MORPHOLOGY, GENESIS, AND CLASSIFICATION
OF SALINE-SODIC SOILS IN
NORTH CENTRAL OKLAHOMA

By

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CHAPTER I

INTRODUCTION

"Slickspots"[1] are found in largest numbers in climates varying from arid to semi-arid, although they occur in humid climates also. These soils occur in larger numbers in the central to western part of Oklahoma. The estimated number of acres affected by high soluble salts in Oklahoma is 897,750 (24). Saline-sodic soils are localized and occur on varying topography. Within this state these soils have received little explanation as to their genesis.

The primary objective of this study was to study the morphology and genesis of these saline-sodic soils through the interpretation of morphological, physical, chemical, and mineralogical data about the additions, removals, transfers, and transformations that have taken place as a result of climate, time, topography, parent material, and vegetation. Since these saline-sodic soils are localized it was assumed that the best possible way to study their morphology and genesis was to study a transect between a typical Mollisol and a saline-sodic soil. Modal pedons of these soils were located adjacent to the proposed contact between the Permian and Pennsylvanian age bedrock in north-central Oklahoma.

The secondary objective of this study was to classify these soils

[1]Henceforth referred to as saline-sodic.

using the criteria presented in the 7th Approximation (31). The vegetation at each transect from the saline-sodic soil to the associated typical Mollisol was described to see if this vegetation indicates the presence of high salts.

CHAPTER II

REVIEW OF LITERATURE

The saline-sodic soils in this study are not presently recognized as a soil series. They have morphological properties similar to the Dwight series mapped in Washington County (22) and the Wing series found in Arkansas[1]. This study should provide data to classify these pedons. These areas are numerous but localized. They will likely be mapped as complexes.

Factors of Soil Formation

Jenny (15) defines soil formation as "the transformation of rock into soil." He considers the soil as mature when the transformation of the rock has been completed and reached an equilibrium state. The genesis and morphology of any pedon are based on the assumption that the pedon is changing as result of the variables; parent material, vegetation, climate, time, and topography. Macro-climate and topography remains constant in this study.

Parent Material and Geology

Rocks that outcrop and underlie the soils of the study area are of early Permian (P) and late Pennsylvanian (IP) age and are members of

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[1] Tentative series classification of southern region. Dr. L. J. Bartelli, principal soil correlator 2/15/57.

the Wellington-Admire and Vanoss-Ada units, respectively (25). See Figure 1.

The members of the Wellington-Admire unit consist of shale, sandstone, limestone, and siltstone. Most of the unit is shale, which is mostly reddish colored and clayey to silty. This shale contains lenses and beds of sandstone, limestone, and a few thin siltstones. The sandstones are usually reddish-brown to tan in color. The limestone is more prominent in northern Osage County and grades to shale and sandstone southward.

The total thickness of this unit is approximately 825 feet. The shale intervals range from 35 to 150 feet thick. The sandstone located within these intervals varies from 3 to 30 feet thick. The limestone varies from 7 to 15 feet thick (25).

The Vanoss-Ada unit consists mostly of shale with some limestone and sandstone. The red and gray shale contains lenses and beds of sandstone and limestone.

The total thickness of this unit is about 250 to 425 feet. Most of the sandstone is less than 10 feet thick, and majority of the limestone beds are 2 feet or less.

Both of these units are made up mainly of alternating strata of shales and limestones, with lenses of sandstone. Sandstone and limestone cap the steeper hills and forms escarpments and slopes. The shale outcrops form U-shaped valleys and rounded hills.

Vegetation

The importance of vegetation on the genesis of soils has been known since the days of Dokuchaev, but it has proven very difficult to study its role in the genesis of soils. This is mainly due to the

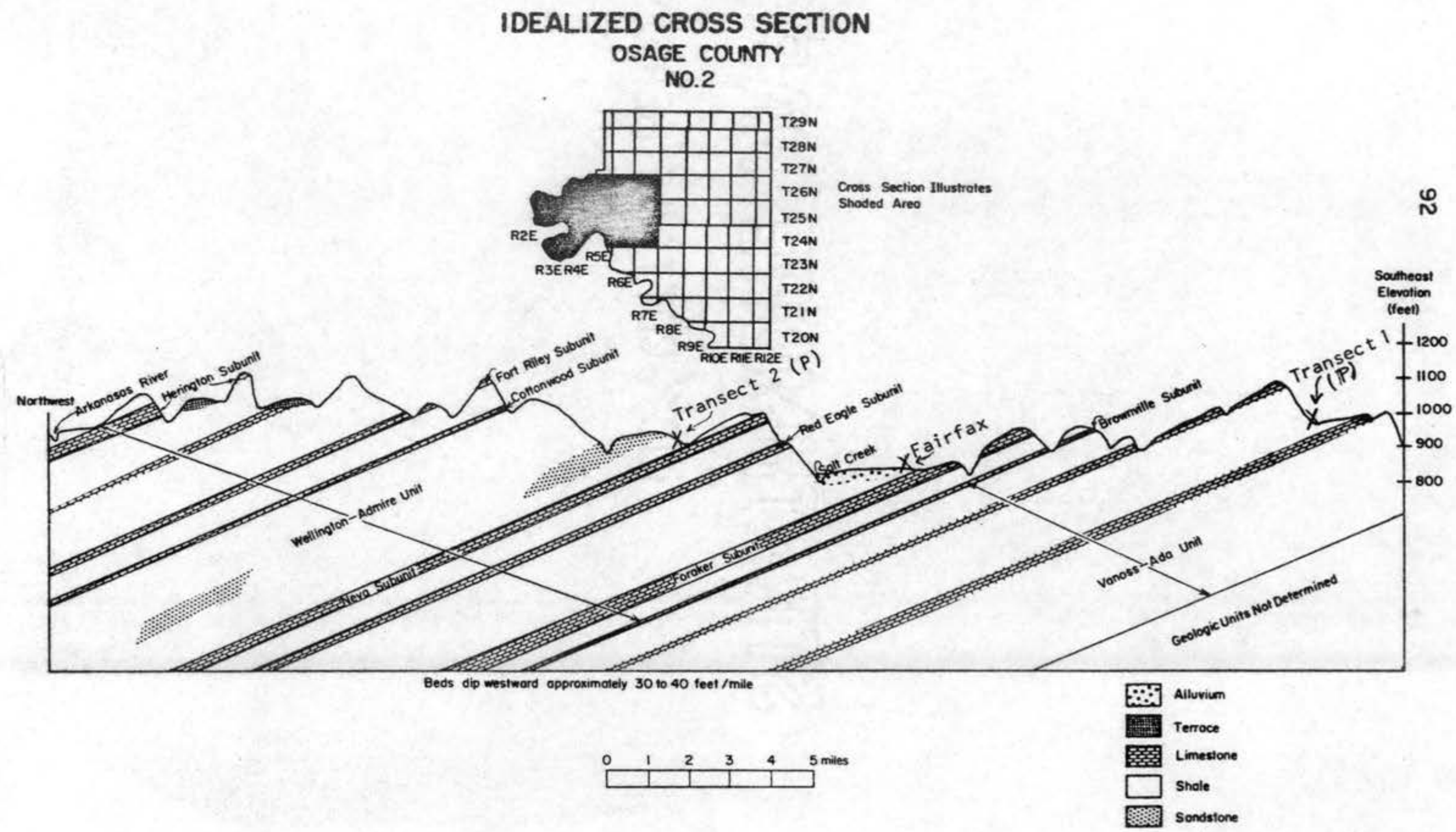


Figure 1. Idealized Cross Section Showing the Geology-Soil Relationship of the Study Area.

climate-vegetation-soil interaction. Vegetation is known to affect the pH, organic carbon, nitrogen, and bulk density of soils (4).

The influence of exchangeable sodium upon the physical properties of soils has been reported by Ratner (23). He found that the replacement by sodium of 1.9 percent of the total exchangeable bases influenced the physical properties of the chernozem soil. The influence of exchangeable sodium on pot tests of oats, spring wheat, and barley begins to be deleterious when it makes up 50 percent of the total exchangeable bases. Ratner explained that exchangeable sodium has more influence upon the physical properties of soils where organic substances are high. The U. S. D. A. Salinity Laboratory (34) reports that when a soil dries from field capacity to the wilting point, the salts in soil solution are approximately doubled in concentration.

Hayward and Wadleigh (12) reported that certain species vary greatly in their ability to accumulate sodium and decrease Ca, Mg, and K content in roots and tops. They suggested the possibility that the species that are more tolerant to high levels of exchangeable sodium are the ones which take in considerable amounts. Kellogg (17) observed that halophytes growing on sodium-solonchak and solodized-solonetz soils recycle the sodium through the solum, but in podzols the sodium is gradually lost to the ground water. As this process goes on halophythic vegetation is displaced by mesophythic plants which use less sodium and more calcium. Slowly, as the development continues, sodium is replaced by hydrogen and calcium in the exchange resulting finally in a normal soil.

The Soil Conservation Service (30) has prepared range site descriptions for several soils in Oklahoma. The decreasers common to saline-sodic soils are alkali sacaton (*Sporobolus airoides*), switchgrass (*Panicum virgatum*), white tridens (*Tridens albescens*), tall dropseed (*Sporobolus asper*), and blue grama (*Bouteloua gracilis*). They represent about 50% of the total vegetation. The common increasers are whorled dropseed (*Sporobolus pyramidatua*), purple threeawn (*Aristida purpurea*), morning lovegrass (*Eragrostis* spp.), gummy lovegrass (*Eragrostis curtipedicellata*), and fall witchgrass (*Leptoloma cognatum*). Yellow neptunia (*Neptunia lutea*) is a decreaser legume. Common forbs are pricklypear (*Opuntia* spp.), curlycup gumweed (*Grindelia squarrosa*), wax goldenweed (*Haplopappus* spp.), and hairy goldaster (*Chrysopsis villosa*).

Some of the decreasers found in the typical Mollisols are big bluestem (*Andropogon gerardi*), little bluestem (*Andropogon scoparius*), indiangrass (*Sorghastrum nutans*), and switchgrass. This vegetation makes up about 70% of the decreasers.

The increaser plants such as jointtail (*Manisuris* spp.), purpletop (*Tridens flavus*), tall dropseed (*Sporobolus asper*), and sideoats grama (*Bouteloua curtipendula*) make up about 30%. The invaders are splitbeard bluestem (*Andropogon ternarious*), windmillgrass (*Chloris verticillata*), buffalograss (*Buchloe dactyloides*), and silver bluestem (*Andropogon saccharoides*). Broomweed (*Gutierrezia dracunculoides*), narrowleaf sumpweed (*Iva* spp.), western ragweed (*Ambrosia psilostachya*) and Baldwin ironweed (*Vernonia baldwini*) readily invade.

The role of vegetation in the genesis of soil should not be overlooked.

Climate

Soils sampled are developing under a warm, temperate, sub-humid, continental climate which influences the morphological losses, gains, transfers, and transformations.

Annual soil temperature is used as a family differentia under the present system of classification. Those soils which have a temperature difference of 9°F. or more between mean summer (June, July, and August) and mean winter (December, January, and February) temperatures and which have a mean annual soil temperature of 59°F. to 72°F. are referred to as thermic (32). In the absence of direct soil temperature measurements, the mean annual soil temperature is approximated by adding 2°F. (1°C.) to the mean annual air temperature. This holds true in the United States except for high altitudes and extreme northern states (31).

The average maximum temperature occurs in the months of July and August and the minimum temperature occurs in January. The mean annual air temperature for Osage County is 60.8°F. The mean winter temperature is 39.2°F. while the mean summer temperature is 81.4°F. for the county. The average annual precipitation for this area is 34.5 inches (6, 9). The average dates of the last killing frost in the spring and the first killing frost in the fall are April 4 and October 29, respectively. This results in an average growing season of 206 days. The area has an annual P-E index between 56 and 58 (10) and an average annual evapotranspiration of about 34 (33).

The mean annual air temperature indicates these soils should be classified thermic.

<u>Time</u>

Geologic time is required for the formation of distinct horizons in soils. Differences in the length of time that parent materials have been in place are commonly reflected in the degree of development and depth of residual soil profiles. Young soils have very little profile development. They show no textural difference between A and B horizons and generally have thin solums. These properties grade to the old soils which have well developed B horizons and thicker solums. These soils have B horizons that are more clayey than the A horizon and are deeper to parent material. The pedons selected for this study are within the Reddish Prairie zone (38). Some of their processes of soil formation may be related to those that form Mollisols.

Topography

Saline-sodic soils have been reported occurring on landscapes from low terraces (13) to flat uplands (7). In Oklahoma these soils chiefly develop on slopes, in depressions, or at the sides or heads of gullies.

This study area occurs on gently to moderately sloping upland prairie with both saline-sodic soils occurring down-slope from their intermediate and associated typical Mollisol. The saline-sodic soils have a concave micro-relief. These soils are located in the east central portion of Osage County and lie within the Osage Plains section of the central lowlands physiographic province of the United States (25).

The drainage in this area is southward into the Arkansas River.

Genesis

The United States Salinity Laboratory (34) has classified soils associated with high soluble salts and exchangeable sodium as saline, saline-alkali, and alkali soils. This closely agrees with the Russian classification of these soils; solonchak, solonetz, solodized-solonetz, and soloth (16).

De Sigmond (28) postulated that the content of exchangeable sodium was important in the solonization process. He stated that after excess salts are removed from a soil, exchangeable sodium causes the dispersion of humic and mineral colloids which results in a columnar structure developing in the black, dispersed B horizon. Hydrolysis of sodium from the exchange complex gives the soil an alkaline reaction with removal of the soluble salts. This leads to the formation of solonetz which forms through the process of solonization. Solodization then starts, which results in the eluviation of the A horizon and deposition of clay and colloidal matter in the B horizon. Under the dispersing effect of sodium, organic matter from the A horizon moves into the B. Such soils are called solodized-solonetz. With further hydrolysis of sodium from the exchange complex sesquioxides are also eluviated into the B from the A horizon. The process of hydrolysis and leaching continues until the profile loses its solonetz characteristics and becomes friable to a considerable depth with more A horizon than B. Such soils are called soloth.

According to Murphy and Daniels (21) the presence of alkali spots are probably due to the accumulation of sodium salts in the sediments laid down by the receding sea, as the water in the deeper surface reservoirs evaporated as a result of arid conditions. The lateral extent of an individual alkali spot is usually quite distinct, indicating definite abrupt surface conditions at the time of deposition, accumulation, and formation of solonchak soils. As the soluble sodium salts reacted with the base exchange complex, sodium clay was formed. As the sodium salts were leached out of the surface soil by rain water, hydrolysis of the sodium clay occurred and sodium hydroxide caused the soil to become alkaline and highly dispersed. This retarded further leaching which helps to develop the morphological characteristics of solonetz soils.

It has been pointed out by Kelley (18) that alkali soils reclaimed by leaching of sodium and soluble salts may not show an immediate improvement in the physical condition of the soil. The return to a normal physical condition develops gradually over a long period of time.

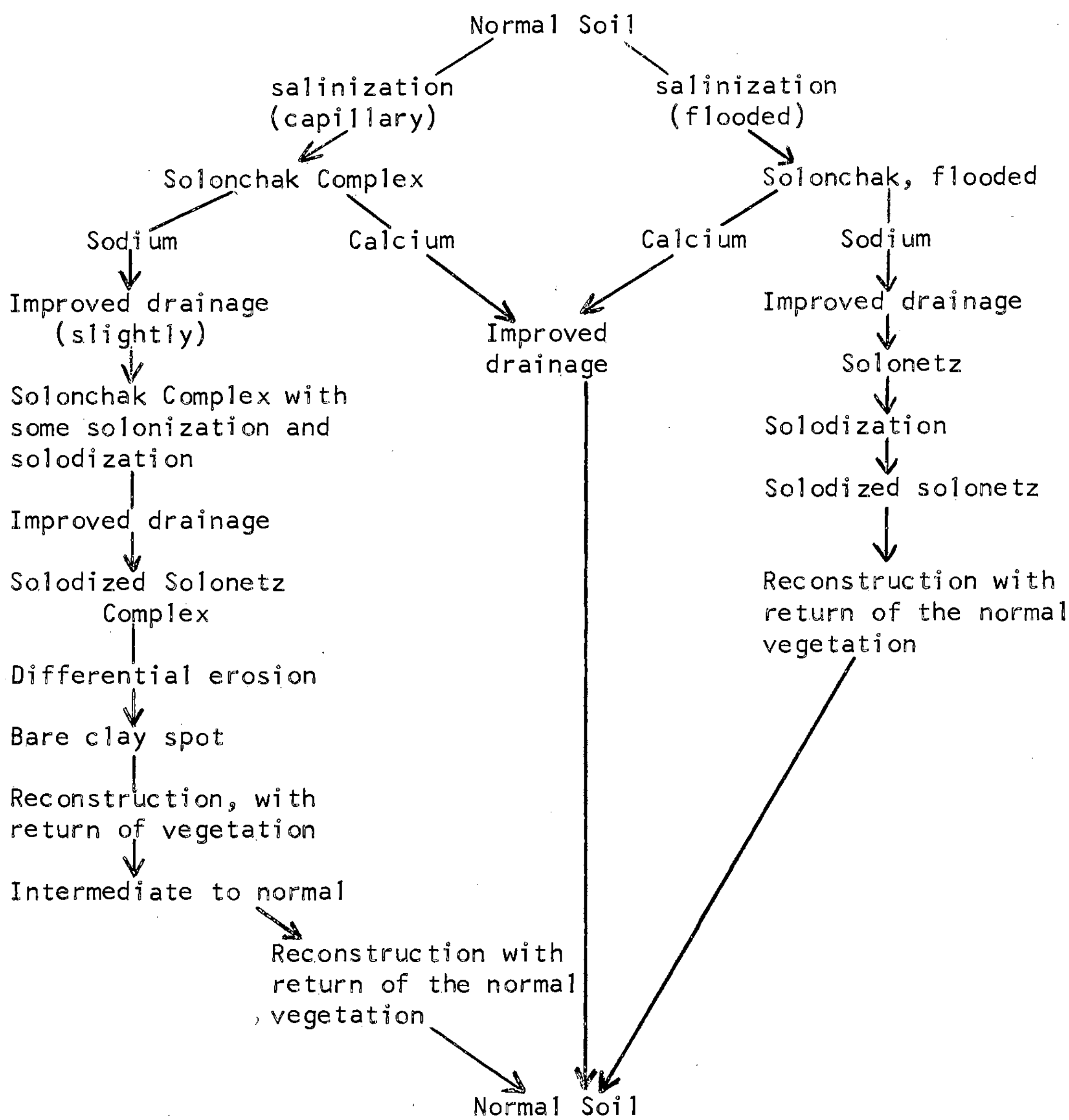
The genesis of "slickspots" in Illinois is related to the accumulation of sodium by means of lateral movement of saline ground water along relatively impervious glacial till layers. This is followed by evaporation and interruption of leaching either by an impervious substrata or by a high water table. Smith (29) also states that a horizon high in exchangeable hydrogen overlying a less permeable horizon can act as a filter in removing calcium from the ground water resulting in an increase in sodium. This ground water can be brought into contact with the surface by impervious layers, hydrostatic pressure, or capillary rise, followed by evaporation.

The physical and chemical properties of an alkali spot and an adjoining normal soil in Kansas were compared by Ahi and Metzger (1). They attributed the unfavorable structure to the hydrolysis of sodium bearing silicates resulting in a high exchangeable sodium percentage. The possible genesis of these soils was due to lateral and vertical seepage of ground water.

Three general groups of solonetz soils are recognized in eastern Arkansas by Horn *et al.* (13). They are: (a) soils of less than ten inches to a sodic horizon, (b) soils with upper horizons acid and a moderate depth to a sodic horizon, and (c) soils with sodic horizons and acid sola. They attributed the initial source of Na and Mg salts to the weathering of the primary minerals in the loess-derived alluvium. Their local concentration was explained by salinization by saline ground water. They found these soils to have a high ratio of Mg to Ca. This was related to the high Na concentrations and strongly alkaline reaction. Sandoval and Shoesmith (27) reported that magnesium was usually the dominant cation followed by sodium, which was associated with the saline glacio-lacustrine area of North Dakota. The salt distribution in the profiles was related to the fluctuating water table. Riecken's (26) work explains the possibility of a preferential adsorption of Mg over Ca in a Na-clay system that is strongly alkaline. This and the process of solodization are a possible explanation of those soils that have high Mg, low Ca and Na system but have solonetzic morphology.

Wilding et al. (37) and Fehrenbacher et al. (7) found that the source of sodium in solonetzic soils of Illinois was the feldspars of the parent loess. They postulated that redistribution of the Na from weathering was responsible for these soils. Features supporting the salt movement theory for the genesis of solonetzic soils are the following: (a) random occurrence on nearly level uplands, (b) similar intensities of weathering between solonetzic and associated soil, (c) distribution of carbonates concretions in B horizons, (d) low exchangeable Na in associated soil but increasing with depth, (e) wider Ca/Mg ratio in associated soils, (f) distribution of Na in solonetzic soils.

Kellogg (17) diagramed the possible genesis of the alkali soils in western North Dakota as follows:


Normal Soil
salinization (capillary)
salinization (flooded)
Solonchak Complex
Solonchak, flooded
Sodium
Calcium
Calcium
Sodium
Improved drainage (slightly)
Improved drainage
Improved drainage
Solonchak Complex with some solonization and solodization
Solonetz
Solodization
Improved drainage
Solodized solonetz
Solodized Solonetz Complex
Reconstruction with return of the normal vegetation
Differential erosion
Bare clay spot
Reconstruction, with return of vegetation
Intermediate to normal
Reconstruction with return of the normal vegetation
Normal Soil

CHAPTER III

LABORATORY METHODS AND PROCEDURES

Bulk soil samples were collected from each horizon, air dried under laboratory conditions and then processed to pass a 2 mm screen. Chemical, physical, and mineralogical analyses were then made from subsamples taken from these bulk samples.

Physical Analysis

Mechanical analysis was determined by the pipette method (19). Approximately 10g samples were used for the mechanical analysis. Organic matter was removed by treating with hydrogen peroxide (H_2O_2). Carbonates were destroyed with hydrochloric acid until the pH remained constant as described by Jackson (14). The pH was lowered to about 5. Soluble salts were washed out of those samples which were high enough to hinder dispersion. Samples were then oven dried and weighed on an analytical balance to determine the exact weight. The samples were dispersed using a five percent solution of sodium hexametaphosphate. The total sand separate was retained on a 300 mesh sieve. The relative proportions of the five subfractions of the sand separate were determined by weighing the sand retained on appropriate sieves. Percent clay was determined by weighing pipetted aliquots which had been evaporated and dried at 105° C. Corrections were made for the sodium hexametaphosphate. The percent silt was determined by difference.

Chemical Analyses

The chemical analyses consisted of the determination of pH, cation exchange capacity, extractable cations, percent organic matter, electrical conductivity, water soluble cations and anions, and total solids.

The soil pH was determined on a soil-distilled water paste and on a 1:1 mixture of soil and 1 N KCl solution. Readings were taken on a model H2 Beckman (glass electrode) pH meter.

The CEC was determined by saturating the samples with sodium acetate (34). Five g samples were washed four times with 30 ml of 1 N sodium acetate, pH 8.2. The excess Na was removed by washing three times with 30 ml of 95% ethanol. Washings consisted of shaking the samples for five minutes on a reciprocating shaker and centrifuging until the soil particles were thrown out of suspension. The sodium acetate and ethanol washings were decanted as completely as possible and discarded. Na was then replaced by NH_4 by washing three times with 30 ml of 1 N ammonium acetate, pH 7.0. These washings were saved and diluted to 250 ml. The sodium was determined with a model 303 Perkins-Elmer atomic adsorption spectrophotometer.

Extractable Ca, Mg, Na, and K in the soil samples were prepared by washing 5 g samples twice with 30 ml and once with 20 ml of 1 N ammonium acetate, pH 7.0. The washings were decanted and diluted to 100 ml.

Calcium and magnesium were determined using the versenate titration described in USDA Handbook 60 (34). An inhibitor was added to eliminate trace element interference resulting in a sharper endpoint. The sodium diethyldithiocarbamate inhibitor solution was prepared by dissolving 1 g in 100 ml of distilled water. Five drops of this inhibitor were added prior to the addition of the other reagents. Low results were obtained on samples high in soluble salts when this inhibitor was not used. Sodium and potassium were determined with the atomic adsorption spectrophotometer. Percent base saturation was calculated by dividing the total exchangeable bases by the CEC and multiplying by 100.

Organic matter was determined by the potassium dichromate wet-oxidation method (34). Ten ml of 0.4 N potassium dichromate and 15 ml of concentrated sulfuric acid were added respectively, to 0.5 g samples of soil. Samples were then heated slowly to 165°C. After cooling, 100 ml of distilled water was added. Two drops of ortho-phenanthroline ferrous sulfate indicator were added prior to titration with 0.2 N ferrous ammonium sulfate.

Electrical conductivity was determined after a 1:1 soil-water extract was prepared on 250 g samples of soil. These samples were shaken on a model DD Burrell wrist shaker for 12 hours before being filtered on buchner funnels. The resistance readings were taken on a model RC1B Industrial Instruments Inc. conductivity bridge.

A 1:1 soil-water extract was analyzed for Ca, Mg, Na, K, Cl, SO_4, HCO_3, and CO_3. Ca, Mg, Na, and K were determined on the atomic adsorption spectrophotometer. The Ca and Mg samples were first prepared by adding 1 ml of 1:1 extract, 1 ml of 5.0 percent lanthanum oxide, and 3 ml of water. These samples were then analyzed on the spectrophotometer.

The carbonates, bicarbonates, and chlorides were analyzed as described in USDA Handbook 60 (34). Twenty ml of water was added to 5 ml aliquots of a 1:1 extract. Three drops of phenolphthalein indicator were added. Samples containing carbonates will turn pink. These samples are titrated back to a colorless end point with 0.1 N HCl. These samples were void of carbonates. Bicarbonates were determined by adding 5 drops of methyl orange indicator prior to titration with 0.1 N HCl.

One ml of potassium chromate indicator was added to 5 ml of 1:1 extract. Chlorides were determined by titration with a standard silver nitrate solution.

The sulfates were determined by a procedure reported by Fritz and Yamanura (8). Ten ml of 1:1 extract was passed through an exchange column which contained hydrogen saturated Dowex-50 resin. The resin was then washed with distilled water. Samples were diluted to 50 ml volume. Forty ml of 100% ethanol and one drop of thorin indicator were added to a 10 ml aliquot of sample which was titrated against 0.005 M barium perchlorate to a permanent pink end point. Sodium adsorption ratio (SAR) was calculated by dividing the sodium concentration (meq/liter) of 1:1 extract by the square root of one-half the sum of calcium plus magnesium concentration (meq/liter) of 1:1 extract.

Total solids were determined by slowly evaporating to dryness 20 ml of a 1:1 extract (34). Samples were then placed in an oven at 105^{o} C. Upon removal, the samples were placed in a desiccator to dry before weighing on an analytical balance.

Mineralogical Analysis

Certain horizons were selected from each profile for X-ray analysis. Total clay was the only fraction separated. X-ray diffraction analyses were completed on three saline-sodic, one intermediate, and three typical Mollisol horizons.

Samples were prepared for fractionation by a procedure similar to Kilmer and Alexander (19). Approximately 25 g of soil were treated with hydrogen peroxide to remove organic matter. Samples were then dispersed by adding 25 ml of 5% calgon and beating 5 minutes on a malt mixer. The samples were transferred to hydrometer jars and brought to volume. They were placed in a constant temperature room at 23° C. After reaching a constant temperature, samples were shaken and siphoned at the appropriate time to fractionate the total clay. Siphonings were repeated for about 6 times.

A portion of the clay was saturated with 0.3 N calcium chloride solution. The excess calcium chloride was removed by washing with 1% glycerol solution until dispersion occurred. Clays were then mounted on slides and scanned from $3^{\circ}2\theta$ to $28^{\circ}2\theta$ on a General Electric XRD 6 diffractometer with Ni-filtered Cu $K\alpha$ radiation generated at 50 kv and 20 ma. Slit sizes were 1°MR bean, HR soller, and 0.2° detector.

CHAPTER IV

RESULTS AND DISCUSSION

Field Studies

A detailed preliminary investigation was made in Osage County to formulate a central concept of the morphological characteristics typical of saline-sodic soils found adjacent to proposed contacts of Pennsylvanian (IP) and Permian (P) age bed rock. The Pennsylvanian and Permian transects will be referred to as transect 1 (IP) and transect 2 (P), respectively. Figure 1 gives the general location of the transects relative to the underlying geology.

A study of the morphology and vegetation was used in locating typical pedons of the associated typical Mollisol and intermediate soils. Sampling pits were dug at the typical Mollisol, intermediate, and saline-sodic soils at each transect location. The morphology of each pedon was studied in detail to determine the thickness and number of soil horizons. These pedons were then described according to the 7th Approximation (31). Samples for laboratory analyses were collected from each horizon. The vegetation on each site was described. Common and scientific names of the vegetative species encountered are given in Table I.

TABLE I

COMMON AND SCIENTIFIC NAMES OF PLANTS DISCUSSED IN PROFILE DESCRIPTIONS

Common Name	Scientific Name
	Grasses
big bluestem	Androgogon gerardi
blue grama	Bouteloua gracilis
buffalograss	Buchloe dactyloides
Canada wildrye	Elymus canadensis
fall witchgrass	Leptoloma cognatum
indiangrass	Sorghastrum nutans
Japanese brome	Bromus japonicus
knotroot bristlegrass	Setaria geniculata
little barley	Hordeum pusillum
little bluestem	Andropogon scoparius
lovegrass	Eragrostis spp.
prairie threeawn	Aristida oligantha
purple lovegrass	Eragrostis spectabilis
purpletop	Tridens flavus
sand dropseed	Sporobolus cryptandrus
sand paspalum	Paspalum stramineum
scribner panicum	Panicum scribnerianum
sedge	Carex spp.
sideoats grama	Bouteloua curtipendula
silver bluestem	Andropogon saccharoides
stinkgrass	Eragrostis cilianensis
switchgrass	Panicum virgatum
tall dropseed	Sporobolus asper
tumblegrass	Schedonnardus paniculatus
windmillgrass	Chloris verticillata
	Forbs
annual broomweed	Gutierrezia dracunculoides
Baldwin ironweed	Vernonia baldwini
beebalm	Monarda spp.
blue wildindigo	Baptisia minor
buckbrush	Symphoricarpos orbiculatus
catclaw sensitivebriar	Schrankia uncinata
clover	Trifolium spp.
compassplant	Silphium laciniatum
coneflower	Rudbeckia spp.
croton	Croton spp.
dogbane	Apocynum spp.
dotted gayfeather	Liatrius punctata
flax	Linum spp.
fringeleaf ruellia	Ruellia humilis

TABLE I (Continued)

Common Name	Scientific Name
gaura	*Gaura* spp.
green antelopehorn	*Asclepiodora viridis*
heathaster	*Aster ericoides*
horsenettle	*Solanum carolinense*
Illinois bundleflower	*Desmanthus illinoensis*
Korean lespedeza	*Lespedeza stipulacea*
Louisiana sagewort	*Artemisia ludoviciana*
marestail	*Erigeron canadensis*
peppergrass	*Lepidium densiflorum*
pitchersage	*Salvia azurea*
pricklypear cactus	*Opuntia* spp.
smartweed	*Polygonum* spp.
trailing wild bean	*Strophostyles helvola*
wavyleaf thistle	*Cirsium undulatum*
western ragweed	*Ambrosia psilostachya*
wild alfalfa	*Psoralea tenuiflora*
woolly verbena	*Verbena stricta*
yarrow	*Achillea* spp.

Descriptions of Transect 1 (IP) and 2 (P)

Transect 1 (IP). The relief is moderate to gently concave. The physiography of this site is a southeast facing upland footslope. The slopes of the associated typical Mollisol, intermediate soil, and saline-sodic soil corresponds to 4, 3, and 2 percent, respectively. The range condition varies from good at the typical Mollisol to poor at the saline-sodic soil. This transect is located 8 miles west and 1 mile south of Pawhuska, Oklahoma.

Typical Mollisol (IP)

Horizon	Inches (cm)	Description
Location:		This site is located about 102 feet west of fence corner near the northeast corner of the NW¼ of Sec. 7, T25N, R8E.
Vegetation:		Dominant grasses were little bluestem, big bluestem, indiangrass, silver bluestem, tall dropseed, switchgrass, with lesser amounts of purple lovegrass, fall witchgrass, sand paspalum, Canada wildrye, purpletop, prairie three-awn, windmillgrass, Japanese brome, buffalograss, and scribner panicum. The forbs were western ragweed, Louisiana sagewort, Korean lespedeza, buckbrush, dogband, heathaster, wavyleaf thistle, Carolina horsenettle, annual broomweed, wild flax, trailing wild bean, wild-indigo, false gaura, catclaw sensitivebriar, compassplant, yarrow, fringeleaf ruellia, woolly verbena, prairie coneflower, prairie clover, Baldwin ironweed, and croton.
A1	0-12 (0-30)	Very dark gray (10YR 3/1) clay loam, dark gray (10YR 4/1) when dry ; moderate medium granular structure; slightly hard, very friable; pH 6.0; abundant roots; clear smooth boundary.
B21t	12-19 (30-48)	Very dark gray (10YR 3/1) light silty clay, dark gray (10YR 4/1) when dry; weak medium sub-angular blocky breaking to moderate medium granular structure; hard, friable; patchy clay films; pH 5.9; few small sandstone pebbles;

		plentiful roots; clear smooth boundary.
B22t	19-32 (48-81)	Dark grayish brown (2.5Y 4/2) light silty clay, light olive brown (2.5Y 5/3) when dry, common fine and medium distinct yellowish brown (10 YR 5/8) mottles; moderate medium subangular blocky breaking to moderate medium granular structure; very hard, firm; continuous clay films; few slickensides; pH 6.3; few small sandstone pebbles; few Fe and/or Mn concretions less than 2 mm; plentiful roots; gradual smooth boundary.
B23t	32-50 (81-127)	Olive brown (2.5Y 4/3) light silty clay, light olive brown (2.5Y 5/3) when dry; mottles as described above; moderate medium and coarse angular blocky structure; extremely hard, firm; continuous clay films; common slickensides; pH 6.5; few small sandstone pebbles; common Fe and/or Mn concretions less than 2 mm; black coating in old root channels; few roots; gradual smooth boundary.
B3	50-60 (127-152)	Dark grayish brown (2.5Y 4.5/2) heavy silty clay loam, grayish brown (2.5Y 5/2) when dry, many medium and coarse distinct yellowish brown (10YR 5/6 and 5/8) mottles; weak to moderate medium angular blocky structure; extremely hard, firm; patchy clay films; few slickensides; pH 6.9; few Fe and/or Mn concretions less than 2 mm; black coatings in old root channels; few roots; gradual smooth boundary.
C1	60-68 (152-173)	Olive gray (5Y 5/2) heavy silt loam, light olive gray (5Y 6/2) when dry, common medium and coarse yellowish brown (10YR 5/6 and 5/8) mottles; weak medium blocky to massive structure; very hard, firm; pH 7.1; few Fe and/or Mn concretions about 2 mm; black coatings in old root channels; gradual boundary.
C2	68-90 (173-229)	Coarsely mottled reddish brown (5YR 4/4 and 5/4) when dry, dark yellowish brown (10YR 4/6) and yellowish brown (10YR 5/6) when dry, dark grayish brown (2.5Y 4/2) and grayish brown (2.5Y 5/2) when dry, clay; massive, very hard, firm; pH 7.1; few Fe and/or Mn concretions about 2 mm; black coatings in old root channels; gradual boundary.
R	90-98+ (229-249+)	Laminated olive shales with brownish steaks and mottles.

Intermediate (IP)

Horizon	Inches (cm)	Description
Location:		Location is about 63 feet northeast of saline-sodic profile or some 140 feet southwest of the typical Mollisol.
Vegetation:		Dominant grasses were prairie threeawn, silver bluestem, little bluestem, windmillgrass, purple lovegrass, with lesser amounts of indiangrass, big bluestem, fall witchgrass, switchgrass, scribner panicum, tumblegrass, sand paspalum, buffalograss, and Japanese brome. The forbs were western ragweed, Korean lespedeza, Louisiana sagewort, heath-aster, dogbane, prairie coneflower, yarrow, trailing wild bean, wavyleaf thistle, marestail, and croton.
A11 or Ap	0-6 (8-15)	Very dark gray (10YR 3/1) silt loam, dark gray (10YR 4/1) when dry; weak medium granular structure; hard, very friable; pH 5.9; abundant roots; abrupt smooth boundary.
A12	6-16 (15-41)	Very dark gray (10YR 3/1) silty clay loam, dark gray (10YR 4/1) when dry; moderate fine and medium granular structure; hard, friable; pH 5.8; abundant roots; clear smooth boundary.
B1	16-20 (41-51)	Very dark gray (10YR 3.5/1) silty clay loam, dark gray (10YR 4.5/1) when dry, few fine faint yellowish brown (10YR 5/6) mottles; moderate medium granular structure; very hard, friable; patchy clay films; pH 5.7; plentiful roots; clear smooth boundary.
B21t	20-32 (51-81)	Very dark grayish brown (10YR 3/2) silty clay, dark grayish brown (10YR 4/2) when dry, common fine and medium distinct yellowish red (5YR 4/6 and 4/8) mottles; moderate coarse blocky breaking to moderate medium granular structure; extremely hard, firm; continuous clay films; few slickensides; pH 5.8; few Fe and/or Mn concretions about 2 mm; plentiful roots; gradual smooth boundary.
B22t	32-44 (81-112)	Dark grayish brown (2.5Y 4/2) clay, grayish brown (2.5Y 5/2) when dry, common medium and coarse distinct yellowish brown (10YR 5/6) mottles; moderate medium and coarse blocky

		structure; extremely hard, firm; continuous clay films; few slickensides; pH 6.2; few small hard lime concretions; few Fe and/or Mn concretions about 2 mm; black coating in old root channels; few roots; gradual smooth boundary.
B3	44-55 (112-140)	Coarsely mottled dark yellowish brown (10YR 4/4) and yellowish brown (10YR 5/4) when dry, gray (5Y 5/1; 6/1) when dry, olive gray (5Y 4/2; 5/2) when dry, silty clay; weak fine blocky structure; extremely hard, firm; patchy clay films; pH 6.7; common Fe and/or Mn concretions about 2 mm; black coatings in old root channels; few roots; gradual smooth boundary.
C	55-75 (140-191)	Coarsely mottled dark yellowish brown (10YR 4/4) and yellowish brown (10YR 5/4) when dry, black (10YR 2/1; 2/1) when dry, reddish gray (5YR 4/2; 5/2) when dry, clay; massive to weak fine subangular blocky structure; extremely hard, firm; pH 7.1; common Fe and/or Mn concretions about 2 mm; few small sandstone pebbles.

Saline-Sodic (P)

Horizon	Inches (cm)	Description
Location:		About 180 feet south and 190 feet west of the northeast corner of the NW¼ of sec. 7, T25N, R8E or about 200 feet southwest of the typical Mollisol.
Vegetation:		Dominant grasses were buffalograss, tumblegrass, silver bluestem, prairie threeawn, and windmillgrass, with lesser amounts of Japanese brome, little barley, morning lovegrass, sand dropseed, and stinkgrass. The forbs were western ragweed, annual broomweed, peppergrass, smartweed, and yarrow.
A1	0-4 (0-10)	Dark gray (10YR 4/1) silt loam, gray (10YR 5/1) when dry; weak fine platy breaking to weak medium granular structure; slightly hard, very friable; pH 6.0; abundant roots; abrupt smooth boundary.

B1	4-10 (10-25)	Very dark gray (10YR 3.5/1) light silty clay loam, dark gray (10YR 4/1) when dry; moderate medium and coarse columnar breaking to moderate medium angular blocky structure; very hard, friable; patchy clay films; grayish coatings on column faces; pH 7.3; plentifyl roots; clear smooth boundary.
B21t	10-18 (25-46)	Very dark gray (10YR 3.5/1) light silty clay, dark gray (10YR 4/1) when dry, few fine distinct yellowish brown (10YR 5/8) mottles; moderate medium and coarse columnar breaking to strong medium angular blocky structure; extremely hard, firm; continuous clay films; pH 7.7; organic stains on peds; plentiful roots; clear smooth boundary.
B22tca	18-26 (46-66)	Dark grayish brown (2.5Y 4/2) silty clay, dark grayish brown (2.5Y 4.5/2) when dry, common fine and medium distinct yellowish brown (10 YR 5/6 and 5/8) mottles; moderate medium angular blocky structure; extremely hard, firm; continuous clay films; pH 7.5; few fine thread like $CaSO_4$ crystals; few Fe and/or Mn concretions about 2 mm; plentiful roots; gradual smooth boundary.
B23tcs	ca26-37 (66-94)	Dark grayish brown (2.5Y 4.5/2) silty clay, light olive brown (2.5Y 5/3) when dry, common fine and medium distinct yellowish brown (10 YR 5/6 and 5/8) mottles; moderate medium and coarse angular blocky structure; extremely hard, firm; patchy clay films; noncalcareous; pH 7.6; few hard lime concretions about 2 mm, few soft lime concretions larger than 10 mm; many crystals of $CaSO_4$; many Fe and/or Mn concretions about 2 mm; few roots; wavy boundary.
B31cs	ca37-42 (94-107)	Olive gray (5Y 5/2) clay, light olive gray (5Y 6/2) when dry, crushed olive brown (2.5Y 4/3), common fine and medium distinct yellowish brown (10YR 5/4 and 5/6 and 5/8) mottles; weak coarse angular blocky structure; extremely hard, firm; patchy clay films; few slickensides; pH 7.6; noncalcareous; few hard lime concretions about 2mm, few coarse soft lime concretions; many crystals of $CaSO_4$; common Fe and/or Mn concretions about 2 mm; few roots; clear wavy boundary.
B32cs	42-49 (107-124)	Color as described above, clay, common medium and coarse distinct yellowish brown (10YR 5/6 and 5/8) mottles; weak coarse angular blocky structure; extremely hard, firm; patchy clay

		films; noncalcareous; pH 7.9; few crystals of $CaSO_4$; common Fe and/or Mn concretions about 2 mm; black coatings in old root channels; few krotovinas; clear wavy boundary.
C	49-66 (124-168)	Olive gray (5Y 5/2) clay, light olive gray (5Y 6/2) when dry, with common medium and coarse distinct yellowish brown (10YR 5/6 and 5/8) mottles; massive to weak coarse blocky structure; extremely hard, firm; few slickensides; noncalcareous; pH 7.8; common Fe and/or Mn concretions about 2 mm; black coatings in old root channels; few krotovinas; abrupt smooth boundary.
R	66-77+ (168-196+)	Thinly bedded olive colored shales and sandstones.

Transect 2 (P)

This transect is quite typical of modal pedons in this complex. The physiography of this transect is an east southeast facing upland footslope. The transect ranges from moderate to gently concave slopes. The slopes of the typical Mollisol, intermediate, and saline-sodic soils correspond to 5, 3.5, and 2 per cent, respectively. The range condition varies from excellent at the typical Mollisol to fair at the saline-sodic soil. This transect is located 6 miles west and 2½ miles south of Burbank, Oklahoma.

Typical Mollisol (P)

Horizon	Inches (cm)	Description
Location:		Location is about 320 feet east of oil well or 100 feet east of road in the NE¼, NE¼, NE¼, of Sec. 11, T25N, R4E.
Vegetation:		Dominant grasses were little bluestem, big bluestem, indiangrass, tall dropseed, sideoats grama, and switchgrass with lesser amounts of silver bluestem, buffalograss, fall witchgrass,

purple lovegrass, Canada wildrye, Japanese brome, windmillgrass, scribner panicum, and knotroot bristlegrass. The forbs were western ragweed, Louisiana sagewort, heathaster, Baldwin ironweed, buckbrush, annual broomweed, Korean lespedeza, fringeleaf ruellia, pitchersage, catclaw sensitivebriar, wild alfalfa, wavyleaf thistle, prairie coneflower, yarrow, green antelopehorn, Carolina horsenettle, and blue wildindigo.

A1	0-13 (0-33)	Very dark gray (10YR 3/1) heavy silty clay loam, very dark gray (10YR 3.5/1) when dry; moderate to strong medium granular structure; hard, friable; pH 6.1; abundant roots; gradual smooth boundary.
B1	13-20 (33-51)	Very dark gray (7.5YR 3/1) silty clay, very dark gray (7.5YR 3.5/1) when dry; moderate medium subangular blocky breaking to moderate medium granular structure; hard, friable; patchy clay films; pH 6.4; plentiful roots; clear smooth boundary.
B2t	20-40 (51-102)	Dark reddish gray (5YR 4/2) silty clay, dark reddish gray (5YR 4.5/2) when dry; weak medium prismatic breaking to moderate medium angular blocky structure; extremely hard, firm; continuous clay films; few slickensides; pH 7.0; common Fe and/or Mn concretion less than 2mm; upper half roots plentiful, lower half few roots; gradual smooth boundary.
B3ca	40-70 (102-178)	Reddish brown (5YR 4/3) silty clay, reddish brown (5YR 4.5/3) when dry; moderate medium angular blocky structure; extremely hard, firm; continuous clay films; few slickensides; noncalcareous; pH 7.9; common small hard lime concretions and lime coated sandstone pebbles; common Fe and/or Mn concretions less than 2 mm; few roots; gradual boundary.
Cca	70-80+ (178-203+)	Reddish brown (2.5YR 4/3) silty clay, reddish brown (2.5YR 4.5/4) when dry; massive or weak medium to coarse subangular blocky structure; extremely hard, firm; noncalcareous; pH 7.9; few small hard lime concretions and lime coated sandstone pebbles; few Fe and/or Mn concretions less than 2 mm.

Intermediate (P)

Horizon	Inches (cm)	Description
Location:		Location is about 155 feet southeast of typical Mollisol or in the NE¼, NE¼, NE¼ of Sec. 11, T25N, R4E.
Vegetation:		Dominant grasses were tall dropseed, buffalograss, blue grama, prairie threeawn, windmillgrass, and silver bluestem with lesser amounts of fall witchgrass, big bluestem, indiangrass, sideoats grama, tumblegrass, Japanese brome, little bluestem, sand paspalum, and scribner panicum. Forbs were western ragweed, Lousiana sagewort, annual broomweed, heathaster, Carolina horsenettle, beebalm, wild alfalfa, false gaura, Korean lespedeza, and dogbane.
A1	0-12 (0-30)	Very dark gray (10YR 3/1) light silty clay loam, dark gray (10YR 4/1) when dry; moderate medium and coarse granular structure; hard, very friable; pH 6.3; abundant roots; clear smooth boundary.
B1	12-16 (30-41)	Very dark brown (7.5YR 2.5/2) silty clay loam, brown (7.5YR 4.5/2) when dry; weak medium angular blocky breaking to weak coarse granular structure; very hard, friable; patchy clay films; pH 6.5; plentiful roots; clear smooth boundary.
B21t	16-27 (41-69)	Dark reddish brown (5YR 3.5/2) silty clay, dark reddish gray (5YR 4.5/2) when dry; weak medium prismatic breaking to moderate medium angular blocky structure; extremely hard, firm; continuous clay films; few to common slickensides; pH 7.3; about 10% of horizon has dark colors similar to above horizon due to worm activity; common Fe and/or Mn concretions less than 2 mm; plentiful roots; gradual smooth boundary.
B22t	27-37 (41-94)	Dark reddish gray (5YR 4/2) silty clay, dark reddish gray (5YR 4/2) when dry, few fine distinct light brown (7.5YR 6/4) mottles; weak medium and coarse angular blocky structure; extremely hard, firm; continuous clay films; few slickensides; pH 8.0; few small hard lime concretions; few Fe and/or Mn concretions less than 2 mm; few roots; gradual smooth boundary.

B23tca 37-48 (94-122)	Reddish brown (5YR 4/3) light silty clay, reddish brown (5YR 4.5/3) when dry, crushed dark reddish gray (5YR 4/2), few medium distinct light brown (7.5YR 6/4) mottles; weak medium and coarse angular blocky structure; extremely hard, firm; continuous clay films; noncalcareous; pH 8.1; common small hard lime concretions, few lime coated sandstone pebbles; few Fe and/or Mn concretions less than 2 mm; few roots; gradual smooth boundary.
B3ca 48-84 (122-213)	Reddish brown (5YR 4/3) light silty clay, reddish brown (5YR 4.5/3) when dry, crushed dark reddish gray (5YR 4/2), mottles as described above; weak medium and coarse angular blocky structure; extremely hard, firm; patchy clay films; noncalcareous; pH 8.2; common hard lime concretions and common lime coated sandstone pebbles; few Fe and/or Mn concretions less than 2 mm.

Saline-Sodic (P)

Horizon	Inches (cm)	Description
Location:		Location is about 370 feet southeast of typical Mollisol profile or in NE¼, NE¼, NE¼ of Sec. 11, T25N, R4E.
Vegetation:		Buffalograss and blue grama were the dominant grasses (90% of total) while the remainder was silver bluestem, prairie threeawn, tall dropseed, and Japanese brome. The forbs were western ragweed, dotted gayfeather, annual broomweed, heathaster, Illinois bundleflower, Carolina horsenettle, and pricklypear.
A1	0-3 (0-8)	Very dark gray (10YR 3/1.5) heavy silt loam, gray (10YR 5/1.5) when dry; weak fine and medium platy breaking to weak fine granular structure; slightly hard, very friable; pH 6.9; abundant roots; abrupt smooth boundary.
B21t	3-10 (8-25)	Very dark brown (7.5YR 2.5/2) silty clay, dark gray (7.5YR 4/1.5) when dry, crushed dark reddish brown (5YR 3.5/2); moderate medium columnar breaking to strong fine angular blocky structure; very hard, firm; continuous clay films; grayish coatings on column faces in upper part; pH 7.5; plentiful roots; clear

	smooth boundary.
B22tca 10-18 (25-46)	Dark reddish gray (5YR 4/2) silty clay, dark reddish gray (5YR 4.5/2) when dry, crushed dark reddish brown (5YR 3.5/2); moderate medium angular blocky structure; extremely hard, firm; continuous clay films; noncalcareous; pH 8.0; many soft lime concretions; few roots; clear wavy boundary.
B23tca 18-30 (46-76)	Reddish brown (5YR 4/3) light silty clay, reddish brown (5YR 4.5/3) when dry, crushed dark reddish gray (5YR 4/2); moderate medium angular blocky structure; extremely hard, firm; continuous clay films; pH 8.0; many soft and hard lime concretions; few Fe and/or Mn concretions less than 2 mm; few roots; gradual smooth boundary.
B24tca 30-50 (76-127)	Reddish brown (5YR 4/3) heavy silty clay loam, reddish brown (5YR 4.5/3) when dry, crushed dark reddish gray (5YR 4/2); weak medium angular blocky structure; extremely hard, firm; patchy clay films; weakly calcareous; pH 8.1; common soft and hard lime concretions; common Fe and/or Mn concretions less than 2 mm; few roots; gradual smooth boundary.
B3ca 50-80 (127-203)	Color same as above, heavy silty clay loam; weak medium and coarse angular blocky structure; extremely hard, firm; patchy clay films; weakly calcareous; pH 8.2; few soft and hard lime concretions; common Fe and/or Mn concretions less than 2 mm.

Morphology of Transects 1 (P̸) and 2 (P)

Both transects showed distinct morphological differences between saline-sodic soil and its associated typical Mollisol. There was little morphological difference between the typical Mollisol and intermediate soil.

Both typical Mollisol and intermediate soils showed similar horizon designations in transect 1 (P̸). Transect 2 (P) showed similar horizons between intermediate and saline-sodic soils. This may be due to slight shift in soil forming factors resulting from a change in chemical composition between these soils. In both transects the A horizon thickness decreased toward the saline-sodic soil. The saline-sodic soil develops a concave micro-relief. This indicates differential erosion of the eluviated A horizon. The B horizon thickness increased in transect 2 (P) from typical Mollisol to saline-sodic soil but remained about the same thickness in transect 1 (ℙ). The thick B horizon may be due to dispersion of the clay by high sodium found in these soils.

Both saline-sodic soils showed distinct dark stained columnar structure in the upper B horizon. This was absent in the associated soils. The A horizon in the saline-sodic soils showed weak platy to granular structure compared to moderate granular structure in the associated soils. The A horizon of the saline-sodic soils had lighter colors and more abrupt boundaries than the associated soils. This is generally associated with high sodium.

Calcium carbonate concretions are more abundant and closer to the surface in the saline-sodic soil. Gypsum crystals are very distinct through most of the B horizon in the saline-sodic soil of transect 1 (ℙ).

Physical Measurement

Particle-size distribution of transect 1 (ℙ) and 2 (P) are presented in Tables II and III. Profile distributions of percent clay are shown in Figure 2. Relative particle-size distributions of transect 1 (ℙ) and 2 (P) show little difference. The dominant separates in each transect are clay and silt with small amounts of sand. In both transects silt was the dominant separate in the A horizon. Percent silt and sand in the A horizon decreased going from the saline-sodic

TABLE II

PARTICLE SIZE DISTRIBUTION OF SOILS IN TRANSECT 1 (PENNSYLVANIAN)

Horizon	Depth	VCS 2-1 mm.	CS 1-.5 mm.	MS .5-.25 mm.	FS .25-.1mm.	VFS .1-.05 mm.	Silt .05-.002 mm.	Clay <.002 mm.
	inches	%						
				Saline-Sodic				
A1	0-4	0.1	0.2	0.2	11.4	16.7	58.0	13.4
B1	4-10	0.0	0.1	0.1	6.5	9.9	56.1	27.3
B21t	10-18	0.2	0.3	0.2	4.4	7.8	45.9	41.2
B22tcs	18-26	0.2	0.2	0.1	3.2	6.8	44.1	45.4
B23tcs ca	26-37	0.2	0.2	0.1	4.1	8.2	40.8	46.4
B31cs ca	37-42	0.5	0.4	0.2	5.2	10.0	34.4	49.3
B32cs	42-49	0.1	0.2	0.2	5.1	10.0	38.0	46.4
C1	49-66	0.0	0.1	0.1	5.7	12.3	39.0	42.8
				Intermediate				
A11	0-6	0.4	0.5	0.4	10.3	12.5	52.2	23.7
A12	6-16	0.1	0.2	0.2	6.8	10.4	50.3	31.9
B1	16-20	0.3	0.2	0.2	5.6	8.6	47.1	38.0
B21t	20-32	0.1	0.1	0.1	4.0	6.8	43.6	45.3
B22t	32-44	0.6	0.8	0.5	12.9	15.7	15.7	53.8
B3	44-55	0.6	0.6	0.3	6.0	10.2	41.2	41.1
C1	55-75	0.2	0.3	0.3	5.8	9.9	37.7	45.8
				Typical Mollisol				
A1	0-12	0.9	0.8	0.3	13.6	12.9	42.2	29.3
B1	12-19	0.1	0.1	0.1	2.2	7.9	49.1	40.5
B21t	19-32	0.3	0.3	0.3	7.1	7.8	41.8	42.4
B22t	32-50	0.5	0.4	0.2	5.7	7.4	43.4	42.4
B3	50-60	0.6	0.5	0.3	8.7	9.5	40.9	39.5
C1	60-68	0.6	0.2	0.1	1.5	4.4	69.5	23.7
C2	68-90	0.1	0.2	0.1	5.9	8.9	36.1	48.7

TABLE III

PARTICLE SIZE DISTRIBUTION OF SOILS IN TRANSECT 2 (PERMIAN)

Horizon	Depth	VCS 2-1 mm.	CS 1-.5 mm.	MS .5-.25 mm.	FS .25-.1 mm.	VFS .1-.05 mm.	Silt .05-.002 mm.	Clay <.002 mm.
	inches	%						
				Saline-Sodic				
A1	0-3	0.2	0.2	0.2	3.1	8.4	63.0	24.9
B21t	3-10	0.0	0.1	0.1	2.1	6.1	46.7	44.9
B22tca	10-18	0.0	0.0	0.1	2.0	6.4	47.5	44.0
B23tca	18-30	0.1	0.1	0.0	2.3	7.3	50.0	40.2
B24tca	30-50	0.2	0.2	0.2	1.7	5.0	53.8	38.9
B3ca	50-80	0.6	0.5	0.2	1.3	4.0	55.3	38.0
				Intermediate				
A1	0-12	0.1	0.2	0.3	3.3	9.3	58.3	28.5
B1	12-16	0.2	0.2	0.3	2.6	9.6	53.6	33.5
B21t	16-27	0	0.1	0.1	2.0	7.0	47.5	43.3
B22t	27-37	0	0.3	0.2	1.9	6.8	48.7	42.1
B23tca	37-48	0.9	0.5	0.3	1.9	6.1	49.1	41.2
B3ca	48-84	0.8	0.7	0.3	1.6	5.2	49.8	41.6
				Typical Mollisol				
A1	0-13	0.0	0.1	0.2	2.6	8.2	49.7	39.2
B1	13-20	0.0	0.1	0.1	2.6	7.8	46.3	43.1
B2t	20-40	0.1	0.2	0.3	2.6	7.0	43.5	46.3
B3ca	40-70	3.0	1.6	0.6	2.2	6.2	42.8	43.6
Cca	70-80	0.1	0.1	0.2	2.5	8.1	41.7	47.3

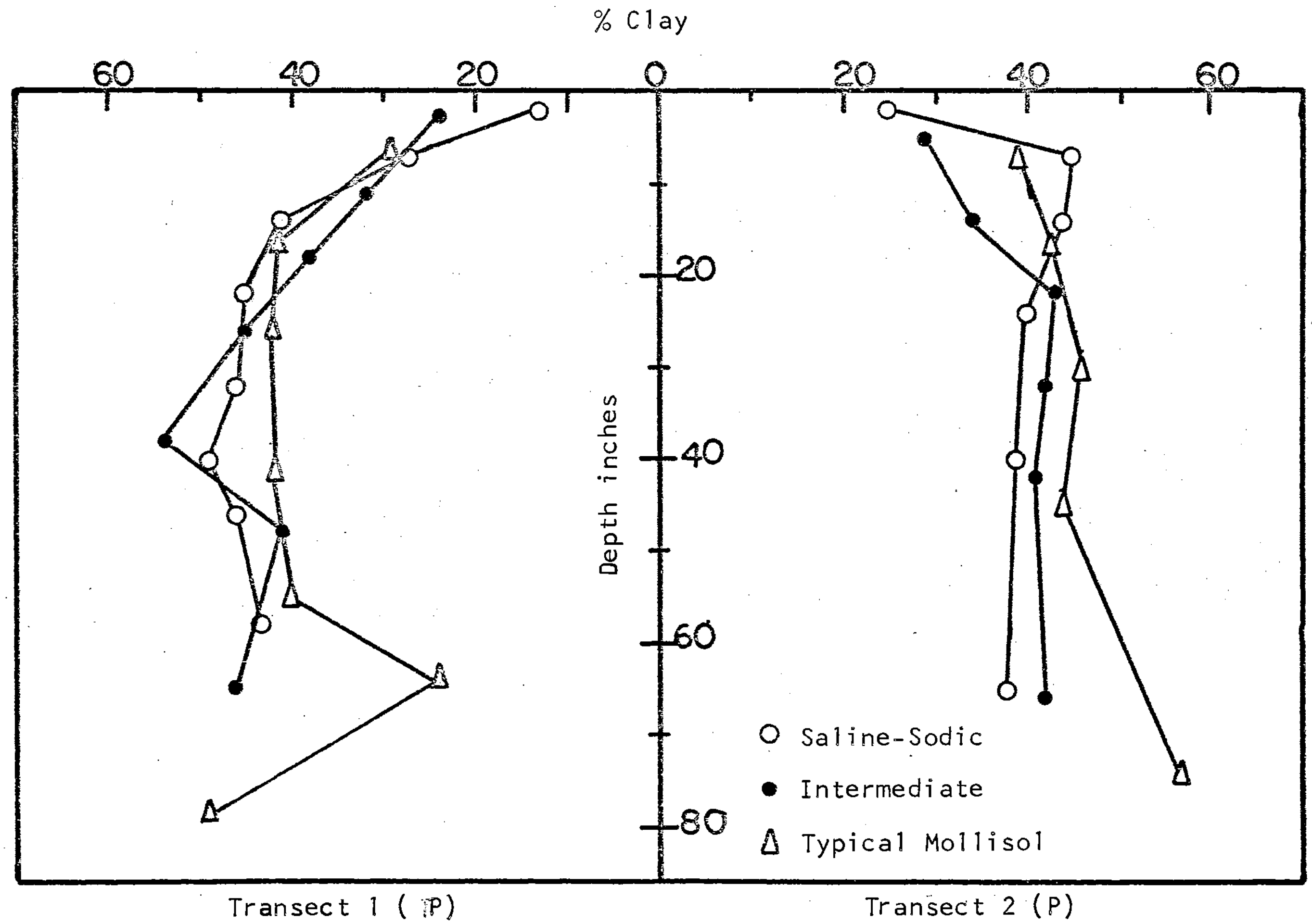


Figure 2. Percent Clay Distribution of Soils in Transect 1 (Pennsylvanian) and 2 (Permian).

soil to the typical Mollisol in both transects. Percent clay increased more abruptly in the upper B horizon of the saline-sodic soils. This likely is due to eluviation of the clay.

Present Vegetation

The vegetation found on the saline-sodic soils showed little indication of saline or alkali conditions. The change from little bluestem, big bluestem, indiangrass, and switchgrass at the typical Mollisol to buffalograss, blue grama, and tumblegrass at the saline-sodic soil was probably due to a change in available moisture of these soils. This change in available moisture may be explained by a change in texture, structure, and thickness of A horizon of these soils. There is little difference in percent clay in the A horizon between the typical Mollisol and saline-sodic soil; 39.2 to 29.4 in transect 2(P) and 29.3 to 13.4 in transect 1 (ℙ), respectively. There is little evidence of change due to texture. Soil structure changes from moderate to coarse granular in the typical Mollisol to weak fine platy and weak moderate granular structure in the saline-sodic soil. This could decrease the infiltration and reduce maximum root development. The thin A horizon in the saline-sodic soil rests abruptly on moderate medium to coarse columnar structure in the B horizon. Each of these factors along with an increase in salt could result in less available moisture resulting in a preclimax vegetation. Buffalograss and blue grama found on these saline-sodic soils are indicators of claypan soils (5). These soils have reduced water holding capacity.

The intermediate soil in transect 1 (ℙ) had properties similar to an Ap horizon and also contained an appreciable number of increaser and invader plants. These indicate that this area may have been disturbed by plowing. This is supported by the very close chemical similarity between the intermediate and typical Mollisol of this transect. This disturbed condition resulted in location of this intermediate soil too close to the typical Mollisol. In transect 2 (P), there was no morphological evidence of disturbance. This intermediate soil shows a good transition between the typical Mollisol and saline-sodic soil.

Chemical Measurements

Chemical data supporting the graphs presented in this section are found in Tables IV, V, VI, and VII of the Appendix.

Soluble salts are high in both saline-sodic soils. Figure 3 shows a profile distribution of soluble salts found in transect 1 (P) and 2 (P). The A horizon of the saline-sodic soil is low in soluble salts. The maximum amount of soluble salts is found in the lower B2 horizons of the saline-sodic soils. Soils in transect 2 (P) show distinctly the relative distribution of soluble salts. Soluble salts found in these soils increased with depth from the typical Mollisol to the saline-sodic soil. Intermediate soil shows accumulation of salts in the B horizon. Thisclosely corresponds to the large amount of salts found in the B horizon of the saline-sodic soil. In both typical Mollisols the salts are highest in the A and lower horizons. This suggests that the intermediate soil of this transect is developing into a saline-sodic soil.

Transect 2 (P) does not show any difference in the distribution of soluble salts of the typical Mollisol and intermediate soil except for higher salts found in the A horizon of the intermediate soil.

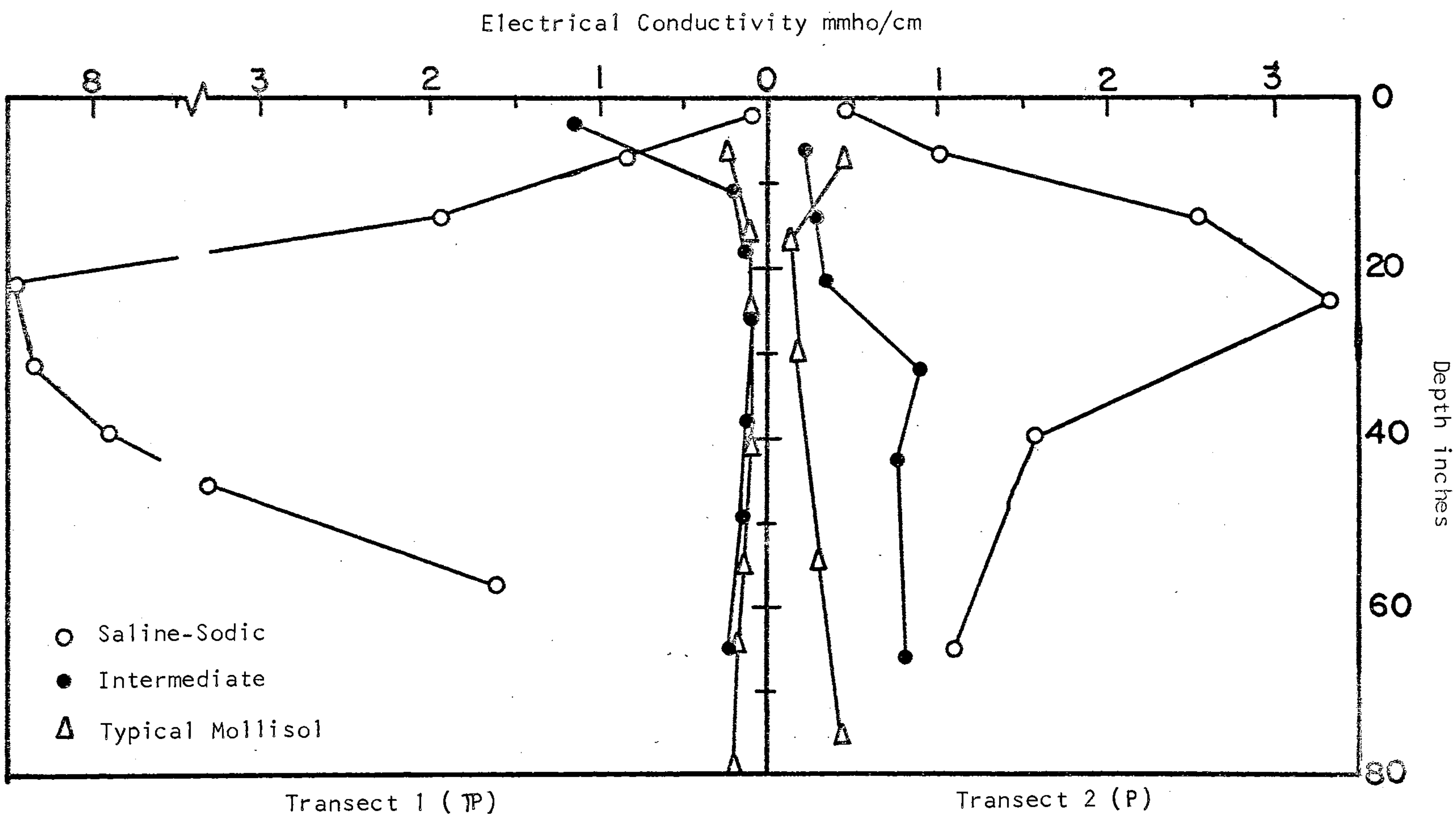


Figure 3. Soluble Salt Distribution in Soils of Transect 1 (Pennsylvanian) and 2 (Permian).

Profile distributions of the different kinds of soluble salts found in the saline-sodic soil of each transect are in Figures 4 and 5. This corresponds to the electrical conductivity distribution of Figure 3. Sulfate is the dominant anion found in the saline-sodic soil of transect 1 (IP). The corresponding cation distribution shows that sodium is the highest followed by calcium and magnesium. The distribution curves show that sodium sulfate (Na_2SO_4), calcium sulfate ($CaSO_4$), and magnesium sulfate ($MgSO_4$) are the dominant salts present. This accumulation of salts in the B horizon corresponds to the calcium sulfate ($CaSO_4$) crystals described in the profile of this soil. The extractable cations of this soil show that calcium is the dominant cation followed by magnesium and sodium respectively. This may be explained by a combination of low solubility of $CaSO_4$ compared to Na_2SO_4 and the ease by which sodium is replaced in the double layer of clay minerals.

The cation-anion distribution of the saline-sodic soil of transect 2 (P) is shown in Figure 5. Sodium is the dominant cation and chloride, sulfate, and bicarbonate are the dominant anions found in this soil. This shows that sodium chloride ($NaCl$), sodium sulfate (Na_2SO_4), and sodium bicarbonate ($NaHCO_3$) salts dominate in this soil.

Exchangeable sodium is graphed in Figure 6. Transect 1 (IP) and 2 (P) show larger amounts of exchangeable sodium in the saline-sodic soils of each transect. There is very little difference between intermediate and the typical Mollisol of transect 1 (IP). The large decrease in exchangeable sodium in the lower B horizon of this transect corresponds to $CaSO_4$ crystals described in this soil. This may be explained by replacement of some of the sodium by calcium when the 1:1 extract was made resulting in extraction of some of the exchangeable sodium.

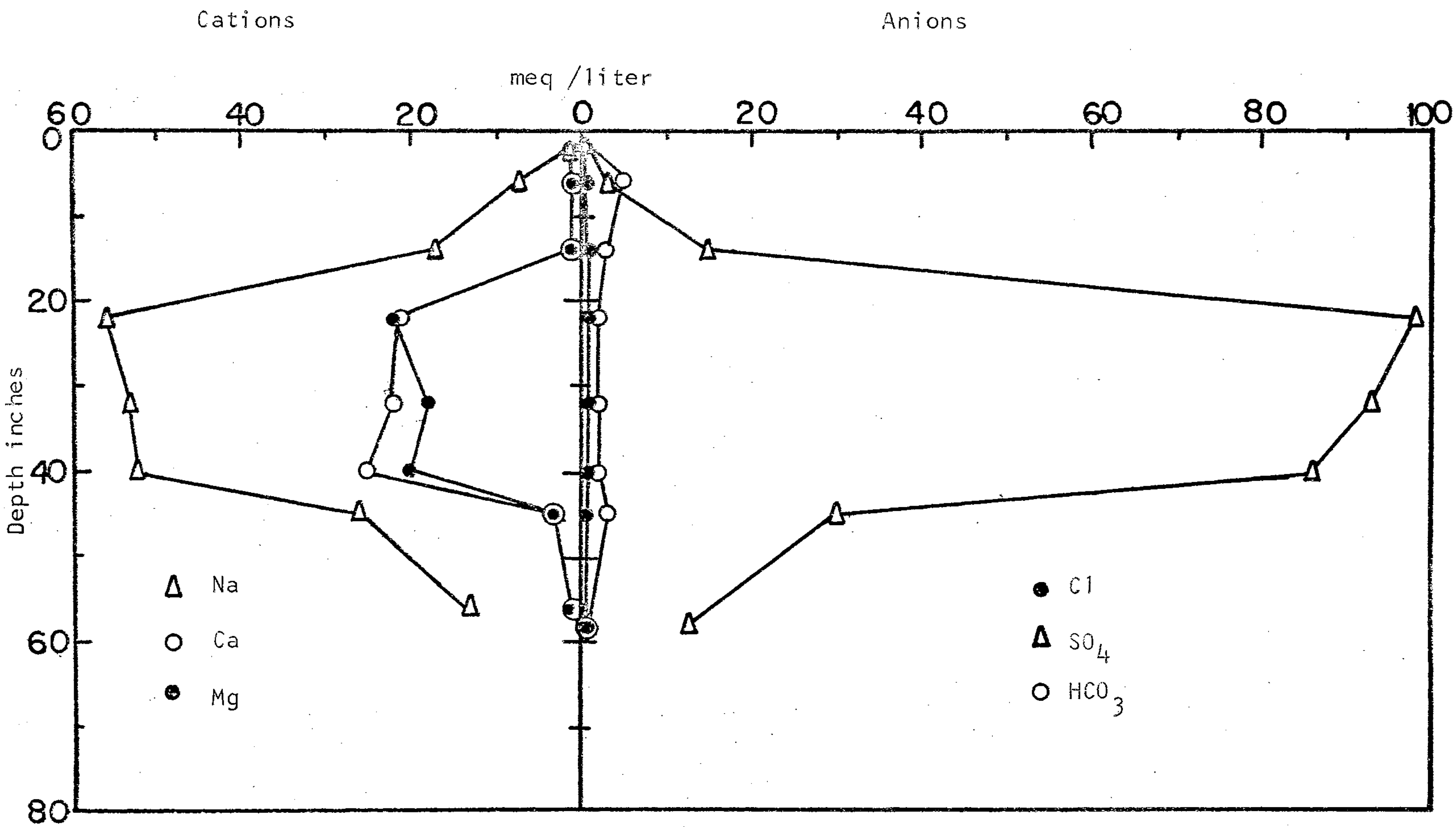


Figure 4. Cation-Anion Distribution in Saline-Sodic Soil of Transect 1 (Pennsylvanian).

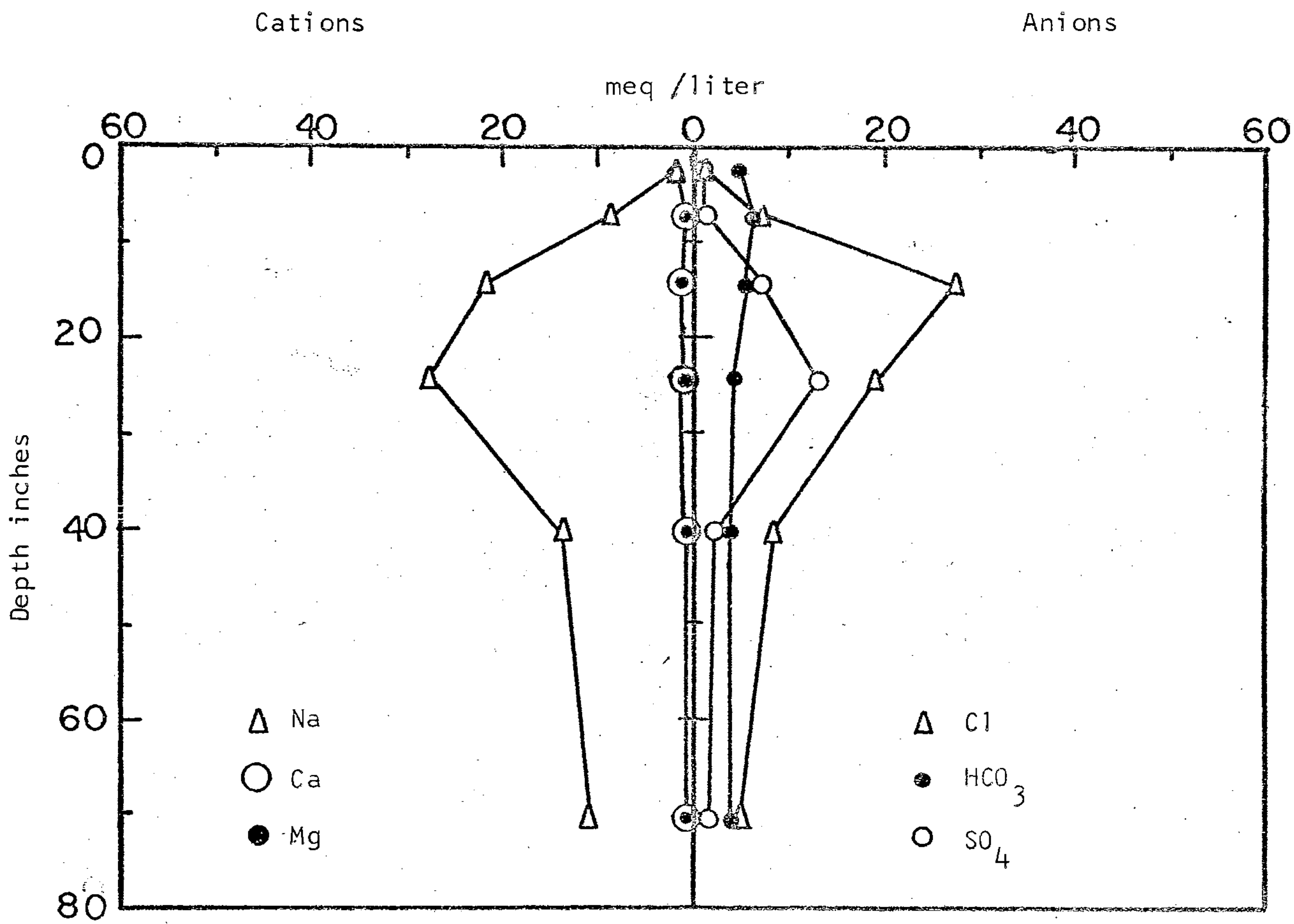


Figure 5. Cation-Anion Distribution in Saline-Sodic Soil of Transect 2 (Permian).

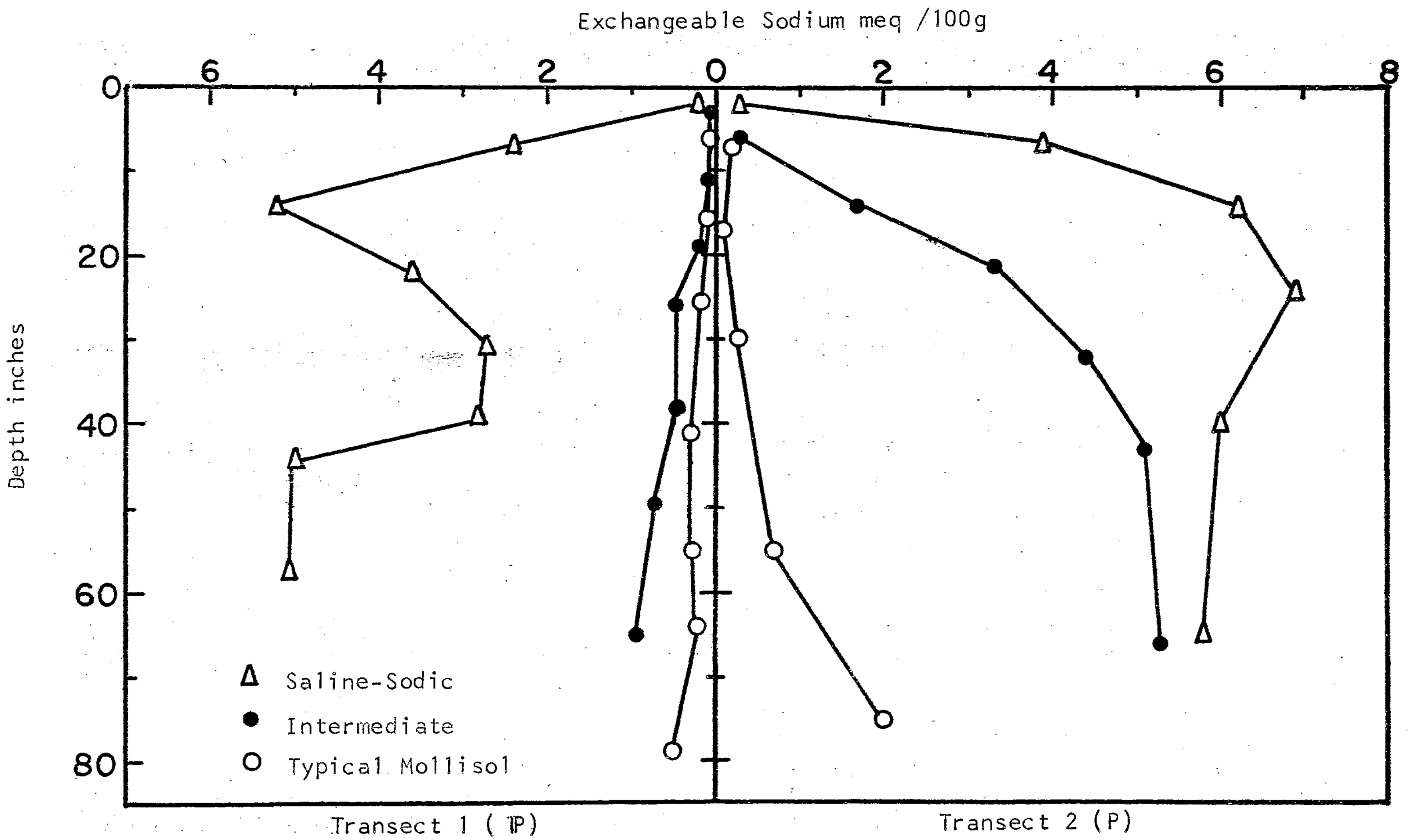


Figure 6. Exchangeable Sodium Distribution in Soils of Transect 1 (Pennsylvanian) and 2 (Permian).

Transect 2 (P) shows a good comparison of the saline-sodic soil to its associated intermediate and typical Mollisol. The saline-sodic soil shows that the maximum amount of exchangeable sodium is found in the B horizon. Exchangeable sodium in the lower horizon of the intermediate soil approaches that of the saline-sodic soil. This suggests that this soil is in the process of forming a saline-sodic soil.

The distribution of pH shown in Figure 7 supports salts distribution figures previously shown. The saline-sodic soils have the highest pH. Most of the soils were slightly acid in surface horizons, but their pH increases with depth.

There is little difference in the distribution of organic matter in transect 1 (IP). Figure 8 shows the relative distribution of organic matter for transect 2 (P). The three soils have about the same percent in the surface, but the saline-sodic soils decrease more rapidly than other soils. This correlated with the decrease in amount of vegetation from typical Mollisol to saline-sodic soil.

Mineralogical Analysis

X-ray diffractograms were made on 2 micron clay from selected horizons of both transects 1 (IP) and 2 (P). Due to the remarkable similarity qualitatively only transect 2 (P) is shown in Figure 9. Only the difference between the two transects will be discussed.

The silicate clay species of importance in these soils are vermiculite, illite, and kaolinite. This conclusion is based on the presence of a 14.7 A, 10.0 A, and 7.2 A peaks in the diffractograms of the Ca-saturated and glycerol solvanted clays. The 14.7 A peak disappears when K-saturated and heated to 300° C. Brown (3) and Walker (36) state

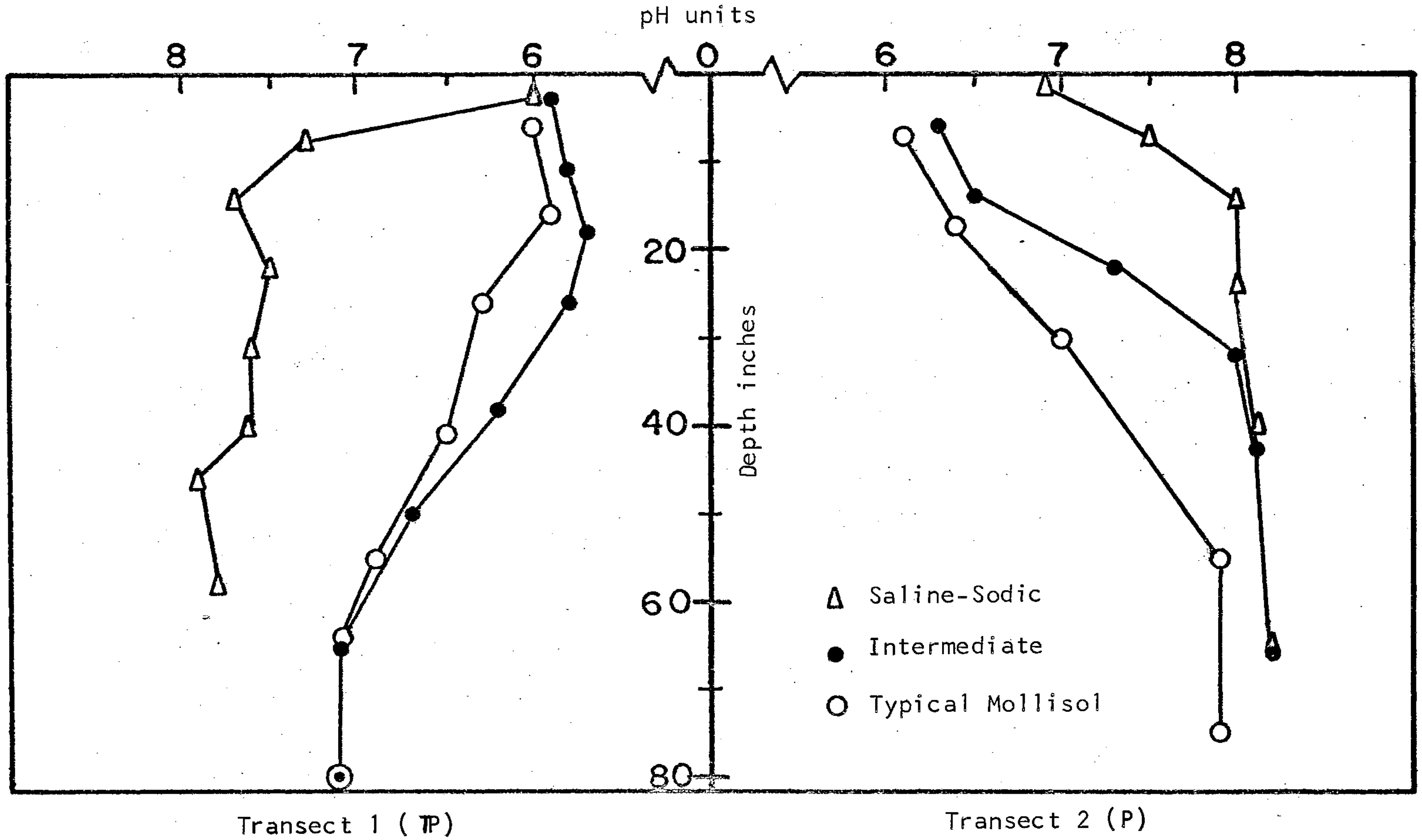


Figure 7. pH Distribution in Soils of Transect 1 (Pennsylvanian) and 2 (Permian).

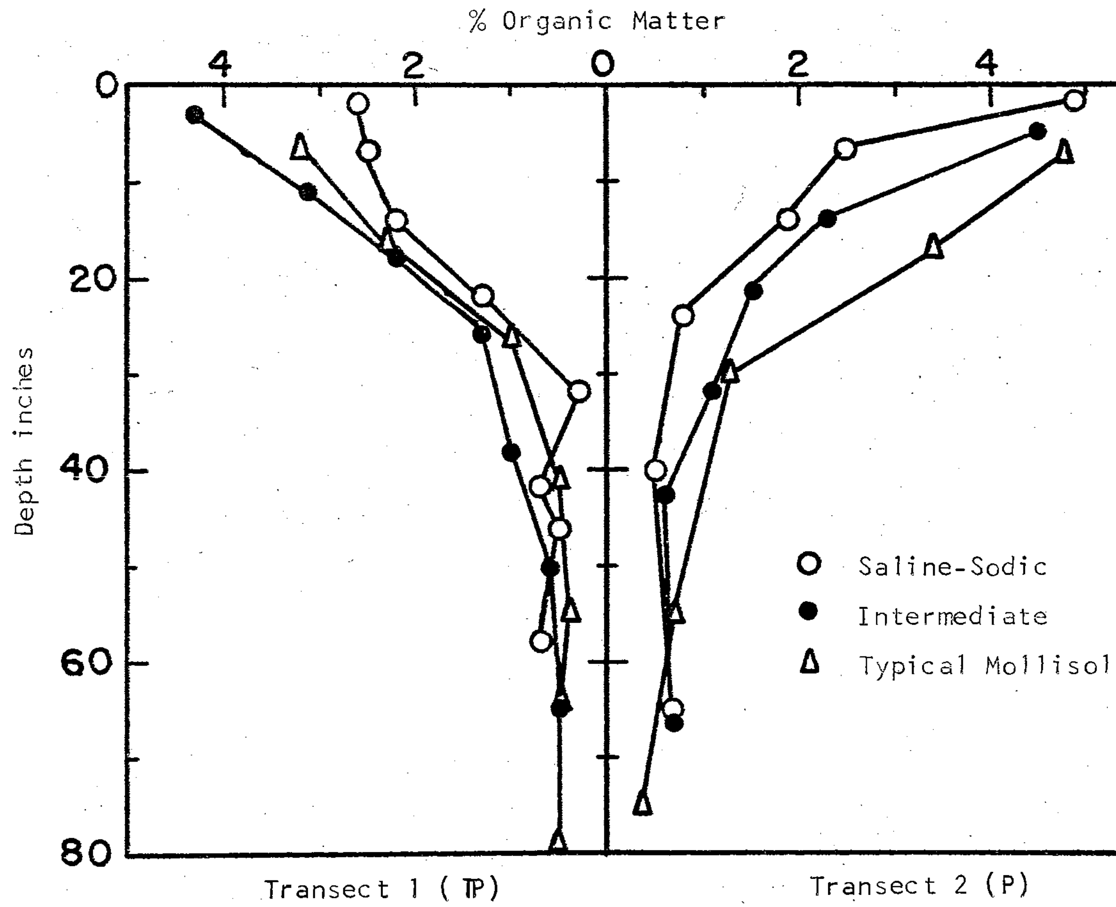


Figure 8. Percent Organic Matter Distribution in Soils of Transect 1 (Pennsylvanian) and 2 (Permian).

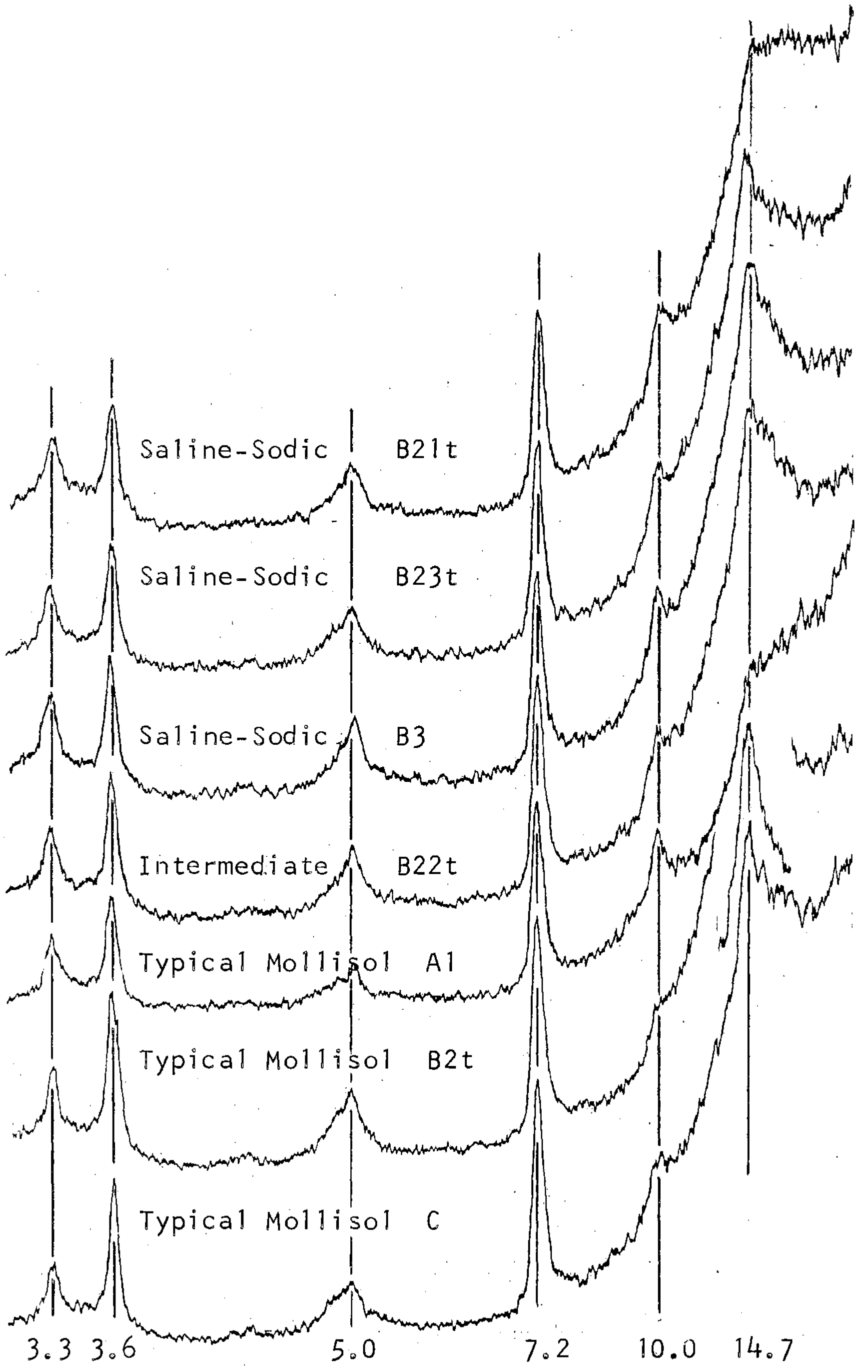


Figure 9. X-Ray Diffractograms on Total Clay (Ca Saturated and Glycerol Solvated) of Saline-Sodic, Intermediate, and Typical Mollisol in Transect 2 (Permian).

that vermiculite may expand to 17-18 A when interlayered with Ca, Sr, Ba, and possibly other ions. Hathaway (11) and Walker (35) have reported vermiculitic minerals occurring in soil-clays which fail to expand beyond 14-15 A when Ca-saturated and treated with ethylene glycol. The 3.3 A peak indicates quartz and 3rd order illite.

Transect 2 (P) has slightly more kaolinite and vermiculite and less micaceous material than transect 1 (ℙ), if the height of the peaks are used as a quantitative guide. All horizons show a strong kaolin peak. There is little vermiculite found in the A horizon, and there appears to be an increase from the A to the B horizon. This may be due to eluviation of the fine clays in the surface horizon. The broad 14-18 A peaks found in the upper horizons may be due to the presence of interstratified minerals. It is difficult to use the 5 A peak for quantitative interpretations since it likely is due to a combination of 2nd order illite and 3rd order vermiculite. The sharp 7.2 A and 3.6 A peak throughout all profiles indicates uniform crystallinity of kaolin. These soils appear to contain more vermiculite and kaolinite and less illite and quartz. A comparison of the similarity of the diffractograms of the saline-sodic soils to the associated typical Mollisol suggests that these minerals are brought in as a part of the parent material and have remained relatively unchanged. The uniformity between diffractograms of transect 1 (ℙ) and 2 (P) suggest that the parent material of these soils came from a similar source. Similar results have been reported by Wilding <u>et al</u>. (37) and Lewis and White (20). The uniformity between diffractograms of saline-sodic and typical Mollisol suggest that the presence of high salts has no influence on the mineralogy.

Genesis

The similarity between diffractograms between transect 1 (ℙ) and 2 (P) suggests these soils developed from similar materials even though the bedrock is of Pennsylvanian or Permian age.

A study of the morphological, physical, chemical, and mineralogical data suggests, as shown in Figure 10, a possible explanation of the origin of these soils. This figure is designed from the theories inspired by Arnold (2) and Culver (6), and the research presented in this study.

This diagram is based on the assumption that both of these transects developed from similar parent materials deposited over the Permian or Pennsylvanian bedrocks. Soil formation begins with the weathering of calcareous sediments to alkaline clays. This stage of soil genesis assumes no losses or gains. The development of a grass vegetation results in the additions of organic matter and increase aggregation which starts the evolution of a mollic epipedon. Very small amounts of bases are removed, and this is only to the depth of water movement. The material in the B horizon starts to form weak structure resulting in the formation of a weak cambic horizon.

As the soil approaches stage B the cambic horizon obtains its maximum thickness. The increased grasses result in a more friable structure for the thick, dark colored mollic epipedon.

Removal of bases from the mollic epipedon leaves a slightly acid to neutral surface which hastens chemical weathering. As bases are leached downward weathering increases. Transformation of fine clays downward is completed by infiltration of water through the pores and channels provided by roots and cracks. This results in the formation

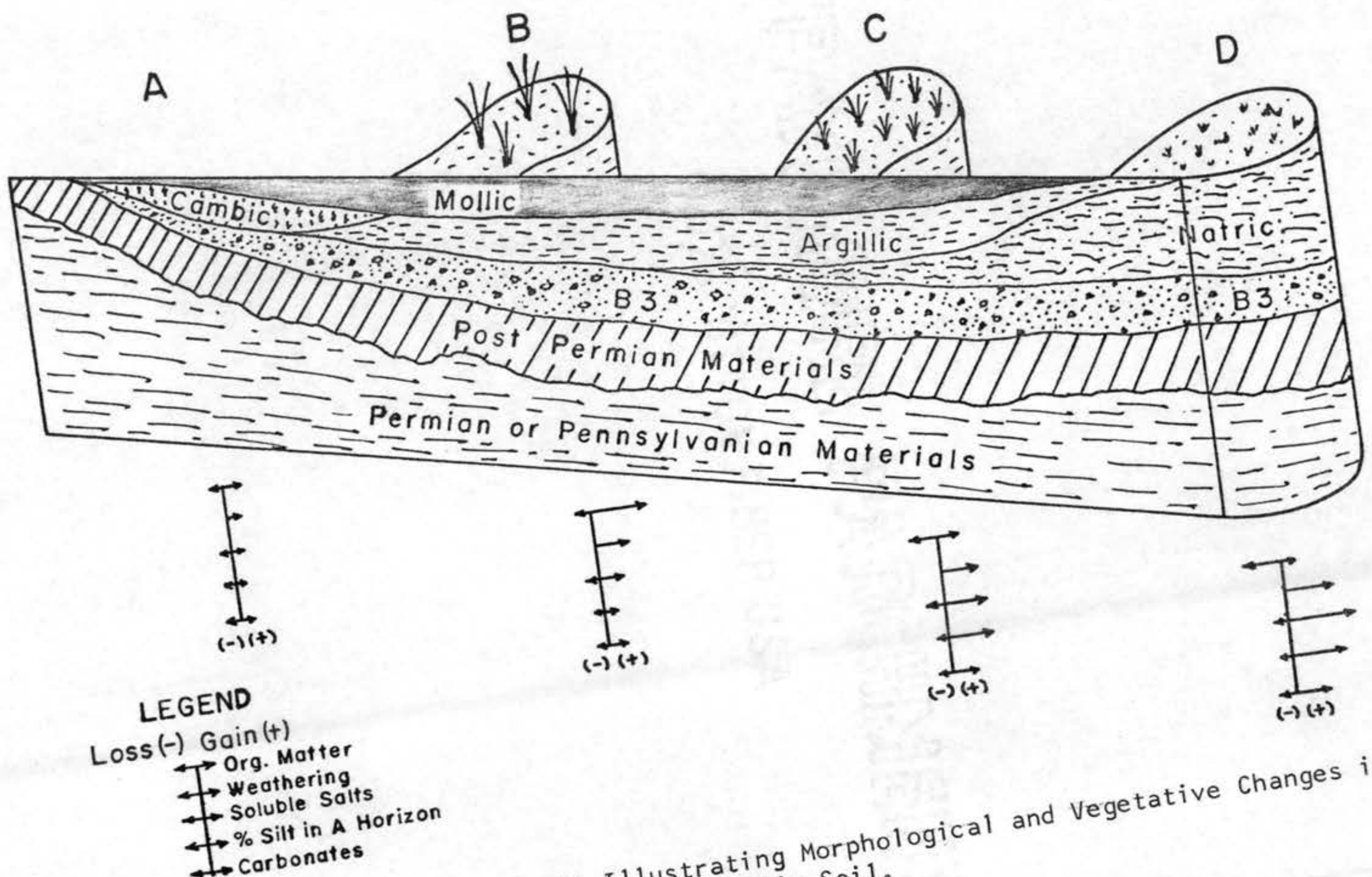


Figure 10. Proposed Hypothesis Illustrating Morphological and Vegetative Changes in the Formation of a Saline-Sodic Soil.

of an argillic horizon.

Stage B occurs later in the stage of soil formation. Weathering is accelerated by losses of bases from the surface. Vegetation has reached its maximum growth producing a thick mollic epipedon high in organic matter. Loss of bases from the surface has resulted in a slightly acid surface which accelerates weathering. These bases are translocated to the lower advancement of water and accumulate. This results in the formation of calcium carbonate concretions. This translocation of materials results in a thicker argillic horizon and saturation of the exchange sites with divalent ions. The colloids are in a floculated state.

As the soil leaves stage B soluble salts start to accumulate in the lower argillic horizon. Many of the divalent cations are replaced by sodium resulting in the formation of a natric horizon. This results in an increase in pH.

In stage C the vegetation has decreased due to a possible reduction in certain nutrients, weaker structure, and decreased moisture. This reduction in organic matter results in a weak granular structure in the A horizon which grades into the underlying B. The mollic epipedon becomes lighter in color. The surface continues to be slightly acid due to the decay of organic matter and leaching of bases to lower horizons. Sodium replaces much of the exchangeable calcium resulting in a thicker more dispersed horizon. This advances until stage D is developed. The natric horizon has increased to a maximum thickness as a result of increased salts high in sodium. Due to an unfavorable structure, the vegetation has decreased to only short grasses. The A horizon has become very thin and light colored. The A horizon no longer meets the color or thickness requirements for a mollic epipedon. Fine clay and the dispersed organic matter are eluviated and leached into the lower horizons. The remaining silty A horizon has developed a thin platy structure, which rests abruptly upon the dark stained columnar structure in the natric horizon. The calcium carbonate concretions are very close to the surface due to the restricted percolation of water.

Possible sources of soluble salts are (a) outcropping ground water which is high in soluble salts from localized evaporites contained within the Permian deposits; (b) lateral outcropping of water high in salts formed by the weathering of soils high in sodium feldspar minerals.

Soil Classification by 7th Approximation

The intermediate soils of this study are Mollisols. The saline-sodic soils have thinner, light colored A horizons which exclude them from Mollisols. They can be classified in the Alfisol order. The typical Mollisol and intermediate soils in transect 2 (P) may be classified as fine, mixed, thermic Vertic Paleustolls. In transect 1 (IP), the typical Mollisol and intermediate soil may be classified as fine, mixed, thermic Vertic Paleudolls. The saline-sodic soils may be classified as fine, mixed, thermic Typic Natrustalfs.

CHAPTER V

SUMMARY AND CONCLUSIONS

The morphology and genesis of saline-sodic soils were studied morphologically and by determining physical, chemical, and mineralogical measurements on two transects. These soils were classified according to the 7th Approximation (31).

The saline-sodic soils contained a concave micro-relief and developed a thin A horizon which contained platy structure, light color, near neutral pH, low soluble salts, and an abrupt boundary at the B horizon. The A horizon of the saline-sodic soils was higher in percent silt and sand when compared to associated soils. The B horizon contained dark stained columnar structure, alkaline pH, high soluble salts of Na_2SO_4, NaCl, $NaHCO_3$, $CaSO_4$, and $MgSO_4$; and had $CaCO_3$ concretions relatively close to the surface. This study suggests possibly a thicker B2 horizon in saline-sodic soils. The saline-sodic soils had a well developed natric horizon. The above mentioned properties change toward the typical Mollisol.

The changes in vegetation from typical Mollisol to the saline-sodic soil are likely associated with decreased available moisture. This restricted available moisture may be due to high salts and unfavorable physical conditions in the soil.

The surface horizons have lost clay, organic matter, carbonates, and soluble salts to the argillic horizons. Cation exchange capacity and clay distribution suggest some accumulations in the B horizon of the saline-sodic soils. X-ray diffraction shows these soils are dominantly vermiculite and kaolinite with small amounts of illite and quartz. The similarity between x-ray diffractograms of transect 1 (P) and 2 (P) suggest these soils developed from similar parent material. This study suggests that there is no mineralogical difference in the total clays between saline-sodic soil and typical Mollisol.

Both transects from typical Mollisol to saline-sodic soil grade from Mollisols to Alfisols. Transect 2 (P) has characteristics associated with dryness. The typical Mollisol and intermediate soil may be classified as fine, mixed, thermic Vertic Paleustolls. The typical Mollisol and intermediate soil in transect 1 (P) may be classified as fine, mixed, thermic Vertic Paleudolls. The saline-sodic soils may be classified as fine, mixed, thermic Typic Natrustalfs.

LITERATURE CITED

1. Ahi, S. M. and W. H. Metzger. Comparative Physical and Chemical Properties of an Alkali Spot and an Adjoining Normal Soil of the Prairie Soils Group. Report Am. Soil Survey Assoc. Proc. 17:9-12. 1936.

2. Arnold, R. W. Multiple Working Hypothesis in Soil Genesis. Soil Sci. Soc. Amer. Proc. 29:717-724. 1965.

3. Brown, G. The X-Ray Identification and Crystal Structures of Clay Minerals. Jarrold and Sons Ltd. Norwich, England. 1961.

4. Crocker, R. L. The Plant Factor in Soil Formation. Selected Papers in Soil Formation and Classification. SSSA Special Publication #1. J. V. Drew, Ed. Soil Sci. Soc. Amer., Inc. Madison, Wisconsin, USA. 1967.

5. Crockett, J. J. Influence of Soils and Parent Materials on Grasslands of the Wichita Mountains Wildlife Refuge, Oklahoma. Ecology 45:326-335. 1964.

6. Culver, J. R. Genesis of Grayish Claypan Soils. M. S. Thesis. Okla. State Univ. 1967.

7. Fehrenbacher, J. B., L. P. Wilding, R. T. Odell, and S. W. Melsted. Characteristics of Solonetzic Soils in Illinois. Soil Sci. Soc. Amer. Proc. 27:421-431. 1963.

8. Fritz, J. S. and S. A. Yamanura. Rapid Microdetermination of Sulfate. Analytical Chemistry 27:1461-1464. 1955.

9. Galloway, H. M. Soil Survey of Pawnee County, Oklahoma. Series 1952, No. 4. 1959.

10. Harlan, J. R. Grasslands of Oklahoma. Okla. State Univ. Processed Teaching Manual, Agron. Dept. 1958.

11. Hathaway, J. C. Some Vermiculite-Type Clay Minerals. W. O. Milligon, Ed. Clays and Clay Minerals. Publication 395, Nat. Acad. Sci., Nat. Res. Coun., Washington. pp. 74-86. 1955.

12. Hayward, H. E. and C. H. Wadleigh. Plant Growth on Saline and Alkali Soils. Advances in Agron. 1:1-40. 1949.

13. Horn, M. E., E. M. Rutledge, H. C. Dean, and M. Lawson. Classification and Genesis of Some Solonetz (Sodic) Soils in Eastern Arkansas. Soil Sci. Soc. Amer. Proc. 28:688-692. 1964.

14. Jackson, M. L. Soil Chemical Analysis, Advanced Course. University of Wisconsin, Madison. 1956.

15. Jenny, H. Factors of Soil Formation. McGraw-Hill Book Co. New York and London. 1941.

16. Joffe, J. S. Pedology. Pedology Publications, New Brunswick, N. J. 1949.

17. Kelley, B. P. Alkali Soils - Their Formation, Properties, and Reclamation. Reinhold Publishing Corporation, New York. 1951.

18. Kellogg, C. E. Morphology and Genesis of the Solonetz Soils of Western North Dakota. Soil Sci. 38:483-501. 1934.

19. Kilmer, V. J. and L. T. Alexander. Methods of Making Mechanical Analysis of Soils. Soil Sci. 68:15-24. 1954.

20. Lewis, G. C. and J. L. White. Chemical and Mineralogical Studies on Slick Spot Soils in Idaho. Soil Sci. Soc. Amer. Proc. 28:805-808. 1964.

21. Murphy, H. F. and H. A. Daniel. Some Chemical and Physical Properties of Normal and Solonetz Soils and Their Relation to Erosion. Soil Sci. 39:453-461. 1935.

22. Polone, D. J. Soil Survey of Washington County, Oklahoma. 1968.

23. Ratner, E. I. The Influence of Exchangeable Sodium in the Soil on its Properties as a Medium for Plant Growth. Soil Sci. 40:459-471. 1935.

24. Reed, L. W. A Study of Saline-Alkali Soils in Oklahoma. Processed Series P-430, Okla. State Univ., Stillwater. pp. 37. 1962.

25. Research and Development Division Oklahoma Highway Department. Engineering Classification of Geologic Materials: Division 8. Okla. Res. Proj. 61-01-1. 1965.

26. Riecken, F. F. Some Considerations in the Magnesium Cycle of Weathering in Solonetz Soils. Soil Sci. Soc. Amer. Proc. 8:391-395. 1944.

27. Sandoval, F. M. and L. Shoesmith. Genetic Soil Relationships in a Saline Glacio-Lacustrine Area. Soil Sci. Soc. Amer. Proc. 25:316-320. 1961.

28. Sigmond, A. A. J. De. The Principles of Soil Science. Thomas Murby Co., London. 1938.

29. Smith, G. D. Intrazonal Soils: A Study of Some Solonetz-Like Soils Found Under Humid Conditions. Soil Sci. Soc. Amer. Proc. 2:461-469. 1937.

30. Soil Conservation Service, U.S.D.A. Range Site Technical Descriptions for Oklahoma. 1961.

31. Soil Survey Staff, SCS, U.S.D.A., 1960, Soil Classification, A Comprehensive System, 7th Approximation as amended June. 1964.

32. Soil Survey Staff, SCS, U.S.D.A., Supplement to Soil Classification System, 7th Approximation. 1967.

33. Thornthwaite, C. W. An Approach Toward a Ration Classification of Climates. Geogr. Rev. 38:55-94. 1948.

34. United States Salinity Laboratory Staff, Diagnosis and Improvement of Saline and Alkali Soils, U.S.D.A. Handbook 60, L. A. Richards, Ed., U. S. Govt. Printing Office, Washington, D. C. 1954.

35. Walker, G. F. Differentiation of Vermiculites and Smectites in Clays. Clay Min. Bull. 3:154-163. 1957.

36. __________. Reactions of Expanding-Lattice Minerals with Glycerol and Ethylene Glycol. Clay Min. Bull. 3:302-313. 1958.

37. Wilding, L. P., R. T. Odell, J. B. Fehrenbacher, and A. H. Beavers. Source and Distribution of Sodium in Solonetzic Soils in Illinois. Soil Sci. Soc. Amer. Proc. 27:432-438. 1963.

38. Yearbook of Agriculture. Soils and Men. Formation of Soils, Byers, H. G., C. E. Kellogg, M. S. Anderson, and J. Thorp, eds. USDA, Washginton, 1939.

APPENDIX

TABLE IV

CHEMICAL PROPERTIES OF SOILS IN TRANSECT 1 (PENNSYLVANIAN)

Horizon	Depth	pH 1:1 H_2O	pH 1:1 KCl	CEC	Extractable Cations Ca	Extractable Cations Mg	Extractable Cations Na	Extractable Cations K	Base Saturation	Organic Matter
	inches			meq/100g					%	
				Saline-Sodic						
A1	0-4	6.0	5.1	11.6	5.9	2.4	0.3	0.1	74	2.6
B1	4-10	7.3	6.4	19.4	4.9	3.7	3.1	0.2	57	2.5
B21t	10-18	7.7	6.6	25.9	10.9	11.4	6.9	0.3	108	2.2
B22tcs	18-26	7.5	6.8	27.2	16.8	14.5	9.2	0.3	114	1.3
B23tcs ca	26-37	7.6	7.0	24.5	67.5	12.7	8.1	0.3	324	0.3
B31cs ca	37-42	7.6	7.1	26.1	53.0	13.3	8.0	0.4	248	0.7
B32cs	42-49	7.9	7.1	27.0	14.1	10.2	7.6	0.4	107	0.5
C1	49-66	7.8	6.9	25.7	10.2	10.2	6.3	0.3	99	0.7
				Intermediate						
A11	0-6	5.9	5.3	19.8	11.3	2.8	0.02	0.6	68	4.3
A12	6-16	5.8	5.1	23.6	13.6	3.8	0.1	0.3	70	3.1
B1	16-20	5.7	5.0	26.3	14.8	5.4	0.2	0.3	79	2.2
B21t	20-32	5.8	5.0	29.6	14.7	7.4	0.5	0.4	77	1.3
B22t	32-44	6.2	5.2	25.1	13.5	6.6	0.5	0.4	83	1.0
B3	44-55	6.7	5.6	23.7	12.3	5.6	0.8	0.3	80	0.6
C1	55-78	7.1	6.1	26.7	15.1	5.4	1.1	0.4	82	0.5

TABLE IV (Continued)

Horizon	Depth	pH 1:1 H_2O	pH 1:1 KCl	CEC	Extractable Cations Ca	Mg	Na	K	Base Saturation	Organic Matter
	inches			meq/100g					%	
				Typical Mollisol						
A1	0-12	6.0	5.2	20.8	11.2	3.4	0.1	0.4	71	3.2
B1	12-19	5.9	5.1	22.9	12.8	4.6	0.1	0.3	77	2.3
B21t	19-32	6.3	5.3	24.6	14.7	6.2	0.2	0.4	87	1.0
B22t	32-50	6.5	5.8	23.2	14.0	6.6	0.3	0.4	92	0.5
B3	50-60	6.9	6.1	20.0	12.1	5.8	0.3	0.3	90	0.4
C1	60-68	7.1	6.2	17.9	11.7	5.2	0.3	0.3	97	0.5
C2	68-90	7.1	6.1	27.4	17.3	7.1	0.6	0.4	92	0.5

TABLE V

CHEMICAL PROPERTIES OF SOILS IN TRANSECT 2 (PERMIAN)

Horizon	Depth	pH 1:1 H_2O	pH 1:1 KCl	CEC	Extractable Cations Ca	Extractable Cations Mg	Extractable Cations Na	Extractable Cations K	Base Saturation	Organic Matter
	inches			meq/100g	meq/100g	meq/100g	meq/100g	meq/100g	%	%
					Saline-Sodic					
A1	0-3	6.9	6.1	20.9	15.1	2.5	0.5	0.5	86	4.9
B21t	3-10	7.5	6.65	31.2	18.6	7.5	4.8	0.5	97	2.5
B22tca	10-18	8.0	7.1	29.5	19.3	7.1	8.4	0.4	111	1.9
B23tca	18-30	8.0	7.1	25.8	13.9	8.4	9.8	0.3	113	0.8
B24tca	30-50	8.1	7.2	22.7	12.8	6.4	7.4	0.3	112	0.5
B3ca	50-80	8.2	7.2	22.2	20.7	9.2	6.9	0.4	162	0.7
					Intermediate					
A1	0-12	6.3	5.4	24.9	16.0	3.7	0.4	0.4	81.2	4.5
B1	12-16	6.5	5.8	25.0	15.2	4.5	1.9	0.3	85.8	2.3
B21t	16-27	7.3	6.3	30.6	17.5	5.4	3.6	0.3	86.8	1.5
B22t	27-37	8.0	6.9	28.9	15.3	5.3	5.2	0.3	87.7	1.1
B23tca	37-48	8.1	7.0	28.4	21.3	6.1	5.8	0.3	115.7	0.6
B3ca	48-84	8.2	7.0	26.7	23.1	6.5	5.9	0.4	131.9	0.7
					Typical Mollisol					
A1	0-13	6.1	5.4	33.3	19.6	3.0	0.2	0.4	68	4.8
B1	13-20	6.4	5.5	33.2	26.5	3.5	0.1	0.3	91	3.4
B2t	20-40	7.0	6.0	32.8	23.9	3.8	0.4	0.3	86	1.3
B3ca	40-70	7.9	7.0	29.6	39.1	3.7	0.9	0.3	148	0.7
Cca	70-80	7.9	6.8	30.4	31.2	5.8	2.5	0.3	129	0.4

TABLE VI

CHEMICAL ANALYSES OF 1:1 EXTRACTS OF SOILS IN TRANSECT 1 (PENNSYLVANIAN)

Horizon	Depth	Electrical Conductivity	Cations			Anions			Total Solids	ESP	SAR
			Ca	Mg	Na	Cl	SO_4	HCO_3			
	inches	mmho/cm	meq/liter						ppm		
					Saline-Sodic						
A1	0-4	0.09	0.2	0.3	0.7	0.2	0.6	1.0	140	1.8	1.4
B1	4-10	0.83	0.5	0.5	7.0	0.8	2.9	4.5	610	12.2	10.0
B21t	10-18	1.93	0.8	1.2	16.8	0.9	14.9	3.1	980	20.0	17.1
B22t ca	18-26	8.47	21.1	21.6	56.0	0.9	98.4	1.7	7310	13.2	12.1
B23t cs ca	26-37	8.32	21.5	17.9	53.6	0.7	93.4	2.0	7030	11.2	12.1
B31 cs ca	37-42	7.90	25.4	19.9	52.2	0.5	86.0	2.3	6450	10.5	11.0
B32 cs	42-49	3.33	3.3	3.2	26.4	0.5	29.8	2.7	2300	18.6	14.7
C1	49-66	1.60	0.7	1.0	13.2	0.4	13.2	0.8	990	19.3	14.7
					Intermediate						
A11	0-6	1.13	2.5	1.3	0.15	0.4	0.4	4.0	540	0.03	0.1
A12	6-16	0.21	1.3	0.8	0.3	0.2	0.3	2.5	380	0.2	0.3
B1	16-20	0.12	0.5	0.5	0.4	0.2	0.3	0.8	180	0.6	0.6
B21t	20-32	0.09	0.2	0.3	0.5	0.2	0.4	0.6	100	1.4	1.1
B22t	32-44	0.11	0.2	0.3	0.7	0.2	0.4	0.6	60	1.9	1.5
B3	44-55	0.13	0.2	0.3	1.0	0.2	0.6	0.7	90	2.8	2.2
C1	55-75	0.22	0.2	0.3	1.5	0.4	0.9	1.0	110	3.7	3.1

TABLE VI (Continued)

Horizon	Depth	Electrical Conductivity	Cations			Anions			Total Solids	ESP	SAR
			Ca	Mg	Na	Cl	SO_4	HCO_3			
	inches	mmho/cm	meq/liter						ppm		
					Typical Mollisol						
A1	0-12	0.24	1.5	0.9	0.2	0.2	0.3	2.5	370	0.2	0.2
B1	12-19	0.11	0.5	0.5	0.2	0.2	0.3	0.9	170	0.3	0.3
B21t	19-32	0.15	0.4	0.5	0.3	0.3	0.3	0.5	180	0.6	0.5
B22t	32-50	0.10	0.2	0.1	0.5	0.2	0.4	0.6	50	1.1	1.3
B3	50-60	0.13	0.3	4.3	0.7	0.2	0.5	0.5	60	1.3	0.5
C1	60-68	0.18	0.4	0.4	1.0	0.2	0.7	1.0	90	1.4	1.5
C2	68-90	0.22	0.5	0.5	1.1	0.3	0.9	0.9	130	1.8	1.6

TABLE VII

CHEMICAL ANALYSES OF 1:1 EXTRACTS OF SOILS IN TRANSECT 2 (PERMIAN)

Horizon	Depth	Electrical Conductivity	Cations Ca	Cations Mg	Cations Na	Anions Cl	Anions SO_4	Anions HCO_3	Total Solids	ESP	SAR
	inches	mmho/cm	meq/liter						ppm		
					Saline-Sodic						
A1	0-3	0.46	2.2	0.6	1.8	0.4	0.5	4.5	430	1.3	1.5
B21t	3-10	1.01	0.8	0.5	9.1	5.4	1.2	6.0	880	12.4	11.2
B22tca	10-18	2.55	1.5	0.9	21.9	26.9	7.2	5.2	1660	20.9	19.9
B23tca	18-30	3.33	1.6	1.1	28.4	19.2	12.9	3.8	2040	26.8	24.6
B24tca	30-50	1.58	0.3	0.5	14.0	8.4	2.4	4.0	890	26.4	23.0
B3ca	50-80	1.10	0.4	0.4	10.7	4.9	1.5	4.0	620	26.1	16.8
					Intermediate						
A1	0-12	0.22	0.8	0.5	1.2	0.3	0.1	2.3	390	1.3	1.5
B1	12-16	0.28	0.3	0.3	2.4	0.3	0.3	2.6	360	6.5	4.7
B21t	16-27	0.35	0.2	0.3	3.1	0.5	0.6	2.2	260	10.9	6.6
B22t	27-37	0.91	0.3	0.3	7.9	0.9	2.6	4.7	530	15.2	14.7
B23tca	37-48	0.77	0.3	0.3	7.3	1.1	2.6	4.0	530	18.0	13.5
B3ca	48-84	0.82	0.3	0.3	6.5	0.9	1.6	4.2	420	19.7	12.1
					Typical Mollisol						
A1	0-13	0.44	3.4	0.9	0.2	0.2	0.3	4.7	650	0.4	0.1
B1	13-20	0.14	1.4	0.3	0.2	0.3	0.2	1.7	280	0.2	0.2
B2t	20-40	0.18	0.7	0.3	0.9	0.1	0.3	1.6	160	1.1	1.2
B3ca	40-70	0.31	0.8	0.3	2.2	0.2	0.4	2.7	250	2.4	3.0
Cca	70-80	0.44	0.3	0.3	4.6	0.2	0.5	4.0	240	6.6	8.1

VITA

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