GENESIS OF GRAYISH CLAYPAN SOILS

By

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CHAPTER I

INTRODUCTION

Unique grayish colored soils, having clayey B2t horizons, occur intermittently among the extensive reddish to brownish hues of the Reddish Prairie soils. Soil genesis and morphological studies, based on quantitative and qualitative characterization data, are limited on modal pedons of these grayish soils.

The primary objective of this study is to define more precisely the genesis of these grayish soils through interpretation of detailed profile descriptions and chemical, physical, and mineralogical data to ascertain the effects of losses, gains, transfer, and transformations of soil constituents as modified by relief, parent material, time, vegetation and climate. The secondary objective is classification of the proposed Nardin soils by the 7th Approximation and to resolve if the central concept encompasses differentia characteristics of such degree as to merit a series distinction from the established Waurika series. The classification of these soils by the 7th Approximation is provisional since they have some properties of both Mollisol and Alfisol orders.

Two modal pedons of a proposed Nardin series in northern Oklahoma and two pedons of the established Waurika series in southern Oklahoma were selected for this study. Materials of weathered and unweathered clays and shales of the Wellington formation - Permian Redbed system, occurring in north-central Oklahoma were also studied in an attempt to develop a realistic sequential model.

Although these specific soils do not comprise large extensive land areas, the processes of soil formation occurring in these soils will be applicable and may indicate trends in soil genesis for other competing and associated soils which have clayey B2t horizons such as Kirkland, Tabler, and Bethany soils. It is hoped that this study will provide needed data to more fully characterize the region of Reddish Prairie soils and add to the growing knowledge of soil science. The behavior of these soils will also be of interest to agriculturalists, engineers, geologists, and urban developers.

CHAPTER II

REVIEW OF LITERATURE

History

The Waurika series was established in Jefferson County, Oklahoma, in 1961 and the tentative Nardin series was recommended in 1964 during a field study of Oklahoma and Kansas soils. Comprising this field study were Messrs. E. H. Templin, J. H. Allen, H. T. Otsuki, Soil Correlators of the Soil Conservation Service, USDA; and Dr. Fenton Gray of the Agronomy Department, Oklahoma State University. The Nardin series was proposed for the soils previously field correlated as Tabler silt loam, wet variant in Kay County, Oklahoma. The name is coined from a small town in the western section of the county.

The extent of areas being mapped by soil scientists are primarily confined to two separate geographic areas. Waurika series was mapped in the southern part of Oklahoma in the vicinity of Cotton, Comanche and Jefferson Counties, while the tentative Nardin series was mapped in Kay and Grant Counties of northern Oklahoma and extended northward into Kansas. Total acreage reported for Waurika soils in the Cotton County Soil Survey Report (30) was 888 acres, while approximately 770 acres have been mapped in Comanche County and nearly 1000 acres in Jefferson County. It is believed that Waurika series will extend southward into Texas. Soils like the tentative Nardin series comprise

10,000 acres in the Kay County Soil Survey and an estimated 3,000 acres occurs in the adjoining westward Grant County.

Soil Formation Factors

The functional analysis of soils is not based on physical, chemical, or biological theories (16). The genesis and morphology of a selected pedon is based on one hypothesis. This hypothesis assumes that the variables -- climate, vegetation, relief, parent material and time, suffice to define any pedon or polypedons.

Climate

The soils selected for this characterization study are presently undergoing morphological losses, gains, transfers, and transformations in a warm, temperate, sub-humid, continental climate (40). There are distinct fluctuations of temperature, cloudiness, wind and precipitation. Soil temperature classes are used as family differentia in all orders of the 7th Approximation. Soil temperature classes of soils with nine degrees F. or more difference between mean summer (June, July, and August) and mean winter (December, January, and February) temperatures, and with mean annual temperatures less than 47 degrees are classified as Frigid; 47 to 59 degrees - Mesic; and more than 59 degrees - Thermic (37). The mean annual soil temperature is higher than mean air temperature over most of the United States (23). This difference is about two degrees F. for the humid southern and central states.

The average monthly maximum and minimum temperature and precipitation are given in Figure 1 and 2 for Kay and Cotton Counties respectively. The mean annual temperature for Kay County is 60.9 degrees F.

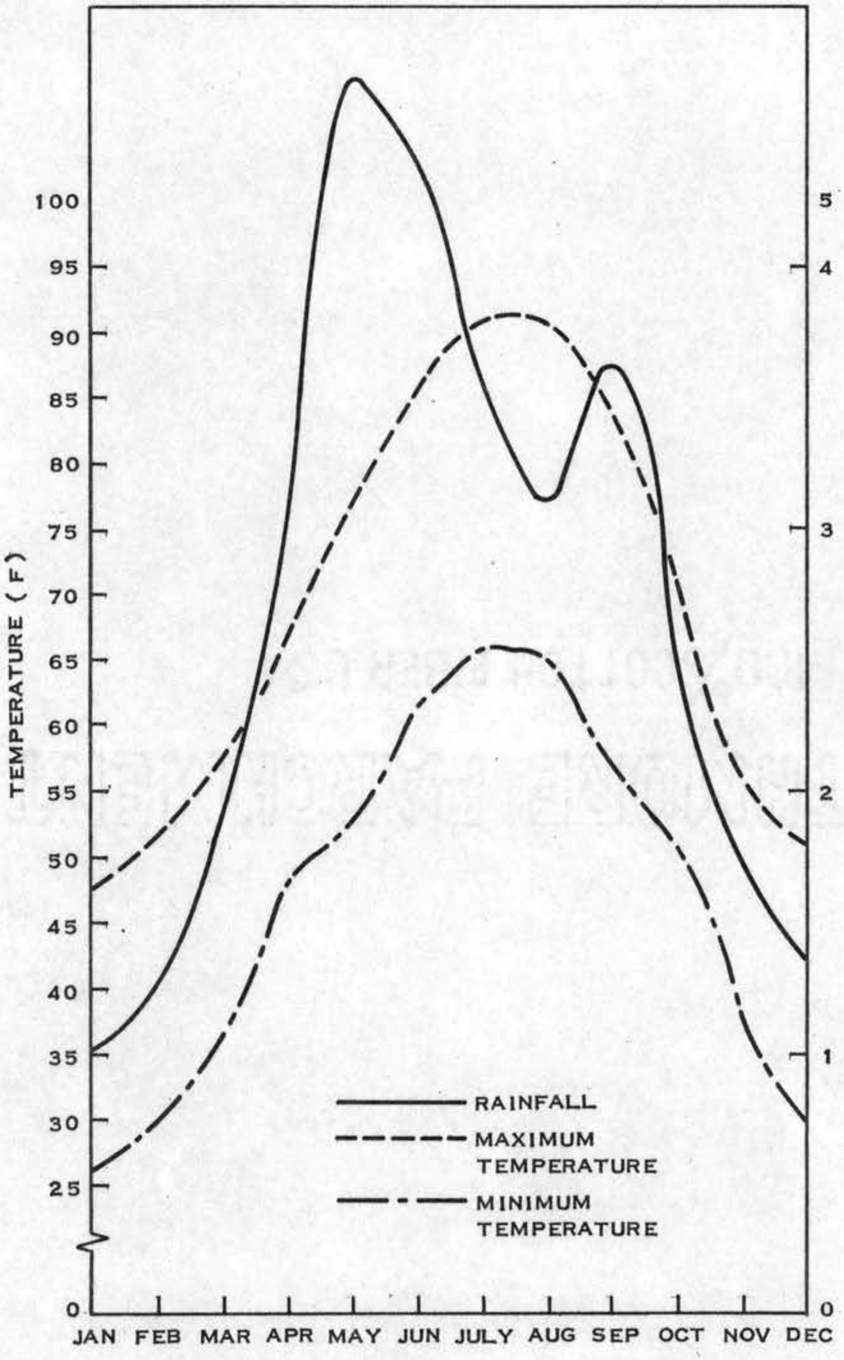

FIG. 1 – AVERAGE MONTHLY MAXIMUM AND MINIMUM TEMPERATURE AND PRECIPITATION OF KAY COUNTY, OKLAHOMA

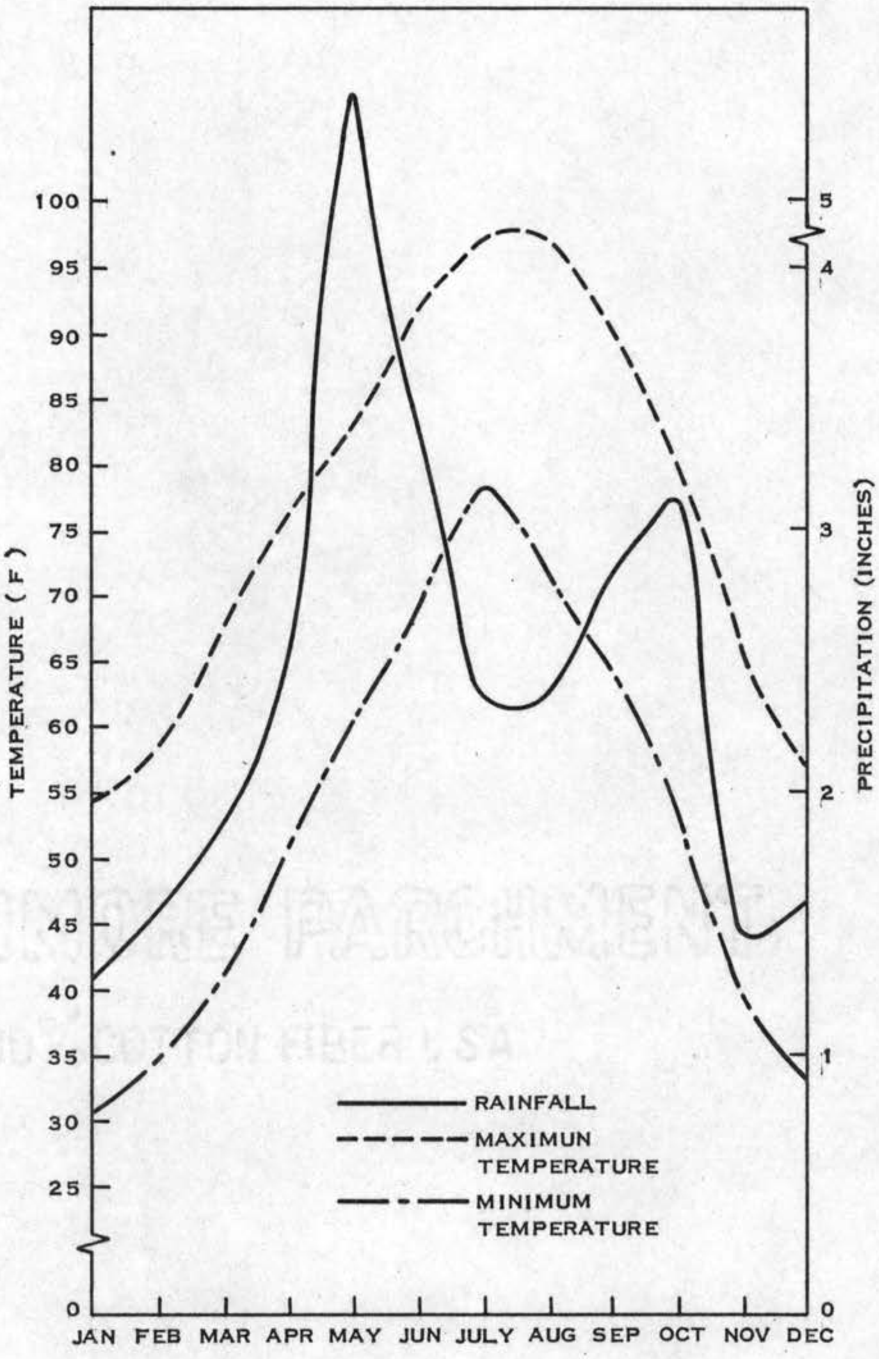

FIG. 2 – AVERAGE MONTHLY MAXIMUM AND MINIMUM TEMPERATURE AND PRECIPITATION OF COTTON COUNTY, OKLAHOMA

as compared to 64.0 degrees F. for Cotton County. The mean winter temperature is 39.1 degrees F. for Kay County and 44.3 degrees F. for Cotton County, while the mean summer temperature is 81.9 degrees F. for Kay County and 83.3 degrees F. for Cotton County. The total average precipitation in Kay County is 30.3 inches as compared to 29.7 inches for Cotton County. The evaporation transpiration ratio is about 37 for the Waurika sample area and four less, or 33, for the Nardin-like sample area of Kay County. The annual P-E index is about 46 for Cotton County and 52 for Kay County.

These mean annual air temperatures indicate that both the Nardin-like and Waurika soils would be classified as thermic.

Vegetation

The native vegetation in Kay County consists primarily of mid and tall prairie grasses, except for a few small areas covered by trees (19, 6). The climax vegetation of the proposed Nardin series consists primarily of little bluestem, switch grass, bluegrama, buffalograss, big bluestem and Indiangrass. There is an abundance of roots in the surface horizons but the clay subsoil slows the absorption of water and restricts the growth of roots.

The soils of the Waurika series formed under short native grasses over clay beds of Permian age (30). About 60 percent of the climax vegetation is decreaser plants, such as side-oats grama, blue grama, western wheatgrass and tall dropseed.

Presently, Waurika and proposed Nardin soils are predominantly in cultivation of field crops.

Relief

The soils studied occupy a remarkable level to concave ecosystem on broad constructional upland plains. Figure 3 shows the general landscape of Nardin-like soils in Kay County (6) with respect to other geomorphic land surfaces. The absence of established drainage patterns combined with the very slowly permeable, clayey B2t horizons contributes to a somewhat poorly drained condition. This lack of surface runoff promotes a micro-humid environment as compared to the associated better drained soils.

Parent Material

The parent material of the soils studied is indistinct. The clays and shales of the Permian Redbeds-Wellington formation (25) underlay the entire study area of Kay County. The origin of the Nardin-like parent material may be illustrated by two multiple working hypotheses. These hypotheses are residum from the Wellington formation or Post-Permian deposits over the older irregular landscapes of the Wellington formation.

The occurrence of Reddish Prairie soils developed in Post-Permian parent materials is widely known (2, 4, 8, 10, 33). Most of these Post-Permian parent materials are sediments which originated from the major rivers which flow through the region.

The Wellington formation, which is about 700 feet thick at its outcrop, attains its greatest thickness in Kansas. Rocks of the Wellington formation are poorly exposed in a broad north-south trending strip which extends from north central Oklahoma to across the

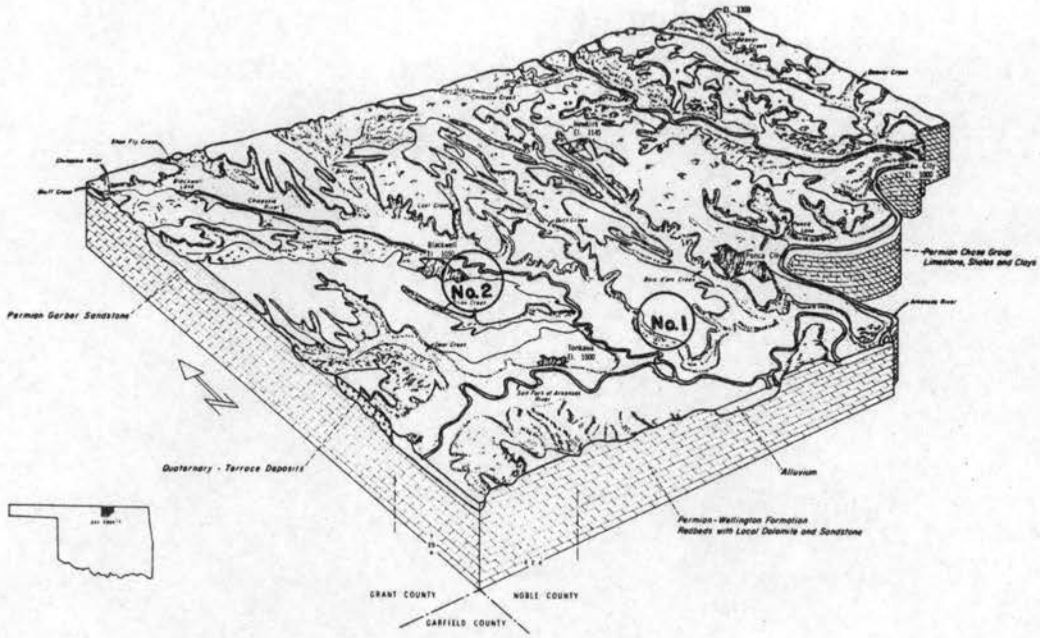

Fig. 3. Generalized Relief Map of Kay County, Oklahoma

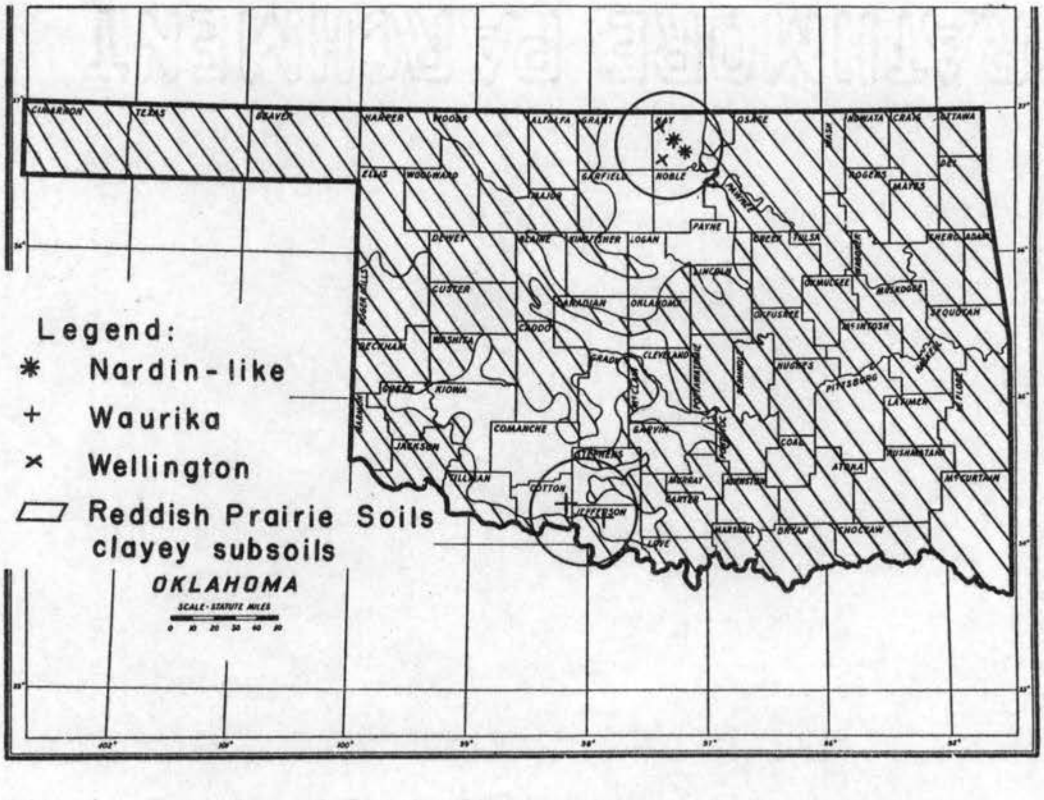

Fig. 4. Location of Sample Sites and General Occurrence of Reddish Prairie Soils with Clayey Subsoils

state of Kansas. The surface exposures of the Wellington formation consists primarily of gray to greenish-gray, somewhat silty shales having subconchoidal fracture. The gray or green color usually has a preponderance of ferrous oxide (39) as compared to the extensive associated reddish Permian formations high in ferric oxide.

Time

Norton (27) in a study of prairie soils, indicated that they pass through orderly stages of development in their advancement toward maturity. Thorp and Smith (41) have suggested that minimal, medial and maximal subgroups be established for various great soil groups. Minimal soils show no textural difference between A and B horizons; the medial soils have a B horizon which is slightly heavier in texture than the A, and the maximal soils have a B horizon that is considerably more clayey than the A horizon. The pedons selected for this study are within the Reddish Prairie great soil group (45), and their processes of soil formation may be related to these subgroups.

CHAPTER III

LABORATORY METHODS AND PROCEDURES

Physical Analyses

Soil samples were air dried under laboratory conditions and processed to pass a 2 mm. screen. Samples of geological parent material were also processed by grinding to pass a 2 mm. screen. Mechanical analysis was determined by the pipette method (18). Twenty-five gram samples were used for the mechanical analysis. Organic matter was removed with H_2O_2 and the soil samples dispersed with Na_2CO_3. The total sand size fractions were retained on a 300 mesh sieve to determine the relative proportions of various size sand fractions. The silt and clay were determined by the concentrations of the pipetted aliquots applying the principles of Stokes Law.

Difficulty was encountered in trying to determine the sand-size fraction of the geological soil materials of the Wellington formation. Most all of the soil material collected on the sieves were not sand but strongly cemented shales. No attempt was made to grind and disperse these sand size shale particles. However, it was apparent from physical properties that these sand size particles were composed primarily of cemented silt and clay size fractions.

The total clay was separated from the silt with an International Centrifuge by using 100 ml. tubes and centrifuge speed of 700 RPM for two minutes and 54 seconds. The total clay was fractionated into coarse clay, 2-.1 micron, and fine clay, less than .1 micron, with a continuous flow, refrigerated Servall Superspeed Centrifuge. The less than .1 micron clay flowed through the centrifuge. The rate of flow was adjusted to allow 100 ml./min. of fine clay to pass through the centrifuge at a speed of 1400 RPM (15 degrees C). The coarse clay and fine clay collected in the centrifuge tubes were redispersed and centrifuged four more times so that only the coarse clays remained in the centrifuge tubes. Bulk density was determined by (29).

Chemical Analyses

Cation exchange capacity was determined by saturating the samples with ammonium acetate and then determining the amount of exchanged ammonium by Kjeldahl distillation.. The ammonium acetate leachate was retained for determination of exchangeable cations. Extractable sodium and potassium were determined on original ammonium acetate extracts with the Beckman DU flame spectrophotometer. Calcium and magnesium were determined by the Versenate titration method. The clay cation exchange capacity was determined on the total clay by saturation with sodium acetate (29) and then determining the amount of sodium with the Beckman DU flame spectrophotometer. The K_2O of the total clay was determined by Jackson's method (14).

The soil pH was determined by using the Beckman pH meter on a 1:1 soil-water mixture and a 1:1 soil-KCl mixture. Soil organic matter was determined by the potassium dichromate wet oxidation method of Schalenberger (32). Total phosphorus determinations were according to Shelton and Harper procedure (35) in which samples were digested by perchloric acid and a molybdate complex was developed.

Mineralogical Analyses

The clay samples for X-ray diffraction were saturated three times with 50 ml. aliquots of 1.0 N. $CaCl_2$. They were then washed free of all excess salts by dispersing with 50 ml. portions of distilled water, centrifuging and decanting the supernatant. The clays were glycerol solvated by Jackson's method (14) for diagnostic vermiculite and montmorillonite peaks.

Preparation of samples for differential thermal analysis consisted of saturation with 1.0 N. $CaCl_2$, removal of excess salts and drying the salt free clay at a low temperature (less than 80° C.). The clay samples were ground to pass a 60 mesh sieve and placed in a desicator containing a slurry of Mg-nitrate so a constant relative humidity of 48% could be maintained. The prepared samples for X-ray diffraction and differential thermal analysis were taken to Dr. Mankin, Geology Department, Oklahoma University, Norman, Oklahoma, for analysis.

Ethylene glycol retention was determined on the total clay by the Southern Regional method (5).

CHAPTER IV

RESULTS AND DISCUSSION

Field Studies - Soils

A detailed preliminary investigation was made to formulate a central concept and allowable range in morphological characteristics of the soils to be characterized. This was done in order to select representative sampling pedons with repetitive genetic response for detailed study. Figure 4 gives the general location of the sampling sites and the distribution of Oklahoma Reddish Prairie soils having clayey subsoils (11).

Sampling pits were dug at each site. 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 standard procedures (38) and samples for laboratory analysis were collected from each horizon.

Morphology of Sampled Pedons

These polypedons exhibit an exceptional light-colored tone on aerial photographs (Figure 5). The light toned spots comprise the level to depressional areas having restricted surface drainage. The colors are of low chroma and high value as compared to the surrounding darker soils with more desirable surface drainage. Areas of individual mapping units range from .45 of an acre to more than several

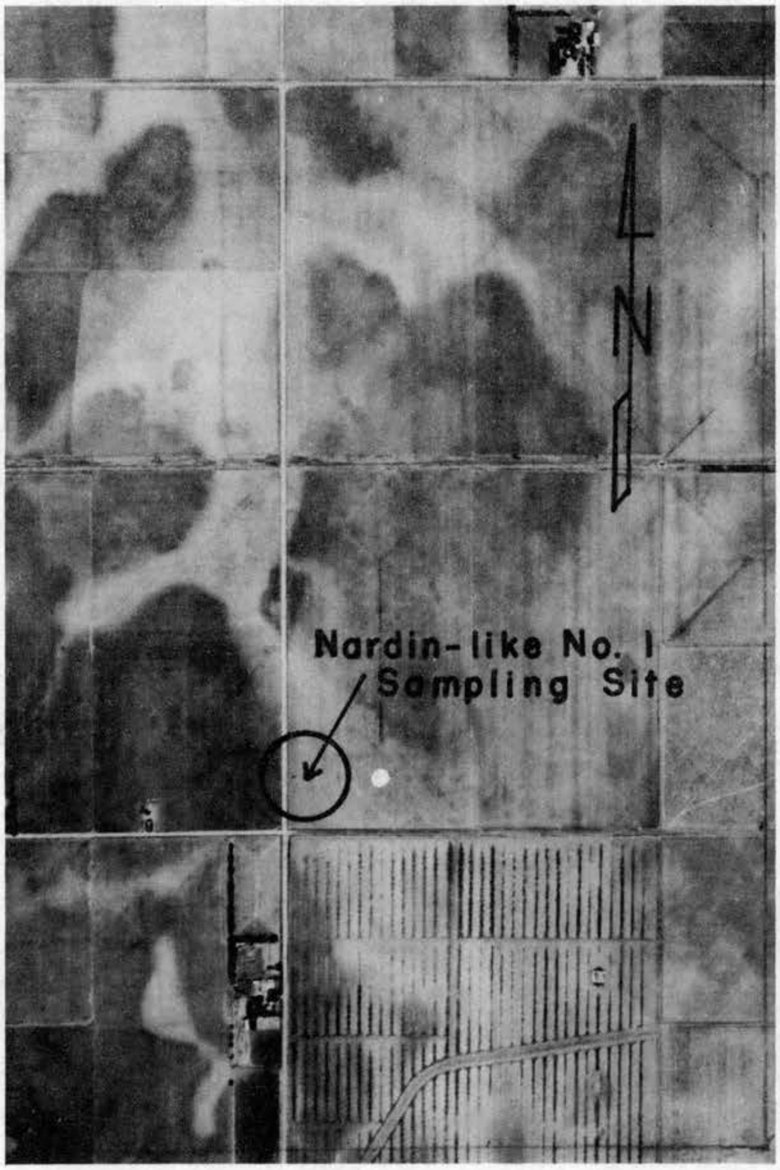

Fig. 5. Aerial Photograph Showing the Light Colored Surface Layer of Nardin-like Soils as Compared to the Associated Darker Colored Bethany and Vanoss Soils

hundred acres. The shape of individual mapping units range from irregular to round. The smaller mapping units tend to be more circular in shape while the larger areas are less circular and more variable. A significant amount of this soil occurs as soil individuals within mapping units of surrounding claypan soils. The transitional zone from these soils to the surrounding, less clayey soils is often quite distinct and narrow. This is especially true of the smaller mapping units.

Certain morphological properties exhibited by these two soils, the Nardin-like and Waurika, show numerous similarities. Both soils are characterized by gray to grayish-brown silt loam Ap horizons and light colored A2 horizons with abrupt to clear textural boundaries of dark grayish-brown and dark gray clayey B2t horizons.

Descriptions of the Sampled Pedons

Nardin-like No. 1 Kay County

This sampling site is within one of the largest mapping units mapped in the Kay County Soil Survey. The physiography consists of a level to slightly concave upland constructional plain laying near the confluence of three rivers. The Salt Fork of the Arkansas River is about four miles south; Chickasha River, two miles west; and Arkansas River, eight miles east. There is no definite established drainage pattern in the mapping unit sampled. Plowing has mixed much of the Ap and A2 horizons. Sample was collected in idle cropland. Grain sorghum and small grains are grown. Legal location is 360 feet north and 100 feet east of the southwest corner of Sec. 4, T. 25N, R. 1E., or about six miles west and one mile south of Ponca City, Oklahoma.

Horizon	Depth Inches	Description
Ap	0-9	Gray (10YR 5/1) silt loam, very dark grayish-brown (10YR 3/2) when moist; massive, very friable when moist, slightly hard when dry; many fine roots; numerous pinholes; pH 5.7; clear to abrupt boundary.
A2	9-12	Gray (10YR 6/1) silt loam, dark gray (10YR 4/1) when moist; massive; very friable when moist, slightly hard to soft when dry; vesicular; numerous pinholes; few fine roots; pH 6.5; clear wavy boundary.
B21t	12-32	Dark gray (10YR 4/1) clay, black (10YR 2/1) when moist; few fine faint mottles of brown (10YR 4/3); weak fine blocky structure; very firm when moist, extremely hard when dry; moderate continuous clay films; light colored soil material similar to above horizon on some vertical ped faces; few small black, shot-like concretions; few fine roots; some fine size sand grains along ped faces; pH 7.0; diffuse smooth boundary.
B22t	32-36	Very dark gray (10YR 3/1) silty clay, very dark grayish-brown (10YR 3/2) when moist; few fine faint mottles of strong brown (7.5YR 5/6); weak fine blocky structure; very firm when moist, extremely hard when dry; clay films on ped faces; light colored soil material similar to A horizon along vertical cleavage planes; few single grains and particles on ped faces; few black shot-like concretions; fine roots common along ped faces; pH 7.7; gradual smooth boundary.
B31	36-42	Dark gray (10YR 4/1) silty clay, very dark grayish-brown (10YR 3/2) when moist; few fine faint mottles of strong brown (7.5YR 5/6); weak fine blocky structure; extremely firm when moist; extremely hard when dry; clay films on ped faces; few very fine roots; few calcium carbonate concretions present; pH 8.3; gradual smooth boundary.
B32	42-64	Dark grayish-brown (10YR 4/2) silty clay loam, very dark grayish-brown (10YR 3/2) when moist; few fine faint mottles of strong brown (7.5YR 5/6); weak fine blocky structure; extremely firm when moist, extremely hard when dry; faint clay skins on ped faces; pH 7.8; gradual smooth boundary.

Horizon	Depth Inches	Description
C1	64-76	Dark grayish-brown (10YR 4/2) clay loam, very dark grayish-brown; common fine distinct mottles of dark yellowish-brown (10YR 4/4); weak fine blocky structure; extremely firm when moist; extremely hard when dry; pH 7.5; gradual smooth boundary.
C2	76-106	Dark yellowish-brown (10YR 4/4) clay loam, dark yellowish-brown (10YR 3/4) when moist, common distinct mottles of light brownish-gray (10YR 6/2) and yellowish-brown (10YR 5/6); massive; extremely firm when moist, extremely hard when dry; few fine black concretions; pH 7.1.

Nardin-like No. 2, Kay County

This site is quite typical of modal pedons in the smaller mapping units. The relief is level to concave. There is no defined surface runoff. The elevation of the site is about 1050 feet and approximately 60 feet above the Chickasha River channel. The area is within a large upland level plain south of Blackwell, Oklahoma and west of the Chickasha River. Tabler silt loam, 0 to 1 percent slopes and Bethany silt loam, 0 to 1 percent slopes are associated soils. Wheat and grain sorghums are main crops. Legal location is 320 feet west and 120 feet north of SE corner of Sec. 16, T. 26 N., R 1 W., or about 1 mile south and 1 mile east of Blackwell, Oklahoma.

Horizon	Depth Inches	Description
Ap	0-9	Grayish-brown (10YR 5/2) silt loam, very dark grayish-brown (10YR 3/2) when moist; weak medium to fine granular structure to massive; very friable when moist, soft when dry; numerous pinholes; many fine roots; pH 5.8; abrupt smooth boundary.

Horizon	Depth Inches	Description
A2	9-13	Light gray (10YR 6/1) silt, dark gray (10YR 4/1) when moist; weak fine granular structure to massive; very friable when moist, soft when dry; somewhat vesicular, many fine pinholes or voids; pH 6.7; abrupt wavy boundary.
B21t	13-31	Dark gray (10YR 4/1) silty clay, black (10YR 2/1) when moist; few fine faint mottles of dark brown (10YR 3/3) when moist; weak fine blocky structure; very firm when moist, extremely hard when dry; distinct continuous clay films; sifting of light colored surface layers observed on vertical ped faces; few fine voids; few larger size quartz grains scattered throughout matrix; few small black, shot-like concretions in lower part of horizon; very fine roots present; pH 6.8; diffuse smooth boundary.
B22t	31-38	Gray (10YR 5/1) silty clay, very dark gray (10YR 3/1) when moist; few fine faint mottles of dark brown (10YR 3/3) when moist; weak fine blocky structure; very firm when moist, extremely hard when dry; thin discontinuous clay films, not as prominent as above horizon; 1/8 inch black shot-like concretions; few larger size quartz grains fractured; sifting of surface layer soil material along vertical ped faces; few very fine roots; pH 7.4; diffuse smooth boundary.
B31	38-45	Gray (10YR 5/1) silty clay, very dark gray (10YR 3/1) when moist; weak fine blocky structure; very firm when moist, extremely hard when dry; clay films not distinct; few fine pinholes; some sifting of light colored soil material along vertical ped faces; few fine black shot-like concretions but not as many as above horizons; very fine roots; few calcium carbonate concretions; pH 7.6; noncalcareous; diffuse smooth boundary.
B32	45-54	Gray (10YR 5/1) silty clay, very dark grayish brown (10YR 3/2) when moist; weak medium to fine blocky structure; very firm when moist, extremely hard when dry; some clay films on natural cleavage structural planes; few fine pinholes; pH 7.7; noncalcareous; diffuse smooth boundary.
B33	54-64	Gray (10YR 5/1) silty clay, dark gray (10YR 4/1) when moist; massive; very firm when moist, extremely hard when dry; clay films not evident; pH 7.8; noncalcareous; gradual smooth boundary.

Horizon	Depth Inches	Description
C1	64-74	Grayish-brown (10YR 5/2) silty clay, dark grayish-brown (10YR 4/2) when moist; few fine faint mottles of dark yellowish-brown (10YR 4/4) when moist; massive; very firm when moist, extremely hard when dry; pH 7.9; noncalcareous; gradual smooth boundary.
C2	74-110	Grayish-brown (10YR 5/2) heavy clay loam, dark grayish-brown (10YR 4/2) when moist, common medium faint mottles of yellowish brown (10YR 5/6) when moist; massive; very firm when moist, extremely hard when dry; pH 7.9; noncalcareous.

Waurika No. 1, Jefferson County*

The physiography of this sampling site is a slightly concave slope of less than one percent on large, nearly level uplands. It is somewhat poorly drained with very slow surface runoff. Samples were collected from a cultivated field under Sudan and Johnson grasses. Location is 127 feet south and 315 feet east of the west quarter corner of Sec. 33, T. 4S., R. 7W., Jefferson County or about two miles east and one-half mile north of intersection of U. S. Highway 70 and 81, east of Waurika, Oklahoma.

Horizon	Depth Inches	Description
A1p	0-5	Grayish-brown (10YR 5/2) silt loam, very dark grayish-brown (10YR 3/2) when moist; nearly structureless with very weak thin plates in upper 2 inches; very friable when moist, slightly hard when dry; fine grass roots are numerous; plowed boundary.
A12	5-10	Dark grayish-brown (10YR 4/2) silt loam, very dark brown (10YR 2/2) when moist; moderate fine granular structure containing numerous worm casts; friable when moist, slightly hard when dry, many fine roots; clear, nearly smooth boundary.

Horizon	Depth Inches	Description
A2	10-14	Light brownish-gray (10YR 6/2) silt loam, dark grayish-brown (10YR 4/2) when moist; porous with moderate number of worm casts; slightly firm (brittle) when moist, slightly hard when dry; few roots; abrupt boundary that is wavy, and the thickness of this horizon varies from 5 inches to nearly nothing in a lateral distance of 18 inches. The underlying horizon bulges nearer the surface where this horizon is thin.
B21t	14-24	Dark grayish-brown (10YR 4/2) clay, dark brown (10YR 3/3) when moist; strong medium angular blocky with wider vertical cracks about 12 inches apart; very firm when moist, very hard when dry, tops of blocks adjacent to A2 not rounded; moderate continuous clay films and many horizontal slickenside faces; many fine roots that penetrate soil mass but more numerous on faces of peds; no discernible boundary.
B22t	24-33	Dark brown (10YR 3/3, moist) clay; essentially same as horizon above; gradual boundary.
B3	33-39	Dark brown (10YR 3/3, moist) silty clay loam; weak medium subangular blocky; firm when moist, very hard when dry, few, hard lime concretions of 1 cm. diameter and few black concretions of 3 to 4 mm. diameter; soil mass is calcareous; gradual boundary.
B3ca	39-44	Brown (10YR 4/3, moist) clay loam with distinct fine mottles of dark brown (10YR 3/3) and reddish-brown (5YR 4/4); moderate to weak medium subangular blocks; friable; black concretions more numerous and slightly larger than above; soil mass is calcareous; clear boundary.
C1	44-59	Reddish-brown (5YR 5/4) clay loam, reddish-brown (5YR 4/4) when moist; weak to moderate medium subangular blocks; friable to slightly firm; calcium concretions are larger and less numerous than above; soil mass is calcareous; black concretions are softer, larger and more numerous than above.
C2	59-68	Red and yellowish-red (2.5YR 5/6 and 5YR 5/6, moist) coarsely mottled clay loam; calcareous.

Horizon	Depth Inches	Description
C3	68-78	Weathered, soft "Red Beds" material of clay loam texture very similar to above.

*The Waurika soil profile descriptions were prepared by Louis E. Derr, former State Soil Scientist, SCS, Stillwater, Oklahoma, presently Soil Survey Staff, Washington, D.C.

Waurika No. 2, Cotton County*

This site is on a large slightly concave upland area with slopes of less than one percent. Surface drainage is somewhat poor and surface runoff is very slow. Pedon was sampled in a field of wheat stubble. Location is 100 feet west and 190 feet south of the northeast corner of Sec. 31, T. 3S., R. 9W., Cotton County, Oklahoma. About three miles east and one mile south of Temple, Oklahoma.

Horizon	Depth Inches	Description
A1p	0-6	Grayish-brown (10YR 5/2) silt loam, very dark grayish-brown (10YR 3/2) when moist; weakly platy in lower 1 inch; friable when moist, soft when dry, many fine roots; plowed boundary.
A12	6-10	Dark grayish-brown (10YR 4/2) silt loam, very dark grayish-brown (10YR 3/2) when moist; few worm casts and little granulation; friable when moist, soft; gradual, nearly smooth boundary.
A2	10-12	Light brownish-gray (10YR 6/2) silt loam, dark grayish-brown (10YR 4/2) when moist; structureless; friable when moist, soft, abrupt, wavy boundary with thickness of A2 varying from 1 to 5 inches in lateral distance of 16 inches.
B21t	12-24	Dark grayish-brown (10YR 4/2) clay, very dark grayish-brown (10YR 3/2) when moist; moderate medium to coarse angular blocky; very firm when moist, very hard when dry, moderate continuous clay films and many horizontal slickenside faces; clear, wavy boundary.

Horizon	Depth Inches	Description
B22t	24-32	Very dark grayish-brown (10YR 3/2, moist) clay; moderate medium angular blocky; very firm when moist, very hard when dry, clay films and slickenside faces less apparent than above; many hard lime concretions (1 percent by volume) up to 1 cm. diameter; soil mass is noncalcareous; fine black pellets of 1 to 2 mm. diameter increase with depth in this horizon; diffuse boundary.
B3ca	32-39	Dark grayish-brown (10YR 4/2, moist) clay; weakly blocky that breaks more easily on horizontal plains; lime concretions more numerous (3 percent by volume); soil mass is calcareous; black pellets are less distinct; gradual boundary.
C1	39-50	Dark grayish-brown (10YR 4/2, moist) heavy clay loam; weak medium to fine subangular blocky; firm when moist, very sticky when wet; segregated lime less than 1 percent by volume and mass is calcareous; diffuse boundary.
C2	50-57	Dark grayish-brown (10YR 4/2, moist) clay loam; soil mass is calcareous but less than above and segregated lime is less than above; black concretions increase in size and number; gradual boundary.
C3	57-72	Light gray (10YR 7/2, moist) clay loam coarsely streaked and mottled with yellowish-red (5YR 5/6, moist); structureless, friable, noncalcareous.

Physical Measurements

Particle-Size Distribution

Nardin-like Soils

The particle-size distribution of the two Nardin-like soils presented in Table I provides an excellent insight to the processes of soil formation. Both soils have Ap and A2 horizons high in silt, especially coarse silt. The particle-size-depth distribution curves in Figures 6 and 7 exhibit maxima clay accumulation in the B2t horizons

TABLE I

PARTICLE-SIZE DISTRIBUTION OF NARDIN-LIKE SOILS

Horizon	Depth	Very Coarse Sand 2-1 mm.	Coarse Sand 1-.5 mm.	Medium Sand .5-.25 mm.	Fine Sand .25-.1 mm.	Very Fine Sand .1-.05 mm.	Coarse Silt .05-.02 mm.	Fine Silt .02-.002 mm.	Clay .002 mm.
	Inches	%	%	%	%	%	%	%	%
				Nardin-like No. 1 Kay County					
Ap	0-9	0.1	0.7	1.9	2.7	9.1	47.1	22.8	15.6
A2	9-12	0.2	1.0	1.9	2.3	1.2	49.3	26.5	17.6
B21t	12-32	0.1	0.4	0.9	1.2	2.8	20.3	19.1	55.2
B22t	32-36	0.3	0.5	1.3	1.6	3.0	17.3	26.5	49.5
B31	36-42	0.8	1.0	1.6	2.1	3.2	18.2	27.6	45.5
B32	42-64	0.3	1.8	3.9	3.7	1.7	33.3	16.6	38.7
C1	64-76	0.5	3.1	6.2	7.3	10.0	21.8	13.4	37.7
C2	76-106	1.0	5.0	9.6	5.9	6.4	22.4	16.4	33.3
				Nardin-like No. 2 Kay County					
Ap	0-9	0.0	0.4	0.7	0.8	8.2	42.3	25.2	22.4
A2	9-13	0.0	0.4	0.6	0.1	0.3	56.3	26.3	16.0
B21t	13-31	0.1	0.4	0.3	0.3	1.8	19.8	25.3	52.0
B22t	31-38	0.1	0.6	0.4	0.1	0.1	22.6	28.0	48.1
B31	38-45	0.4	0.5	0.4	0.3	1.6	25.7	30.1	41.0
B32	45-54	0.1	0.5	0.4	0.3	1.2	22.8	34.6	40.1
B33	54-64	0.1	0.6	0.5	0.4	1.3	21.6	33.9	41.6
C1	64-74	0.2	0.7	0.6	0.4	1.6	22.7	32.6	41.2
C2	74-106	1.7	4.1	3.5	2.4	5.0	22.0	23.2	38.1

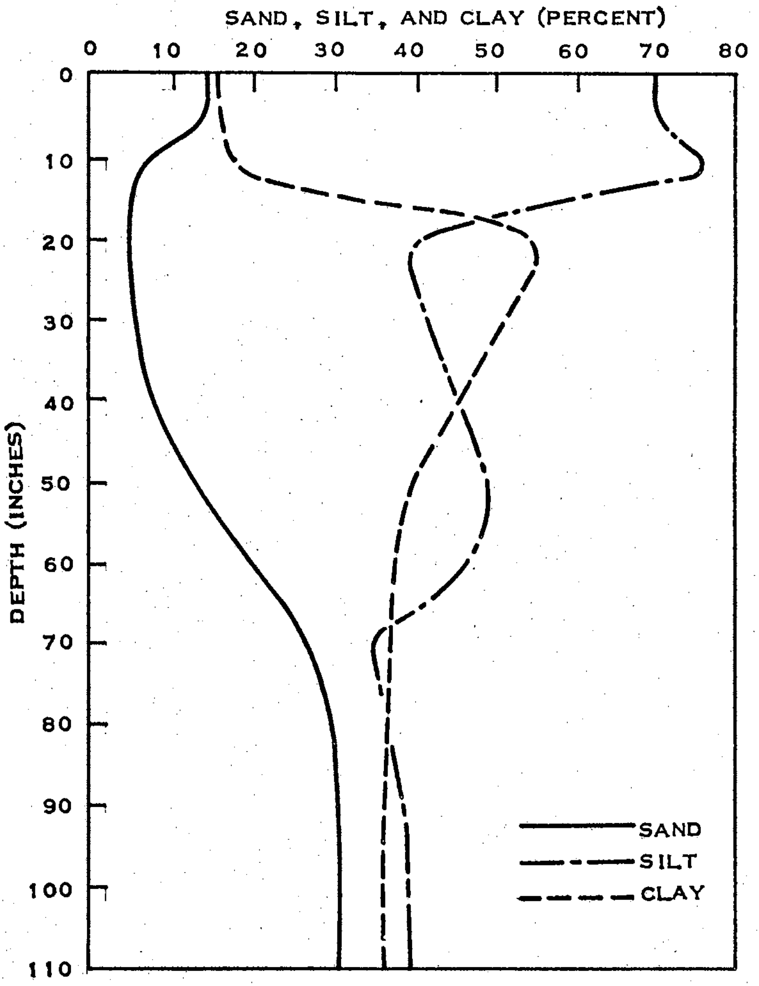

FIG. 6 – PARTICLE SIZE – DEPTH DISTRIBUTION CURVE FOR NARDIN – LIKE NO. 1 IN KAY COUNTY, OKLAHOMA

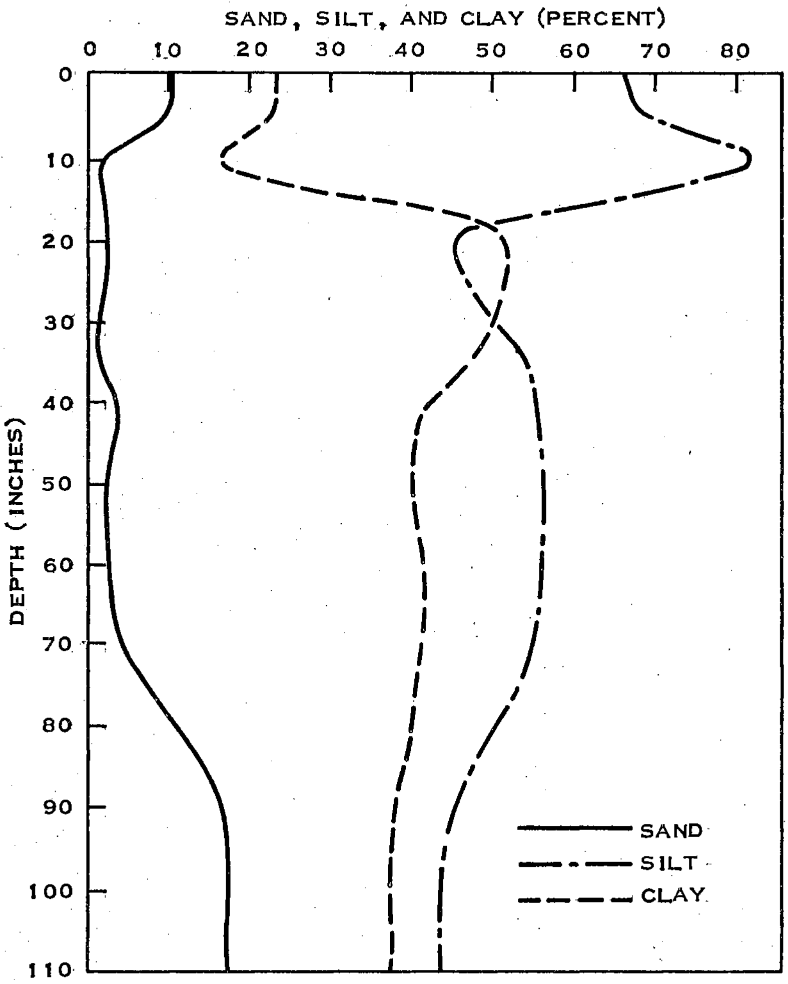

FIG. 7 – PARTICLE SIZE – DEPTH DISTRIBUTION CURVE FOR NARDIN – LIKE NO. 2 IN KAY COUNTY, OKLAHOMA

with clay content ranging from 55.2 to 52.0 percent for Nardin-like No. 1 and No. 2 respectively. The high clay values of the B2t horizons are similar to work published by Whiteside (43) and Fanning (7). Whiteside reported 59 percent clay in the B horizon of Putnam silt loam, whereas Fanning found 59 percent in the corresponding horizon of Parsons silt loam. He found fine clay, less than 0.1 micron, to be dominant, comprising 77 percent of the total clay in the Parsons silt loam. This is slightly less than the 85 percent fine clay of the Nardin-like No. 1 B2t horizon. The translocation of clays has contributed to losses in the A horizons and subsequent gains in the B2t horizons. The significant increase in coarse silt over fine silt in the Ap and A2 horizons of both pedons is a reflection of vertical movement of fine silt in the A horizon with accumulation in the illuviated B horizons. The A2 horizon of the Nardin-like No. 1 shows a slight increase in clay over the A1 horizon but the Nardin-like No. 2 has an eluviated A2 horizon lower in clay than the Ap horizon. The described profile descriptions indicate this difference. The boundary between the A2 and B21t of the Nardin-like No. 1 is clear to abrupt instead of abrupt as the Nardin-like No. 2. The abrupt boundary between the A2 and the B21t horizons may indicate greater translocation of silt and clay from the A horizon of soils with clayey subsoils.

Some interpretation of clay translocation by percolating water can be ascertained by a comparison of the two profiles. The microtopography of the two sampling areas is such that the more concave Nardin-like No. 2 receives more water for percolation. A depth distribution study of clay indicates that additional water moving through the profile tends to translocate fine clay to a greater depth.

In Bray's work (3) the accumulation of clay occurs mainly at about 20 to 30 inches although movement to 50 inches was still significant. Sawhney's, et al. (31) work on profile disconformity and soil formation showed clay accumulation on ped surfaces in the lower part of the solum and extending into the upper portion of the substratum. The Nardin-like No. 1 receives slightly less water for percolation and has the greatest percentage of clay in the control section. Although this indicates a general trend, these differences of clay content in the lower horizons could be due to the stratified depositional differences. Both profiles are comparably low in total sand.

Waurika Soils

Table II gives the particle-size distribution of Waurika soils. The particle-size depth distribution curves of Figures 8 and 9 show A horizons higher in silt and sand while B horizons have distinct clay maxima. The Waurika No. 2 is slightly higher in both clay and silt. The particle-size distribution of the sand fractions indicates that the materials of the Waurika No. 1 are quite uniform to a depth of 58 inches. Below this depth the relative amounts of fine and very fine sand change indicating a change in materials. Discontinuities in the relative proportions of the sand fractions are not evident in the Waurika No. 2.

Comparison of Particle-Size Distribution Data

The distribution curves (Figures 6, 7, 8, and 9) for clay follow a more characteristic pattern than silt or sand between these two soils.

TABLE II

PARTICLE-SIZE DISTRIBUTION OF WAURIKA SOILS*

Horizon	Depth	Very Coarse Sand 2-1 mm.	Coarse Sand 1-.5 mm.	Medium Sand .5-.25 mm.	Fine Sand .25-.1 mm.	Very Fine Sand .1-.05 mm.	Silt .05-.002 mm.	Clay .002 mm.
	Inches	%	%	%	%	%	%	%
				Waurika No. 1 Jefferson County				
A1p	0-5	<0.1	0.2	0.6	12.3	18.5	58.2	10.2
A12	5-10	<0.1	0.1	0.4	10.1	15.8	57.0	16.6
A2	10-14	<0.1	0.4	0.6	9.9	14.8	56.0	18.3
B21t	14-24	<0.1	0.2	0.4	8.6	11.2	37.6	42.0
B22t	24-33	0.3	0.3	0.5	10.0	12.2	38.3	38.4
B3	33-39	1.4	0.5	0.5	9.2	12.0	39.0	37.4
B3ca	39-44	0.7	0.4	0.5	12.0	16.9	37.2	32.3
C1	44-59	0.7	0.7	0.7	14.4	19.9	34.6	29.0
C2	59-68	0.1	0.1	0.2	5.9	15.7	47.9	30.1
C3	68-78	5.6	1.6	0.4	5.2	17.2	43.5	26.5
				Waurika No. 2 Cotton County				
A1p	0-6	<0.1	0.1	0.1	4.7	17.8	63.0	14.3
A12	6-10	0.1	0.1	0.1	4.1	15.3	59.3	21.0
A2	10-12	<0.1	0.2	0.1	4.4	15.4	57.5	22.4
B21t	12-24	0.2	0.1	0.1	3.0	9.4	38.2	49.0
B22t	24-32	0.5	0.4	0.2	3.8	10.4	42.3	42.4
B3ca	32-39	1.6	0.9	0.3	4.4	10.8	46.0	36.0
C1	39-50	0.7	0.5	0.2	4.5	11.9	45.2	37.0
C2	50-57	0.6	0.6	0.2	5.1	12.8	43.8	36.9
C3	57-72	0.3	0.4	0.3	6.9	16.8	40.8	34.5

*Mechanical Analysis by Soil Conservation Service Laboratory, Lincoln, Nebraska. Samples S59-Okla-17-1 (1-9) and S59-Okla-17-2 (1-10).

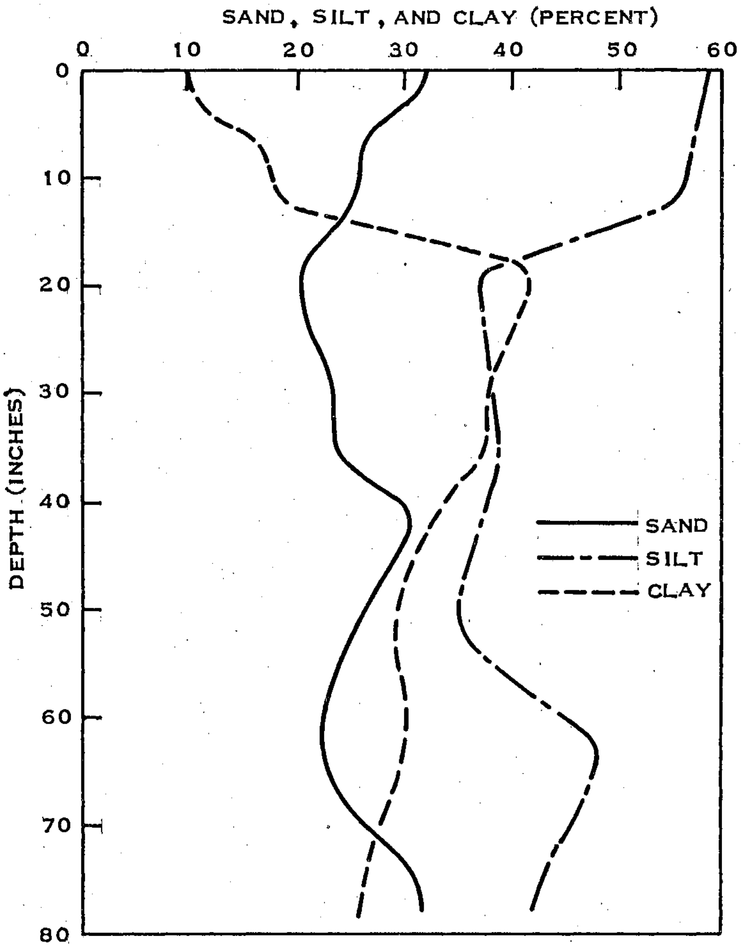

FIG. 8 – PARTICLE SIZE – DEPTH DISTRIBUTION CURVE FOR WAURIKA NO. 1 IN JEFFERSON COUNTY, OKLAHOMA

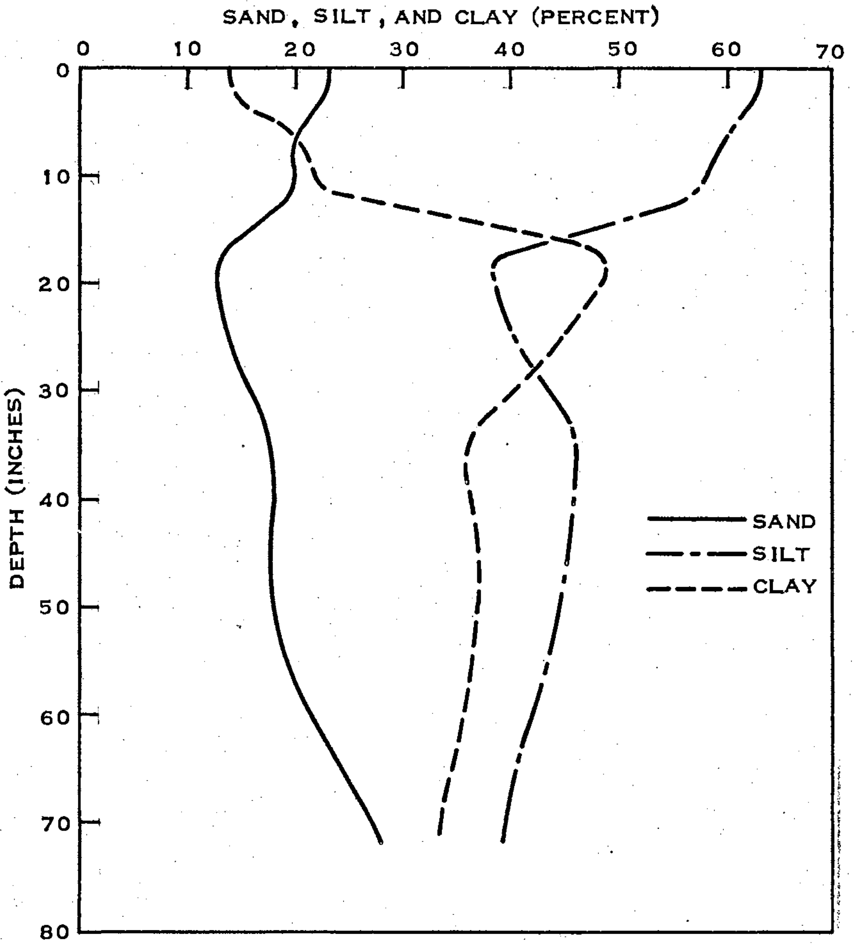

FIG. 9 – PARTICLE SIZE – DEPTH DISTRIBUTION CURVE FOR WAURIKA NO. 2 IN COTTON COUNTY, OKLAHOMA

The asymmetry of the clay distribution curve with depth of all four pedons sampled is characteristic of maximal profile development as suggested by Thorp and Smith (41). All pedons show a marked increase in translocation of clay to the argillic horizon. The distribution curve for silt shows a different pattern when making a comparison of these two soils. The Waurika has its greatest percent of silt in the Ap horizon with a gradual decrease in silt through the A2 to a minimum amount of silt in the B2t horizons with a slight increase in lower horizons. The Nardin-like soils have a distinct increase in silt from the Ap to the A2 horizons which the Waurika lacked. The strong maxima of silt in the A2 horizons of the Nardin-like soils and the high percentage of coarse silt indicate greater loss of fine silt and clay in the A2 leaving a dominance of coarse silt. The sand size fractions show a characteristic curve for each soil. The Nardin-like soils are lower in total sand throughout the profile with minimum value in the highly illuviated B2t horizon.

The differentia criteria used in the 7th Approximation with respect to particle size distribution will permit all four pedons to have argillic horizons, abrupt textural changes from the A to the B horizons. All sampled pedons classified at the family level would be fine clayey. This data indicates that the Nardin-like soils have reached a more advanced stage of soil maturity as noted by more silty A2 horizons, and more clayey argillic horizons with lower content of sand throughout the pedon.

Bulk Density

The high bulk density of the Nardin-like and Waurika soils given in Table III shows no significant differences between these four pedons. The bulk density of A horizons range from 1.42 to 1.56 gms./cc. and increase in the control section ranging from 1.84 to 2.00 gms./cc. The lower horizons have slightly lower values. The high bulk density of the A horizon is indicative of the massive to weak, fine granular structure and high silt content which are characteristic of these soils. The high clay content and blocky structure have contributed to high bulk density values of the B21t horizons.

Chemical Measurements

Exchangeable Cations

The cation exchange capacity (CEC) and extractable cations of the Nardin-like and Waurika soils are similar (Tables IV and V). The CEC is greater than 24 me./100 grams in all profiles. The B2t horizons had the highest CEC with values of 25.0 to 33.8 me./100 grams. Work on the competing Tabler soils and the associated Bethany soils in Kansas shows similar CEC values as these soils (21).

The relationship of CEC to percent clay in Figures 10, 11, 12, and 13 shows a good correlation. The A horizons have lowest values, the B21t the highest with a gradual decrease through the lower B and C horizons. The percent clay, in relation to the CEC of the Nardin-like No. 2 plotted in Figure 11, lacks the uniformity of the Nardin-like No. 1. The more highly eluviated A2 horizon of the Nardin-like No. 2 and a suggestion of stratification in the C horizon is indicated.

TABLE III

BULK DENSITY OF NARDIN-LIKE AND WAURIKA SOILS

Nardin-like					
No. 1			No. 2		
Horizon	Depth	gms./cc.	Horizon	Depth	gms./cc.
Ap	0-9	1.56	Ap	0-9	1.43
A2	9-12	1.56	A2	9-13	1.57
B21t	12-32	1.86	B21t	13-31	1.88
B22t	32-36	2.00	B22t	31-38	1.91
B31	36-42	1.95	B31	38-45	1.89
			B32	45-54	1.84
Waurika					
No. 1			No. 2		
A1p	0-5	1.47	A1p	0-6	1.42
B22t	24-33	1.89	B21t	12-24	1.84
C1	44-59	1.84	C3	57-72	1.82

TABLE IV

CHEMICAL PROPERTIES OF NARDIN-LIKE SOILS

Horizon	Depth	Cation Exchange Capacity	Extractable Cations				1:1 pH-H20	1:1 pH-KCL	% Organic Matter	Total Phos. p.p.m.
			Ca	Mg	Na	K				
	Inches	--------me./100 g. of Soil------								
			Nardin-like No. 1							
Ap	0-9	8.8	3.3	3.2	-	0.3	5.7	4.7	1.12	39.6
A2	9-12	9.5	6.2	3.2	-	0.1	6.5	5.0	.94	26.4
B21t	12-32	30.3	21.4	14.0	2.2	0.4	7.0	5.5	1.25	52.8
B22t	32-36	30.1	19.3	10.1	2.8	0.2	7.7	6.1	1.20	64.1
B31	36-42	29.7	29.2	15.9	2.9	0.2	8.3	6.9	.82	79.2
B32	42-64	25.9	17.6	13.0	2.9	0.2	7.8	6.8	.44	67.1
C1	64-76	23.3	15.3	10.2	3.0	0.2	7.5	6.5	.27	45.2
C2	76-106	20.1	12.7	8.5	2.6	0.2	7.1	5.9	.15	36.6
			Nardin-like No. 2							
Ap	0-9	7.4	3.6	2.9	-	0.4	5.8	4.9	1.55	60.3
A2	9-13	6.0	3.2	2.4	-	0.2	6.7	5.6	.51	26.0
B21t	13-31	25.0	15.6	8.1	0.7	1.1	6.8	5.7	.89	62.2
B22t	31-38	24.6	14.0	7.0	0.9	1.1	7.4	6.2	.63	95.8
B31	38-45	23.6	14.0	8.4	0.9	1.1	7.6	6.4	.50	151.6
B32	45-54	23.4	15.0	7.9	0.9	1.1	7.7	6.5	.41	147.0
B33	54-64	24.0	16.0	9.6	1.0	1.3	7.8	6.5	.36	148.5
C1	64-74	24.5	14.4	8.0	1.0	1.3	7.9	6.6	.36	107.1
C2	74-106	21.1	11.7	6.3	.4	1.0	7.9	6.7	.31	50.9

TABLE V

CHEMICAL PROPERTIES OF WAURIKA SOILS

Horizon	Depth	Cation Exchange Capacity	Extractable Cations				pH with 1:1 Soil-Water Ratio	% Organic Matter
			Ca	Mg	Na	K		
	Inches	----------me./100 g. of Soil----------						
		Waurika No. 1 Jefferson County						
A1p	0-5	7.6	4.4	1.6	0.1	0.4	6.6	1.19
A12	5-10	10.2	6.4	2.5	0.1	0.2	6.8	.98
A2	10-14	11.3	6.4	3.0	0.2	0.2	7.1	.72
B21t	14-24	25.1	15.3	9.3	1.5	0.5	7.4	.81
B22t	24-33	24.2	15.7	10.0	2.8	0.4	7.7	.78
B3	33-39	23.9	20.1	10.6	4.5	0.4	8.3	.57
B3ca	39-44	18.5	16.2	8.5	4.3	0.3	8.3	.35
C1	44-59	15.6	12.7	6.7	3.6	0.3	8.3	.14
C2	59-68	16.8	11.5	6.1	3.0	0.3	8.5	.02
C3	68-78	15.7	--	--	2.6	0.2	9.2	.05
		Waurika No. 2 Cotton County						
A1p	0-6	9.4	6.1	2.0	0.1	0.4	5.9	1.28
A12	6-10	12.9	8.6	3.4	0.5	0.3	6.6	1.26
A2	10-12	14.8	8.8	3.6	0.8	0.2	7.0	1.00
B21t	12-24	33.8	22.0	12.0	4.2	0.5	7.3	1.15
B22t	24-32	28.9	24.2	10.9	5.4	0.4	7.8	.76
B3ca	32-39	25.2	28.4	9.9	5.4	0.4	7.7	.43
C1	39-50	25.7	19.7	9.4	6.2	0.4	7.8	.29
C2	50-57	24.7	17.0	8.8	6.1	0.4	7.9	.19
C3	57-72	23.1	13.9	7.5	5.2	0.4	7.8	.08

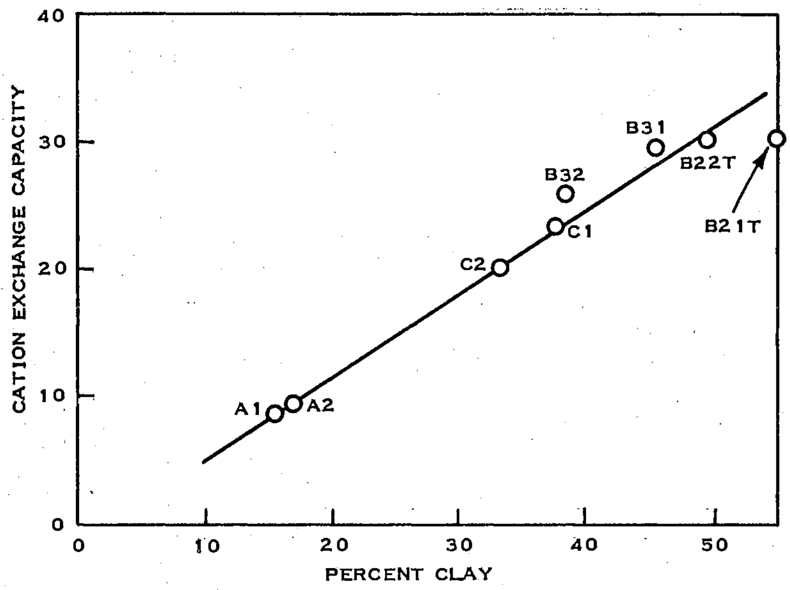

FIG. 10 – CATION EXCHANGE CAPACITY IN RELATION TO PERCENT CLAY FOR PROFILE OF NARDIN – LIKE NO. 1

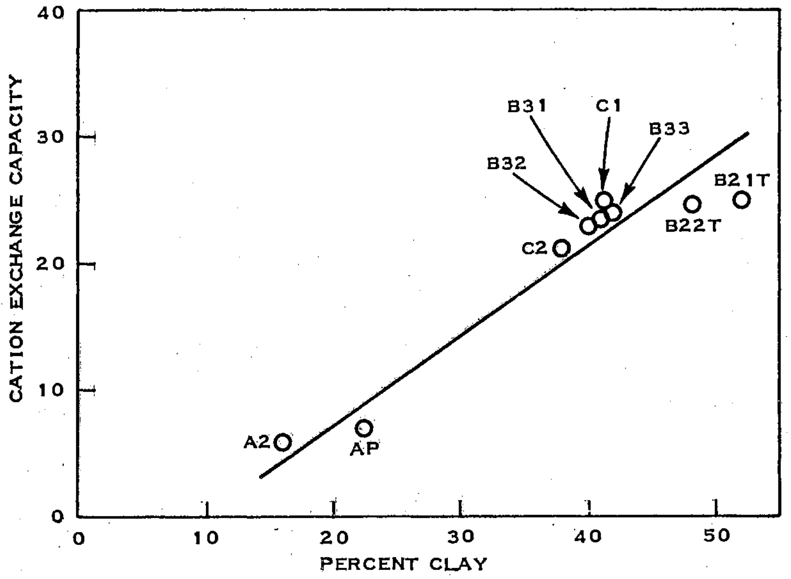

FIG. 11 – CATION EXCHANGE CAPACITY IN RELATION TO PERCENT CLAY FOR PROFILE OF NARDIN – LIKE NO. 2

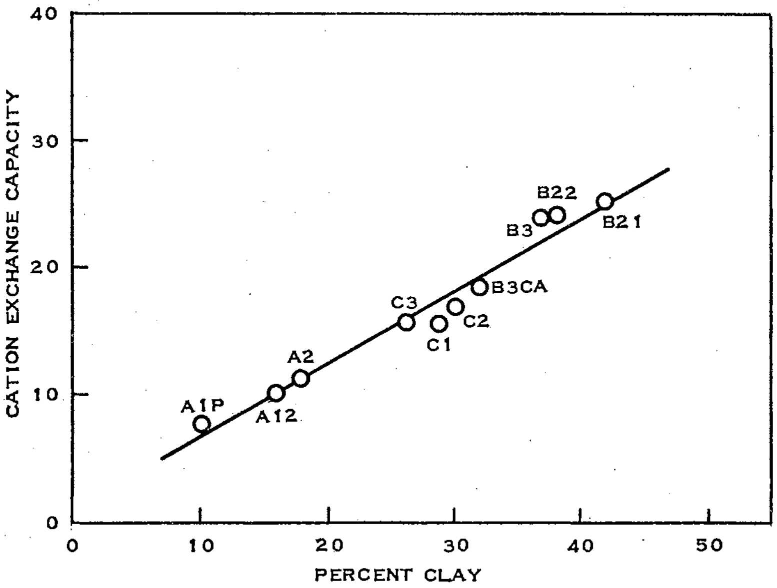

FIG. 12 – CATION EXCHANGE CAPACITY IN RELATION TO PERCENT CLAY FOR PROFILE OF WAURIKA NO. 1

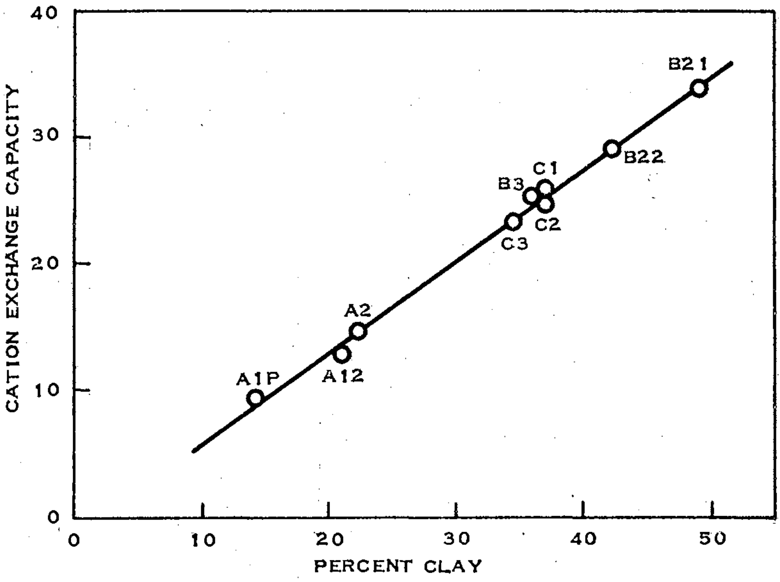

FIG. 13 – CATION EXCHANGE CAPACITY IN RELATION TO PERCENT CLAY FOR PROFILE OF WAURIKA NO. 2

Ca is the dominant cation of all pedons studied. The active forces of soil weathering are indicated by loss of Ca and Mg in the A horizons and accumulations in the B horizons. The Na and K content of the Waurika are slightly higher than the Nardin-like indicating a less intense weathering cycle in the Waurika. The A horizons of the Nardin-like soils have been leached of extractable Na. The decrease of K in the A2 horizons appears to be indicative of movement of dissolved or suspended soil materials from A2 to B horizons in these prairie soils. The base saturation is 77.3 percent for the Ap of the Nardin-like No. 1 and 100.0 percent or greater for the other horizons. The Nardin-like No. 2 has a base saturation of 93.2 percent for the Ap, 83.3 percent in the A2 while lower horizons have values which excel 100 percent. The base saturation of Waurika soils was greater than 85.5 percent in the A horizons and exceeded 100 percent in the B2t horizons.

Organic Matter

The distribution of organic matter in all four pedons has a distinct curve (Figures 14 and 15) unconforming to normal Reddish Prairie soils. Prairie soils have the highest organic matter content in the surface layer and a gradual decline of organic matter with depth (17, 44, 36.) The soils studied exhibit two maxima in organic matter content. The first is in the Ap and the second occurs in the clayey B21t horizons. The organic matter content is higher in the Ap horizons of all pedons except the Nardin-like No. 1. The secondary accumulation of organic matter in the 12 to 36 inch zone exceeds the content of the Nardin-like No. 1 A horizons. This secondary gain in organic matter

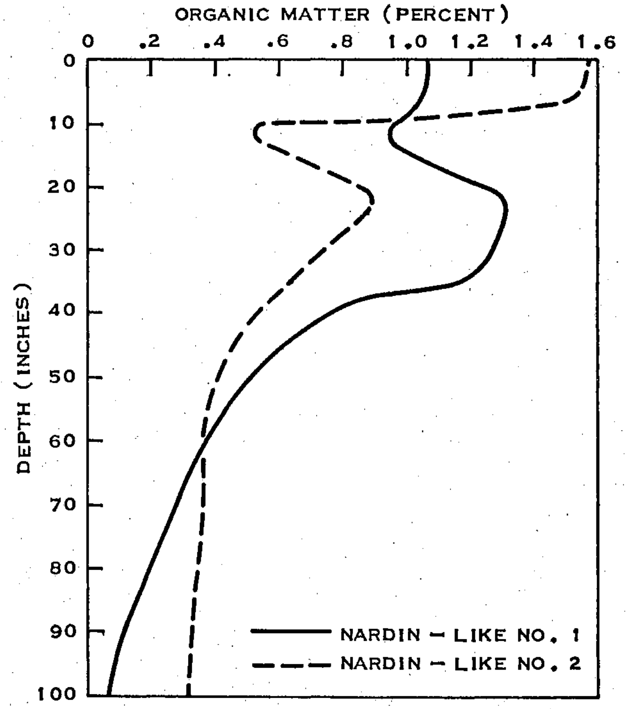

FIG. 14 – DISTRIBUTION OF ORGANIC MATTER WITH DEPTH IN NARDIN – LIKE SOILS.

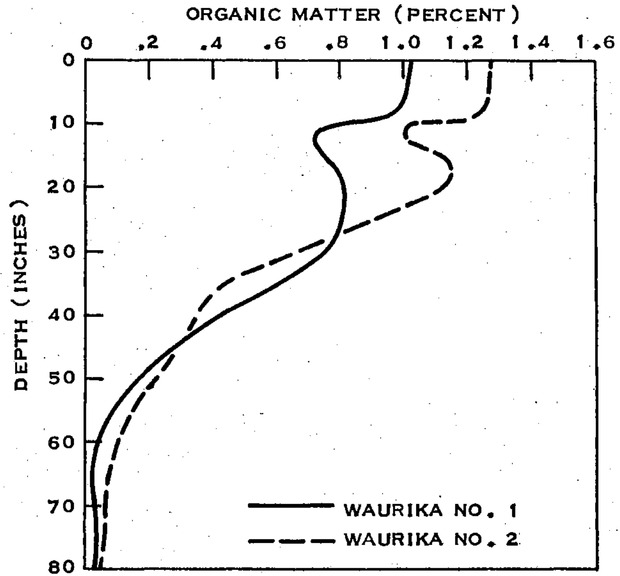

FIG. 15 – DISTRIBUTION OF ORGANIC MATTER WITH DEPTH IN WAURIKA SOILS.

in the illuviated B2t horizon is more characteristic of degraded prairie soils (45).

The Nardin-like No. 2 appears to have a more eluviated A2 horizon. The A2 horizon of this profile has the greatest loss of organic matter when compared to the above or below horizons. The thick B horizons of the Nardin-like No. 1 and Waurika No. 2 have greater gain of organic matter and clay content than the other pedons sampled. This higher organic matter content in the B21t and B22t horizons is suggestive of organic matter movement simultaneously with the translocation of fine clay. A close examination of the Nardin-like No. 1 in the sample pit showed distinct thin accumulations of dark colored material intermixed with lighter colored soil material on vertical ped faces. The organic matter content and particle size distribution suggest that these thin colloidal coatings on vertical ped faces are high in organic matter and that clay and fine silt largely comprise these coatings.

The average organic matter content of the upper 10 inches of each epipedon studied has greater than one percent organic matter required for a mollic epipedon. The Waurika has an organic matter content of .98 in the A12 horizon from 5 to 10 inches, however, the total combined upper 10 inches of the surface layer has greater than one percent organic matter and may thus qualify as a mollic epipedon.

Soil pH

The pH values of both Nardin-like soils are 0.1 to 0.5 lower than the Waurika soils. The pH values of the Waurika soils in the A horizons are only slightly more basic but the soil mass of the B horizon beginning at about 24 inches is calcareous in the Waurika. The

Nardin-like soils do not have calcareous soil mass in any horizon. Calcium carbonate concretions commonly occur below 30 inches in Nardin-like soils.

The pH data indicates that the Nardin-like soils have been subject to more loss of bases through leaching. The data also suggests the Waurika is developing under more xeric conditions. The depth to calcium carbonate concretions is a good indicator as to the depth which water moves in the profile. The calcareous soil mass occurred at about 24 inches in the Waurika, while depth to calcium carbonate concretions was about 31 inches in Nardin-like soils. These more alkaline to calcareous conditions in the Waurika, resulting from lower rainfall and higher evaporation, support more short grasses which return carbonates to the upper horizons. Shantz (34) reports that plant distribution is correlated with the depth below the surface of the layer of carbonate accumulations. Where this depth is less than two feet, he concluded, a plains-type vegetation predominates. Where this layer was about 30 inches or lacking entirely, a prairie type of grassland occurs. This indication of more abundant vegetation growth may have contributed to the slightly higher organic matter content of the Nardin-like soils.

The pH determined by 1:1 KCL ranged from .9 to 1.6 lower than the 1:1 H_2O method. The Nardin-like No. 1 has the largest decrease in the A2 and B horizons.

Phosphorous

The total phosphorous in the Nardin-like soils as given in Table IV is low. The amount of total phosphorous closely follows the depth distribution curve of organic matter. There is a greater loss in the

A2 than the Ap with a gain in the B horizons. The 36 to 42 inch horizon of No. 2 Nardin-like contain largest amounts of total phosphorous and both pedons have a gradual decrease below this depth.

Mineralogical Measurements

Cation Exchange Capacity of Clay

The total clay cation exchange capacity of the Nardin-like soils presented in Table VI shows an interesting relationship of percent clay, total soil CEC and clay CEC as a function of soil depth. The CEC of the soil increases directly in proportion to the percent of clay. The A horizons with low CEC have the lowest percent of clay and the B21t horizon with the highest CEC in both profiles has a corresponding highest value for percent of clay. The CEC of clay increases as the percent of clay in the profile increases; however, the maximum clay CEC occurs in the lower, less clayey horizons and remains rather uniform to a depth of 76 inches.

This somewhat different zone of high CEC increase may be due to translocation of fine clay to greater depth within the soil profile. As the clay size particles are translocated from the A to B horizon this data suggests that a larger amount of coarse clay is trapped in the B21t or upper B horizon and that the finer clays high in exchangeable cations tend to be more abundant in the lower B horizon. Fanning and Gray (7) in a study of Prairie soils showed that fine clays exhibit a higher exchange capacity than coarse clays. The percent clay, total soil CEC and clay CEC are lower in the A2 horizons of the Nardin-like No. 2 than either the above Ap horizon or the B21t horizon on which it

TABLE VI

IDENTIFYING CRITERIA FOR CLAY MINERALS OF NARDIN-LIKE SOILS

Total Clay (2.0 Microns)

NARDIN-LIKE NO. 1

Horizon	C.E.C. m.e./100 g.	Ethylene Glycol Retention mg/g Total	Ethylene Glycol Retention mg/g Internal	% K_2O	X-Ray** Analysis	D.T.A.**
Ap	18.6	258.0	182.7	1.47	I*K	IK
A2	21.1	255.9	179.4	1.91	-	-
B21t	40.8	264.6	167.1	1.95	M/IK	MI
B22t	46.6	243.9	104.0	2.65	-	-
B31	56.5	249.9	119.5	2.76	-	-
B32	60.6	276.7	149.0	2.87	-	-
C1	52.3	252.9	132.8	3.35	-	-
C2	32.3	260.7	149.8	2.85	M/IK	MI

NARDIN-LIKE NO. 2

Horizon	C.E.C. m.e./100 g.	Ethylene Glycol Retention mg/g Total	Ethylene Glycol Retention mg/g Internal	% K_2O	X-Ray** Analysis	D.T.A.**
Ap	27.2	221.0	139.1	1.50	IK	IK
A2	17.0	124.6	79.6	6.35	-	-
B21t	37.0	236.5	91.2	3.15	M/IK	MI
B22t	55.4	227.1	127.8	3.15	-	-
B31	42.1	226.0	75.2	4.66	-	-
B32	45.5	243.5	118.9	5.33	-	-
B33	46.2	262.8	151.7	4.43	-	-
C1	41.6	240.7	72.8	3.70	-	-
C2	51.2	211.5	89.6	3.88	M/IK	MI

*I - Illite, M - Montmorillonite, K - Kaolinite

**X-ray analyses and D.T.A. by Dr. Charles Mankin, Geology Department, Oklahoma University.

rests. These lower clay CEC suggest that this horizon has lost much of the fine clay through eluviation and that micaceous clay minerals are in abundance. The ethylene glycol retention and K_2O data indicate that this eluvial horizon contains the greatest amount of micaceous material of all horizons sampled.

Non-exchangeable Potassium

Non-exchangeable potassium has been used by Mehra and Jackson (24) to estimate the content of illite or micaceous clay minerals. They used 10 percent K_2O content as representative of illite minerals.

The percent K_2O in the Ap horizons is much lower than amounts indicated by DTA, X-ray analysis and CEC of clay. Wilkinson and Gray (42) found highest non-exchangeable potassium in medium clay rather than fine clay. However, these A horizons high in coarse clay lack strong K_2O values characteristic for micaceous minerals. There is a suggestion that a significant portion of the illite or micaceous minerals of the Ap horizons have been partially stripped of potassium.

The K_2O values of the Nardin-like No. 1 are lower than the No. 2 site. This data is supported by higher CEC of clay and EGR values indicating site No. 1 having a higher percentage of montmorillonite. The high micaceous content of the No. 2 A2 horizon is quite evident. Below the A horizon the K_2O values for both sites correlate well with CEC of clay and EGR indicating relatively uniform horizons with no significant difference in clay mineralogy.

Ethylene Glycol Retention

The ethylene glycol data reflect clay minerals with high expanding lattice in both Nardin-like pedons. A comparison of the EGR values and the CEC of total clay in the 42-64 inch horizon of the Nardin-like No. 1 with the 54-64 inch of the No. 2 gives a suggestion as to depth of clay mineral translocation. These horizons have highest total EGR values and the clays have the greatest CEC values. Also the internal values of EGR are greater for these horizons. These greater values indicate that fine clay is translocated to considerable depth. EGR values suggest no significant changes in the clay mineralogy of these two pedons.

X-ray Diffraction

Total clay X-ray diffraction patterns of Ap B21t and lower C horizons of the two Nardin-like soils are not uniform. These X-ray patterns suggest increase in montmorillonite with increasing depth. This difference may be explained by translocation of fine clay, however, there is a suggestion of weathering montmorillonite with an increase in micaceous material or stratification of parent material.

Nardin-like No. 1

There is an indication of significant loss of soil constituents from the A horizon and accumulation in the B horizons or a strong suggestion of a thin mantle consisting of micaceous soil material high in silt overlaying the clayey argillic horizons. The Nardin-like No. 1 in Figure 16 shows strong maxima at 10.0, 5.0, 3.34 and 2.5A° which are indicative of micaceous material (illite). The 7.2 and 3.57A° diffraction maxima indicate kaolinite. Grim (13) has shown that

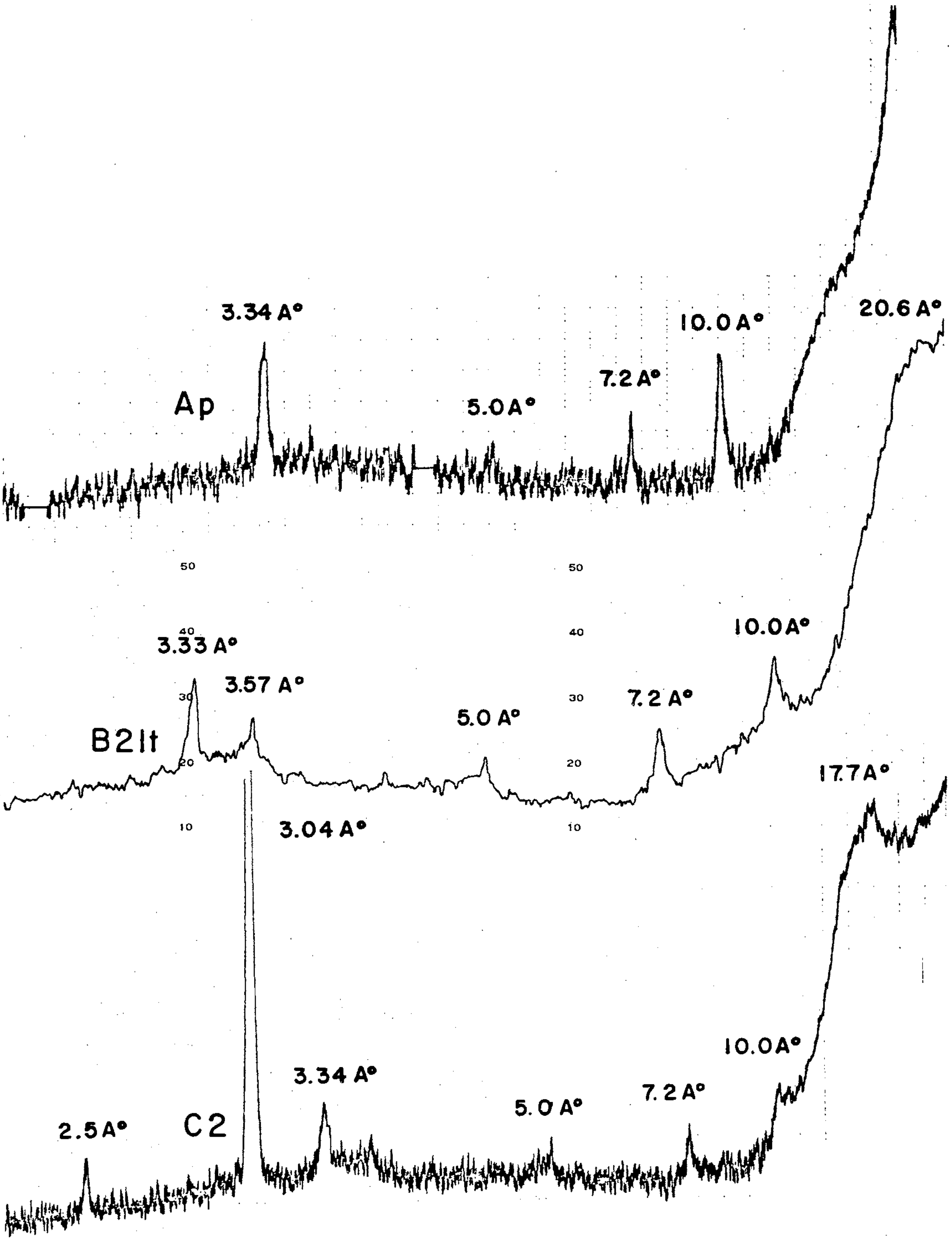

Fig. 16. X-ray Spectographs of Total Clay - Nardin-like No. 1

chlorite rich in iron gives weak first and third orders and strong second and fourth orders. This type of chlorite is difficult to distinguish from kaolinite.

The B21t is randomly crystallized as compared to the upper Ap horizon. The maxima at 10.0, 5.0, and 3.33A° for micaceous material are weaker than the Ap horizon. The rather broad maxima at 20.6A° suggest interstratified montmorillonite. Some difficulty was encountered in getting complete solvation or dispersion with glycerol which may have had an adverse effect on the characteristic montmorillonite maxima. The weak 7.2 and 3.57A° maxima suggest a small amount of kaolinite. This horizon contains highly interstratified clay minerals with the 2:1 lattice clay minerals prevalent. Montmorillonite is the more extensive clay mineral with illite occurring in significant amounts.

The lower C2 horizon has a good 17.7A° maximum for montmorillonite. There are weak micaceous maxima at 10.0, 5.0, and 3.34A°. The 7.2A° maximum suggests a small amount of kaolinite. This is the only layer having a strong 3.04A° calcite maximum. The sample contains a dominance of poorly crystallized montmorillonite interstratified with low order micaceous material.

Nardin-like No. 2

The X-ray diffraction patterns for the Ap, B21t, and C2 horizons of the Nardin-like No. 2 are given in Figure 17. The maxima for the Ap horizon indicate low crystallization of clay minerals. Due to the extremely strong calcite maximum at 3.03A°, the other maxima are of less magnitude than typical. The 10.0, 3.34, and 2.5A° reflect the major

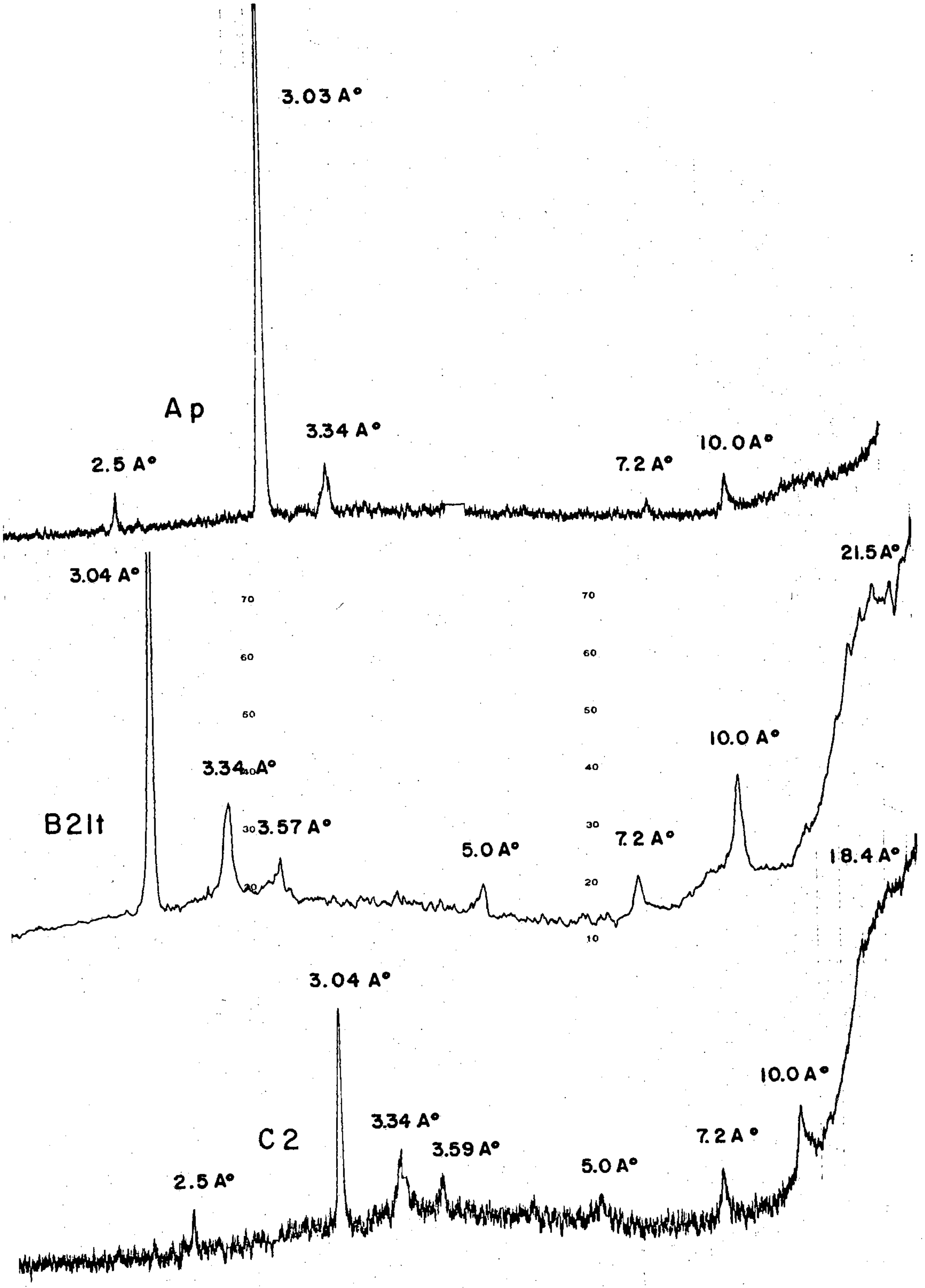

Fig. 17. X-ray Spectographs of Total Clay - Nardin-like No. 2

clay mineral to be micaceous (illite). The weak 7.2A° indicates occurrence of kaolinite. It is quite likely that the large amount of commercial fertilizer used by the farmer has some effect on the X-ray diffraction pattern to show less crystallized clay minerals than one would expect had no commercial fertilizer been used.

The B21t horizon pattern shows greater crystallization than the Ap horizon. Again there is a sharp calcite maximum at 3.04A° with other maxima at 10.0, 5.0, 3.34, and 2.5A° for micaceous clay minerals (illite). There is a broad maximum in the vicinity of 21.5A° for interstratified montmorillonite. Weak maxima at 7.2 and 3.57A° reflect a small amount of kaolinite. Illite and montmorillonite appear to be major clay minerals of this B21t horizon.

The C3 horizon shows characteristic maxima which are very similar to the B21t. The calcite maximum is less intense and the broad diffuse 18.4A° maximum suggests interstratification of montmorillonite with chlorite. This sample contains a dominance of poorly crystallized montmorillonite interstratified with poorly crystallized micaceous (illite).

Fine, Coarse, and Total Clay Comparison of B21t Nardin-like No. 1

A comparison of the B21t horizon X-ray diffraction patterns of the Nardin-like No. 1 in Figure 18 provides a keen insight to the relative proportions of montmorillonite in the total clay. Strong differences are noted in the degree of organization and kind of dominant clay minerals between the total, fine, and coarse clay.

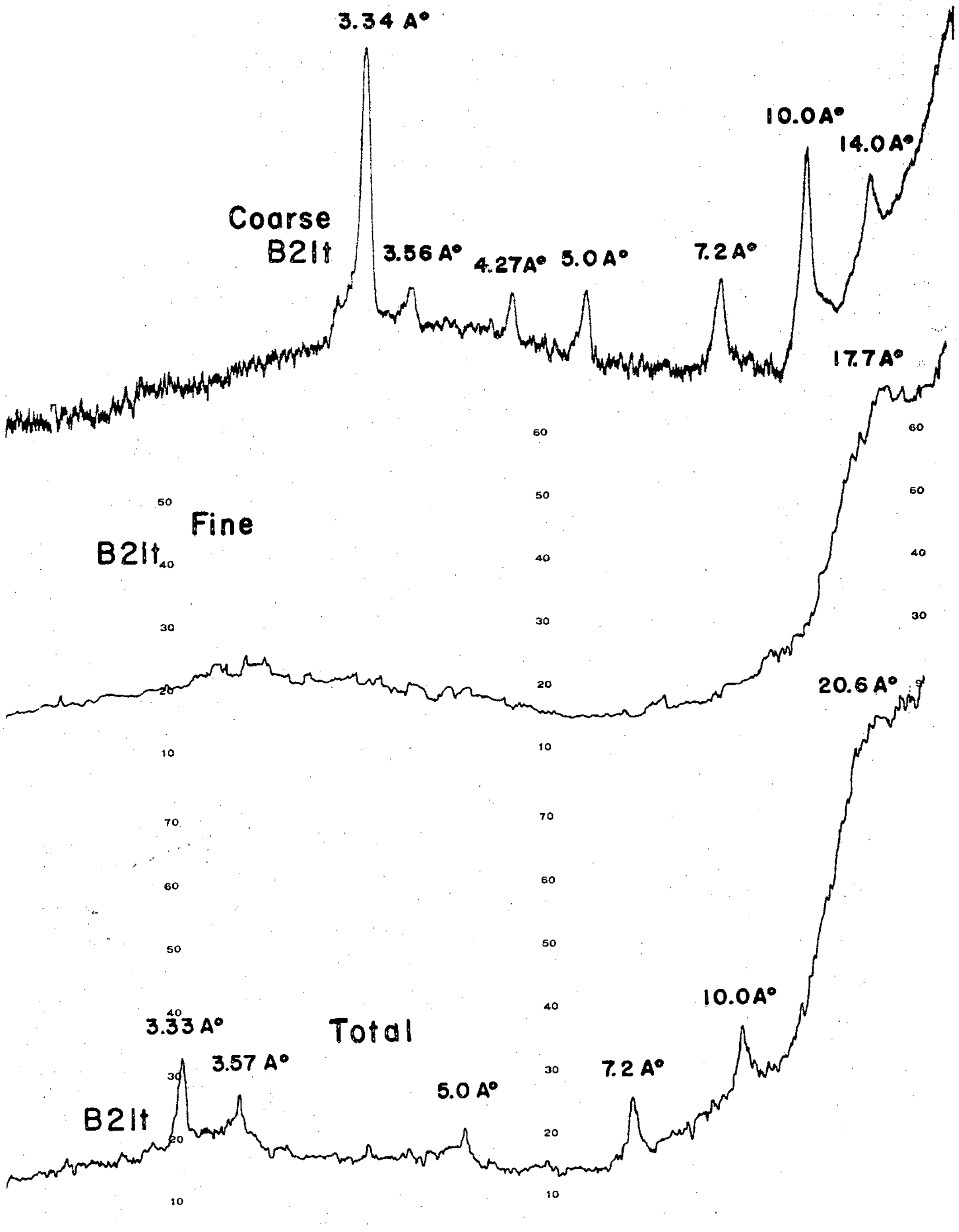

Fig. 18. X-ray Spectographs of Nardin-like No. 1 B21t Horizon Showing Coarse, Fine, and Total Clay

The diffraction maxima for the total clay are indicative of interstratified montmorillonite and micaceous clay minerals. The fine clay fraction shows the presence of randomly crystallized clay minerals with the broad 17.7A° maximum for Montmorillonite.

The coarse clay fraction consists of more crystalline clay minerals present than the fine clay as indicated by the stronger intensity of peaks. Chlorite at 14.0A°; micaceous material at 10.0, 5.0, and 3.3A° and kaolinite at 7.2 and 3.56A° are shown to be definitely more dominant in the coarse clay than the fine clay.

Figure 22 shows a sharp contrast in the DTA curves for the total, fine, and coarse clay. Weak endothermic reaction of the coarse clay at about 100° C. and only a slight one at 510° C. with a near straight line thereafter is strongly indicative of micaceous material (22). The fine clay shows extremely strong endothermic reaction at 130° C. and 510° C. for montmorillonite. The DTA curves of the total clay have a similar but less intense maxima than the fine clay. Considering that the fine clay comprised 85 percent of the total clay fraction suggests that montmorillonite comprises a large percent of the total clay fraction.

Fine, Coarse, and Total Clay Comparison of
C2 Nardin-like No. 1

The fine clay in Figure 19 is predominantly montmorillonite and shows no strong X-ray diffraction maxima for identifiable micaceous material. The strong X-ray diffraction maxima of coarse clay indicate the occurrence of chlorite at 14.0A, micaceous material at

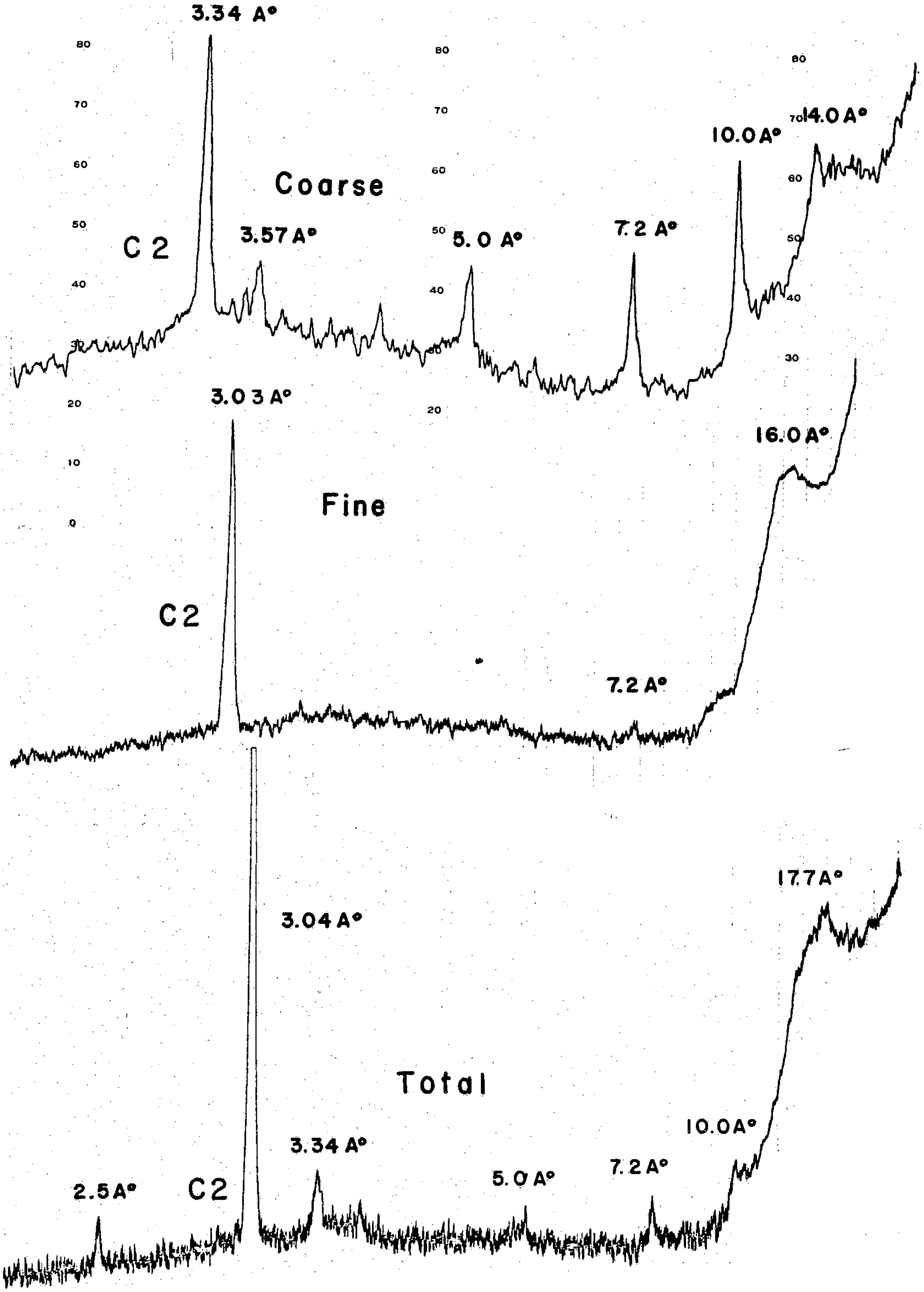

Fig. 19. X-ray Spectographs of Nardin-like No. 1 C2 Horizon Showing Coarse, Fine, and Total Clay

10.0, 5.00, 3.34, and 2.00A. The 7.2 and 3.57 are maxima for kaolinite. Total clay gives diffraction maxima which are diagnostic for montmorillonite interstratified with micaceous material and some kaolinite.

The DTA curves (Figure 23) further substantiate the X-ray diffraction data by the weak endothermic reaction at 110° C. and very weak 500° C. endothermic peak characteristic of coarse clay high in micaceous material. Fine clay has the most predominant exothermic reaction showing a greater amount of high expanding clay minerals. The characteristic curves for the total clay show a high amount of expandable clay minerals but less than the fine clay. Gray, Reed, and Mothan (12) in a study of clay formation and accumulation in Oklahoma soils concluded that montmorillonite is prominent in the fine clay fractions and most of the kaolinite and vermiculite are restricted to the coarse clays.

X-ray Diffraction of Waurika Soils[1]

The coarse clay fraction of the Waurika A12 horizons contains diffraction maxima for vermiculite, mica and kaolinite. The asymmetry of these diffraction maxima suggest well crystallized clay minerals in the coarse clay fraction. The fine clay of these surface horizons shows an assemblage of poorly crystallized interlayered micaceous clay minerals.

The coarse clay of the Waurika No. 1 B21t horizon contains well crystallized illite, kaolinite, and randomly interstratified

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[1] The X-ray diffraction analysis of the Waurika soils were under the leadership of Dr. Lester Reed, Agronomy Department, Oklahoma State University.

montmorillonite. The coarse clay of the B21 horizon of site No. 2 is comprised of well crystallized micaceous, kaolin and montmorillonite minerals. The fine clay maxima of the Waurika No. 1 B21t horizon are largely montmorillonite with some interstratification of micaceous material as indicated by the rather broad diffraction maxima. Montmorillonite also comprises the dominant portion of fine clay in the B21t horizon of Waurika No. 2.

The coarse clay diffraction patterns of Waurika No. 1 C1 horizon indicate less crystallized micaceous material (illite) interstratified with montmorillonite and minor amounts of chlorite. The coarse clay of site No. 2 is largely interstratified micaceous material with well crystallized kaolinite. The fine clay X-ray diffraction pattern of the Waurika No. 1 C1 horizon is indicative of micaceous clay minerals heavy chloritized. The C3 horizon of the No. 2 site contains montmorillonite and a montmorillonite-mica randomly interstratified with chloritized fine clay.

Differential Thermal Analysis

The differential thermal analysis of the two Nardin-like soils shows similar clay minerals (Figures 20 and 21) except for the occurrence of calcite in the Nardin-like No. 1. The B21t horizon of the Nardin-like No. 1 is higher in expanding clay minerals. Higher cation exchange capacity, ethylene glycol retention and lower K_2O values indicate the Nardin-like No. 1 to have more montmorillonite in the B horizon. A comparison of the lower C horizons shows more expanding clay minerals and calcite in the Nardin-like No. 1. The characteristic 500° C. endothermic peak has been shown by Jackson (14) to be diagnostic

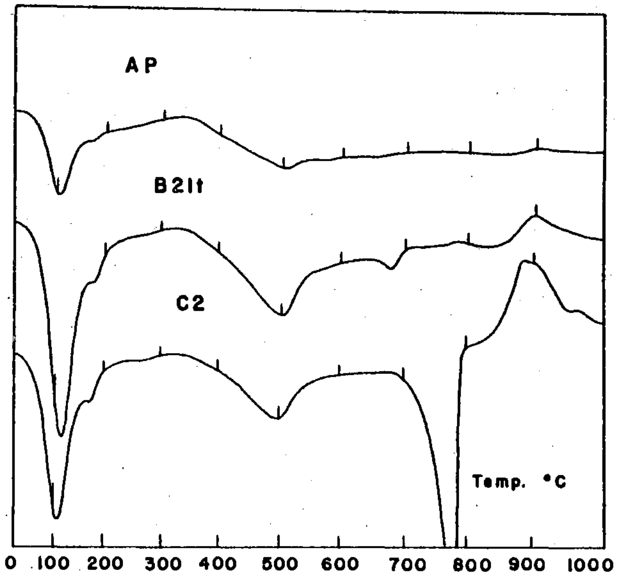

Fig. 20. Differential Thermal Curves for the Total Clay of Nardin-like No. 1

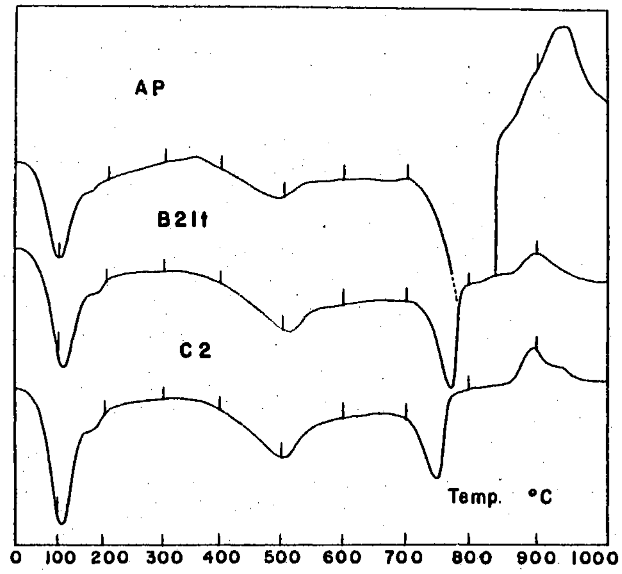

Fig. 21. Differential Thermal Curves for the Total Clay of Nardin-like No. 2

of nontronite. Figures 22 and 23 display fine clay to be dominant and higher in montmorillonite than either coarse clay or total clay in the B21t and C2 horizons of the Nardin-like No. 1.

Wellington Formation Studies

Location, Site No. 1

Weathered and only slightly altered or unweathered dark colored clays and shales were collected at this site. The site forms part of a north facing escarpment between the topographic high which contains the level Tabler and Nardin-like soils to the south and the alluvial soils of the Chickasha River to the north. Legal location is about 1900 feet North of NW corner Sec. 24, T. 28 N., R. 1 W.

Location Site No. 2

This site includes a northeast facing escarpment of a topographic high southwest of Tonkawa, Oklahoma. Samples of weathered and unweathered material were collected in the vicinity of a shale pit 2000 feet north of SW corner Sec. 31, T. 25 N., R. 1 W.

Physical and Chemical Analyses

The lack of complete dispersion makes the comparison of particle size distribution (Table VII) between the Wellington formation and the C horizons of the Nardin-like soils difficult. The sand size fraction of the Wellington formation was primarily cemented shales and clays. The clay content of the No. 1 site is less than the No. 2 site. The fine silt is high in all four samples.

The cation exchange capacity of the weathered soil material of both sample sites was greater than the unweathered clays and shales of

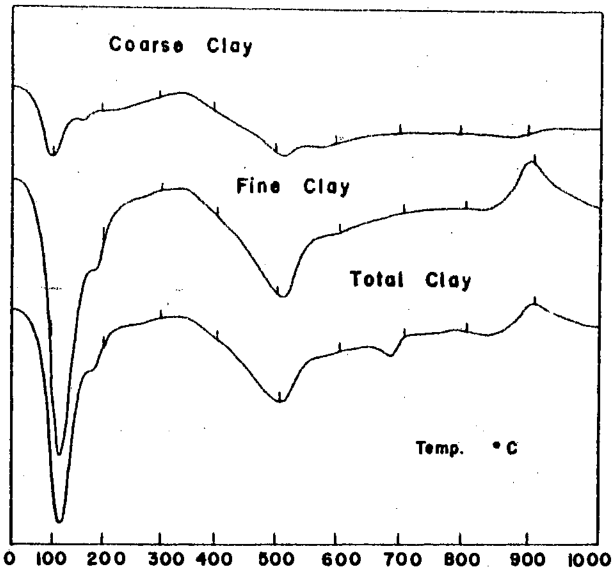

Fig. 22. Differential Thermal Curves for Coarse, Fine, and Total Clay of B21t Horizon of Nardin-like No. 1

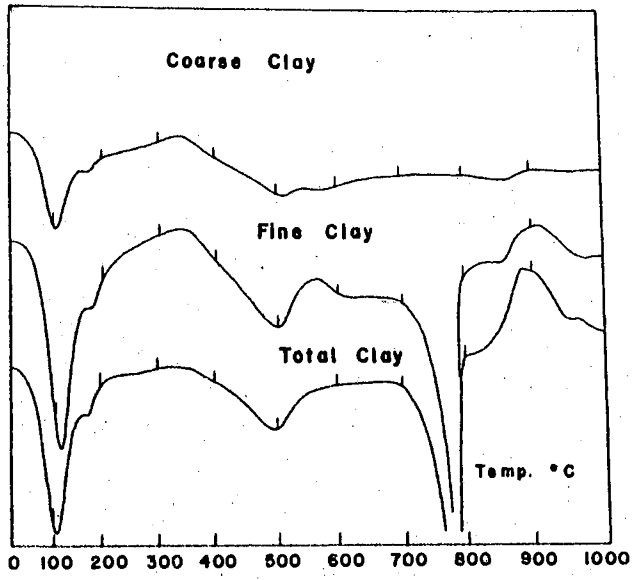

Fig. 23. Differential Thermal Curves for Coarse, Fine, and Total Clay of C2 Horizon of Nardin-like No. 1

TABLE VII

ANALYSIS OF WELLINGTON FORMATION SAMPLES

PARTICLE SIZE DISTRIBUTION

Site No.	Very Coarse Sand 2-1 mm.	Coarse Sand 1-.5 mm.	Medium Sand .5-.25 mm.	Fine Sand .25-.1 mm.	Very Fine Sand .1-.05 mm.	Coarse Silt .05-.02 mm.	Fine Silt .02-.002 mm.	Clay .002 mm.
No. 1 Weathered	--	2.4	7.1	13.8	8.1	8.3	26.9	33.4
No. 1 Unweathered	.1	1.9	4.9	10.2	5.9	9.0	39.6	28.3
No. 2 Weathered	--	.5	2.1	5.7	3.8	5.3	39.3	43.3
No. 2 Unweathered	--	4.2	8.2	9.8	5.2	4.2	26.3	41.9

CHEMICAL MEASUREMENTS

Site No.	Cation Exchange Capacity	Extractable Cations Ca	Mg	Na	K	% Organic Matter	pH with 1:1 Soil-Water Ratio	pH with 1:1 Soil-Kcl Ratio
	--------m.e./100 g. of Soil---------							
No. 1 Weathered	20.84	22.4	13.7	.19	.49	.48	7.9	6.8
No. 1 Unweathered	17.30	7.8	15.7	.09	.49	.24	8.0	6.8
No. 2 Weathered	20.97	24.9	13.7	.09	.82	.51	8.0	6.9
No. 2 Unweathered	17.57	15.1	18.5	--	.60	.41	8.1	6.9

MINERALOGICAL MEASUREMENTS

Site No.	C.E.C. m.e./100 g.	Ethylene Glycol Retention-Total	% K_2O	X-ray Analysis**	D.T.A.**
No. 1 Weathered	27.7	111.6	4.74	I/C M*	IM
No. 1 Unweathered	27.7	114.4	4.59	I/C	IM
No. 2 Weathered	25.0	108.2	6.01	I/C	IM
No. 2 Unweathered	26.3	89.4	2.75	I/C M	IM

*I - Illite, C - Chlorite, M - Montmorillonite

**X-ray Analysis and D.T.A. by Dr. Mankin, Geology Department, Oklahoma University the Wellington formation. The cation exchange capacity of the total clay shows no significant difference between the weathered and unweathered clays and shales. This suggests that the higher cation exchange capacity of the weathered material may be due to the increase of organic matter.

There is a definite trend in the amounts of exchangeable calcium and magnesium between the weathered and unweathered material. Calcium and magnesium are the dominant exchangeable cations. The weathered clays and shales of both sites have more exchangeable calcium and the unweathered clays and shales have the greater percentage of magnesium. The pH values are quite uniform in all samples with values ranging from 7.9 to 8.1 for 1:1 water and 6.8 to 6.9 for 1:1 KCL.

Mineralogical Analyses

The predominant clay minerals of these Wellington clays and shales are illite and chlorite with some indication of interstratified montmorillonite (Figures 24 and 25). This data suggests no trend or difference between the unweathered and weathered Wellington formation. The cation exchange capacity of the total clay reflects a high micaceous content and is supported by low ethylene glycol retention and high K_2O values.

Genesis of Nardin-like Soils

Field studies suggest the processes of soil formation are functioning on a relatively stable level to concave surface. Penck's (28) study of geomorphic landscapes postulates that slopes of an eroding upland retreat parallel to themselves. He concludes that a soil

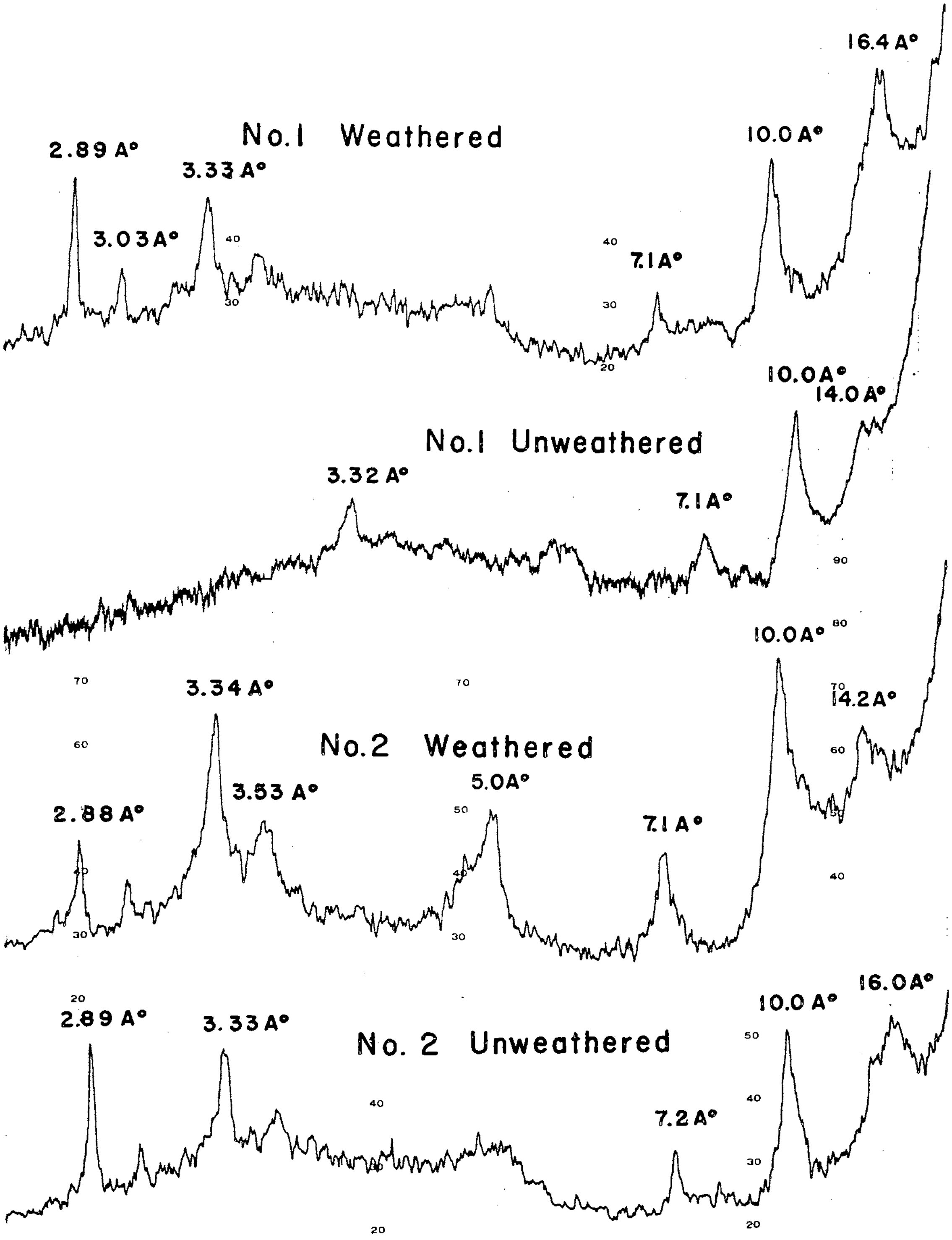

Fig. 24. Total Clay X-ray Spectographs of Wellington Formations Samples

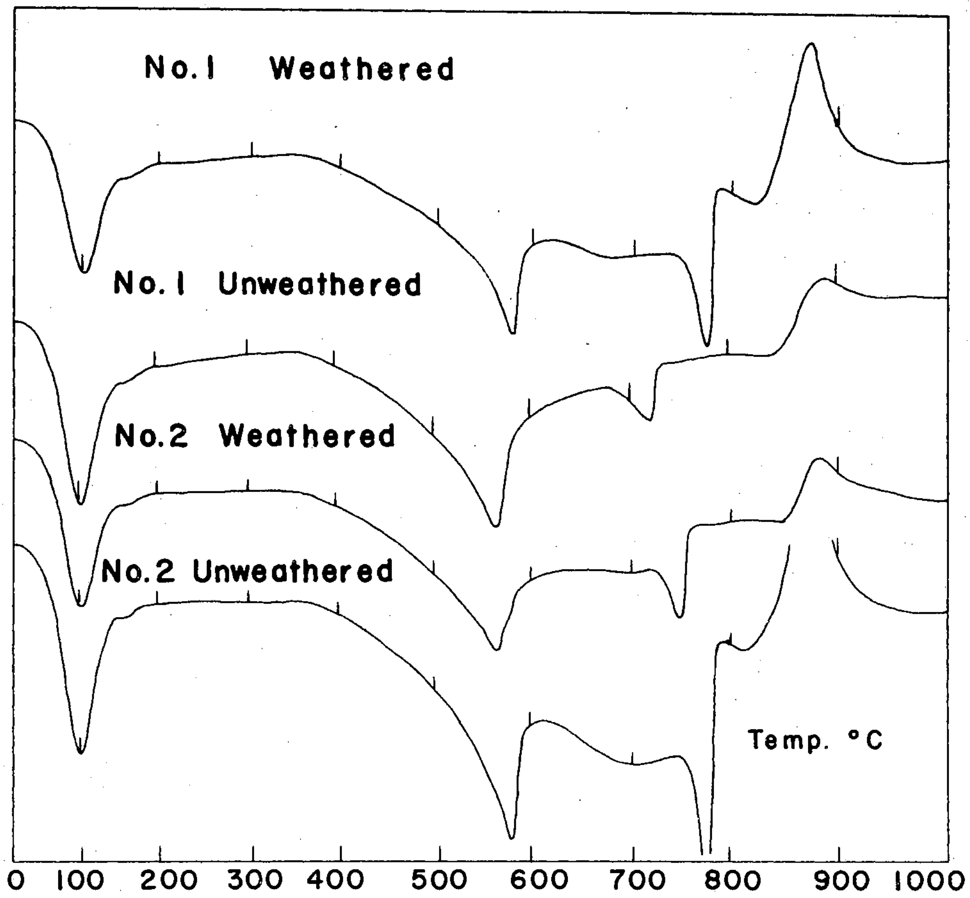

Fig. 25. Differential Thermal Curves for Total Clay of Wellington Formation Samples

does not reach a stage of equilibrium with geologic down-wearing, but that it continues to change in time to an older and older product until the retreating slope destroys it. Frye and Leonard's (9) regional study on origin of loess in Kansas disclosed the topographic position of loess on an extensive divide area included the highest elements in local topography.

A general hypothesis on the soil genesis of the Nardin-like soils would thus assume that they are not in equilibrium with their environment but are continuously aging slowly and ultimately will be catastrophically destroyed by retreating slopes of geological down-wearing.

A study of morphological, physical, chemical, and mineralogical data reveals two scientific models explaining the origin of Nardin-like soils. These models are built on the research of this problem and the theories it inspires (1).

The first approach in Model 1 (Figure 26) is based on a geomorphically stable landscape with the Nardin-like solum being developed in thick Post-Permian materials which have been deposited over the older eroded Wellington formation land surfaces. The minimal state of soil development begins with a calcareous to alkaline clay loam slightly interstratified with sandy loam to clays. This stage of soil genesis assumes no losses or gains. The prairie vegetation in the minimal stage of soil development enhances the addition of organic matter and aggregation of surface layer to commence the evolution of a mollic epipedon. The high carbonate content of the parent material acts as an inhibitor in the leaching of bases and weathering of silicate clay minerals. Percolating water moving through the solum transfers

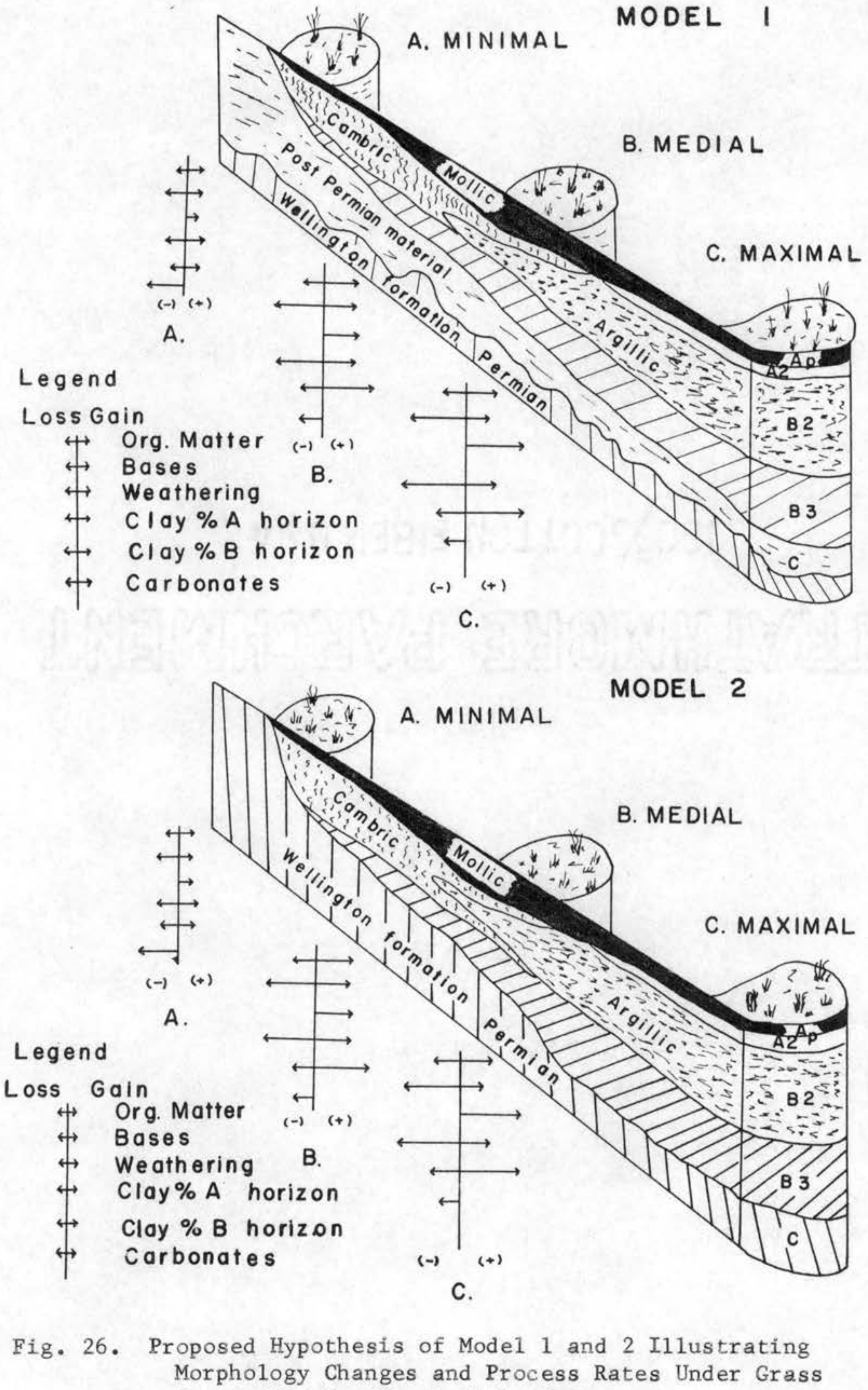

Fig. 26. Proposed Hypothesis of Model 1 and 2 Illustrating Morphology Changes and Process Rates Under Grass Vegetation for Nardin-like Soils

some bases to the depth of water movement. A weak cambic horizon high in bases containing little if any more clay than the mollic epipedon dominates this first stage of soil genesis. The recycling of bases by grasses contributes to a predominantly alkaline surface layer.

As the soil leaves the minimal stage and approaches a medial stage, the cambic horizon reaches its maximum thickness. The continued accumulated effects of grasses is denoted by the friable, dark colored mollic epipedon high in organic matter. Leaching of bases leaving a slightly acid to neutral mollic epipedon hastens the rate of weathering. As bases are leached downward weathering increases. Desiccation of the solum produces deep vertical cracks. The translocation of inherited fine clay is physically moved down the numerous pores and channels provided by the fibrous grasses and desiccation cracks to form an enriched clay zone or the beginning of an argillic horizon. The next successive stage of development, maximal, is strongly encouraged by the level relief which indirectly influences a more humid micro-climate. The loss of bases and lowering of pH accelerates soil weathering in the surface layer. Eluviation of clay and silt, especially fine clay with subsequent strong gains in the argillic horizon, characterizes the maximal stage. As the fine clays plug up the small pores and channels there is a build-up in the lower argillic horizon and the argillic horizon tends to move upward. The thickness of the surface layer decreases as more clays are translocated to the argillic horizon. When the argillic horizon increases in clay, the permeability rate becomes very slow and the percolation of water downward through the profile is severely restricted. This very slow percolation rate holds the water near the surface creating a more humid environment (microclimate) which accelerates soil weathering. A light colored A2 horizon is formed and the once dark, organic rich mollic epipedon becomes lighter in color and loses much of its organic matter to the upper argillic horizon. The structure of the argillic is more massive and the illuviation of largely fine clay from the A horizon high in montmorillonite produces many cracks throughout B horizons during occasional periods of desiccation. Following heavy rains, soil material of the light colored A2 and Ap moves downward in a colloidal suspension with water leaving light colored silty coatings (neoskeletons) on ped faces deep in the solum. The surface layers lose the granular structure and may not have enough organic matter to qualify as mollic epipedon. Properties of the order Alfisol become more prevalent in the maximal stage.

Model 2 (Figure 26) is based on the assumption that the Nardin-like soils are formed on a relatively stable geomorphic landscape in residum from the Wellington formation. Because of more clayey calcareous parent material it would be anticipated that a longer time would be required for the development of the maximal stage. The relative rates of losses, gains, transfers, and translocations under grass vegetation can be assumed to develop along the same path as Model 1. This hypothesis would intimate the C horizon having properties similar to the Wellington formation with increasing dissimilarity in the agrillic and epipedon horizons.

Distinct differences in clay mineralogy and particle size distribution indicate that Nardin-like soils developed in thick soil material deposited over the older irregular Wellington surface as discussed in Model 1. The cation exchange capacity of the total soil, exchangeable cations, and pH in the C horizon of the Nardin-like soils as compared to the Wellington formation samples show a close relationship. However, the ethylene glycol retention, K_2O, cation exchange capacity of clay, X-ray diffraction and differential thermal analysis show a well-marked difference in clay mineralogy. The Wellington formation samples are dominantly micaceous (illite) and chlorite while the C horizons of the Nardin-like soils indicate interstratified montmorillonite and illite. The near absence of quartz grains in the Wellington formation samples and presence of quartz grains throughout the Nardin-like soils further support this hypothesis.

The assumption that the Nardin-like soils have developed in place would indicate a significant change of clay mineralogy during the processes of soil formation from the parent material. The high base saturation of the Wellington formation is not receptive to weathering or transformations of clay minerals. Previously related clay mineralogical studies of Permian Redbed soils (15, 20, 26) suggest no significant changes in clay mineralogy due to weathering.

The rather uniform clay mineralogical data between the C and B horizons suggest that these horizons have formed in similar materials. The high illite content of the A horizon may be associated to a more recent depositional deposit. However, the data strongly suggests that this difference of clay mineralogy, particle size distribution, pH and cation exchange capacity is due to physical translocation of silicate clays, mainly fine clays from the A horizons to the argillic horizon.

This loss of clay from the A horizons could well account for the high silt content of the Ap and A2 horizons.

The quantitative and qualitative data of this study indicate that the various rates of losses, gains and transfers proposed in Model 1 are realistic.

Physical, chemical, and mineralogical properties indicate similar polygenetic processes for both the Nardin-like and Waurika soils.

Soil Classification by 7th Approximation

The classification of the Nardin-like and Waurika soils by the June, 1964, Supplement of the 7th Approximation shows these soils as intergrades between Mollisols and Alfisols.

CHAPTER V

SUMMARY AND CONCLUSIONS

Grayish-colored soils having clayey B2t horizons occur intermittently on level landscapes among extensive reddish to brownish soils in the Reddish Prairie zone. Four profiles, two Waurika and two of the proposed Nardin series were studied morphologically and by physical, chemical, and mineralogical determinations.

These somewhat poorly-drained soils have thin Ap horizons high in silt; especially coarse silt, with high value, low chroma, silty, massive A2 horizons and abrupt A2-B2t horizon boundaries. Clay content of argillic horizons ranges from 55 to 42 percent, with fine clay dominant. The soils have high base status with calcium and magnesium the dominant cations. A secondary maximum of organic matter accumulation occurs in the B2t horizons.

Surface horizons have lost clay, fine silt, organic matter, and carbonates, to the argillic horizons. Cation exchange capacity and ethylene glycol retention of clay suggest inherited fine clays are physically translocated down deep verticle cracks in the solum following desiccation periods. X-ray diffraction, differential thermal and K_2O analysis show surface layers to be highly illitic and argillic horizons to be interstratified montmorillonitic and illitic. Coarse clays are dominantly illitic and fine clays montmorillonitic.

The Nardin-like and Waurika soils have developed from similar pedogenic processes. Two scientific models created based on studies of the Nardin-like soils and the underlying Wellington formation suggest Nardin-like soils formed from Post-Permian sediments.

These soils are intergrades between Mollisols and Alfisols. The properties of the Nardin-like and Waurika pedons were similar except for slight differences. The A and B horizons of the Nardin-like soils have lower chroma, lower pH values, and higher organic matter contents. Carbonates have been leached to greater depths in Nardin-like soils. The Nardin-like soils have more silty A horizons, more clayey, faintly mottled B horizons and contain less sand throughout their solum. Waurika soils have B3ca horizons which Nardin-like soils lack and have a stronger grade of blocky structure in the B2t horizons.

Although slight differences were recognized in the properties of Nardin-like and Waurika pedons it is concluded from the data obtained that little justification exists for maintaining separate series for Nardin-like and Waurika as classified in Oklahoma. Pedons similar to those studies cannot be accurately classified by the definitions that presently exist in the 7th Approximation (37) because it is difficult to place in correct order, the first category. These soils can be classified as Planosols (45).

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