	9.9	11.2	13.2	25.10	A	16.80	A	C

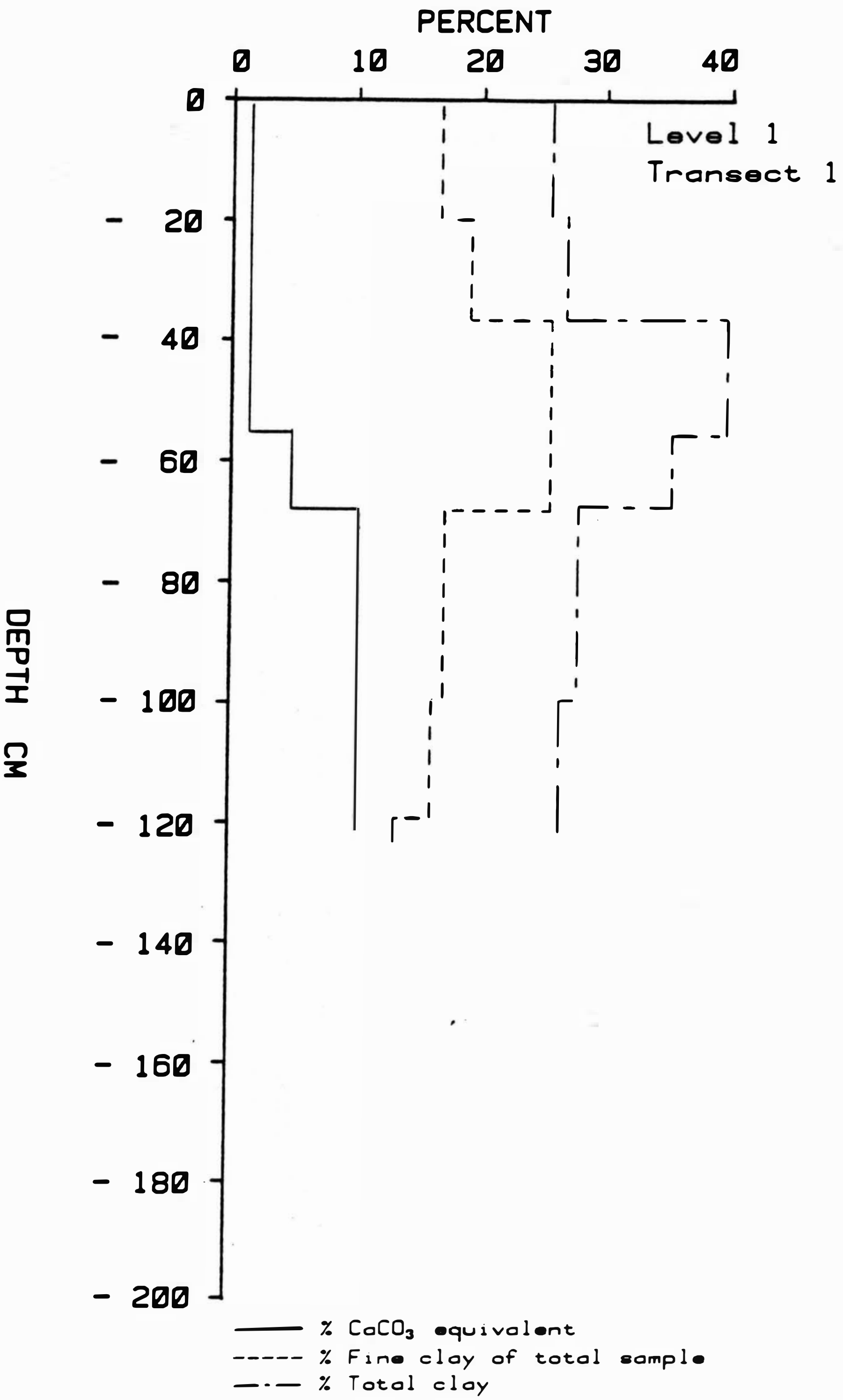
¶ A = Measured value from pressure plate.
P = Predicted value from regression analysis.

§ Organic Carbon

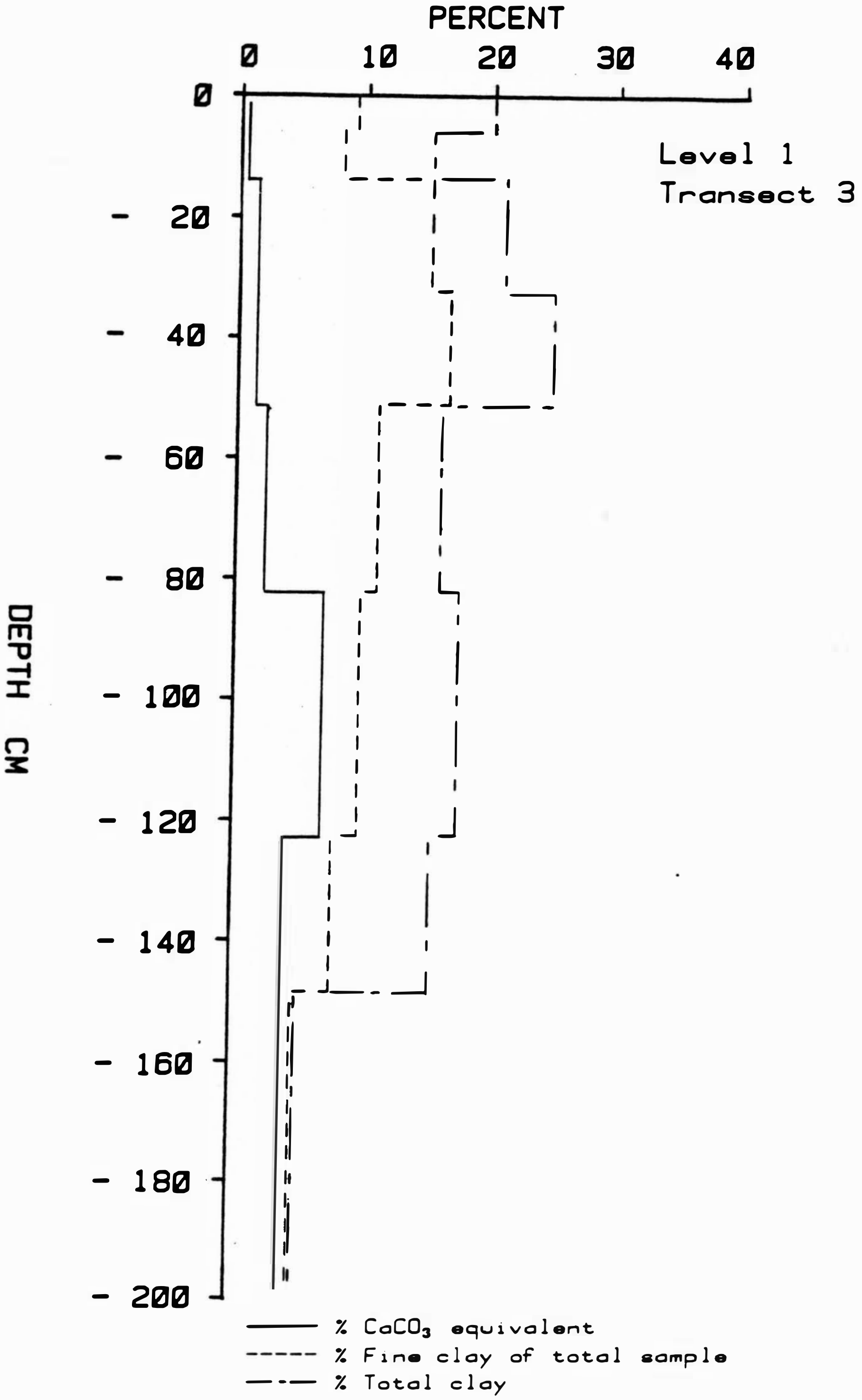
APPENDIX D

PEDON TOTAL CLAY, FINE CLAY AND CALCIUM CARBONATE DISTRIBUTIONS

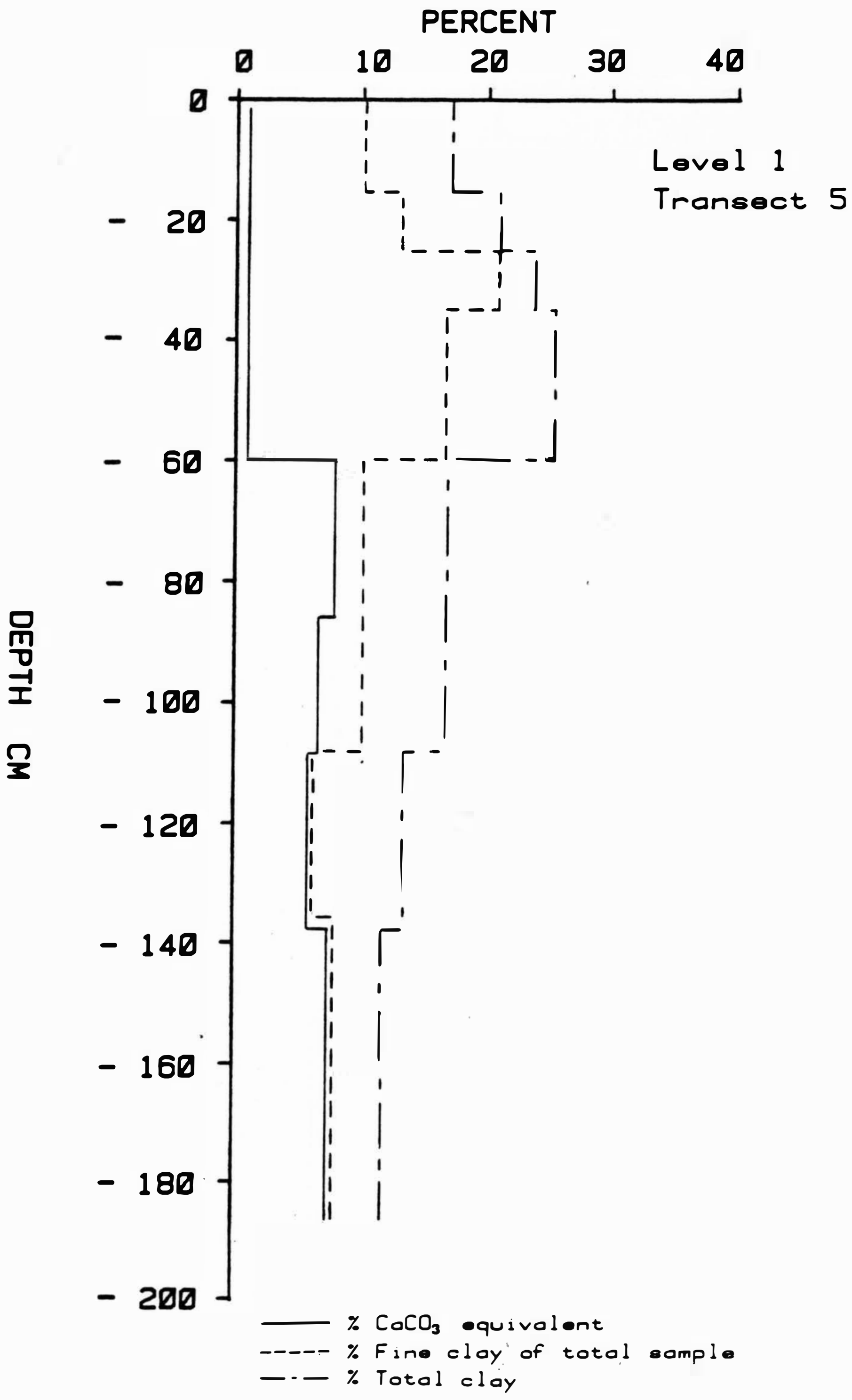
Clay and $CaCO_3$ Distribution



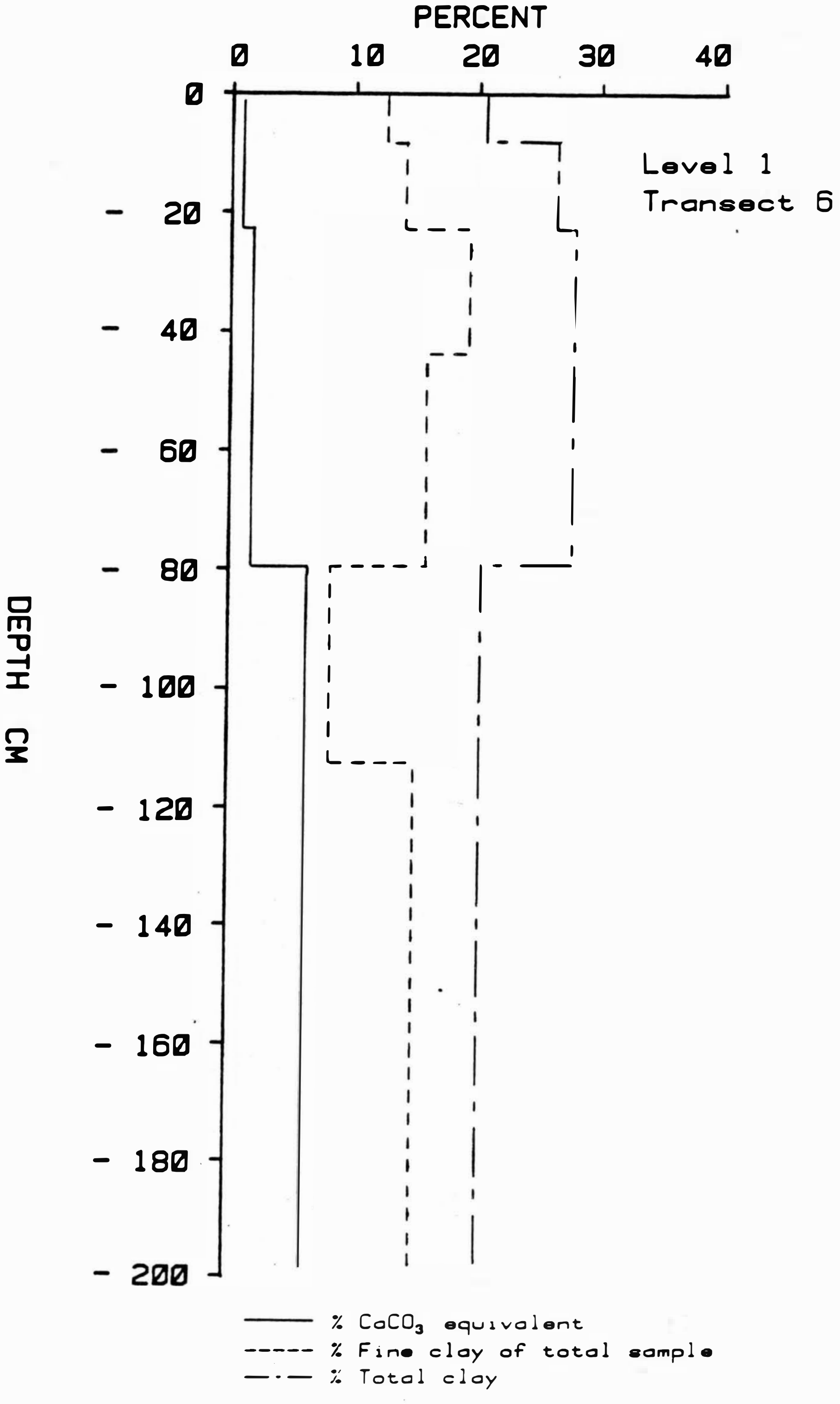
Clay and CaCO$_3$ Distribution



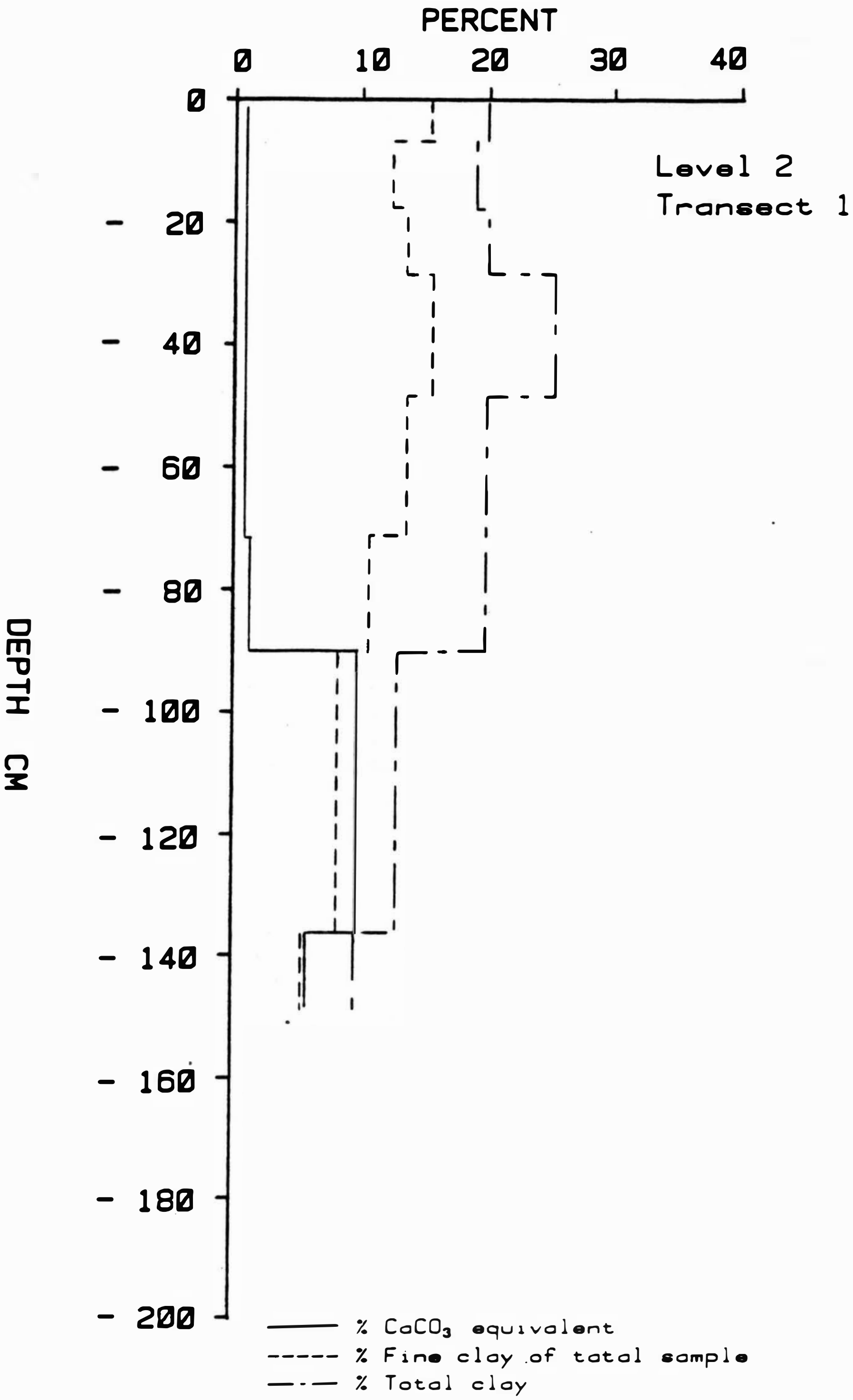
Clay and $CaCO_3$ Distribution



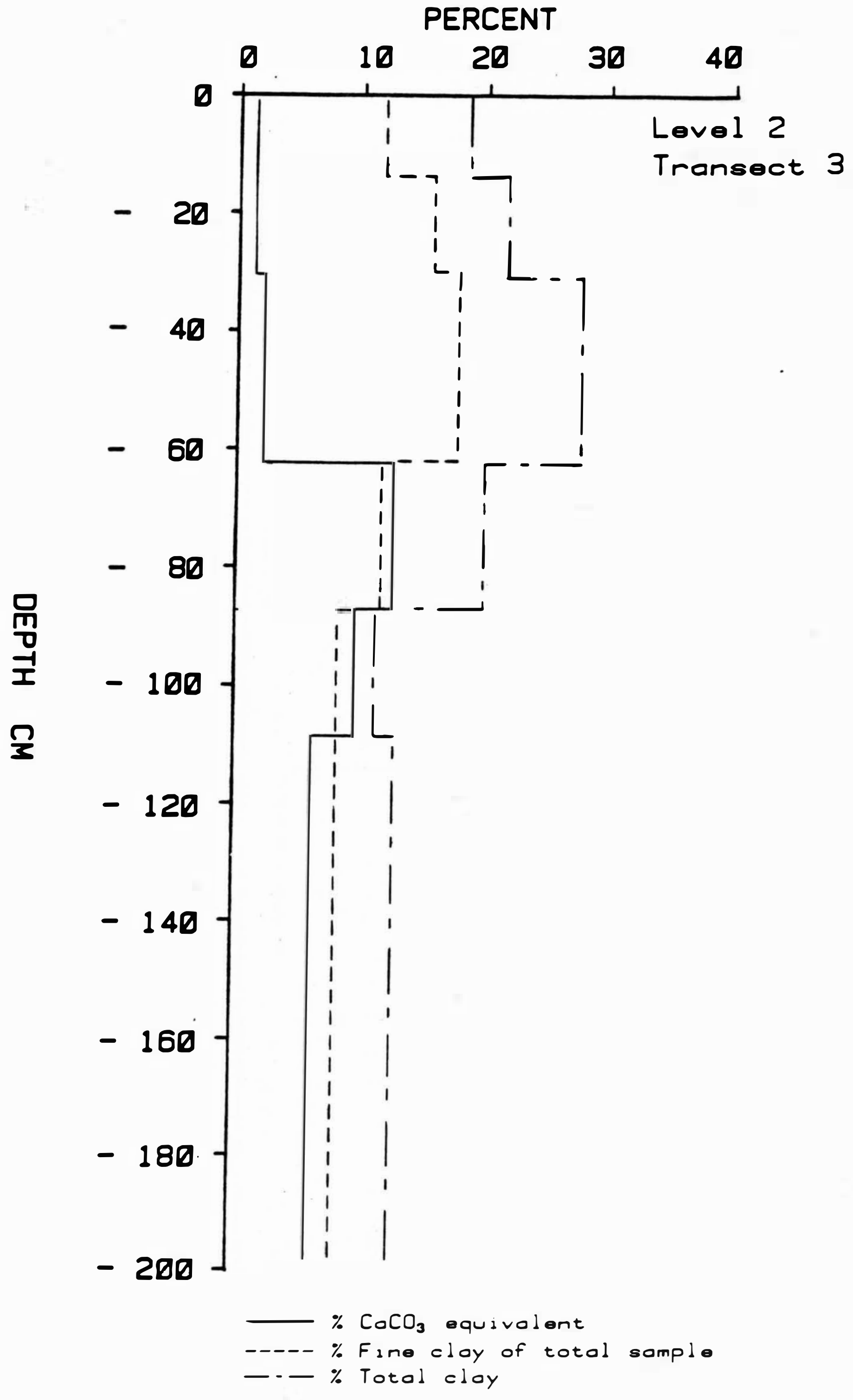
Clay and $CaCO_3$ Distribution



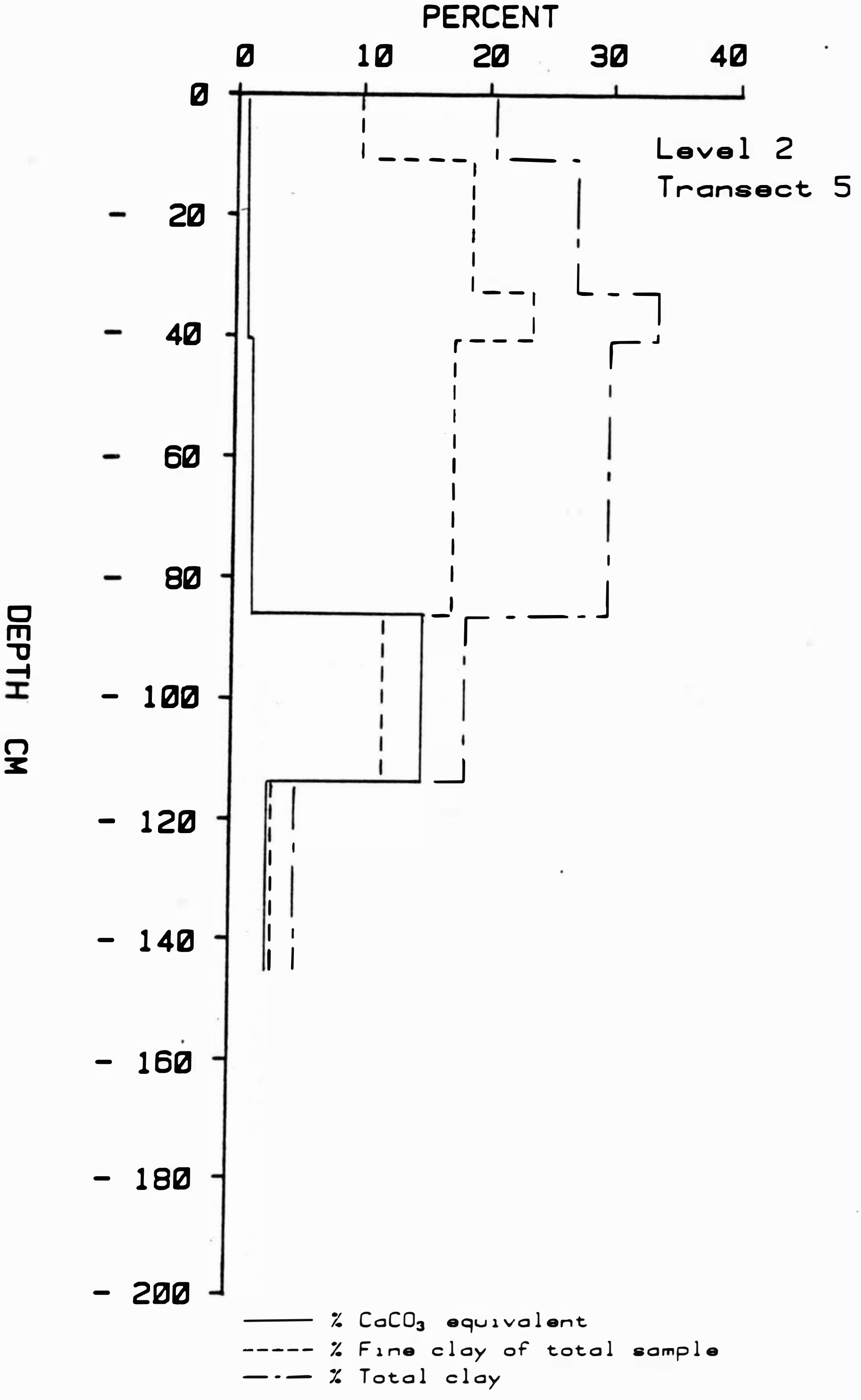
Clay and CaCO$_3$ Distribution



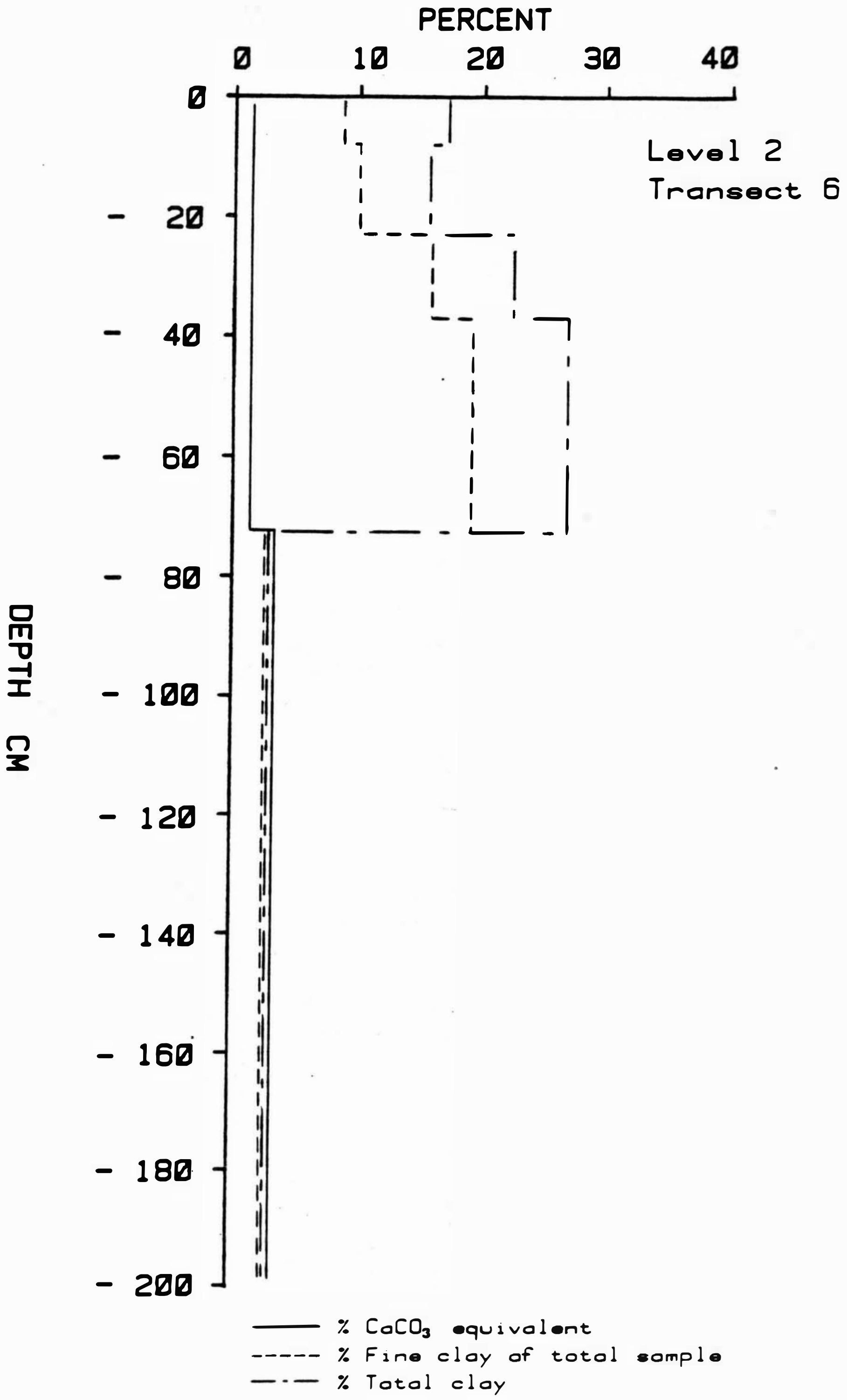
Clay and $CaCO_3$ Distribution



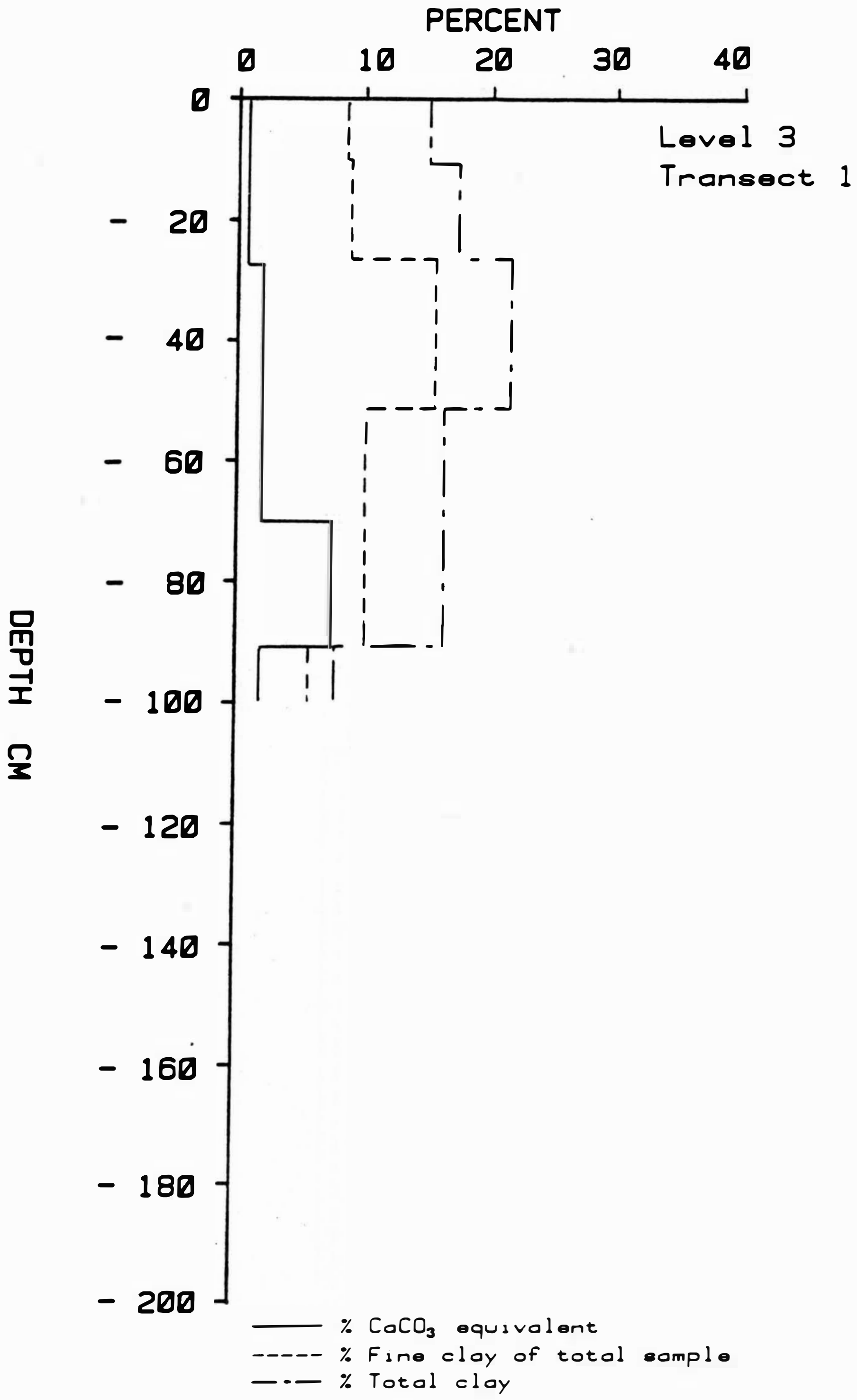
Clay and $CaCO_3$ Distribution



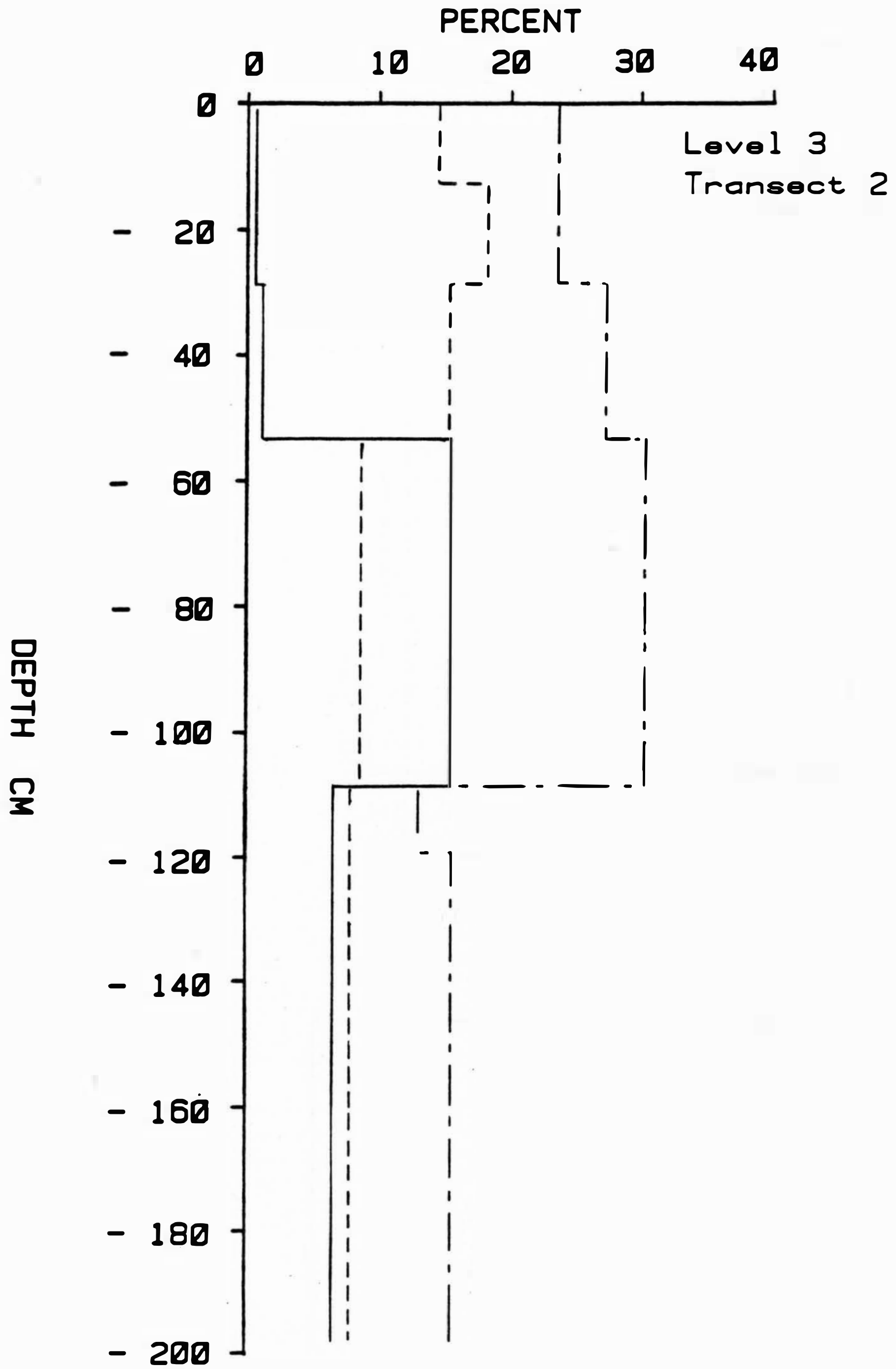
Clay and $CaCO_3$ Distribution



Clay and $CaCO_3$ Distribution

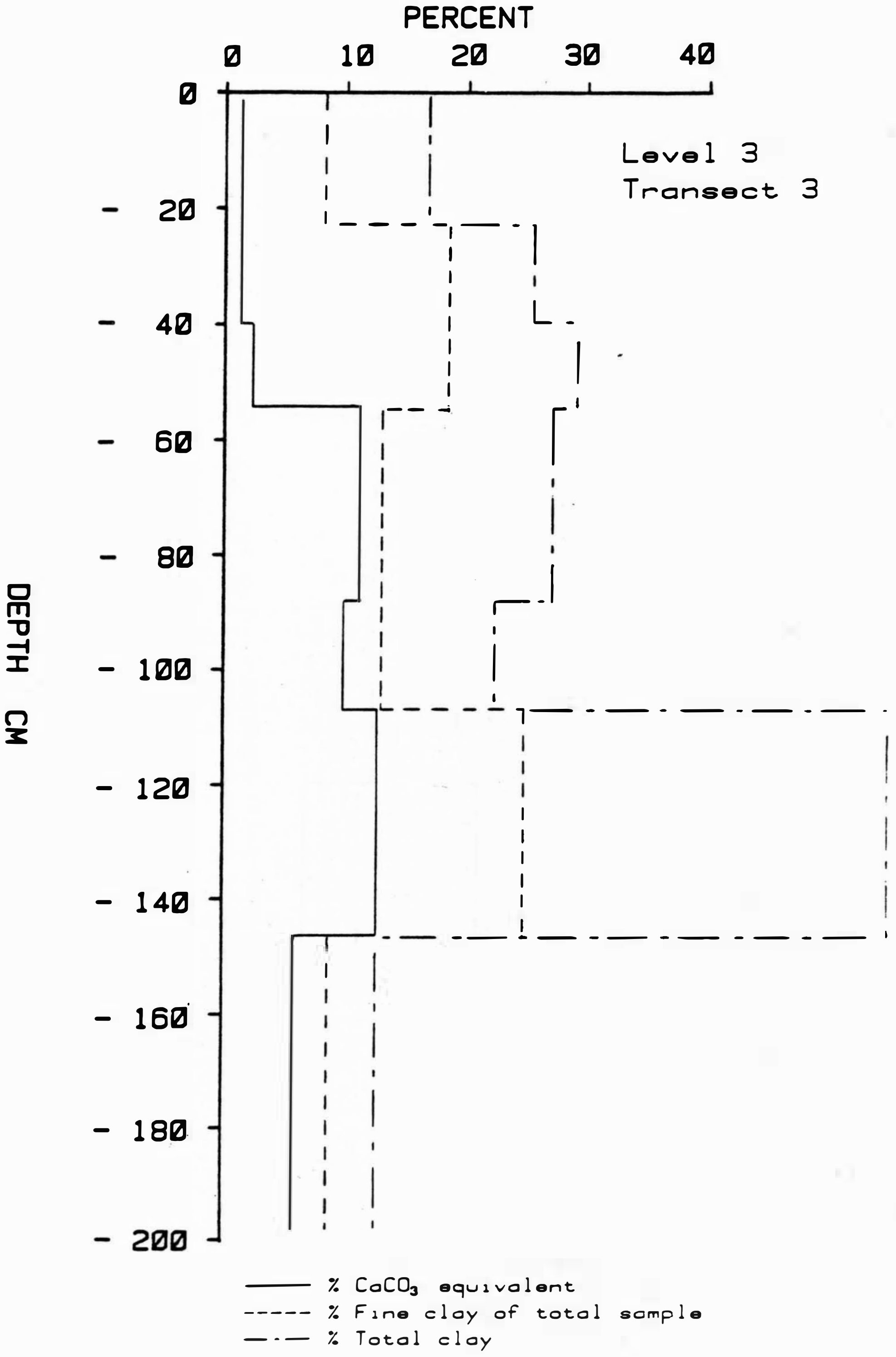


Clay and $CaCO_3$ Distribution

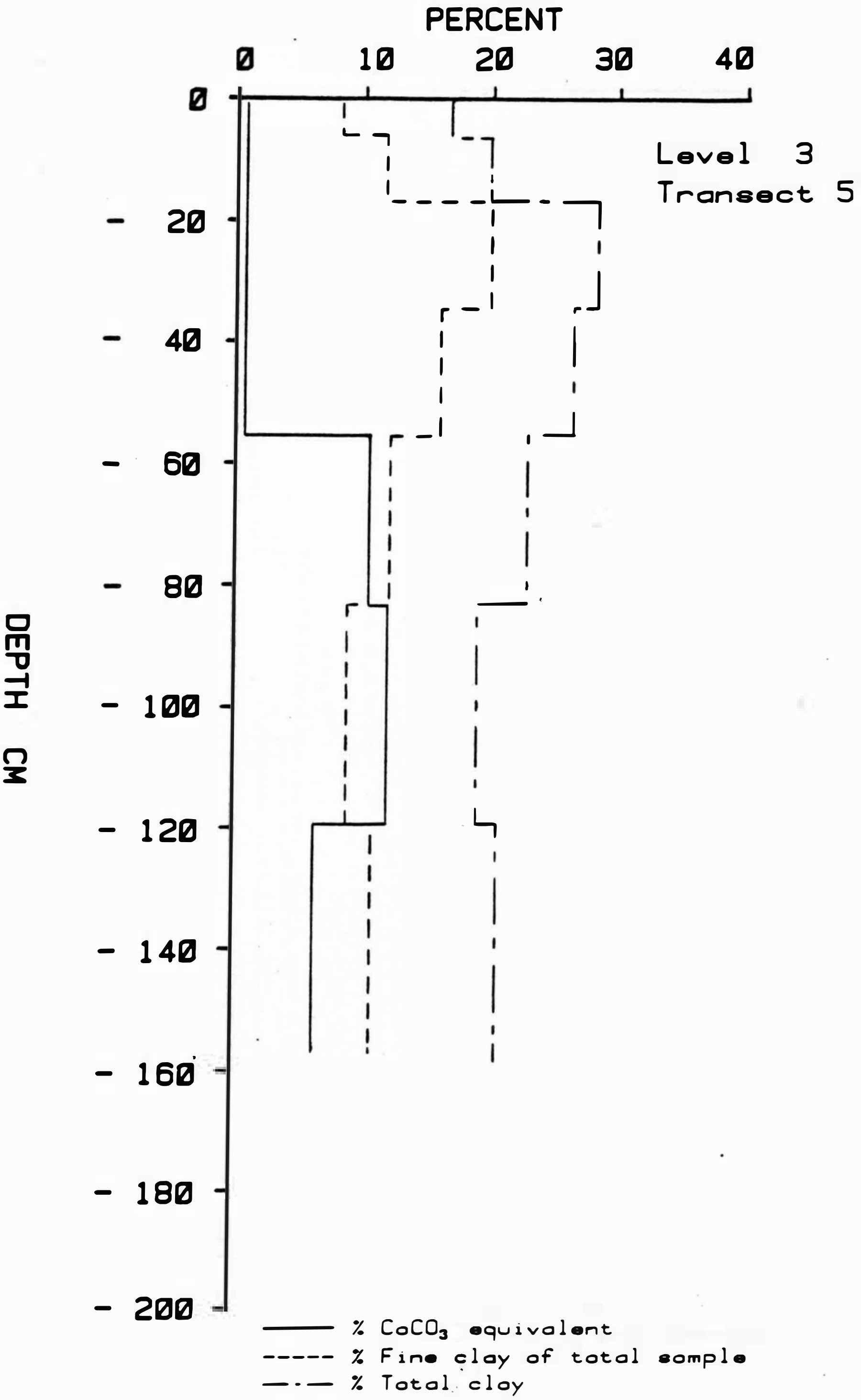


——— % $CaCO_3$ equivalent
----- % Fine clay of total sample
—·— % Total clay

Clay and $CaCO_3$ Distribution



Clay and $CaCO_3$ Distribution



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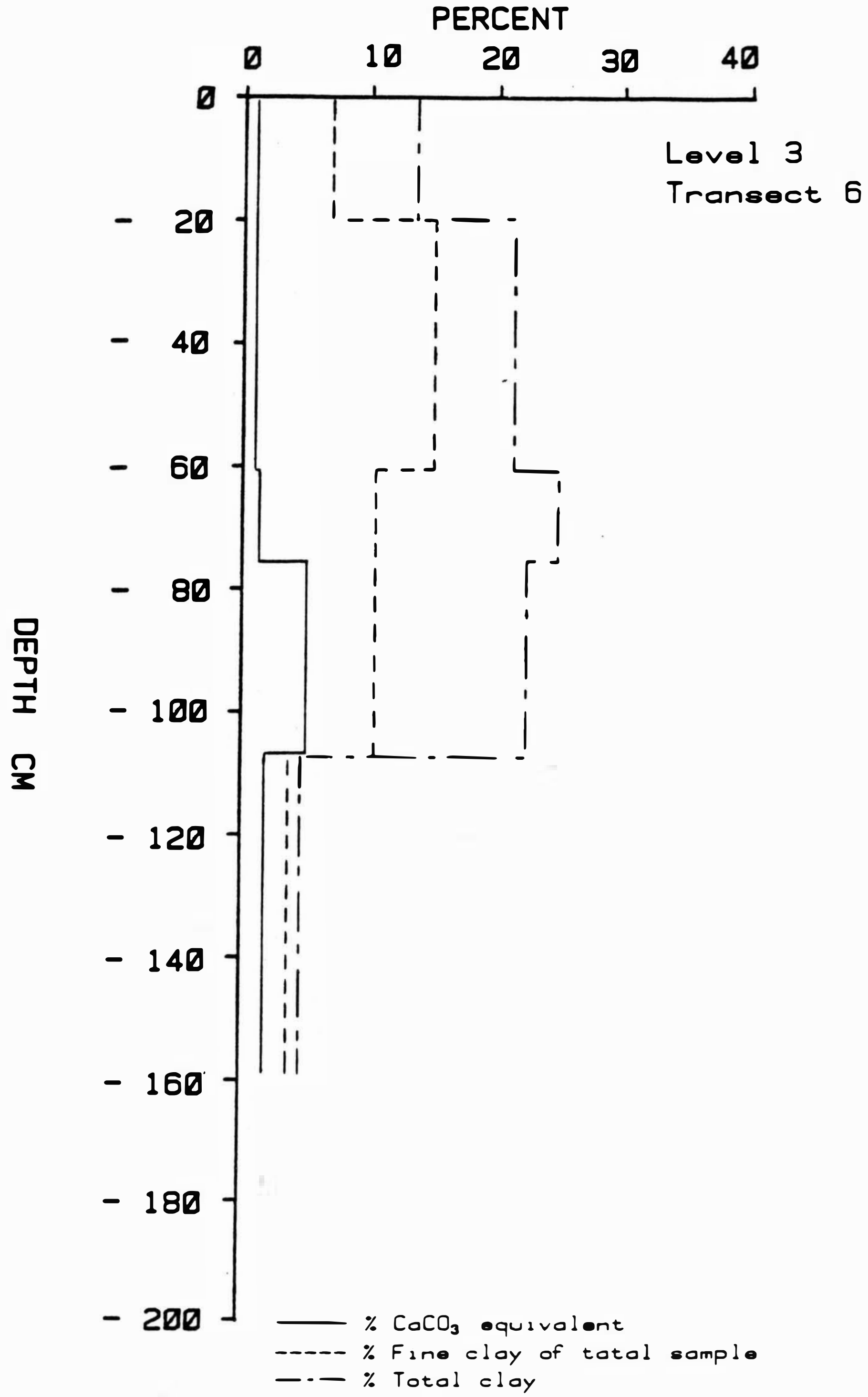
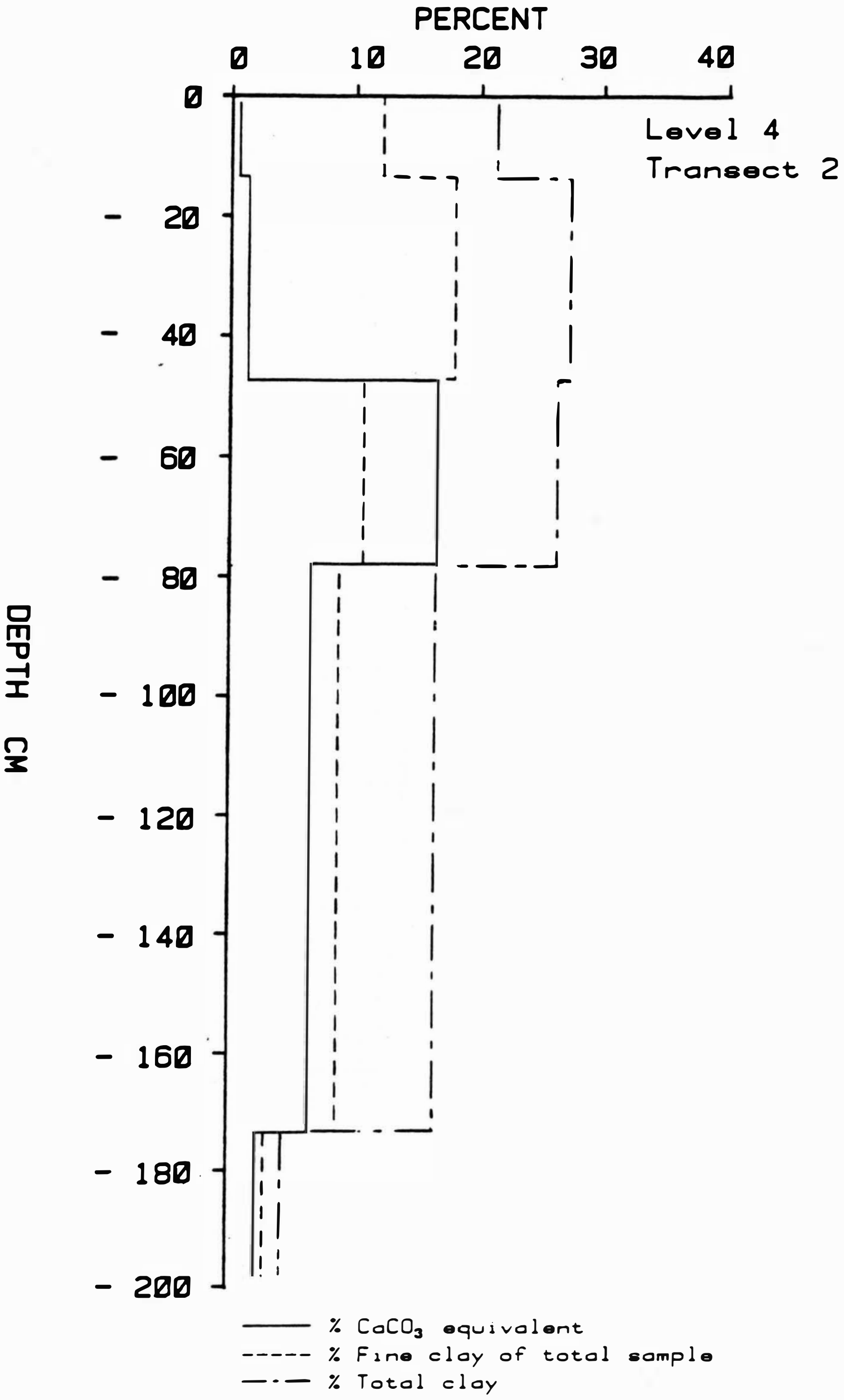
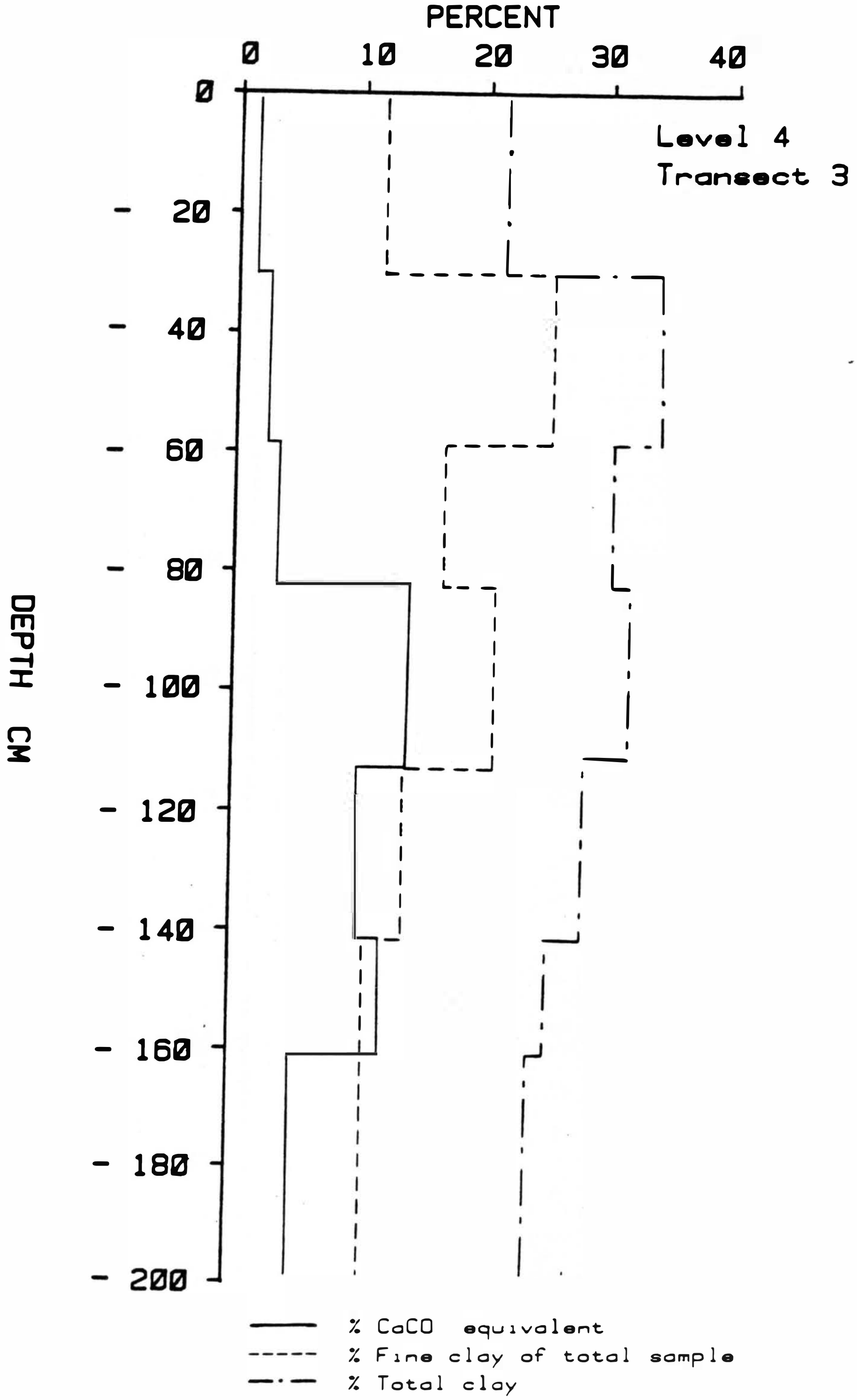


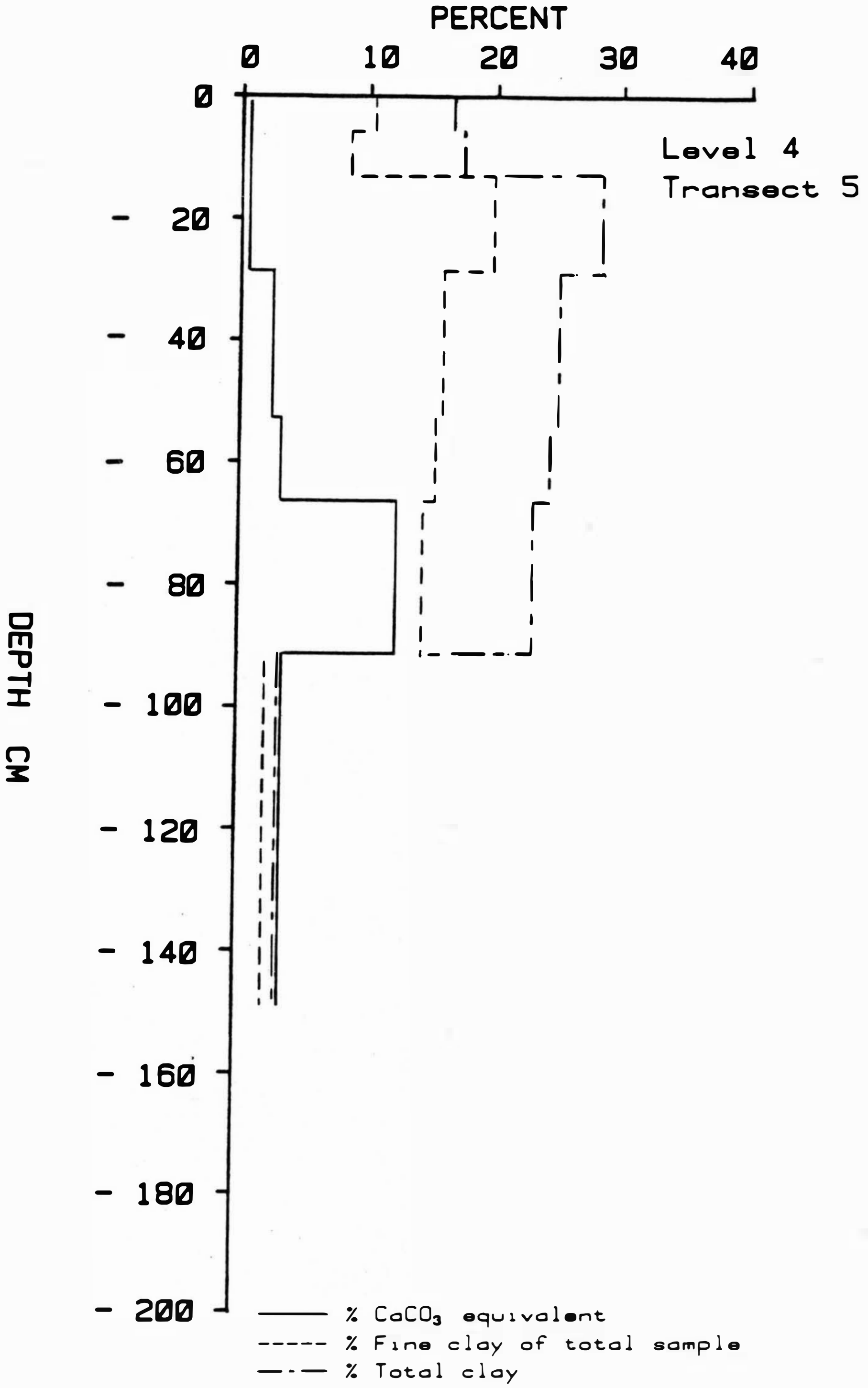
Clay and $CaCO_3$ Distribution



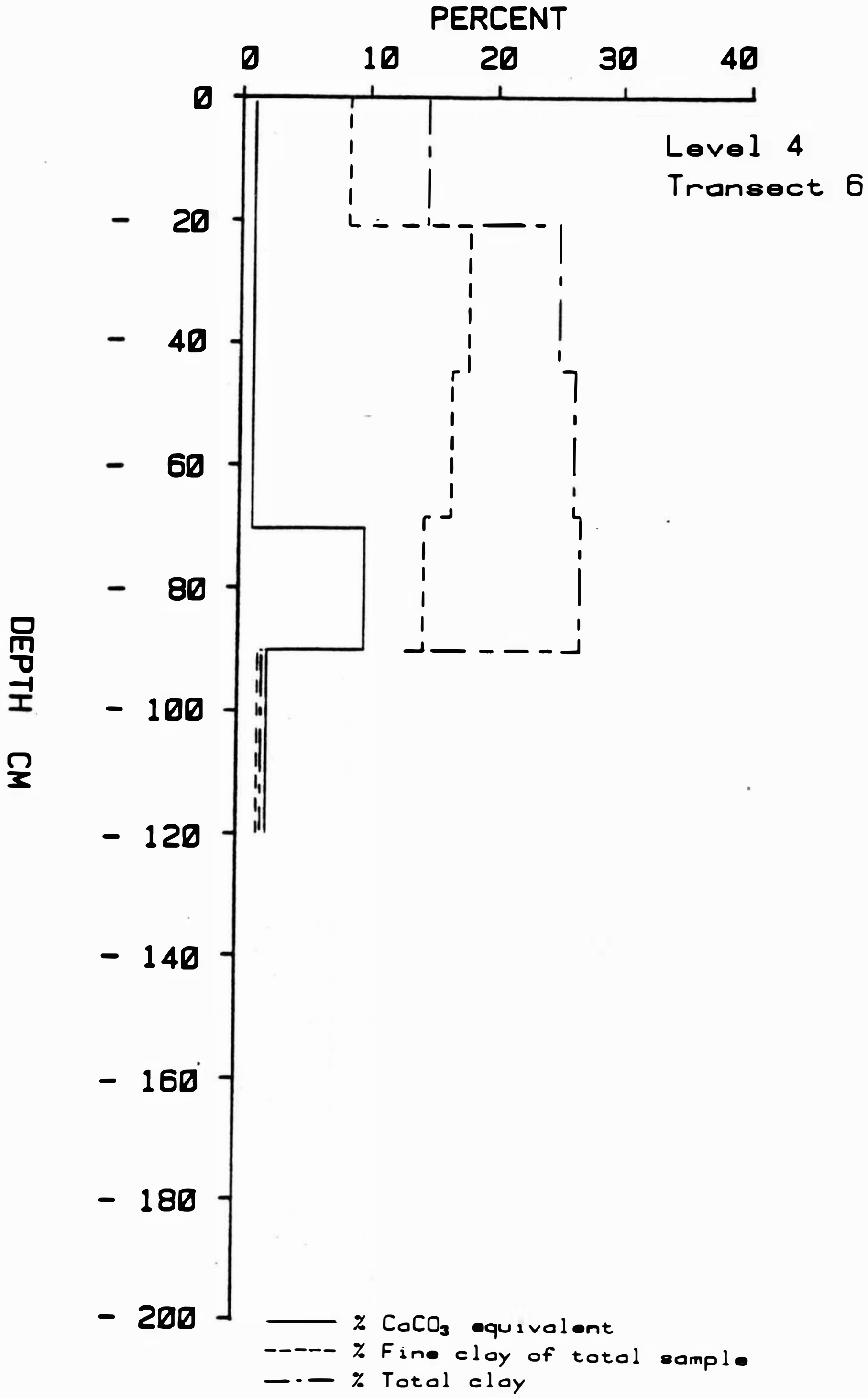
Clay and $CaCO_3$ Distribution



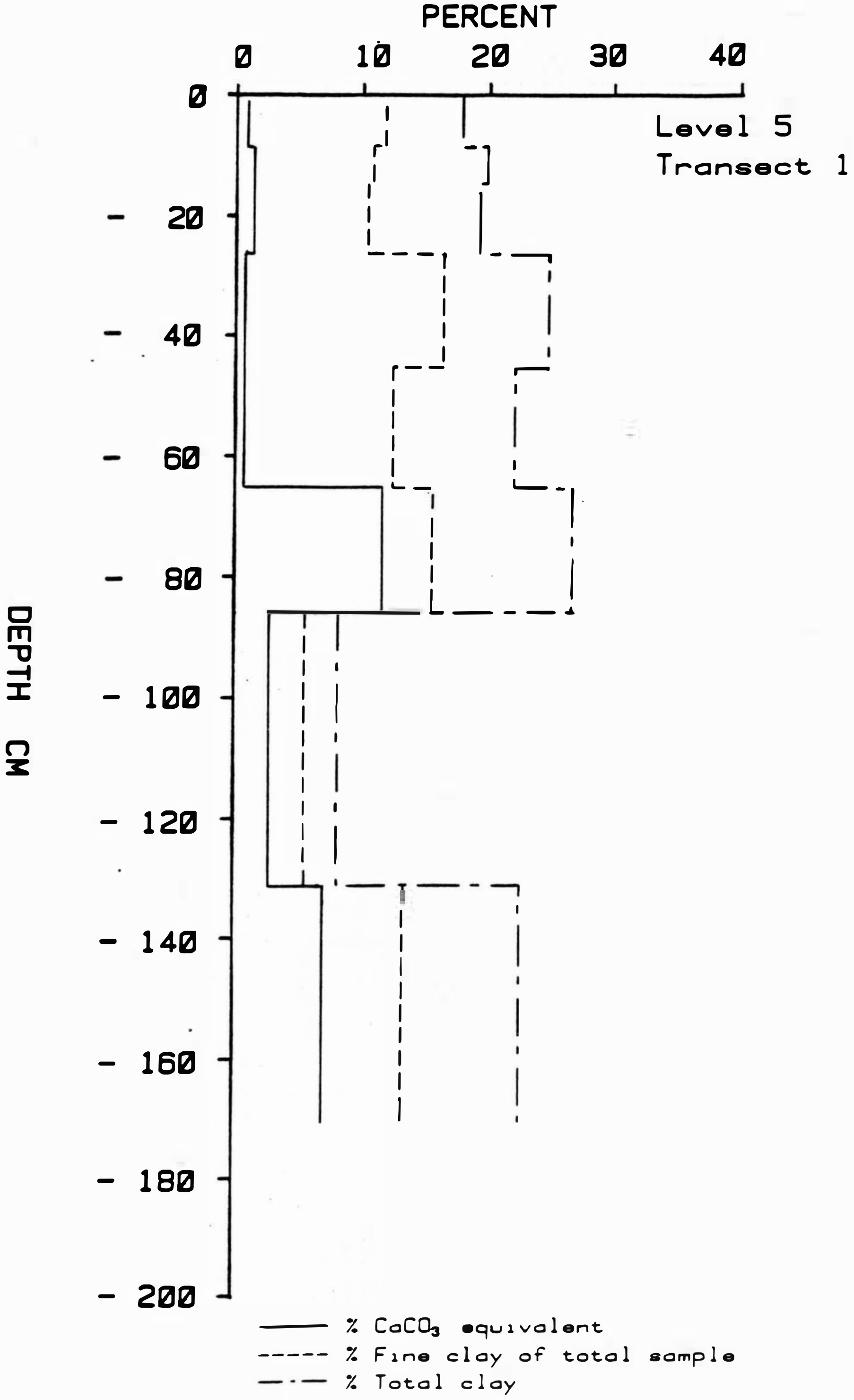
Clay and $CaCO_3$ Distribution



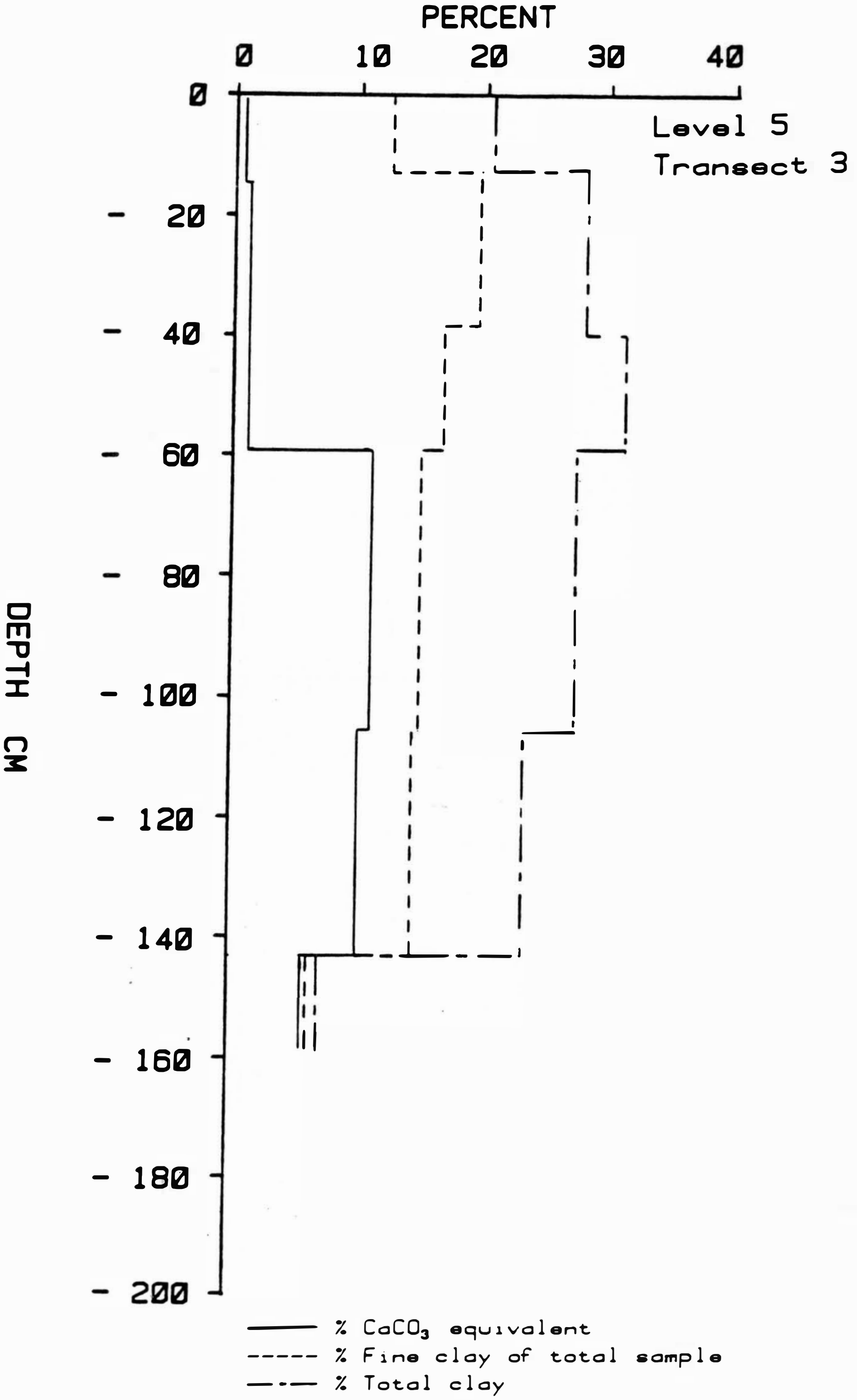
Clay and $CaCO_3$ Distribution



Clay and $CaCO_3$ Distribution

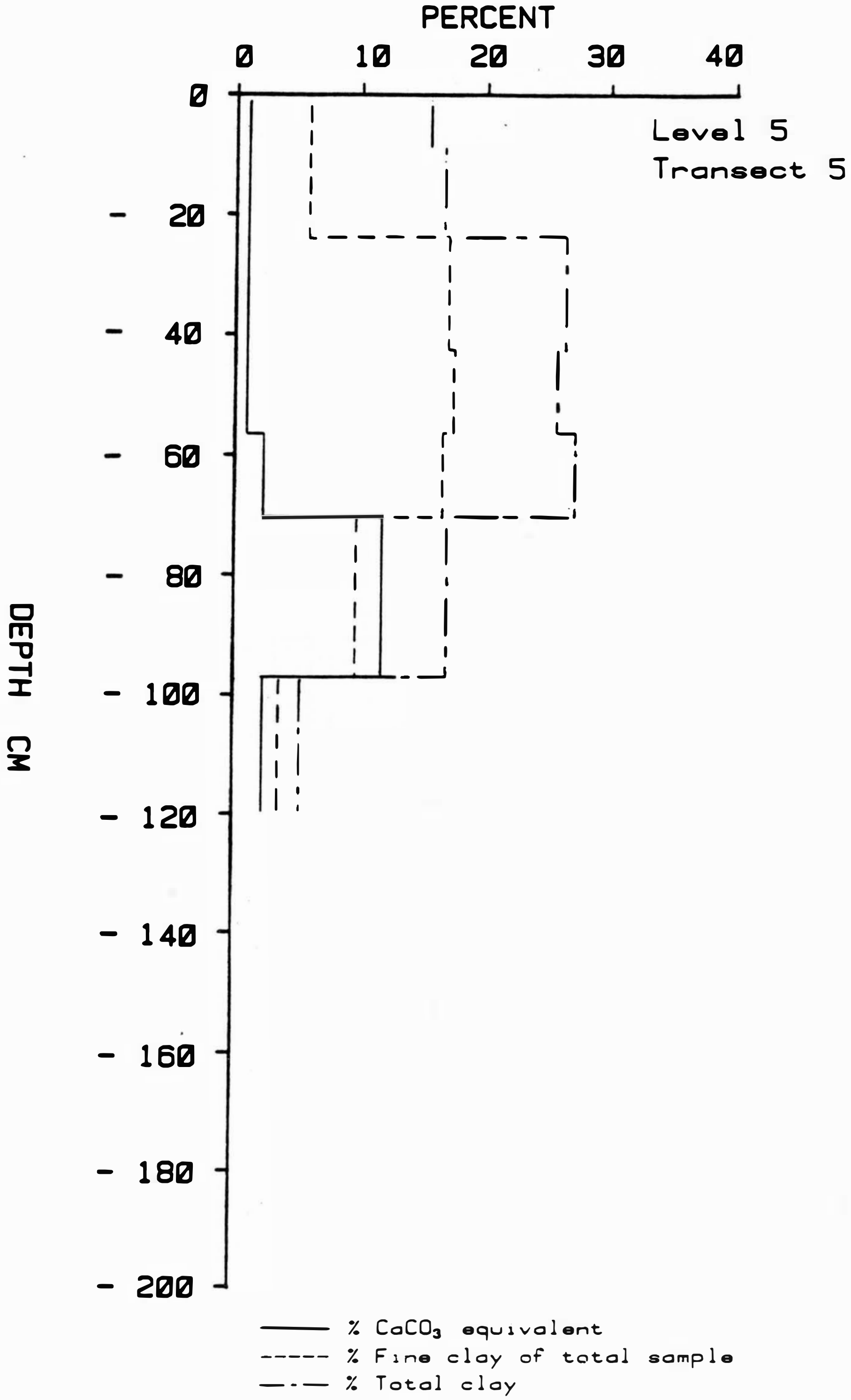


Clay and $CaCO_3$ Distribution

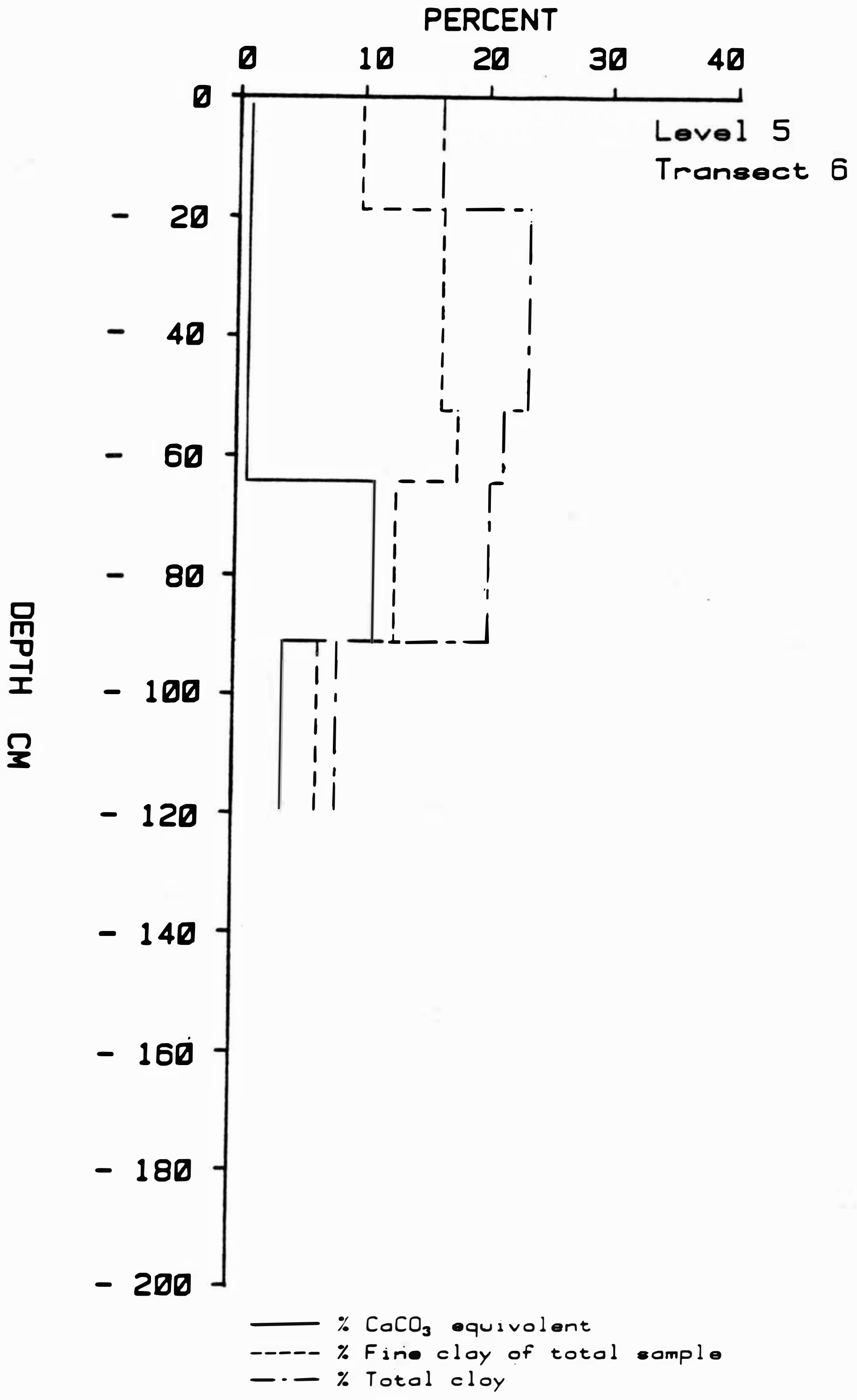


——— % $CaCO_3$ equivalent
----- % Fine clay of total sample
—·— % Total clay

Clay and $CaCO_3$ Distribution



Clay and $CaCO_3$ Distribution



APPENDIX E

REE SOIL SERIES DESCRIPTION

LOCATION REE 4/86 SD+NE

Established Series
Rev. RER-RLS
4/86

REE SERIES

The Ree series consists of deep, well drained soils formed in loamy sediments on terraces and uplands. Permeability is moderate. Slopes range from 0 to 15 percent. Mean annual temperature is about 48 degrees F, and mean annual precipitation is about 17 inches.

TAXONOMIC CLASS: Fine-loamy, mixed, mesic Typic Argiustolls.

TYPICAL PEDON: Ree loam - on a plane slope of 2 percent in a cultivated field. (Colors are for dry soil unless otherwise stated.)

Ap--0 to 6 inches; dark gray (10YR 4/1) crushing to dark grayish brown (10YR 4/2) loam, very dark grayish brown (10YR 3/2) moist; moderate medium granular structure; soft, friable; neutral; abrupt smooth boundary. (4 to 12 inches thick)

Bt1--6 to 13 inches; dark gray (10YR 4/1) crushing to dark grayish brown (10YR 4/2) clay loam, very dark grayish brown (10YR 3/2) moist; moderate medium prismatic structure parting to moderate medium subangular blocky; slightly hard, friable, slightly sticky and slightly plastic; shiny film on faces of peds; neutral; clear smooth boundary.

Bt2--13 to 18 inches; grayish brown (2.5Y 5/2) clay loam, very dark grayish brown (2.5Y 3/2) moist; moderate medium prismatic structure parting to moderate medium subangular blocky; hard, firm, slightly sticky and slightly plastic; shiny film on faces of peds; mildly alkaline; clear smooth boundary. (Combined thickness of the Bt horizons is 8 to 22 inches.)

Btk--18 to 25 inches; light brownish gray (2.5Y 6/2) clay loam, dark grayish brown (2.5Y 4/2) moist; weak coarse prismatic structure parting to weak coarse subangular blocky; slightly hard, friable, slightly sticky and slightly plastic; few fine accumulations of carbonate; slight effervescence; moderately alkaline; clear smooth boundary. (0 to 10 inches thick)

Bk--25 to 46 inches; light brownish gray (2.5Y 6/2) clay loam, grayish brown (2.5Y 5/2) moist; weak coarse subangular structure; slightly hard, friable, slightly sticky and slightly plastic; common fine soft accumulations of carbonate; strong effervescence; moderately alkaline; clear smooth boundary. (10 to 24 inches thick)

C--46 to 60 inches; light brownish gray (2.5Y 6/2) loam, grayish brown (2.5Y 5/2) moist; massive; soft, friable; strong effervescence; moderately alkaline.

TYPE LOCATION: Sully County, South Dakota; about 8 miles south and 10 miles east of Onida; 420 feet east and 1440 feet north of the southwest corner of sec. 20, T. 113 N., R. 75 W.

RANGE IN CHARACTERISTICS: The depth to carbonates ranges from 12 to 34 inches and typically is about 18 to 24 inches. The thickness of the mollic epipedon ranges from 7 to 20 inches.

The A horizon has hue of 10YR, value of 3 to 5 and 2 or 3 moist, and chroma of 1 or 2. It commonly is loam but is silt loam or fine sandy loam in some pedons. It is slightly acid or neutral.

The Bt horizon has hue of 10YR or 2.5Y, value of 4 to 6 and 2 to 4 moist, and chroma of 1 to 4. It commonly is clay loam but is sandy clay loam or silty clay loam in some pedons. It has an average clay content of 27 to 35 percent. It ranges from slightly acid to mildly alkaline in the upper part and mildly or moderately alkaline in the lower part. Some pedons do not have carbonates as disseminated lime or few fine accumulations of carbonate in the lower part.

The Bk horizon has hue of 10YR or 2.5Y, value of 5 to 7 and 4 to 6 moist, and chroma of 2 to 4. It is loam, clay loam, fine sandy loam, or sandy clay loam. It has common to many accumulations of carbonates. It is mildly or moderately alkaline.

The C horizon has hue of 10YR or 2.5Y, value of 5 to 7 and 4 to 6 moist, and chroma of 2 to 4. It ranges from sandy loam to clay loam, but some pedons have sandy materials, sand and gravel or clay materials at a depth of 40 to 60 inches. It is mildly or moderately alkaline.

COMPETING SERIES: These are the Glenham, Gosper, Houdek, Wewela and Wineg series in the this family and the Canning, Farland, Keya, Kirley, Paka, and Satanta series. Glenham and Houdek soils formed in glacial till. Gosper soils typically contain less clay in the argillic horizon and become more sandy with increasing depth. Wewela soils have shale bedrock within a depth of 40 inches. Wineg soils have a drier climate. Canning soils have sand and gravel within a depth of 40 inches. Farland soils have a frigid temperature regime. Keya soils have a mollic epipedon thicker than 20 inches. Kirley soils have a fine textured argillic horizon. Paka soils have a fine-silty argillic horizon. Satanta soils have an aridic moisture regime.

GEOGRAPHIC SETTING: Ree soils are on terraces and uplands. Slopes are plane to slightly convex and range from 0 to 15 percent. Ree soils formed mainly in loamy alluvial sediments. The mean annual temperature ranges from 45 to 50 degrees F, and the mean annual precipitation ranges from 16 to 21 inches.

GEOGRAPHICALLY ASSOCIATED SOILS: These are the competing Canning, Keya, and Kirley soils and the Durrstein, Mosher, Oahe, and Onita soils. Canning, Kirley, and Oahe soils are in the same landscape. Oahe soils have more than 35 percent gravel within a depth of 40 inches. Keya and Onita soils are in swales. Onita soils have a fine textured argillic horizon. Durrstein and Mosher soils have a natric horizon and are on similar landscapes.

DRAINAGE AND PERMEABILITY: Well drained. Runoff is slow on nearly level areas to medium on the strongly sloping areas. Permeability is moderate.

USE AND VEGETATION: Many areas are cultivated. Corn, sorghum, small grain, and alfalfa are the main crops. Some areas remain in native grass. The native vegetation includes western wheatgrass, green needlegrass, needleandthread, sideoats grama, blue grama, big bluestem, little bluestem, porcupine grass, sedges and forbs.

DISTRIBUTION AND EXTENT: Central and south-central South Dakota and north-central Nebraska. The series is extensive.

SERIES ESTABLISHED: Hughes County, South Dakota, 1970.

REMARKS: Diagnostic horizons and features recognized in this pedon are: mollic epipedon - the zone from the surface of the soil to a depth of about 18 inches (Ap, Bt1, and Bt2 horizons); argillic horizon - the zone from about 6 to 25 inches (Bt1, Bt2, and Btk horizons).

National Cooperative Soil Survey
U.S.A.

APPENDIX F

FIELD DESCRIPTION SHEETS

FIELD DESCRIPTION SHEET

Level 1 | Transect 1 | Elevation 655.3 Meters (m) | Date 7/84

Location: Northwest corner, SW 1/4, Section 36, T5N, R18E
Haakon County, South Dakota.

Native veg..or crop:

Described by: S.G.Wangemann
G.D.Lemme, R.L.Schlepp

Additional Notes:

1. A1 and A2 samples were combined for laboratory analysis.
2. Verticle and horizontal orientation of clay films was more evident in the Btk1 than the Bt or Btk2.
3. Soft lime accumulations in the Btk1 were commonly oriented along verticle ped faces.
4. Profile was moist to somewhat dry.

Classification; Typic Argiustoll, Fine-Silty, Mixed, Mesic

HORIZON	DEPTH	SOIL COLOR		TEXTURE	SOIL STRUCTURE		DRY	REACTION	BOUNDARY	SOFT LIME
	cm	DRY	MOIST		PRIMARY	SECONDARY	CONSISTANCE			ACCUM.
A1	4	10YR4/1	10YR3/1	SiL	2m&fgr	1tpl&vtpl	s	none	as	none
A2	19	10YR4/2	10YR3/2	SiL	2m&fsbk	2mpr	s	none	cs	none
Bt	36	10YR4/2	10YR3/2	SiL	2m&fsbk	2mpr	s/sh	none	cw	none
Btk1	55	10YR5/3	10YR4/2	SiCL	2m&fsbk	2mpr	h	ev	gw	f1
Btk2	69	10YR5/3	10YR4/2	CL	2m&fsbk	2mpr	sh/h	ev	gw	c2
Bk	100	10YR6/3	10YR5/3	CL	1m&fsbk	1mpr	sh	ev	gw	m2
C1	120	10YR5/3	10YR4/3	L	m	---	s	ev	cs	c2
C2	122	10YR6/2	10yr5/2	L	m	---	h	ev	--	m2

FIELD DESCRIPTION SHEET

Level 1 | Transect 3 | Elevation 645 Meters (m) | Date 7/84

Location: 61 m east and 61 m south of the NW corner, Sec. 22, T7N, R20E, Haakon County, South Dakota.

Native veg. or crop: grassland | Described by: S.G.Wangemann, G.D.Lemme, R.L.Schlepp

Additional Notes:

1. Soft lime accumulations from the 2Bk1 to the 2Bk2 were inter-connected.
2. Profile was somewhat dry throughout.

Control Section: Typic Argiustoll, Fine-Loamy, Mixed, Mesic

HORIZON	DEPTH	SOIL COLOR		TEXTURE	SOIL STRUCTURE		DRY	REACTION	BOUNDARY	SOFT LIME
	cm	DRY	MOIST		PRIMARY	SECONDARY	CONSISTANCE			ACCUM.
A1	5	10YR5/3	10YR3/2	SiL	2vt&tpl	---	s	none	as	none
AB	13	10YR5/3	10YR3/2	SiL	2msbk	2m&cpr	s	none	cs	none
Bt1	32	10YR5/3	10YR3/2	L	2c&msbk	2mpr	sh	none	cw	none
Bt2	51	10YR5/3	10YR3/2	L	2msbk	2mpr	sh	none	cw	none
2Bk1	82	10YR5/3	10YR4/2	SCL	1f&msbk	1mpr	s	ev	gw	cl
2Bk2	123	10YR5/3	10YR4/2	SL	1msbk	1mpr	s	ev	cw	cl
2Bk3	150	10YR5/3	10YR4/3	SL	1msbk	---	s	ev	cs	f&cl
3C	210	10YR5/3	10YR4/2	FSL	m	---	l	ev	--	fl

FIELD DESCRIPTION SHEET

Level 1 | Transect 5 | Elevation 603.5 Meters (m) | Date 7/84

Location: Southwest corner, SW1/4, SEC. 36, T8N, R22E,
Haakon County, South Dakota.

Native veg. or crop: | Described by: S.G.Wangemann, G.D.Lemme, R.L.Schlepp

Additional Notes:

1. Verticle and horizontal orientation of clay films was more evident in the Bt2 than the Bt1.
2. Profile was moist throughout.

Classification: Typic Argiustoll, Fine-Loamy, Mixed, Mesic

HORIZON	DEPTH cm	SOIL COLOR DRY	SOIL COLOR MOIST	TEXTURE	SOIL STRUCTURE PRIMARY	SOIL STRUCTURE SECONDARY	DRY CONSISTANCE	REACTION	BOUNDARY	SOFT LIME ACCUM.
Ap	14	10YR4/2	10YR3/2	L	1m&fgr	---	s/sh	none	as	none
A2	24	10YR4/2	10YR3/2	L	1fgr	1mpr	s	none	cs	none
Bt1	33	10YR5/3	10YR4/3	L	2mskb	1mpr	sh	none	cw	none
Bt2	59	10YR5/3	10YR4/3	L	1msbk	2mpr	h	none	cw	none
Bk	86	10YR6/2	10YR5/3	FSL	1msbk	1mpr	s/sh	ev	gw	fl
Bk2	107	10YR5/2	10YR4/2	SL	1msbk	---	s/sh	ev	gw	fl
C1	138	10YR6/3	10YR5/3	SL	sg	---	s	ev	cw	fl
C2	188	10YR6/3	10YR5/3	SL	sg	---	l	ev	--	fl

FIELD DESCRIPTION SHEET

Level 1 | Transect 6 | Elevation 597 Meters (m) | Date 7/84

Location: 91 m east and 152 m south of the NW corner, Sec. 12, T8N, R23E, Haakon County, South Dakota.

Native veg. or crop: small grain | Described by: S.G.Wangemann, G.D.Lemme, R.L.Schlepp

Additional Notes:

1. Verticle and horizontal orientation of clay films was more evident in the Bt2 than the Bt1.
2. Soft lime accumulations were thread like and on verticle ped faces in the Btk1 and Btk2.
4. Profile was moist throughout.

Control Section: Typic Argiustoll, Fine-Silty, Mixed, Mesic

HORIZON	DEPTH cm	SOIL COLOR DRY	MOIST	TEXTURE	SOIL STRUCTURE PRIMARY	SECONDARY	DRY CONSISTANCE	REACTION	BOUNDARY	SOFT LIME ACCUM.
A1	7	10YR4/2	10YR3/2	SiL	1m&fg	2t&mpl	--	none	as	none
Bt	22	10YR4/2	10YR3/2	SiL	2f&mgr	1f&msbk	--	none	cw	none
Btk1	43	10YR5/2	10YR4/2	CL	2f&msbk	1fpr	--	es	cw	f1
Btk2	79	10YR6/3	10YR5/3	CL	2f&msbk	1fpr	--	ev	gw	f1
2Bk	113	10YR6/3	10YR5/3	SCL	1f&msbk	---	--	ev	gw	f2
3C	200	10YR6/2	10YR5/2	L	sg	---	--	ev	--	f1

FIELD DESCRIPTION SHEET

Level 2 | Transect 1 | Elevation 672.1 Meters (m) | Date 7/84

Location: 61 m west and 518 m north of SE corner, Sec. 3, T6N, R18E, Haakon County, South Dakota.

Native veg. or crop:

Described by: S.G.Wangemann, G.D.Lemme, R.L.Schlepp

Additional Notes:

1. Clay films were more pronounced on verticle ped faces in Bt2 than the Bt1.
2. Soft lime accumulations in the Bk2, within the range of many medium (m2), were more abundant between 110 cm to 130 cm.
3. Profile was somewhat dry.

Control Section: Typic Argiustoll, Fine-Loamy, Mixed, Mesic

HORIZON	DEPTH	SOIL COLOR		TEXTURE	SOIL STRUCTURE		DRY	REACTION	BOUNDARY	SOFT LIME
	cm	DRY	MOIST		PRIMARY	SECONDARY	CONSISTANCE			ACCUM.
A1	6	10YR5/2	10YR3/2	SiL	1fgr	1fpl	s	none	as	none
A2	17	10YR4/2	10YR3/1	SiL	2m&fsbk	2mpr	sh	none	cs	none
AB	28	10YR4/2	10YR3/2	L	2f&msbk	2mpr	sh	none	cs	none
Bt	48	10YR4/2	10YR3/2	L	2msbk	2mpr	sh	none	cw	none
Bt2	71	10YR4/2	10YR3/3	L	1f&msbk	1mpr	h	none	cw	none
Bk1	90	10YR5/3	10YR4/3	L	2msbk	1mpr	sh	ev	gw	m2
Bk	137	10YR6/2	10YR5/3	FSL	1msbk	1mpr	s	ev	gw	m2
2C	150	10YR6/2	10YR4/2	LS	m	---	1	ev	--	f1&2

FIELD DESCRIPTION SHEET

Level 2 | Transect 3 | Elevation 658 Meters (m) | Date 7/84

Location: 229 m east and 701 m north of SW corner, Sec. 22, T7N, R20E, Haakon County, South Dakota.

Native veg. or crop: small grain | Described by: S.G.Wangemann, G.D.Lemme, R.L.Schlepp

Additional Notes:
1. Clay films on ped faces in Bt1 and Bt2.

Control Section: Typic Argiustoll, Fine-Loamy, Mixed, Mesic

HORIZON	DEPTH	SOIL COLOR		TEXTURE	SOIL STRUCTURE		DRY	REACTION	BOUNDARY	SOFT LIME
	cm	DRY	MOIST		PRIMARY	SECONDARY	CONSISTANCE			ACCUM.
Ap	15	10YR4/2	10YR3/2	SiL	1m&fgr	1msbk	sh	none	as	none
Bt1	30	10YR4/2	10YR3/2	SiL	2msbk	2m&cpr	sh	none	cw	none
Bt2	62	10YR5/3	10YR4/3	CL	2mskb	2m&cpr	h	none	cw	none
Bk	87	10YR6/2	10YR5/3	L	2msbk	1mpr	sh	none	cw	f2
2Bk	109	10YR6/2	10YR5/3	SL	1msbk	---	s/sh	ev	gw	c2
2C	210	10YR6/2	10YR5/3	FSL	sg	---	s	ev	--	f1

FIELD DESCRIPTION SHEET

Level 2 | Transect 5 | Elevation 655.3 Meters (m) | Date 7/84

Location: 152 m north and 107 m west of SE corner, Sec. 27, T8N, R22E, Haakon County, South Dakota.

Native veg. or crop: grassland | Described by: S.G.Wangemann, G.D.Lemme, R.L.Schlepp

Additional Notes:

1. Verticle and horizontal orientation of clay films on ped faces was more evident in the Btk than the overlying Bt horizons.
2. Soft lime accumulations in vertical root channels and along verticle ped faces of the Btk were present as thin continuous films.
3. Soft lime concretions approximately 7 mm in diameter in the Bk and 2 mm in diameter in the 2C.
4. A Thin discontinuous gravel lag between the 114 cm to 120 cm profile depth also contained clay bands.
5. Profile was moist throughout.

Control Section: Typic Argiustoll, Fine-Loamy, Mixed, Mesic

HORIZON	DEPTH	SOIL COLOR		TEXTURE	SOIL STRUCTURE		DRY	REACTION	BOUNDARY	SOFT LIME
	cm	DRY	MOIST		PRIMARY	SECONDARY	CONSISTANCE			ACCUM.
Ap	10	10YR4/2	10YR3/2	SiL	1f&mgr	---	sh	none	as	none
Bt1	32	10YR4/2	10YR3/2	CL	2mpr	---	sh	none	cs	none
Bt2	40	10YR5/2	10YR3/2	CL	2mskb	2mpr	h	none	as	none
Btk	86	10YR5/3	10YR4/3	L	2msbk	2mpr	h	ev	cw	f1&2
Bk	114	10YR6/2	10YR5/3	L	1msbk	1mpr	h	ev	cs	m&c2
2C	146	10YR5/3	10YR4/3	LCS	sg	---	1	ev	--	f1

FIELD DESCRIPTION SHEET

Level 2 | Transect 6 | Elevation 643 Meters (m) | Date 7/84

Location: 914 m south and 46 m east of NW corner of Sec. 14, T8N, R23E, Haakon County, South Dakota.

Native veg. or crop: grassland | Described by: S.G.Wangemann, G.D.Lemme, R.L.Schlepp

Additional Notes:
1. Verticle and horizontal orientation of clay films more evident in the Bt2 than Bt1.
2. Carbonate precipitation on underside of gravel in 2C horizon.
3. Approximately 25 % gravel in 2C horizon.
4. Profile moist to somewhat dry throughout.

Control Section: Typic Argiustoll, Fine-Loamy, Mixed, Mesic

HORIZON	DEPTH	SOIL COLOR		TEXTURE	SOIL STRUCTURE		DRY	REACTION	BOUNDARY	SOFT LIME
	cm	DRY	MOIST		PRIMARY	SECONDARY	CONSISTANCE			ACCUM.
A1	7	10YR4/2	10YR3/2	SiL	2f&mgr	2vtpl	s	none	as	none
A2	22	10YR4/2	10YR3/2	L	1f&msbk	1fpr	s	none	cw	none
Bt1	36	10YR5/4	10YR4/3	L	2f&msbk	2fpr	s/sh	none	cw	none
Bt2	71	10YR5/3	10YR3/2	CL	2f&msbk	2fpr	sh/h	none	cw	none
2C	200	10YR7/3	10YR7/2	GRV-CS	sg	---	l	ev	--	lvf

FIELD DESCRIPTION SHEET

Level 3 | Transect 1 | Elevation 708.1 Meters (m) | Date 7/84

Location: 91 m west and 183 m south of NE corner Sec. 14, T6N, R18E, Haakon County, South Dakota.

Native veg. or crop: | Described by: S.G.Wangemann, G.D.Lemme, R.L.Schlepp

Additional Notes:

1. The Ap horizon had a surface dust layer of 2 cm.
2. Verticle and horizontal orientation of clay films was more evident in the Bt2 than the Bt1.
3. Soft lime accumulations on horizontal ped faces in Bk, some 2 to 3 cm patches of crystals that appeared to be gypsum were also observed.
4. Carbonate precipitation on underside of pebbles in 2C horizon.
5. Profile moist throughout.

Control Section: Typic Argiustoll, Fine-Loamy, Mixed, Mesic

HORIZON	DEPTH	SOIL COLOR		TEXTURE	SOIL STRUCTURE		DRY	REACTION	BOUNDARY	SOFT LIME
	cm	DRY	MOIST		PRIMARY	SECONDARY	CONSISTANCE			ACCUM.
Ap	10	10YR4/2	10YR3/2	L	1fgr	1mpl	s	none	as	none
BA	27	10YR4/2	10YR3/2	L	1&2f&msbk	2mpr	s	none	cs	none
Bt1	51	10YR5/3	10YR4/3	L	2f&msbk	2mpr	s/sh	none	cw	none
Bt2	70	10YR5/3	10YR4/3	L	1f&msbk	2mpr	sh/h	none	cw	none
Bk	91	19YR6/3	10YR5/4	FSL	1msbk	1mpr	sh	ev	gw	2m&c
2C	100	10YR6/3	10YR5/3	CS	sg	---	1	ev	--	1f&m

FIELD DESCRIPTION SHEET

Level 3 | Transect 2 | Elevation 704 Meters (m) | Date 7/84

Location: 244 m east and 427 m north of SW corner, Sec. 10, T6N, R19E, Haakon County, South Dakota.

Native veg. or crop: small grain | Described by: S.G.Wangemann, G.D.Lemme, R.L.Schlepp

Additional Notes:

1. Clay films were more evident on verticle ped faces in Bt2 than the Bt1.
2. Soft lime accumulations in the Bk were concentrated between a profile depth of 83 to 109 cm.
3. Discontinuous very fine sand band between a profile depth of 155 to 163 cm.
4. A gravel lag of 15 % gravel made up of rounded stone from 2.5 to 5 cm was noted at the 218 cm profile depth.
5. Profile was moist throughout.

Control Section: Typic Argiustoll, Fine-Silty, Mixed, Mesic

HORIZON	DEPTH	SOIL COLOR		TEXTURE	SOIL STRUCTURE		DRY	REACTION	BOUNDARY	SOFT LIME
	cm	DRY	MOIST		PRIMARY	SECONDARY	CONSISTANCE			ACCUM.
Ap	12	10YR4/2	10YR3/2	SiL	1f&mgr	1msbk	s	none	as	none
Bt1	28	10YR4/2	10YR3/2	SiL	2fsbk	1mpr	sh	none	cw	none
Bt2	53	10YR5/3	10YR4/3	CL	2fsbk	1mpr	h	none	aw	none
Bk	109	10YR6/2	10YR4/2	SiCL	1fsbk	1mpr	h	ev	gw	c2
2Bk	120	10YR6/2	10YR5/3	FSL	1fsbk	1mpr	s/1	ev	gw	f1
2C	218	10YR6/2	10YR5/3	FSL	m	---	--	ev	--	c2

FIELD DESCRIPTION SHEET

Level 3 | Transect 3 | Elevation 689 Meters (m) | Date 7/84

Location: 61 m north and 183 m east of the SW corner, NW 1/4, Sec. 12, T6N, R20E, Haakon County, South Dakota.

Native veg. or crop: small grain | Described by: S.G.Wangemann, G.D.Lemme, R.L.Schlepp

Additional Notes:

1. Verticle and horizontal orientation of clay films was more evident in the Bt2 than the Bt1.
2. Common distinct 10YR5/6 mottles in 2C.
3. Few prominent 5YR5/8 mottles in 3C.
4. Profile was moist throughout.

Control Section: Typic Argiustoll, Fine-Loamy, Mixed, Mesic

HORIZON	DEPTH	SOIL COLOR		TEXTURE	SOIL STRUCTURE		DRY	REACTION	BOUNDARY	SOFT LIME
	cm	DRY	MOIST		PRIMARY	SECONDARY	CONSISTANCE			ACCUM.
Ap	22	10YR4/2	10YR3/2	L	1vf&fgr	1msbk	sh	none	as	none
Bt1	39	10YR4/2	10YR3/3	L	2f&msbk	1&2mpr	h	none	cw	none
Bt2	54	10YR5/3	10YR3/3	CL	2f&msbk	2mpr	h	none	cw	none
Btk	86	10YR6/3	10YR5/3	CL	2f&msbk	1mpr	h	none	gw	c2
2Bk	107	10YR6/3	10YR5/3	SCL	1f&msbk	1mpr	s	ev	cs	c2
3C	147	10YR5/3	10YR4/3	C	m	---	sh	ev	gs	f2&3
4C	200	10YR6/2	10YR5/3	FSL	sg	---	1	ev	--	f1

FIELD DESCRIPTION SHEET

Level 3 | Transect 5 | Elevation 658 Meters (m) | Date 7/84

Location: SE corner of SE 1/4, Sec. 1, T7N, R22E, Haakon County, South Dakota.

Native veg. or crop: | Described by: S.G.Wangemann, G.D.Lemme, R.L.Schlepp

Additional Notes:

1. Verticle and horizontal orientation of clay films was more evident in the Bt2 than the Bt1.
2. Soft lime accumulations in the Bk1, within the range of common medium (c2), were larger between a profile depth of 74 cm to 85 cm.
3. Gravel layer at a profile depth of 158 cm.
4. Profile was moist throught.

Control Section: Typic Argiustoll, Fine-Silty, Mixed, Mesic

HORIZON	DEPTH cm	SOIL COLOR DRY	SOIL COLOR MOIST	TEXTURE	SOIL STRUCTURE PRIMARY	SOIL STRUCTURE SECONDARY	DRY CONSISTANCE	REACTION	BOUNDARY	SOFT LIME ACCUM
Ap	5	10YR5/2	10YR3/1	SiL	2m&fsbk	2tpl	s	none	as	none
BA	16	10YR4/2	10YR3/2	SiL	2m&fsbk	1mpr	s	none	cs	none
Bt1	34	10YR4/3	10YR3/3	CL	2mskb	2mpr	sh/h	none	cw	none
Bt2	56	10YR5/3	10YR4/3	SiL	2&3f&msbk	2M&cpr	h	none	cw	none
Bk1	83	10YR6/2	10YR5/3	L	1msbk	2mpr	h	ev	cs	c2
Bk2	120	10YR6/2	10YR5/2	L	1msbk	1mpr	sh	ev	gw	f1
C	158	10YR6/3	10YR5/3	L	sg	---	l	ev	--	f1

FIELD DESCRIPTION SHEET

Level 3 | Transect 6 | Elevation 652 Meters (m) | Date 7/84

Location: 46 m east and 106 m north of SW corner, Sec. 35, T8N, R23E, Haakon County, South Dakota.

Native veg. or crop: fallow | Described by: S.G.Wangemann, G.D.Lemme, R.L.Schlepp

Additional Notes:

1. Soft lime accumulations in the Btk, within the range of common fine and medium (c1&2), were more common between a profile depth of 87 cm to 106 cm.
2. Profile was moist throughout.

Control Section: Typic Argiustoll, Fine-Loamy, Mixed, Mesic

HORIZON	DEPTH cm	SOIL COLOR DRY	SOIL COLOR MOIST	TEXTURE	SOIL STRUCTURE PRIMARY	SOIL STRUCTURE SECONDARY	DRY CONSISTANCE	REACTION	BOUNDARY	SOFT LIME ACCUM.
Ap1	7	10YR4/2	10YR3/1	L	1f&mgr	---	s/sh	none	as	none
Ap2	19	10YR4/2	10YR3/1	L	1f&mgr	1msbk	sh	none	as	none
Bt1	42	10YR5/3	10YR4/3	L	1msbk	1mpr	sh	none	cs	none
Bt2	60	10YR5/3	10YR4/3	L	2msbk	1mpr	h	none	gw	none
Bt3	75	10YR5/3	10YR4/2	L	1f&msbk	1mpr	sh	none	cw	none
Btk	108	10YR6/2	10YR5/3	L	1f&msbk	1mpr	h	ev	cs	c1&2
2C	160	10YR7/2	10YR7/3	CS	sg	---	l	ev	--	f1&2

FIELD DESCRIPTION SHEET

Level 4 | Transect 2 | Elevation 716 Meters (m) | Date 7/84

Location: 61 m west and 274 m south of the NW corner, Sec. 15, T6N, R19E, Haakon County, South Dakota.

Native veg. or crop: | Described by: S.G.Wangemann, G.D.Lemme, R.L.Schlepp

Additional Notes:
1. Films 10YR3/2 in color on ped faces in the Bt.
2. Stratification of parent material observed in lower 2C.
3. Profile was moist throughout.

Control Section: Typic Argiustoll, Fine-Silty, Mixed, Mesic

HORIZON	DEPTH cm	SOIL COLOR DRY	SOIL COLOR MOIST	TEXTURE	SOIL STRUCTURE PRIMARY	SOIL STRUCTURE SECONDARY	DRY CONSISTANCE	REACTION	BOUNDARY	SOFT LIME ACCUM.
Ap	13	10YR4/2	10YR3/2	L	1fgr	1msbk	--	none	as	none
Bt	47	10YR4/2	10YR3/2	Cl	2msbk	1m&cpr	--	none	cw	none
Btk	78	10YR6/2	10YR5/3	SiL	1msbk	---	--	ev	cw	c2
2C	176	10YR6/2	10YR5/3	L	m	---	--	ev	cw	f1
3C	200	10YR4/6	10YR4/4	CS	sg	---	--	ev	--	none

FIELD DESCRIPTION SHEET

Level 4 | Transect 3 | Elevation 708 Meters (m) | Date 7/84

Location: 30 m south and 91 m west of the NW corner, NW 1/2, Sec. 22, T6N, R20E, Haakon County, South Dakota.

Native veg. or crop: | Described by: S.G.Wangemann, G.D.Lemme, R.L.Schlepp

Additional Notes:
1. Verticle and horizontal orientation of clay films was more evident in the Bt2 than the Bt1.
2. Profile was very moist throughout.

Control Section: Typic Argiustoll, Fine-Silty, Mixed, Mesic

HORIZON	DEPTH cm	SOIL COLOR DRY	MOIST	TEXTURE	SOIL STRUCTURE PRIMARY	SECONDARY	DRY CONSISTANCE	REACTION	BOUNDARY	SOFT LIME ACCUM.
Ap	29	10YR4/2	10YR3/1	SiL	1vf&fgr	1msbk	sh	none	cs	none
Bt1	58	10YR4/2	10YR3/2	SiCl	2f&msbk	2mpr	h	none	gw	none
Bt2	82	10YR5/3	10YR3/3	SiCl	2f&msbk	2mpr	h	none	cw	none
Btk1	113	10YR5/3	10YR4/3	SiCl	1f&msbk	1mpr	h	ev	gw	f1
Btk2	142	10YR5/2	10YR4/2	Cl	1f&msbk	1mpr	h	ev	gw	f2
Bk	162	10YR6/3	10YR5/3	SiL	1mpr	---	sh	ev	gw	f2
C	200	10YR6/3	10YR5/3	L	m	---	s/sh	es	--	f1

FIELD DESCRIPTION SHEET

Level 4 | Transect 5 | Elevation 670 Meters (m) | Date 7/84

Location: 35 m north and 213 m east of SW corner of NW 1/4, NW 1/4, Sec. 21, T7N, R23E, Haakon County, South Dakota.

Native veg.. or crop: small grain | Described by: S.G.Wangemann, G.D.Lemme, R.L.Schlepp

Additional Notes:

1. Verticle and horizontal orientation of clay films was more evident on ped faces in the Bt2 than the Bt1.
2. Some soft lime accumulations in the Btk formed horizontal films on ped faces.
3. Carbonate precipitation on underside of pebbles in 2C horizon.
4. Profile was moist from 0 to 28 cm and somewhat dry from 28 to 150 cm.

Control Section: Typic Argiustoll, Fine-Loamy, Mixed, Mesic

HORIZON	DEPTH	SOIL COLOR		TEXTURE	SOIL STRUCTURE		DRY	REACTION	BOUNDARY	SOFT LIME
	cm	DRY	MOIST		PRIMARY	SECONDARY	CONSISTANCE			ACCUM.
Ap	5	10YR3/2	10YR3/1	L	1m&fgr	1vtpl	s	none	as	none
A2	12	10YR4/2	10YR3/2	L	2msbk	1mpr	s	none	cs	none
Bt1	28	10YR5/3	10YR4/4	CL	2mskb	2mpr	h	none	cw	none
Bt2	52	10YR5/4	10YR4/3	L	2msbk	2mpr	h	none	cw	none
Bt3	66	10YR6/4	10YR5/4	SiL	2f&msbk	1mpr	h/sh	none	cw	none
Btk	91	10YR6/2	10YR5/3	SiL	2msbk	1mpr	sh	ev	cw	f1&c2
2C	150	10YR7/2	10YR7/3	CS	sg	---	l	es	--	none

FIELD DESCRIPTION SHEET

Level 4 | Transect 6 | Elevation 668 Meters (m) | Date 7/84

Location: 152 m east and 610 m north of SW corner, Sec. 11, T7N, R23E, Haakon County, South Dakota.

Native veg. or crop: | Described by: S.G.Wangemann, G.D.Lemme, R.L.Schlepp

Additional Notes:

1. Verticle and horizontal orientation of clay films was more evident in the Bt2 than the Bt1.
2. Soft lime accumulations in the Btk were generally few fine (f1) above the 84 cm profile depth and common medium (c2) between the 84 cm to 93 cm depth.
3. Carbonate precipitation on underside of pebbles in 2C horizon.
4. Discontinuous gravel lag at contact between Btk and 2C.
5. Profile was moist throughout.

Control Section: Typic Argiustoll, Fine-Loamy, Mixed, Mesic

HORIZON	DEPTH cm	SOIL COLOR DRY	MOIST	TEXTURE	SOIL STRUCTURE PRIMARY	SECONDARY	DRY CONSISTANCE	REACTION	BOUNDARY	SOFT LIME ACCUM.
Ap1	6	10YR4/2	10YR3/1	L	1m&fgr	---	s	none	as	none
Ap2	20	10YR4/2	10YR3/1	L	1m&fgr	1msbk	s/sh	none	as	none
Bt1	44	10YR4/3	10YR3/3	L	2mskb	1mpr	h	none	gw	none
Bt2	70	10YR4/3	10YR3/3	L	2msbk	1mpr	h	none	cw	none
Btk	90	10YR6/2	10YR5/3	SiL	1msbk	1mpr	h	ev	cw	f1&c2
2C	120	10YR7/2	10YR7/3	CS	sg	---	1	es	--	c2

FIELD DESCRIPTION SHEET

Level 5 | Transect 1 | Elevation 725 Meters (m) | Date 7/84

Location: 290 m west and 335 m west of NE corner, Sec. 24, T6N, R18E, Haakon County, South Dakota.

Native veg. or crop: | Described by: S.G.Wangemann, G.D.Lemme, R.L.Schlepp

Additional Notes:

1. Thin dust layer on surface of A1 horizon.
2. Clay films evident on both verticle and horizontal oriented ped faces in Bt1 and Bt2.
3. Carbonate precipitation on underside of pebbles in 2C horizon.
4. Discontinuous gravel layer between the 99 cm to 108 cm profile depth.
5. Profile was moist throughout.

Classification: Typic Argiustoll, Fine-Loamy, Mixed, Mesic

HORIZON	DEPTH cm	SOIL COLOR DRY	SOIL COLOR MOIST	TEXTURE	SOIL STRUCTURE PRIMARY	SOIL STRUCTURE SECONDARY	DRY CONSISTANCE	REACTION	BOUNDARY	SOFT LIME ACCUM.
A1	8	10YR4/2	10YR3/2	SiL	1f&mgr	1vt&tpl	s	none	as	none
A2	15	10YR4/2	10YR3/2	L	2m&fgr	2msbk	sh	none	cs	none
AB	26	10YR4/2	10YR3/2	L	2mgr	2msbk	h	none	cs	none
Bt1	45	10YR4/2	10YR3/2	L	2f&msbk	2mpr	h	none	gw	none
Bt2	65	10YR5/4	10YR4/3	L	2f&msbk	2mpr	h	none	cw	none
Btk	86	10YR5/3	10YR4/3	CL	1&2f&msbk	1mpr	h/sh	ev	gw	c2
2C	132	10YR5/4	10YR4/3	LS	sg	---	--	ev	cw	f1
3C	172	10YR5/2	10YR3/2	L	m	---	--	--	--	f1

FIELD DESCRIPTION SHEET

Level 5 | Transect 3 | Elevation 719 Meters (m) | Date 7/84

Location: 207 m east and 30 m south of the NW corner, NW 1/4, NE 1/4, Sec. 27, T6N, R20E, Haakon County, South Dakota.

Native veg. or crop: | Described by: S.G.Wangemann, G.D.Lemme, R.L.Schlepp

Additional Notes:

1. Verticle and horizontal orientation of clay films was more evident in the Bt2 than the Bt1.
2. Few 5 mm clay balls evident in the lower 2C. Clay balls were the same color as the dry matrix color of the Bk.
3. Carbonate precipitation on underside of pebbles in 2C horizon.
4. Profile was moist throughout.

Control Section: Typic Argiustoll, Fine-Silty, Mixed, Mesic

HORIZON	DEPTH	SOIL COLOR		TEXTURE	SOIL STRUCTURE		DRY	REACTION	BOUNDARY	SOFT LIME
	cm	DRY	MOIST		PRIMARY	SECONDARY	CONSISTANCE			ACCUM.
Ap	14	10YR4/2	10YR3/2	SiL	1f&vfgr	1msbk	s/sh	none	ss	none
Bt1	39	10YR5/3	10YR3/3	SiCl	2f&msbk	2mpr	h	none	cw	none
Bt2	59	10YR5/3	10YR3/3	SiCl	2f&msbk	2mpr	h	none	cw	none
Btk	106	10YR6/3	10YR5/4	SiCl	2msbk	1mpr	h	ev	gw	f2
Bk	144	10YR6/3	10YR5/3	L	1msbk	1mpr	h/sh	ev	cs	f2
2C	150	10YR5/2	10YR4/2	LCS	m	---	1	ev	--	f1&2

FIELD DESCRIPTION SHEET

Level 5 | Transect 5 | Elevation 683 Meters (m) | Date 7/84

Location: 18 m east and 61 m north of SW corner, SW 1/4, SE 1/4, Section 21, T7N, R23E, Haakon County, South Dakota.

Native veg. or crop:

Described by: S.G.Wangemann
G.D.Lemme, R.L.Schlepp

Additional Notes:

1. Verticle and horizontal orientation of clay films was more evident in the Bt2 than the Bt1.
2. Clay films evident only on verticle ped faces of 2Btk.
3. Carbonate precipitation on underside of pebbles in 2C.
4. Profile moist to somewhat dry.

Classification: Typic Argiustoll, Fine-Loamy, Mixed, Mesic

HORIZON	DEPTH	SOIL COLOR		TEXTURE	SOIL STRUCTURE		DRY	REACTION	BOUNDARY	SOFT LIME
	cm	DRY	MOIST		PRIMARY	SECONDARY	CONSISTANCE			ACCUM.
Ap	8	10YR4/1	10YR3/2	L	1f&mgr	1vtpl	s	none	as	none
AB	23	10YR4/2	10YR3/2	L	2msbk	1mpr	sh/h	none	cs	none
Bt1	42	10YR5/3	10YR4/3	L	2f&msbk	2mpr	sh/h	none	cw	none
Bt2	58	10YR5/3	10YR4/3	L	2msbk	1mpr	h	none	cw	none
2Btk	77	10YR5/3	10YR4/3	SiL	2msbk	1mpr	sh/h	ev	cw	c2
3Bk	97	10YR6/2	10YR5/3	L	1f&msbk	1mpr	s	ev	cw	m2
4C	120	10YR7/2	10YR7/3	CS	sg	---	l	ev	--	f1

FIELD DESCRIPTION SHEET

Level 5 | Transect 6 | Elevation 679 Meters (m) | Date 7/84

Location: 168 m west and 381 m of north SE corner, NE 1/4, SE 1/4, Sec. 14, T7N, R23E, Haakon County, South Dakota.

Native veg. or crop:

Described by: S.G.Wangemann, G.D.Lemme, R.L.Schlepp

Additional Notes:

1. Verticle and horizontal orientation of clay films was more evident in the Bt2 than the Bt1. Clay films were more continuous on the verticle ped faces throughout the Bt2.
2. Soft lime accumulations in the Btk, within the range of common medium (c2), were more abundant at a profile depth between 81 cm to 91 cm.
3. Carbonate precipitation on underside of pebbles in 2C.
4. Few silty-clay filaments 15 to 25 cm long and .5 x length wide were present in the 2C.
5. Profile was moist throughout.

Control Section: Typic Argiustoll, Fine-Loamy, Mixed, Mesic

HORIZON	DEPTH	SOIL COLOR		TEXTURE	SOIL STRUCTURE		DRY	REACTION	BOUNDARY	SOFT LIME
	cm	DRY	MOIST		PRIMARY	SECONDARY	CONSISTANCE			ACCUM.
Ap	18	10YR4/2	10YR3/1	L	1m&fgr	1m&fsbk	s/sh	none	as	none
Bt1	52	10YR5/3	10YR4/3	L	2m&fsbk	1mpr	sh	none	cw	none
Bt2	64	10YR5/3	10YR4/2	SiL	1f&msbk	1mpr	h	none	cw	none
Btk	91	10YR6/2	10YR6/2	L	1&2msbk	2mpr	sh/h	ev	cw	c2
2C	120	10YR7/2	10YR7/3	CS	sg	---	1	ev	--	c1&2

APPENDIX G

SUMMARY OF LABORATORY DATA

SUMMARY OF LABORATORY DATA

Particle Size Data in % of Total
(fraction separations in microns)

LEVEL	TRANSECT	HORIZON	LOWER BOUNDARY CM	Total			Sand Fraction					Silt Fraction				
				CLAY <2	SILT 2-50	SAND 50 -2000	VC 1000 -2000	C 500 -1000	M 250 -500	F 100 -250	VF 50 -100	C 20 -50	M 5 -20	F 2 -5	FINE CLAY <.21	TEXTURAL CLASS
1	1	A	19	25.60	59.80	14.60	0.45	1.10	1.50	2.25	9.30	42.05	12.60	5.15	16.50	**SiL**
1	1	BT1	36	26.95	56.20	16.85	0.40	1.65	1.80	2.50	10.50	35.70	14.40	6.10	19.10	**SiL**
1	1	BTK1	55	39.95	44.55	15.50	0.55	2.15	3.20	3.45	6.15	27.90	12.30	4.35	25.85	**SiCL**
1	1	BTK2	69	35.65	34.15	30.20	3.75	5.55	6.20	6.25	8.45	20.05	10.40	3.70	25.05	**CL**
1	1	BK	100	28.10	40.70	31.20	3.85	7.25	6.85	6.95	6.30	25.90	10.45	4.35	17.30	**CL**
1	1	C1	120	26.60	45.45	27.95	1.90	5.35	5.60	6.05	9.05	31.05	11.30	3.10	16.10	**L**
1	1	C2	122	24.15	31.35	44.50	5.00	8.35	9.60	8.70	12.85	20.65	9.05	1.65	13.85	**L**

LEVEL	TRANSECT	HORIZON	FINE CLAY TOTAL CLAY RATIO	CLAY FREE SILT %	CLAY FREE SAND %	OC § %	$CACO_3$ %	PH (1:1)	0.03 MPa θm %	¶	1.5 MPa θm %	¶
1	1	A	0.64	80.38	19.62	2.32	0.95	6.5	21.56	P	12.88	P
1	1	BT1	0.71	76.93	23.07	2.16	1.20	7.0	21.56	P	13.12	P
1	1	BTK1	0.65	74.19	25.81	0.96	0.90	7.4	22.93	P	15.89	P
1	1	BTK2	0.70	53.07	46.93	0.80	4.55	7.4	19.97	P	14.22	P
1	1	BK	0.62	56.61	43.39	0.64	9.70	7.4	18.26	P	11.43	P
1	1	C1	0.61	61.92	38.08	0.64	10.00	7.4	19.16	P	10.92	P
1	1	C2	0.57	41.33	58.67	0.56	9.55	7.8	16.41	P	9.98	P

¶ A = Measured value from pressure plate.
P = Predicted value from regression analysis.

§ Organic carbon

SUMMARY OF LABORATORY DATA

Particle Size Data in % of Total
(fraction separations in microns)

				Total			Sand Fraction					Silt Fraction				
LEVEL	TRANSECT	HORIZON	LOWER BOUNDARY CM	CLAY <2	SILT 2-50	SAND 50 -2000	VC 1000 -2000	C 500 -1000	M 250 -500	F 100 -250	VF 50 -100	C 20 -50	M 5 -20	F 2 -5	FINE CLAY <.21	TEXTURAL CLASS
1	3	A1	5	19.90	53.45	26.65	0.60	1.85	3.60	8.90	11.70	42.80	9.00	1.65	9.05	**SiL**
1	3	AB	13	15.20	58.30	26.50	0.40	1.90	3.60	8.40	12.20	43.80	11.20	3.30	7.80	**SiL**
1	3	BT1	32	21.05	41.80	37.10	1.25	3.70	6.25	12.35	13.55	27.55	11.25	3.00	15.05	**L**
1	3	2B12	51	25.30	23.80	50.90	2.05	6.60	11.85	19.90	10.50	15.10	6.20	2.50	16.50	**L**
1	3	2BK1	82	15.95	20.10	63.95	2.15	8.80	14.75	24.85	13.40	14.35	3.20	2.55	10.80	**SCL**
1	3	2BK2	123	16.40	31.15	52.45	0.85	3.70	9.15	20.10	18.65	20.10	6.25	4.80	9.30	**SL**
1	3	2BK3	150	14.50	21.40	64.10	0.40	5.20	15.00	28.65	14.85	14.90	3.95	2.55	7.55	**SL**
1	3	3C	210	8.70	13.55	77.75	0.55	6.00	20.00	39.65	11.55	9.70	2.60	1.25	4.50	**FSL**

LEVEL	TRANSECT	HORIZON	FINE CLAY TOTAL CLAY RATIO	CLAY FREE SILT %	CLAY FREE SAND %	OC[§] %	$CACO_3$ %	PH (1:1)	0.03 MPa θm %	¶	1.5 MPa θm %	¶
1	3	A1	0.45	66.73	33.27	1.12	0.10	6.70	18.91	P	9.31	P
1	3	AB	0.51	68.75	31.25	0.88	0.10	6.70	18.33	P	7.38	P
1	3	BT1	0.71	52.98	47.02	0.88	0.70	6.95	17.46	P	9.37	P
1	3	2B12	0.65	31.86	68.14	0.32	0.70	7.35	14.95	P	10.05	P
1	3	2BK1	0.68	23.91	76.09	0.32	1.80	7.70	11.66	P	6.87	P
1	3	2BK2	0.57	37.26	62.74	0.24	6.55	8.00	14.86	P	6.92	P
1	3	2BK3	0.52	25.03	74.97	0.00	3.80	8.10	11.68	P	5.94	P
1	3	3C	0.52	14.84	85.16	0.00	3.45	8.10	7.65	P	3.97	P

¶ A = Measured value from pressure plate.
P = Predicted value from regression analysis.

§ Organic carbon

SUMMARY OF LABORATORY DATA

Particle Size Data in % of Total
(fraction separations in microns)

				Total			Sand Fraction					Silt Fraction				
LEVEL	TRANSECT	HORIZON	LOWER BOUNDARY CM	CLAY <2	SILT 2-50	SAND 50 -2000	VC 1000 -2000	C 500 -1000	M 250 -500	F 100 -250	VF 50 -100	C 20 -50	M 5 -20	F 2 -5	FINE CLAY <.21	TEXTURAL CLASS
1	5	AP	14	17.15	45.50	37.35	0.70	4.70	9.25	12.40	10.30	33.40	9.55	2.55	9.90	**L**
1	5	A2	24	20.70	44.45	34.85	0.75	3.85	8.65	12.95	8.65	30.30	11.40	2.75	12.85	**L**
1	5	BT1	33	24.50	36.30	39.20	0.70	2.35	6.30	14.05	15.80	23.30	8.65	4.35	21.10	**L**
1	5	BT2	59	25.65	31.35	43.05	1.55	5.15	10.95	15.95	9.45	20.45	7.35	3.55	16.80	**L**
1	5	BK1	86	16.35	26.75	56.90	3.15	7.50	13.75	20.95	11.55	17.85	8.35	0.55	10.20	**FSL**
1	5	BK2	107	16.00	19.10	64.90	4.80	9.85	16.35	22.50	11.40	13.65	4.50	0.95	10.85	**SL**
1	5	C1	138	13.25	18.70	68.05	3.55	9.90	16.95	24.55	13.10	13.05	4.15	1.50	6.00	**SL**
1	5	C2	188	11.60	12.30	76.10	1.60	8.80	22.40	29.30	14.00	8.70	2.55	1.05	7.60	**SL**

LEVEL	TRANSECT	HORIZON	FINE CLAY TOTAL CLAY RATIO	CLAY FREE SILT %	CLAY FREE SAND %	OC § %	$CACO_3$ %	PH (1:1)	0.03 MPa θm %	¶	1.5 MPa θm %	¶
1	5	AP	0.58	54.92	45.08	1.36	1.00	6.70	16.23	P	8.70	P
1	5	A2	0.62	56.05	43.95	0.80	0.75	6.75	16.92	P	9.14	P
1	5	BT1	0.86	48.08	51.92	0.80	1.40	7.10	18.01	P	10.43	P
1	5	BT2	0.65	42.14	57.86	0.56	1.60	7.30	16.28	P	10.49	P
1	5	BK1	0.62	31.98	68.02	0.40	7.50	7.80	12.69	P	7.12	P
1	5	BK2	0.68	22.74	77.26	0.32	6.05	7.90	11.11	P	6.89	P
1	5	C1	0.45	21.56	78.44	0.08	5.70	7.85	10.43	P	5.63	P
1	5	C2	0.66	13.91	86.09	0.00	7.20	7.90	8.85	P	4.96	P

¶ A = Measured value from pressure plate.
P = Predicted value from regression analysis.

§ Organic carbon

SUMMARY OF LABORATORY DATA

Particle Size Data in % of Total
(fraction separations in microns)

				Total			Sand Fraction					Silt Fraction				
LEVEL	TRANSECT	HORIZON	LOWER BOUNDARY CM	CLAY <2	SILT 2-50	SAND 50 -2000	VC 1000 -2000	C 500 -1000	M 250 -500	F 100 -250	VF 50 -100	C 20 -50	M 5 -20	F 2 -5	FINE CLAY <.21	TEXTURAL CLASS
1	6	A1	7	20.70	56.00	23.35	0.30	0.75	1.75	5.15	15.40	40.75	13.50	1.75	12.70	SiL
1	6	BI	22	26.65	51.55	21.80	0.20	0.75	2.55	7.10	11.20	35.70	12.10	3.75	13.95	SiL
1	6	BIK1	43	27.60	44.95	27.45	0.10	1.00	3.70	10.65	12.00	31.55	10.25	3.15	19.25	CL
1	6	BIK2	79	28.25	46.20	25.55	0.20	0.85	3.20	9.75	11.55	28.95	12.05	5.20	16.00	CL
1	6	2BK	113	20.70	23.95	55.35	0.55	3.30	9.50	25.65	16.35	17.75	4.85	1.35	8.00	SCL
1	6	3C	200	21.20	38.75	40.25	0.10	0.55	2.10	15.90	21.60	27.85	7.65	3.25	15.05	L

LEVEL	TRANSECT	HORIZON	FINE CLAY TOTAL CLAY RATIO	CLAY FREE SILT %	CLAY FREE SAND %	OC § %	$CACO_3$ %	PH (1:1)	0.03 MPa θm %	¶	1.5 MPa θm %	¶
1	6	AI	0.61	70.57	29.43	3.68	0.40	6.65	22.8	A	15.6	A
1	6	BI	0.52	70.28	29.72	1.20	0.35	7.30	19.8	A	12.0	A
1	6	BIK1	0.70	62.09	37.91	0.56	1.30	8.00	20.0	A	12.0	A
1	6	BIK2	0.57	64.39	35.61	0.88	1.35	7.50	20.7	A	13.4	A
1	6	2BK	0.39	30.20	69.80	0.16	6.10	8.00	12.3	A	7.4	A
1	6	3C	0.71	49.05	50.95	0.24	6.30	8.00	13.0	A	7.9	A

¶ A = Measured value from pressure plate.
P = Predicted value from regression analysis.

§ Organic carbon

Summary of Laboratory Data

Particle Size Data in % of Total
(fraction separations in microns)

				Total			Sand Fraction					Silt Fraction				
LEVEL	TRANSECT	HORIZON	LOWER BOUNDARY CM	CLAY <2	SILT 2-50	SAND 50 -2000	VC 1000 -2000	C 500 -1000	M 250 -500	F 100 -250	VF 50 -100	C 20 -50	M 5 -20	F 2 -5	FINE CLAY <.21	TEXTURAL CLASS
2	1	A1	6	20.00	60.00	20.00	0.15	1.25	3.00	5.70	9.90	42.20	15.55	2.25	15.50	SiL
2	1	A2	17	18.90	52.40	28.70	0.35	2.25	5.10	8.85	12.15	38.05	9.85	4.50	12.25	SiL
2	1	BA	28	20.30	45.90	33.80	0.55	2.80	6.35	11.70	12.40	33.10	10.15	2.65	13.55	L
2	1	B11	48	25.30	40.70	34.00	0.80	3.30	7.00	13.15	9.75	27.60	9.60	3.50	15.50	L
2	1	B12	71	20.20	30.85	48.95	0.75	4.35	10.40	21.20	12.25	19.20	8.25	3.40	13.35	L
2	1	BK1	90	19.55	32.10	48.35	0.40	2.65	8.15	20.10	17.05	21.40	8.60	2.10	10.25	L
2	1	BK2	137	12.80	33.75	53.45	0.90	3.30	10.30	21.00	17.95	22.65	8.10	3.00	8.00	FSL
2	1	2C	150	9.20	9.85	80.95	1.45	10.15	19.75	36.05	13.55	6.00	2.90	0.95	5.60	LS

LEVEL	TRANSECT	HORIZON	FINE CLAY TOTAL CLAY RATIO	CLAY FREE SILT %	CLAY FREE SAND %	OC [§] %	CACC$_3$ %	PH (1:1)	0.03 MPa θm %	¶	1.5 MPa θm %	¶
2	1	A1	0.78	75.00	25.00	3.12	0.10	5.50	19.83	P	12.07	P
2	1	A2	0.65	64.61	35.39	1.68	0.55	5.90	18.46	P	9.73	P
2	1	BA	0.67	57.59	42.41	1.20	0.90	6.25	17.76	P	9.55	P
2	1	B11	0.61	54.48	45.52	0.80	0.60	6.40	17.97	P	10.70	P
2	1	B12	0.66	38.66	61.34	0.40	0.75	6.35	14.88	P	8.42	P
2	1	BK1	0.52	39.90	60.10	0.40	1.00	7.00	15.79	P	8.20	P
2	1	BK2	0.63	38.70	61.30	0.48	9.65	7.50	14.00	P	6.02	P
2	1	2C	0.61	10.85	89.15	0.16	5.50	7.75	7.50	P	4.36	P

¶ A = Measured value from pressure plate.
P = Predicted value from regression analysis.

§ Organic carbon

SUMMARY OF LABORATORY DATA

Particle Size Data in % of Total
(fraction separations in microns)

				Total			Sand Fraction					Silt Fraction				
LEVEL	TRANSECT	HORIZON	LOWER BOUNDARY CM	CLAY <2	SILT 2-50	SAND 50 -2000	VC 1000 -2000	C 500 -1000	M 250 -500	F 100 -250	VF 50 -100	C 20 -50	M 5 -20	F 2 -5	FINE CLAY <.21	TEXTURAL CLASS
2	3	AP	15	18.75	52.25	29.00	0.35	4.10	6.00	9.45	9.10	37.15	11.80	3.30	11.60	**SiL**
2	3	B11	30	21.95	50.80	27.25	0.60	2.85	6.30	9.30	8.20	34.20	12.15	4.45	15.25	**SiL**
2	3	B12	62	27.95	32.05	40.00	0.50	3.05	8.90	15.10	12.45	21.15	9.40	1.50	17.60	**CL**
2	3	BK	87	20.20	36.95	42.85	0.40	2.65	7.15	15.60	17.05	26.25	6.45	4.25	11.55	**L**
2	3	2BK	109	10.90	17.35	71.75	1.60	10.95	18.05	23.50	17.65	12.95	2.70	1.70	8.00	**SL**
2	3	2C	210	12.75	25.05	62.20	0.35	4.90	16.35	27.95	12.65	16.80	4.95	3.30	8.25	**FSL**

LEVEL	TRANSECT	HORIZON	FINE CLAY TOTAL CLAY RATIO	CLAY FREE SILT %	CLAY FREE SAND %	OC § %	$CACO_3$ %	PH (1:1)	0.03 MPa θm %	¶	1.5 MPa θm %	¶
2	3	AP	0.62	64.31	35.69	2.00	0.80	6.20	17.81	P	10.12	P
2	3	B11	0.69	65.09	34.91	0.96	0.85	6.70	18.44	P	9.78	P
2	3	B12	0.63	44.48	55.52	0.64	1.70	6.55	17.74	P	11.38	P
2	3	BK	0.57	46.30	53.70	0.56	12.35	7.35	16.92	P	8.64	P
2	3	2BK	0.73	19.47	80.53	0.24	9.25	7.75	10.24	P	5.05	P
2	3	2C	0.65	28.71	71.29	0.24	6.00	7.90	11.37	P	5.68	P

¶ A = Measured value from pressure plate.
P = Predicted value from regression analysis.

§ Organic carbon

Summary of Laboratory Data

Particle Size Data in % of Total
(fraction separations in microns)

LEVEL	TRANSECT	HORIZON	LOWER BOUNDARY CM	Total CLAY <2	 SILT 2-50	 SAND 50 -2000	Sand Fraction VC 1000 -2000	 C 500 -1000	 M 250 -500	 F 100 -250	 VF 50 -100	Silt Fraction C 20 -50	 M 5 -20	 F 2 -5	FINE CLAY <.21	TEXTURAL CLASS
2	5	AP	10	20.60	54.50	24.90	1.80	4.05	4.25	4.00	10.80	37.80	11.95	4.75	9.8	SIL
2	5	BT1	32	27.35	49.55	23.10	1.50	3.85	4.00	4.05	9.70	31.45	13.25	4.85	18.7	CL
2	5	BT2	40	34.05	46.35	19.60	0.90	3.05	4.25	4.75	6.65	29.65	12.95	3.75	23.7	CL
2	5	BTK	86	30.35	39.55	30.10	1.40	4.80	7.35	8.55	8.00	23.40	10.95	5.20	17.2	CL
2	5	BK	114	18.40	37.45	44.15	0.60	3.20	10.35	15.40	14.60	26.90	8.55	2.00	12.9	L
2	5	2C	146	4.55	7.15	88.30	11.85	29.50	27.90	15.15	3.90	4.05	2.10	1.00	3.7	LCS

LEVEL	TRANSECT	HORIZON	FINE CLAY TOTAL CLAY RATIO	CLAY FREE SILT %	CLAY FREE SAND %	OC § %	$CACO_3$ %	PH (1:1)	0.03 MPa θm %	¶	1.5 MPa θm %	¶
2	5	AP	0.48	68.64	31.36	2.08	0.30	6.55	19.17	P	10.85	P
2	5	BT1	0.68	68.20	31.80	1.44	0.20	6.40	20.30	P	12.27	P
2	5	BT2	0.70	70.28	29.72	0.88	0.55	7.00	21.38	P	13.78	P
2	5	BTK	0.57	56.78	43.22	0.64	1.10	7.50	19.12	P	12.20	P
2	5	BK	0.70	45.89	54.11	0.48	15.20	7.80	15.95	P	7.92	P
2	5	2C	0.81	7.49	92.51	0.16	2.50	7.55	3.63	P	2.78	P

¶ A = Measured value from pressure plate.
P = Predicted value from regression analysis.

§ Organic carbon

Summary of Laboratory Data

Particle Size Data in % of Total
(fraction separations in microns)

				Total			Sand Fraction					Silt Fraction				
LEVEL	TRANSECT	HORIZON	LOWER BOUNDARY CM	CLAY <2	SILT 2-50	SAND 50 -2000	VC 1000 -2000	C 500 -1000	M 250 -500	F 100 -250	VF 50 -100	C 20 -50	M 5 -20	F 2 -5	FINE CLAY <.21	TEXTURAL CLASS
2	6	A1	7	16.95	52.10	30.95	5.60	9.35	7.2	4.40	4.40	34.9	14.00	3.20	8.80	SIL
2	6	A2	22	15.55	46.95	37.50	8.15	11.90	8.5	5.10	3.85	29.4	13.00	4.55	9.70	L
2	6	B11	36	22.50	36.75	40.75	8.35	11.75	10.7	6.75	3.20	22.0	10.60	4.15	15.75	L
2	6	B12	71	27.30	32.40	40.30	7.30	11.70	9.9	7.25	4.15	19.3	10.35	2.75	18.25	CL
2	6	2C	200	2.40	2.50	95.10	19.65	22.15	29.0	22.25	2.05	0.8	0.00	1.70	2.40	GRV-CS

LEVEL	TRANSECT	HORIZON	FINE CLAY TOTAL CLAY RATIO	CLAY FREE SILT %	CLAY FREE SAND %	OC § %	$CACO_3$ %	PH (1:1)	0.03 MPa θm %	¶	1.5 MPa θm %	¶
2	6	A1	0.52	62.73	37.27	2.80	0.90	6.25	16.30	P	10.60	P
2	6	A2	0.62	55.60	44.40	1.36	1.05	6.30	14.76	P	8.16	P
2	6	B11	0.70	47.42	52.58	0.64	1.10	6.20	15.06	P	9.53	P
2	6	B12	0.67	44.57	55.43	0.56	1.30	6.60	16.04	P	11.05	P
2	6	2C	1.00	2.56	97.44	0.24	3.20	7.20	1.69	P	2.16	P

¶ A = Measured value from pressure plate.
P = Predicted value from regression analysis.

§ Organic carbon

SUMMARY OF LABORATORY DATA

Particle Size Data in % of Total
(fraction separations in microns)

				Total			Sand Fraction					Silt Fraction				
LEVEL	TRANSECT	HORIZON	LOWER BOUNDARY CM	CLAY <2	SILT 2-50	SAND 50 -2000	VC 1000 -2000	C 500 -1000	M 250 -500	F 100 -250	VF 50 -100	C 20 -50	M 5 -20	F 2 -5	FINE CLAY <.21	TEXTURAL CLASS
3	1	AP	10	15.00	46.40	38.60	3.05	8.40	10.25	10.25	6.65	31.70	12.05	2.65	8.30	**L**
3	1	BA	27	17.75	39.70	42.55	4.30	9.05	11.35	12.05	5.80	28.20	9.55	1.95	8.85	**L**
3	1	BT1	51	21.70	31.55	46.75	3.25	9.30	14.15	14.00	6.05	21.55	8.00	2.00	15.75	**L**
3	1	BT2	70	16.30	38.50	44.80	2.85	7.95	13.15	14.05	6.80	24.60	8.05	5.85	9.60	**L**
3	1	BK	91	16.50	28.45	55.05	2.65	8.00	19.20	15.70	9.50	18.85	6.50	3.10	10.15	**FSL**
3	1	2C	100	5.20	3.45	91.35	12.30	22.05	22.95	28.75	5.30	2.70	0.30	0.45	5.50	**CS**

LEVEL	TRANSECT	HORIZON	FINE CLAY TOTAL CLAY RATIO	CLAY FREE SILT %	CLAY FREE SAND %	OC § %	CACO$_3$ %	PH (1:1)	0.03 MPa θm %	¶	1.5 MPa θm %	¶
3	1	AP	0.55	54.59	45.41	2.08	0.20	6.30	15.00	P	8.95	P
3	1	BA	0.50	48.27	51.73	1.12	0.35	6.50	14.51	P	8.58	P
3	1	BT1	0.73	40.29	59.71	0.48	1.75	6.30	14.35	P	9.04	P
3	1	BT2	0.59	46.22	53.78	0.56	1.85	6.60	13.98	P	7.32	P
3	1	BK	0.62	34.07	65.93	0.56	7.25	7.80	12.67	P	7.39	P
3	1	2C	1.06	3.64	96.36	0.00	1.65	8.05	3.42	P	2.79	P

¶ A = Measured value from pressure plate.
P = Predicted value from regression analysis.

§ Organic carbon

SUMMARY OF LABORATORY DATA

Particle Size Data in % of Total
(fraction separations in microns)

				Total			Sand Fraction					Silt Fraction				
LEVEL	TRANSECT	HORIZON	LOWER BOUNDARY CM	CLAY <2	SILT 2-50	SAND 50 -2000	VC 1000 -2000	C 500 -1000	M 250 -500	F 100 -250	VF 50 -100	C 20 -50	M 5 -20	F 2 -5	FINE CLAY <.21	TEXTURAL CLASS
3	5	AP	5	16.70	60.50	22.80	2.80	5.15	3.50	4.05	7.30	39.45	15.05	6.00	8.00	SiL
3	5	BA	16	19.80	56.65	23.55	3.35	4.65	3.15	3.80	8.60	37.45	14.25	4.95	11.45	SiL
3	5	BT1	34	28.55	47.30	24.15	3.25	4.35	3.00	4.35	9.20	32.45	10.55	4.30	19.95	CL
3	5	BT2	56	26.65	50.15	23.20	3.20	3.95	2.65	4.05	9.35	34.30	12.30	3.55	16.05	SiL
3	5	BK1	83	23.10	45.15	31.80	0.80	1.60	2.55	9.70	17.15	31.70	8.90	4.55	12.05	L
3	5	BK2	120	19.85	44.50	35.65	0.80	2.65	4.25	9.85	18.10	31.00	7.90	5.60	8.75	L
3	5	C	158	20.65	40.85	38.50	2.90	7.50	5.80	7.30	15.00	26.80	9.20	4.85	10.80	L

LEVEL	TRANSECT	HORIZON	FINE CLAY TOTAL CLAY RATIO	CLAY FREE SILT %	CLAY FREE SAND %	OC [§] %	$CACO_3$ %	PH (1:1)	0.03 MPa θm %	¶	1.5 MPa θm %	¶
3	5	AP	0.48	72.63	27.37	4.80	0.10	5.50	18.33	P	13.24	P
3	5	BA	0.58	70.64	29.36	2.56	0.10	5.90	18.89	P	11.24	P
3	5	BT1	0.70	66.20	33.80	0.80	0.10	6.25	20.19	P	11.80	P
3	5	BT2	0.60	68.37	31.63	0.72	0.35	6.60	20.11	P	11.05	P
3	5	BK1	0.52	58.67	41.33	0.24	10.50	7.60	19.45	P	9.19	P
3	5	BK2	0.44	55.52	44.48	0.00	11.85	8.30	18.41	P	7.76	P
3	5	C	0.52	51.48	48.52	0.00	6.00	8.35	17.42	P	8.03	P

¶ A = Measured value from pressure plate.
P = Predicted value from regression analysis.

§ Organic carbon

SUMMARY OF LABORATORY DATA

Particle Size Data in % of Total
(fraction separations in microns)

LEVEL	TRANSECT	HORIZON	LOWER BOUNDARY CM	Total CLAY <2	Total SILT 2-50	Total SAND 50 -2000	Sand Fraction VC 1000 -2000	Sand Fraction C 500 -1000	Sand Fraction M 250 -500	Sand Fraction F 100 -250	Sand Fraction VF 50 -100	Silt Fraction C 20 -50	Silt Fraction M 5 -20	Silt Fraction F 2 -5	FINE CLAY <.21	TEXTURAL CLASS
3	2	AP	12	23.80	57.30	18.90	0.50	1.35	2.00	4.95	10.10	38.80	15.25	3.25	14.45	SiL
3	2	B11	28	23.95	53.05	23.00	0.80	1.50	2.50	5.75	12.45	35.15	12.35	5.55	18.15	SiL
3	2	B12	53	27.15	46.45	26.40	0.20	0.95	1.80	4.50	18.95	31.50	12.25	2.70	15.30	CL
3	2	BK	109	30.65	50.30	19.05	0.15	0.55	0.90	2.20	15.25	35.40	12.60	2.30	8.35	SiCL
3	2	2BK	120	13.15	21.90	64.95	1.50	5.50	11.80	25.40	20.75	16.60	3.15	2.15	7.95	FSL
3	2	2C	218	15.45	28.55	56.00	0.25	1.80	6.15	24.00	23.80	22.30	3.45	2.80	7.80	FSL

LEVEL	TRANSECT	HORIZON	FINE CLAY TOTAL CLAY RATIO	CLAY FREE SILT %	CLAY FREE SAND %	OC § %	$CACO_3$ %	PH (1:1)	0.03 MPa θm %	¶	1.5 MPa θm %	¶
3	2	AP	0.61	75.20	24.80	1.28	0.20	6.10	20.64	P	10.85	P
3	2	B11	0.76	69.76	30.24	0.80	0.90	6.40	20.33	P	10.24	P
3	2	B12	0.56	63.76	36.24	0.56	2.80	7.40	21.39	P	11.00	P
3	2	BK	0.27	72.53	27.47	0.32	15.25	8.00	22.59	P	11.86	P
3	2	2BK	0.60	25.22	74.78	0.16	6.40	8.25	12.43	P	5.70	P
3	2	2C	0.50	33.77	66.23	0.24	6.40	8.10	15.02	P	6.59	P

¶ A = Measured value from pressure plate.
P = Predicted value from regression analysis.

§ Organic carbon

SUMMARY OF LABORATORY DATA

Particle Size Data in % of Total
(fraction separations in microns)

				Total			Sand Fraction					Silt Fraction				
LEVEL	TRANSECT	HORIZON	LOWER BOUNDARY CM	CLAY <2	SILT 2-50	SAND 50 -2000	VC 1000 -2000	C 500 -1000	M 250 -500	F 100 -250	VF 50 -100	C 20 -50	M 5 -20	F 2 -5	FINE CLAY <.21	TEXTURAL CLASS
3	3	AP	22	16.65	45.15	38.20	1.35	5.55	10.75	13.40	7.15	25.75	15.20	4.20	8.05	L
3	3	B11	39	25.85	39.90	34.25	1.20	3.85	8.50	13.85	6.85	24.95	12.35	2.60	18.35	L
3	3	B12	54	27.70	48.10	24.20	0.55	2.35	5.40	9.95	5.95	27.50	17.40	3.20	18.95	CL
3	3	B1K	86	27.10	48.30	24.60	0.25	1.10	2.35	5.00	15.90	30.25	12.40	5.65	12.95	CL
3	3	2BK	107	22.55	27.80	49.65	1.45	5.90	9.50	18.00	14.80	20.15	6.15	1.50	13.00	SCL
3	3	3C	147	55.25	34.25	10.50	0.25	1.15	1.90	3.85	3.35	9.85	11.20	13.20	25.60	C
3	3	4C	200	12.60	10.80	76.60	1.70	2.95	14.65	48.40	8.90	6.75	2.85	1.20	8.35	FSL

LEVEL	TRANSECT	HORIZON	FINE CLAY TOTAL CLAY RATIO	CLAY FREE SILT %	CLAY FREE SAND %	OC § %	CACO$_3$ %	PH (1:1)	0.03 MPa θm %	¶	1.5 MPa θm %	¶
3	3	AP	0.48	54.17	45.83	0.88	1.05	6.10	13.10	A	7.70	A
3	3	B11	0.71	53.81	46.19	0.64	0.90	6.55	17.20	A	11.20	A
3	3	B12	0.68	66.53	33.47	0.56	1.95	6.85	20.20	A	13.00	A
3	3	B1K	0.48	66.26	33.74	0.24	11.10	8.00	19.60	A	10.90	A
3	3	2BK	0.58	35.89	64.11	0.08	9.70	8.25	15.58	P	8.78	P
3	3	3C	0.46	76.54	23.46	0.16	12.70	8.30	25.10	A	16.80	A
3	3	4C	0.66	12.36	87.64	0.00	5.80	8.30	7.50	A	4.70	A

¶ A = Measured value from pressure plate.
P = Predicted value from regression analysis.

§ Organic carbon

SUMMARY OF LABORATORY DATA

Particle Size Data in % of Total
(fraction separations in microns)

				Total			Sand Fraction					Silt Fraction				
LEVEL	TRANSECT	HORIZON	LOWER BOUNDARY CM	CLAY <2	SILT 2-50	SAND 50 -2000	VC 1000 -2000	C 500 -1000	M 250 -500	F 100 -250	VF 50 -100	C 20 -50	M 5 -20	F 2 -5	FINE CLAY <.21	TEXTURAL CLASS
3	6	AP	19	13.40	42.25	44.35	6.40	18.10	10.85	5.20	3.80	27.60	10.90	3.75	6.8	L
3	6	BT1	42	22.35	36.40	41.25	5.60	15.95	11.15	4.65	3.90	26.40	8.90	1.10	14.9	L
3	6	BT2	60	21.30	40.35	38.35	4.55	14.75	10.80	4.50	3.75	27.85	12.05	0.45	15.1	L
3	6	BT3	75	24.85	48.40	26.75	2.65	8.90	6.30	2.50	6.40	34.55	9.60	4.25	10.2	L
3	6	BTK	108	22.25	48.50	29.25	4.25	9.00	5.85	2.40	7.75	34.80	11.00	2.70	10.4	L
3	6	2C	160	4.35	7.85	87.80	9.30	36.05	28.20	11.25	3.00	4.95	1.85	1.05	3.2	CS

LEVEL	TRANSECT	HORIZON	FINE CLAY TOTAL CLAY RATIO	CLAY FREE SILT %	CLAY FREE SAND %	OC[§] %	$CACO_3$ %	PH (1:1)	0.03 MPa θm %	¶	1.5 MPa θm %	¶
3	6	AP	0.51	48.79	51.21	1.36	0.40	5.65	14.1	A	7.1	A
3	6	BT1	0.67	46.88	53.12	0.48	0.50	6.30	16.4	A	9.8	A
3	6	BT2	0.71	51.27	48.73	0.48	0.50	6.55	17.3	A	9.8	A
3	6	8T3	0.41	64.40	35.60	0.56	0.95	6.70	19.1	A	11.0	A
3	6	BTK	0.47	62.38	37.62	0.56	4.75	7.70	19.2	A	9.9	A
3	6	2C	0.74	8.21	91.79	0.16	1.45	8.00	3.2	A	2.0	A

¶ A = Measured value from pressure plate.
P = Predicted value from regression analysis.

§ Organic carbon

SUMMARY OF LABORATORY DATA

Particle Size Data in % of Total
(fraction separations in microns)

				Total			Sand Fraction					Silt Fraction				
LEVEL	TRANSECT	HORIZON	LOWER BOUNDARY CM	CLAY <2	SILT 2-50	SAND 50 -2000	VC 1000 -2000	C 500 -1000	M 250 -500	F 100 -250	VF 50 -100	C 20 -50	M 5 -20	F 2 -5	FINE CLAY <.21	TEXTURAL CLASS
4	2	AP	13	21.40	47.35	31.25	2.10	5.50	4.95	6.55	12.15	33.65	13.10	0.6	12.00	L
4	2	BT	47	27.45	50.80	21.75	1.05	2.25	3.00	4.60	10.85	35.45	11.45	3.9	18.05	CL
4	2	BTK	78	26.35	56.15	17.50	0.35	1.20	1.45	2.70	11.80	40.60	13.65	1.9	10.60	SIL
4	2	2C	176	16.45	32.15	51.40	0.85	3.60	6.65	23.75	16.55	24.75	5.70	1.7	8.40	L
4	2	3C	200	3.90	5.70	90.40	7.30	24.40	44.40	11.05	3.25	3.95	1.15	0.6	2.70	CS

LEVEL	TRANSECT	HORIZON	FINE CLAY TOTAL CLAY RATIO	CLAY FREE SILT %	CLAY FREE SAND %	OC[§] %	CACO$_3$ %	PH (1:1)	0.03 MPa θm %	[¶]	1.5 MPa θm %	[¶]
4	2	AP	0.56	60.24	39.76	1.20	0.30	5.95	18.35	P	9.92	P
4	2	BT	0.66	70.02	29.98	0.56	1.00	6.90	20.79	P	11.10	P
4	2	BTK	0.40	76.24	23.76	0.32	16.80	8.00	21.59	P	10.40	P
4	2	2C	0.51	38.48	61.52	0.24	6.25	8.65	14.67	P	6.93	P
4	2	3C	0.69	5.93	94.07	0.16	1.90	8.10	3.02	P	2.56	P

[¶] A = Measured value from pressure plate.
P = Predicted value from regression analysis.

[§] Organic carbon

SUMMARY OF LABORATORY DATA

Particle Size Data in % of Total
(fraction separations in microns)

				Total			Sand Fraction					Silt Fraction				
LEVEL	TRANSECT	HORIZON	LOWER BOUNDARY CM	CLAY <2	SILT 2-50	SAND 50 -2000	VC 1000 -2000	C 500 -1000	M 250 -500	F 100 -250	VF 50 -100	C 20 -50	M 5 -20	F 2 -5	FINE CLAY <.21	TEXTURAL CLASS
4	3	AP	29	21.65	62.30	16.05	0.90	1.80	1.75	2.25	9.35	39.30	16.35	6.65	11.15	SIL
4	3	BT1	58	34.20	54.20	11.65	0.40	1.30	1.50	1.95	6.50	33.90	15.25	5.05	25.50	SICL
4	3	BT2	82	30.85	57.25	11.90	0.15	0.65	0.60	1.70	8.80	31.65	16.20	9.40	16.65	SICL
4	3	BTK1	113	32.10	53.25	14.65	0.20	0.45	0.55	2.00	11.45	32.45	13.85	6.95	20.90	SICL
4	3	BTK2	142	28.30	44.45	27.25	0.85	2.05	2.05	6.45	15.85	31.15	9.15	4.15	14.30	CL
4	3	BK	162	25.35	53.60	21.05	0.20	0.90	1.30	4.15	14.50	36.90	9.70	7.00	10.50	SIL
4	3	C	200	24.00	40.35	35.65	1.10	3.80	5.20	9.60	15.95	24.05	11.60	4.70	10.60	L

LEVEL	TRANSECT	HORIZON	FINE CLAY TOTAL CLAY RATIO	CLAY FREE SILT %	CLAY FREE SAND %	OC[§] %	$CACO_3$ %	PH (1:1)	0.03 MPa θm %	¶	1.5 MPa θm %	¶
4	3	AP	0.52	79.51	20.49	1.68	0.90	5.70	20.71	P	10.66	P
4	3	BT1	0.75	82.31	17.69	0.72	2.20	6.25	22.87	P	13.61	P
4	3	BT2	0.54	82.79	17.21	0.72	3.05	7.50	22.75	P	12.48	P
4	3	BTK1	0.65	78.42	21.58	0.40	13.90	7.90	22.92	P	12.46	P
4	3	BTK2	0.51	61.99	38.01	0.24	9.80	8.10	20.82	P	10.96	P
4	3	BK	0.41	71.80	28.20	0.24	10.80	7.90	21.29	P	9.95	P
4	3	C	0.44	53.09	46.91	0.24	4.20	7.85	18.63	P	9.50	P

¶ A = Measured value from pressure plate.
P = Predicted value from regression analysis.

§ Organic carbon

SUMMARY OF LABORATORY DATA

Particle Size Data in % of Total
(fraction separations in microns)

				Total			Sand Fraction					Silt Fraction				
LEVEL	TRANSECT	HORIZON	LOWER BOUNDARY CM	CLAY <2	SILT 2-50	SAND 50 -2000	VC 1000 -2000	C 500 -1000	M 250 -500	F 100 -250	VF 50 -100	C 20 -50	M 5 -20	F 2 -5	FINE CLAY <.21	TEXTURAL CLASS
4	5	AP	5	16.70	48.75	34.55	7.20	10.75	6.40	4.40	5.80	29.80	13.90	5.05	10.30	L
4	5	A2	12	17.30	47.35	35.35	7.50	11.05	6.55	4.65	5.60	28.85	13.75	4.75	8.40	L
4	5	BT1	28	28.80	39.80	31.40	6.00	9.00	6.25	3.85	6.30	23.70	12.75	3.35	20.00	CL
4	5	BT2	52	25.20	47.15	27.65	5.25	8.00	5.35	3.40	5.65	33.70	10.10	3.35	15.95	L
4	5	BT3	66	24.95	52.40	22.65	3.15	4.65	3.30	2.25	9.30	33.80	13.95	4.65	15.50	SiL
4	5	BTK	91	23.30	50.60	26.10	4.15	6.80	5.45	2.95	6.75	35.95	11.25	3.40	14.35	SiL
4	5	2C	150	3.35	6.35	90.30	12.30	29.90	27.30	15.40	5.40	4.90	0.30	1.15	1.85	CS

LEVEL	TRANSECT	HORIZON	FINE CLAY TOTAL CLAY RATIO	CLAY FREE SILT %	CLAY FREE SAND %	OC§ %	$CACO_3$ %	PH (1:1)	0.03 MPa θm %	¶	1.5 MPa θm %	¶
4	5	AP	0.62	58.52	41.48	2.72	0.20	5.80	15.85	P	10.40	P
4	5	A2	0.49	57.26	42.74	2.88	0.10	5.70	15.75	P	10.83	P
4	5	BT1	0.69	55.90	44.10	0.80	0.10	6.25	18.33	P	11.89	P
4	5	BT2	0.63	63.03	36.97	0.80	2.25	6.80	18.37	P	10.67	P
4	5	BT3	0.62	69.82	30.18	0.80	2.90	7.05	19.96	P	10.58	P
4	5	BTK	0.62	65.97	34.03	0.64	12.20	7.90	18.59	P	9.80	P
4	5	2C	0.55	6.57	93.43	0.08	3.40	8.10	3.36	P	2.27	P

¶ A = Measured value from pressure plate.
P = Predicted value from regression analysis.

§ Organic carbon

SUMMARY OF LABORATORY DATA

Particle Size Data in % of Total
(fraction separations in microns)

				Total			Sand Fraction					Silt Fraction				
LEVEL	TRANSECT	HORIZON	LOWER BOUNDARY CM	CLAY <2	SILT 2-50	SAND 50 -2000	VC 1000 -2000	C 500 -1000	M 250 -500	F 100 -250	VF 50 -100	C 20 -50	M 5 -20	F 2 -5	FINE CLAY <.21	TEXTURAL CLASS
4	6	AP	20	14.45	45.15	40.40	6.85	12.75	10.35	6.45	4.00	26.65	13.20	5.30	8.10	L
4	6	BT1	44	25.25	38.85	35.90	5.45	10.25	9.90	6.55	3.75	24.45	12.20	2.20	17.95	L
4	6	BT2	70	26.50	43.75	29.75	4.25	7.95	8.05	4.75	4.75	29.35	12.15	2.25	16.75	L
4	6	BTK	90	27.05	50.85	22.20	1.85	3.65	4.65	3.80	8.25	36.00	11.10	3.75	14.30	SiL
4	6	2C	120	1.70	2.95	95.35	8.75	23.85	45.00	16.75	1.00	2.20	0.45	0.30	1.50	CS

LEVEL	TRANSECT	HORIZON	FINE CLAY TOTAL CLAY RATIO	CLAY FREE SILT %	CLAY FREE SAND %	OC § %	$CACO_3$ %	PH (1:1)	0.03 MPa θm %	¶	1.5 MPa θm %	¶
4	6	AP	0.56	52.78	47.22	1.60	0.6	5.8	14.08	P	8.11	P
4	6	BT1	0.71	51.97	48.03	0.64	0.8	6.8	16.48	P	10.47	P
4	6	BT2	0.63	59.52	40.48	0.56	0.8	6.8	18.01	P	10.78	P
4	6	BTK	0.53	69.61	30.39	0.48	9.9	8.0	20.17	P	10.86	P
4	6	2C	0.88	3.00	97.00	0.08	2.0	7.9	1.34	P	1.71	P

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P = Predicted value from regression analysis.

§ Organic carbon

SUMMARY OF LABORATORY DATA

Particle Size Data in % of Total
(fraction separations in microns)

				Total			Sand Fraction					Silt Fraction				
LEVEL	TRANSECT	HORIZON	LOWER BOUNDARY CM	CLAY <2	SILT 2-50	SAND 50 -2000	VC 1000 -2000	C 500 -1000	M 250 -500	F 100 -250	VF 50 -100	C 20 -50	M 5 -20	F 2 -5	FINE CLAY <.21	TEXTURAL CLASS
5	1	A1	8	18.00	52.85	29.15	5.80	7.10	5.40	4.75	6.10	34.70	15.35	2.80	11.70	SIL
5	1	A2	15	19.95	48.90	31.15	7.40	7.35	6.10	4.50	5.80	34.05	12.95	1.90	10.80	L
5	1	AB	26	19.65	49.10	31.25	6.50	7.55	6.00	4.90	6.30	36.45	9.90	2.75	10.40	L
5	1	BT1	45	24.90	37.30	37.80	7.15	10.15	7.60	6.25	6.65	28.10	0.00	9.20	16.65	L
5	1	BT2	65	22.30	39.10	38.60	6.95	10.35	8.50	6.80	6.00	29.15	8.50	1.45	12.25	L
5	1	BTK	86	27.10	50.50	22.40	2.70	4.00	2.80	2.70	10.20	30.50	16.75	3.25	15.75	CL
5	1	2C	132	8.15	9.55	82.30	25.50	30.35	16.20	7.45	2.80	6.45	2.50	0.60	5.15	LS
5	1	3C	172	22.80	32.90	44.30	8.65	11.40	9.35	6.20	8.70	23.10	8.15	1.65	13.15	L

LEVEL	TRANSECT	HORIZON	FINE CLAY TOTAL CLAY RATIO	CLAY FREE SILT %	CLAY FREE SAND %	OC § %	$CACO_3$ %	PH (1:1)	0.03 MPa θm %	¶	1.5 MPa θm %	¶
5	1	A1	0.65	64.45	35.55	2.40	0.20	5.9	16.9	A	10.4	A
5	1	A2	0.54	61.09	38.91	1.28	0.25	6.0	14.4	A	8.7	A
5	1	AB	0.53	61.11	38.89	1.04	0.60	6.2	14.9	A	9.2	A
5	1	BT1	0.67	49.67	50.33	0.64	0.55	6.5	16.5	A	4.4	A
5	1	BT2	0.55	50.32	49.68	0.56	0.45	6.5	15.1	A	9.4	A
5	1	BTK	0.58	69.27	30.73	0.56	11.60	7.8	18.6	A	9.8	A
5	1	2C	0.63	10.40	89.60	0.16	2.80	8.1	6.2	A	3.2	A
5	1	3C	0.58	42.62	57.38	0.56	6.95	7.8	15.6	A	9.1	A

¶ A = Measured value from pressure plate.
P = Predicted value from regression analysis.

§ Organic carbon

SUMMARY OF LABORATORY DATA

Particle Size Data in % of Total
(fraction separations in microns)

				Total			Sand Fraction					Silt Fraction			
LEVEL	TRANSECT	HORIZON	LOWER BOUNDARY CM	CLAY <2	SILT 2-50	SAND 50 -2000	VC 1000 -2000	C 500 -1000	M 250 -500	F 100 -250	VF 50 -100	C 20 -50	M 5 -20	F 2 -5	FINE CLAY <.21	TEXTURAL CLASS
5	3	AP	14	20.45	57.50	22.05	2.30	5.80	3.75	2.65	7.55	37.35	17.65	2.50	12.10	SIL
5	3	BT1	39	28.35	55.95	15.70	1.50	3.90	2.75	2.00	5.55	34.05	15.15	6.75	19.70	SICL
5	3	BT2	59	31.00	56.00	13.00	0.35	1.05	0.90	0.80	9.90	38.15	14.50	3.35	16.65	SICL
5	3	BTK	106	27.85	56.70	15.45	0.15	0.45	0.50	1.50	12.85	39.80	12.75	4.15	15.00	SICL
5	3	BK	144	23.90	47.80	28.30	0.85	2.40	2.70	4.30	18.05	34.40	10.30	3.10	14.35	L
5	3	2C	150	7.10	8.25	84.65	19.90	37.25	17.65	5.75	4.10	4.95	0.85	2.45	5.85	LCS

LEVEL	TRANSECT	HORIZON	FINE CLAY TOTAL CLAY RATIO	CLAY FREE SILT %	CLAY FREE SAND %	OC § %	$CACO_3$ %	PH (1:1)	0.03 MPa θm %	¶	1.5 MPa θm %	¶
5	3	AP	0.59	72.28	27.72	1.44	0.15	6.00	18.7	A	11.1	A
5	3	BT1	0.69	78.09	21.91	0.64	0.60	6.60	24.3	A	14.1	A
5	3	BT2	0.54	81.16	18.84	0.64	0.85	7.35	25.5	A	15.0	A
5	3	BTK	0.54	78.59	21.41	0.24	11.95	8.10	23.6	A	12.0	A
5	3	BK	0.60	62.81	37.19	0.24	9.65	8.25	19.4	A	10.6	A
5	3	2C	0.82	8.88	91.12	0.00	5.40	8.30	6.0	A	3.4	A

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§ Organic carbon

SUMMARY OF LABORATORY DATA

Particle Size Data in % of Total
(fraction separations in microns)

				Total			Sand Fraction					Silt Fraction				
LEVEL	TRANSECT	HORIZON	LOWER BOUNDARY CM	CLAY <2	SILT 2-50	SAND 50 -2000	VC 1000 -2000	C 500 -1000	M 250 -500	F 100 -250	VF 50 -100	C 20 -50	M 5 -20	F 2 -5	FINE CLAY <.21	TEXTURAL CLASS
5	5	AP	8	15.65	33.05	51.30	4.00	15.55	13.95	10.90	6.90	20.90	9.20	2.95	5.55	L
5	5	AB	23	16.70	49.05	34.25	4.00	11.05	6.70	6.80	5.70	29.55	13.95	5.55	5.40	L
5	5	BT1	42	26.60	41.50	31.90	3.20	9.50	5.30	7.50	6.40	24.95	12.05	4.50	16.70	L
5	5	BT2	58	24.95	46.00	29.05	3.80	10.40	4.75	5.55	4.55	28.75	13.40	3.85	17.30	L
5	5	2BTK	77	26.25	60.20	13.55	0.40	1.35	0.90	1.45	9.45	41.40	14.30	4.50	16.30	SIL
5	5	3BK	97	16.95	38.70	44.35	6.20	14.45	6.35	8.60	8.75	25.70	9.45	3.55	9.70	L
5	5	4C	120	4.55	5.85	89.60	20.15	43.45	7.10	11.80	7.10	4.00	1.00	0.85	3.15	CS

LEVEL	TRANSECT	HORIZON	FINE CLAY TOTAL CLAY RATIO	CLAY FREE SILT %	CLAY FREE SAND %	OC § %	CACO$_3$ %	PH (1:1)	0.03 MPa θm %	¶	1.5 MPa θm %	¶
5	5	AP	0.35	39.18	60.82	2.48	0.55	5.75	12.76	P	9.72	P
5	5	AB	0.32	58.88	41.12	1.60	0.10	6.45	15.88	P	8.87	P
5	5	BT1	0.63	56.54	43.46	0.96	0.40	6.45	17.93	P	11.36	P
5	5	BT2	0.69	61.29	38.71	0.56	0.50	6.65	17.87	P	10.26	P
5	5	2BTK	0.62	81.63	18.37	0.80	2.00	7.45	21.88	P	11.02	P
5	5	3BK	0.57	46.60	53.40	0.48	11.60	8.00	14.60	P	7.43	P
5	5	4C	0.69	6.13	93.87	0.16	2.10	8.20	3.98	P	2.78	P

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P = Predicted value from regression analysis.

§ Organic carbon

Summary of Laboratory Data

Particle Size Data in % of Total
(fraction separations in microns)

				Total			Sand Fraction					Silt Fraction				
LEVEL	TRANSECT	HORIZON	LOWER BOUNDARY CM	CLAY <2	SILT 2-50	SAND 50 -2000	VC 1000 -2000	C 500 -1000	M 250 -500	F 100 -250	VF 50 -100	C 20 -50	M 5 -20	F 2 -5	FINE CLAY <.21	TEXTURAL CLASS
5	6	AP	18	16.25	40.15	43.60	2.75	14.15	13.60	7.65	5.45	23.70	13.00	3.45	9.8	L
5	6	BT1	52	23.65	35.25	41.10	3.35	13.70	13.20	6.65	4.20	19.20	14.50	1.55	16.6	L
5	6	BT2	64	21.75	50.90	27.35	1.85	7.85	6.75	3.75	7.15	31.75	12.50	6.65	17.8	SiL
5	6	BIK	91	20.25	43.90	35.85	2.50	11.95	9.65	5.05	6.70	30.60	9.95	3.35	12.6	L
5	6	2C	120	8.05	6.80	85.15	7.40	31.70	27.85	13.95	4.25	3.15	2.25	1.40	6.6	CS

LEVEL	TRANSECT	HORIZON	FINE CLAY TOTAL CLAY RATIO	CLAY FREE SILT %	CLAY FREE SAND %	OC § %	$CACO_3$ %	PH (1:1)	0.03 MPa θm %	¶	1.5 MPa θm %	¶
5	6	AP	0.60	47.94	52.06	1.60	0.25	5.35	14.02	P	8.72	P
5	6	BT1	0.70	46.17	53.83	0.88	0.20	5.80	15.36	P	10.25	P
5	6	BT2	0.82	65.05	34.95	0.32	0.50	6.90	18.20	P	8.84	P
5	6	BIK	0.62	55.05	44.95	0.24	11.00	7.70	16.30	P	8.22	P
5	6	2C	0.82	7.40	92.60	0.00	3.55	8.00	4.80	P	3.75	P

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§ Organic carbon