CHARACTERISTICS OF SODIC SOILS IN A TOPOGRAPHIC SEQUENCE IN STILLWATER, OKLAHOMA

By

GHAZI MALEH MUTTER

Bachelor of Science

University of Baghdad

Baghdad, Iraq

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Thesis Approved:

Fenton Gray
Thesis Adviser

John F. Stone

Lester W. Reed

Norman N. Durham
Dean of the Graduate College

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CHAPTER I

INTRODUCTION AND LITERATURE REVIEW

"Sodic soils", "Slick spots", "Alkali spots", and "Solonetz" are different names of soils affected by excessive exchangeable sodium. The domination of exchangeable sodium on the soil complex has a marked influence on the soil characteristics which leads to limit the land uses for both agriculture and engineering purposes in wide areas in the world. Alkaline soils usually contain approximately 15% or more exchangeable sodium and have a pH of 8.4 or more (Richards, 1954).

The purposes of this study were: (1) to relate the topographic sequence as one of the soil-forming factors to the morphology, physics, and chemistry of soils in the Stillwater Creek area; (2) to classify these soils accurately by Soil Taxonomy (Soil Survey Staff, 1975); and (3) to evaluate the interpretations of these soils for suitability potentials for both agricultural and engineering uses.

Many researchers have dealt with sodic soils and their characteristics in the U.S. and have explained the effect of exchangeable soidum on their properties. Norton and Bray (1929) reported that the exchangeable sodium is responsible for high pH values (8.0 to 9.1) and the poor physical conditions of these soils. Sodium replacement to the soil complex also affects the hydraulic properties of soils. Pupisky et al. (1979) found that the hydraulic conductivity of a sandy soil was very affected by the ESP in low salt concentration. Shainberg et al. (1971) evaluated

The relative effect of clay swelling and dispersion which caused by the sodium on soil permeability. They reported that the sodium caused clay dispersion in the soil which caused blockage of pores and permeability reduction in low ESP. Some of the engineering properties of soils are also affected by the high pH values of the alkali soils. Ramanof (1957) reported that the alkali soils were often very corrosive on buried metals. He found that the soils with pH value of 9.4 had the highest corrosivity. Sodium can also affect the soil structure because it causes the colloids to disperse and makes unfavorable structure for tillage, entry of water, and root development. Horn (1964) cited that the common structure in the sodium-affected horizons is prismatic or columnar. Kelly (1951) reported that the columnar structure through the profiles of some sodic soils belongs to the presence of the exchangeable sodium. White (1964) studied the morphological-chemical properties of solodized soils and reported that the sodium can be estimated in the B horizon from the morphology. The organic matter percentage in soils are also affected by sodium. The sodium replaces the other cations and saturates colloidal particles of the organic matter, forming sodium humates, which is easily leached deeper into the profile (Bakhtar, 1973). The salt-affected areas usually appear in the aerial photograph as an irregular spot, lighter than surrounding land due to the lack of vegetation.

Many researchers studied the sources of sodium in the sodic soils. Wilding et al. (1963) gave four possible sources of extractable sodium in Illinois solonetzic soils: (a) Pennsylvania bedrock, (b) calcareous/ or leached Illinoian till, (c) composite Farmdale and Peorian loess, and (d) ocean spray salts precipitated via rain. Ahi (1936) reported that the sodium sources in prairie soils in Arkansas due to the ground water seepage. Horn (1964) studied the main sources of sodium and magnesium in eastern Arkansas and said the probable sources for that are the primary minerals in loess. At the same time, he did not consider that weathering within the soil profile alone could lead to development of a sodic soil. Norton and Bray (1929) and Smith (1937) suggested the source of sodium is due to the interruption of leaching by impervious layers.

Many studies had been done in Oklahoma about formation of sodic soils. Plice (1947), Singh (1959), and Mehta (1954), in different projects, referred the formation of some sodic soils to the uneven erosion of the topsoil with an occasional exposure of saline-alkali subsoil. Other sodic soils are caused by "perched" water table above impervious soil horizon and the process of evaporation of water from the soil surface. They also reported that these soils occur in some places according to the soil parent materials of saline-saturated Permian and Pennsylvanian shales. Bakhtar (1973), in his study of sodic soils in North Central Oklahoma, concluded that the parent materials and external agents, such as wind and water, are responsible for sodium origin. Reinsch (1979) reported the existence of "slick spots" in many locations which have drainage and water movement problems. He compared many "slick spots" in Grant County and found that there were many differences between "slick spots" soils in morphological and chemical properties with the topography. Reed (1962) also noticed the differences between the "alkali-spots" themselves in locations, soluble salts, lime, and other characteristics. He also mentioned many soil series in Oklahoma that have "alkali-spots" as in Kirkland, Zaneis, Drummond, Renfrow, Vernon, Hollister, Foard, and Chickasha.

Many other projects discussed the reclamation of the sodic soils. All the reclamation studies concentrated on the problem of minimizing the time of reclamation by keeping high permeability during the time of leaching (Jury, 1979). Reeve and Bower (1960) suggested reclaiming of sodic soils with progressive dilutions of saline-irrigated water, which causes rapid leaching, but maximizes salt discharge. Prather et al. (1978) mentioned that the soil properties, amount of exchangeable Na^+ to be removed from the soil complex, and the cost of amendments have to be considered during the time of reclamation. He also suggested that in the reclamation of such soils, irrigation water can be added to the soil to provide the soil complex with some divalent cations (usually Ca^{+2}) to replace the sodium in the soil complex.

CHAPTER II

MATERIALS AND METHODS

Geography of the Study Area

The field study of this project is located in Section 21, T19N, R2W which is near Stillwater Creek in southwest Stillwater, Oklahoma near the intersection of Western and 19th Streets (Figure 1). The elevation of this area is approximately 260 m above sea level (Figure 2).

Relief and Locations

Pedon 1 is located on an occasionally-flooded floodplain about 410 feet north and 820 feet west of the southeast corner of Section 21, T19N, R2E. The area slope shapes are uneven micro convex, concave with less than 1% slope. Pedon 2 is located on an occasionally-flooded floodplain adjacent to the upland soils; about 100 feet north and 1160 feet west of the southeast corner of Section 21, T19N, R2E. Pedon 3 is located on an upland footslope with 7% slope adjacent to the floodplain, about 1600 feet west and 200 feet south of the northeast corner of Section 28, T19N, R2E. Pedon 4 is located on an occasionally-flooded floodplain. It is northeast of pedon 1, about 650 feet west and 780 feet north of the southeast corner of Section 21, T19N, R2E with slope less than 1%.

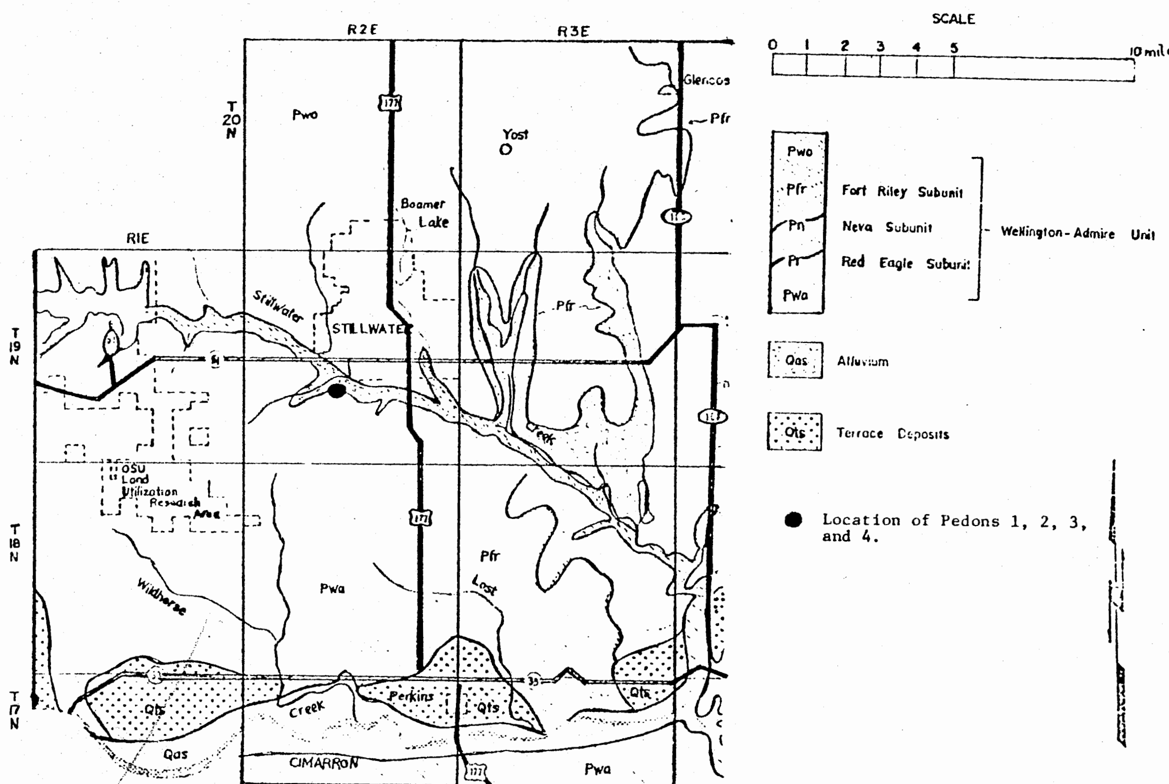

Figure 1. Location of Pedons on Geologic Units of Payne County

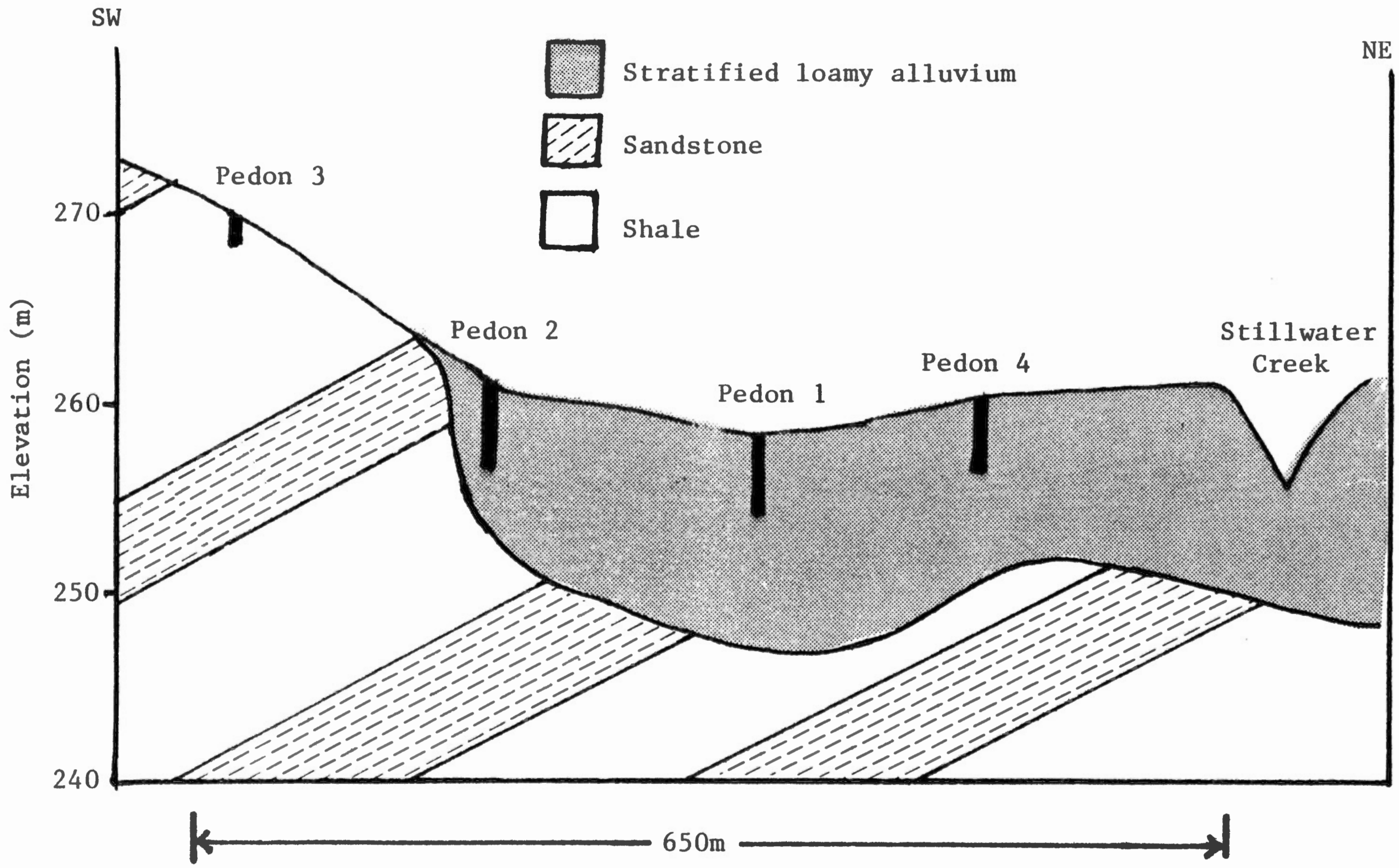

Figure 2. Diagrammatic Cross-section of the Study Area and Locations of Pedons

Geology

This area has soils of the Reddish Prairie Land resource area of Renfrow-Zaneis-Vernon Association (RZA) developed on red clays, shales, siltstones, and sandstones mostly of the Hennessy shale, Garber sandstone, and Wellington formation and alluvium derived from these formations (Figures 1 and 2). The bedrock of this area is of Permian geologic time (Gray and Galloway, 1959 and Hartronft, 1969).

Climate

This area is located in a moist, subhumid climate with a mean annual precipitation of 85 cm and an average annual potential evapotranspiration of 82.5 cm. The area is in the Ustic moisture regime. The mean annual temperature is 15.5°C to 16.1°C and is in the thermic temperature regime (Gray and Galloway, 1959, Gray and Bakhtar, 1973).

Natural Vegetation

Soils occurring in this area are in the western prairie plains developed under a native cover of tall grasses and cross timbers (Gray, 1959). Three of the four sites were cultivated in the past except the upland area of pedon 3. The present natural vegetation consists of a thin stand of Texas gummy dropseed (*Sporobolus texanus*) on pedon 1, a fair ground cover of little bluestem grasses (*Andropogon scoparius*) on the upland (pedon 3), and a good stand of bermuda grass (*Cynodon dactylon*) on pedons 2 and 4.

Methods

According to the topography variations, four profiles were studied in the area. The morphological properties of each horizon, such as depth, color, texture, structure, consistency, and boundary between horizons, were described in the field. About 2 kg soil samples from each horizon were collected for physical and chemical analyses. The samples were air-dried and sieved through a 2 mm screen. Air-dried, natural pedons from each horizon were used for mechanical analyses. The hydrometer was used to determine the clay in the suspension prepared by the procedure outlined by Black (1965). Soil pH was determined on a saturated paste with a Corning Model #7 pH-meter. The exchangeable Na^{+}, K^{+}, Mg^{+2}, and Ca^{+2} were extracted by leaching the soil samples with neutral 1N NH_4Ac, pH 7, and then measured by the atomic absorption spectrophotometry. Exchangeable H^{+} was removed by leaching the sample with $BaCl_2$-TEA, pH 8.0 and titrating with HCl (Peech et al., 1947). Cation exchange capacity (CEC) was determined by the procedure outlined by Bower et al. (1952). Electrical conductivity (EC) of the saturated extract was measured using YSI Model 31 Conductivity Bridge. Organic matter percentage was determined by a modified method of Walkley's rapid method and outlined by Richards (1954). Soluble salts were determined from a 1:1 soil/water extract. Soluble Na^{+}, K^{+}, Mg^{+2}, and Ca^{+2} were measured by the atomic absorption spectrophotometry. All anions were estimated as described by Richards (1954). Cl^{-} was measured by titration with silver nitrate. HCO_3^{-} and CO_3^{-2} were determined by titration with acid. SO_4^{-2} was measured by precipitating as $CaSO_4$ by 1N $CaCl_2$ in 1:1 soil/water extract and also in the saturated extract.

CHAPTER III

RESULTS AND DISCUSSION

According to topography, the four selected pedons are affected by the additions, removals, transfers, and transformations of both organic and inorganic soil materials during the time of formation. These processes caused many differences through the horizons, properties, and formation of these soils.

Pedons 1, 2, and 4 were developed in alluvium materials derived from red clay, shale, and sandstone parent materials, therefore, buried soils underlying these alluvium soils exist in depths of 155 to 163 cm. On the other hand, Pedon 3 is located on an upland area developed in shale materials. The 7% slope and the dominant soil texture enhances the surface runoff and the erodibility of the surface horizon and that increases removals and transfers of soil materials from this area.

According to data of the four pedons shown in Tables I, II, III, and IV, remarkable differences can be reported.

Pedon 1 (Table I)

This pedon is very affected by salt accumulation which can be noticed even in the field from the white salt crystals accumulated on the surface. Because of salt accumulation, vegetation was sparse and the surface horizon was light in color. Another possible reason for this light color is due to formation of sodium humates which are easily

TABLE I

DESCRIPTION, CHEMICAL, AND PHYSICAL ANALYSES OF PEDON 1

Profile Description: Fine-silty, mixed, thermic Typic Natrustalfs

Sample No.	Horizon	Depth (cm)	Color (moist)	Texture[1]	Structure[1]	Consistence[1]	Boundary[1]
80-OK-60-15-1	A11	0-13	5YR(4/4)	L	1csbk-1fgr	mfr	c
2	B1t	13-33	5YR(3/3)	SiCL	1cpl-1fgr 2msbk	mfi	c
3	B21t	33-81	2.5YR(3/4)	SiCL		mfi	g
4	B22t	81-127	2.5YR(4/4)	SiL	1cpr-1msbk	mfr	c
5	IIAb	127-147	5YR(3/2)	SiCL	1csbk-1fsbk	mfi	g
6	IIB23	147-211	5YR(4/4)	SiCL	1mpr-1msbk	mfi	c
7	IIB24	211-270	5YR(3/2)	SiC	1mpr-1msbk	mfr	g
8	IIB25	270-313	5YR(4/3)	SiCL	1mpr-1msbk	mfi	

Chemical Data

Horizon	pH[2]	CEC meq/100gm	Exchangeable Cations meq/100 gms Na^{+}	K^{+}	Ca^{+2}	Mg^{+2}	H^{+}	% Base Saturation[3]	% O.M.	ESP	EC25°C mmhos/cm[2]
A11	7.9	13.4	3.0	0.3	7.3	2.3	3.6	78.2	1.3	22.4	1.37
B1t	9.5	14.9	2.8	0.4	10.1	2.1	0.5	97.2	1.2	18.9	3.66
B21t	9.6	15.9	12.6	0.4	6.8	2.6	2.0	91.7	0.7	79.4	0.59
B22t	9.2	13.8	12.0	0.3	6.8	3.3	0.9	96.1	0.5	87.2	0.54
IIAb	8.4	23.6	11.6	0.4	7.7	7.0	2.3	92.1	1.5	49.0	0.34
IIB23	8.2	30.0	12.3	0.5	6.7	8.9	1.8	94.0	1.3	40.9	0.78
IIB24	8.0	30.8	7.0	0.5	18.6	9.6	2.5	93.5	0.9	22.8	0.86
IIB25	7.9	25.9	6.1	0.5	18.1	9.1	1.8	93.2	0.6	23.6	0.93

TABLE I (Continued)

Horizon	Soluble Salts (1:1) meq/100 gms								
	Na^+	K^+	Ca^{+2}	Mg^{+2}	Cl^-	CO_3^{-2}	HCO_3^-	SO_4^{-2}	SAR
A11	0.86	0.006	0.06	0.03	0.71	0.12	0.31	0.16	4.1
B1t	3.65	0.008	0.04	0.02	0.72	0.10	0.34	1.92	20.3
B21t	2.52	0.005	0.02	0.01	1.78	0.14	1.24	0.84	21.0
B22t	2.44	0.006	0.03	0.02	1.94	0.14	1.33	0.72	16.3
IIAb	1.46	0.003	0.06	0.03	1.14	0.14	0.56	0.24	6.6
IIB23	2.82	0.005	0.05	0.03	2.20	0.31	0.92	0.96	14.1
IIB24	1.41	0.004	0.05	0.04	0.95	0.01	0.65	0.56	6.7
IIB25	0.78	0.004	0.05	0.06	0.77	0	0.52	0.24	3.4

Physical Data

Horizon	% Gravel	Sand Subfractions %					------------%-----------		
		VCS	CS	MS	FS	VFS	Sand	Silt	Clay
A11	----	0.05	0.05	0.08	25.48	14.30	39.96	36.51	23.53
B1t	----	----	0.05	0.23	7.49	5.77	13.54	54.48	31.98
B21t	----	----	0.03	0.05	2.57	9.00	11.65	58.32	30.03
B22t	----	----	0.03	0.16	6.32	7.7	14.21	60.31	25.48
IIAb	----	0.08	0.08	0.13	2.91	9.75	12.95	56.37	30.68
IIB23	----	0.05	0.08	0.16	4.50	7.36	12.15	59.12	28.73
IIB24	0.03	0.55	0.05	0.08	4.29	5.28	10.28	48.02	41.73
IIB25	0.08	0.16	0.05	0.09	3.54	6.37	10.29	50.64	39.15

[1]Commonly used soil survey abbreviations (Soil Survey Staff, 1951).
[2]pH was determined in the saturated paste; EC in the saturated extract.
[3]Base saturation percentage calculated by the sum of exchangeable cations.

TABLE II

DESCRIPTION, CHEMICAL, AND PHYSICAL ANALYSES OF PEDON 2

Profile Description: Fine, mixed, thermic, Fluventic Haplustolls

Sample No.	Horizon	Depth (cm)	Color (moist)	Texture[1]	Structure[1]	Consistence[1]	Boundary[1]
80-OK-60-16-1	A1	0-25	5YR(3/3)	SiC	2msbk-2mabk	mfi	c
2	B21	25-99	2.5YR(4/4)	SiCL	1fpr-1fsbk	mfi	c
3	B22	99-163	2.5YR(4/4)	SiCL	1mpr-2msbk	mfr	c
4	IIAb	163-203	5YR(3/1)	SiCL	2mpr-2msbk	mfr	g
5	IIB23	203-317	2.5YR(4/4)	CL	1mpr-1csbk	mfi	c
6	IIC11	317-406	2.5YR(4/4)	L	---	mfi	-
7	IIC12	406-495	2.5YR(3/4)	CL	---	---	-
8	IIC13	495-584	2.5YR(3/4)	CL	---	---	-

Chemical Data

Horizon	pH[2]	CEC meq/100gm	Exchangeable Cations meq/100 gms Na^+	K^+	Ca^{+2}	Mg^{+2}	H^+	% Base Saturation[3]	% O.M.	ESP	EC25°C mmhos/cm[2]
A1	7.4	34.4	1.0	0.5	18.4	8.2	1.6	94.6	3.7	2.9	0.78
B21	7.5	18.2	1.3	0.3	12.6	10.2	2.0	92.4	1.0	7.2	0.76
B22	7.7	15.6	1.0	0.3	9.8	8.1	1.8	91.4	0.8	6.4	0.78
IIAb	7.7	29.0	1.4	0.4	8.4	13.2	2.7	90.0	1.6	4.7	0.80
IIB23	7.9	17.4	1.2	0.3	13.3	11.6	1.8	93.6	0.5	7.0	0.63
IIC11	8.0	12.7	1.0	0.2	15.6	7.6	1.6	93.8	0.4	8.2	0.76
IIC12	7.9	14.1	0.9	0.3	22.5	6.0	1.8	94.3	0.5	6.4	0.59
IIC13	7.9	15.0	0.9	0.3	17.4	5.5	1.8	93.1	0.4	6.0	0.59

TABLE II (Continued)

Horizon	Soluble Salts (1:1) meq/100 gms								SAR
	Na^+	K^+	Ca^{+2}	Mg^{+2}	Cl^-	CO_3^{-2}	HCO_3^-	SO_4^{-2}	
A1	0.52	0.015	0.46	0.30	0.84	0	0.52	0.20	.84
B21	1.57	0.017	0.42	0.91	1.51	0	0.72	0.96	1.93
B22	0.80	0.010	0.14	0.48	1.09	0.07	0.60	0.24	1.42
IIAb	0.50	0.006	0.12	0.24	0.65	0	0.40	0.20	1.19
IIB23	0.63	0.005	0.13	0.35	0.88	0	0.55	0.24	1.29
IIC11	0.60	0.005	0.14	0.29	0.80	0	0.52	0.20	1.28
IIC12	0.67	0.009	0.35	0.34	0.95	0	0.64	0.24	1.14
IIC13	0.82	0.018	0.38	0.48	1.15	0	0.70	0.4	1.25

Physical Data

Horizon	% Gravel	Sand Subfractions %					------------%----------		
		VCS	CS	MS	FS	VFS	Sand	Silt	Clay
A1	----	0.03	0.03	0.05	3.48	6.99	10.58	45.22	44.20
B21	0.13	0.08	0.05	0.10	6.43	11.40	18.06	45.24	36.70
B22	----	----	0.03	0.03	7.20	12.17	19.43	46.77	33.80
IIAb	----	----	0.03	0.05	6.12	12.48	18.68	49.60	31.72
IIB23	----	0.05	0.08	0.08	9.28	12.64	22.05	48.83	29.12
IIC11	0.21	0.05	0.05	0.10	8.15	22.06	30.41	42.76	26.83
IIC12	0.83	0.18	0.08	0.18	14.34	19.77	34.55	38.45	27.00
IIC13	0.03	0.08	0.08	0.34	6.79	22.31	29.60	39.84	30.56

[1]Commonly used soil survey abbreviations (Soil Survey Staff, 1951).
[2]pH was determined in the saturated paste; EC in the saturated extract.
[3]Base saturation percentage calculated by the sum of exchangeable cations.

TABLE III

DESCRIPTION, CHEMICAL, AND PHYSICAL ANALYSES OF PEDON 3

Profile Description: Fine, mixed, thermic; Vertic Haplustalfs

Sample No.	Horizon	Depth (cm)	Color (moist)	Texture[1]	Structure[1]	Consistence[1]	Boundary[1]
80-OK-60-17-1	A1	0-13	5YR(4/4)	L	2fgr	mfr	a
2	B2t	13-51	5YR(4/4)	CL	1fpr-3fabk	mvfr	c
3	B3	51-89	5YR(4/4)	SiCL	1csbk-1msbk	mvfr	c
4	C	89-97	2.5YR(4/4)	SiCL	shale structure	----	-

Chemical Data

Horizon	pH[2]	CEC meq/100gm	Exchangeable Cations meq/100 gms: Na^+	K^+	Ca^{+2}	Mg^{+2}	H^+	% Base Saturation[3]	% O.M.	ESP	EC25°C mmhos/cm[2]
A1	6.9	13.7	0.18	0.34	7.59	3.10	3.16	78.0	1.9	1.3	0.34
B2t	7.9	16.1	1.54	0.28	22.93	8.46	1.13	95.4	1.12	9.6	0.63
B3	8.2	20.6	6.84	0.29	20.39	12.64	1.58	96.2	0.45	33.2	2.54
C	8.3	12.7	6.93	0.27	18.15	11.89	2.03	94.8	0.5	54.6	3.41

TABLE III (Continued)

Horizon	Soluble Salts (1:1) meq/100 gms								SAR
	Na^+	K^+	Ca^{+2}	Mg^{+2}	Cl^-	CO_3^{-2}	HCO_3^-	SO_4^{-2}	
A1	0.15	0.02	0.14	0.18	0.58	0	0.32	0.16	0.38
B2t	0.86	0.01	0.14	0.22	1.275	0	0.76	0.32	2.05
B3	3.52	0.01	0.09	0.21	3.26	0	0.72	0.56	9.03
C	2.70	0.01	0.08	0.22	2.37	0	0.68	0.24	7.09

Physical Data

Horizon	% Gravel	Sand Subfraction %					------------%-----------		
		VCS	CS	MS	FS	VFS	Sand	Silt	Clay
A1	0.26	1.56	0.63	1.0	17.8	14.2	35.2	39.9	24.9
B2t	0.99	0.78	0.81	3.1	5.7	9.8	20.2	41.6	38.2
B3	0.05	0.10	0.39	0.3	2.1	6.3	9.1	51.2	39.7
C	0.03	0.13	0.16	0.2	2.5	7.6	10.6	50.3	39.1

[1]Commonly used soil survey abbreviations (Soil Survey Staff, 1951).
[2]pH was determined in the saturated paste; EC in the saturated extract.
[3]Base saturation percentage calculated by the sum of exchangeable cations.

TABLE IV

DESCRIPTION, CHEMICAL, AND PHYSICAL ANALYSES OF PEDON 4

Profile Description: Fine-loamy, mixed, thermic; Fluventic Ustochrepts

Sample No.	Horizon	Depth (cm)	Color (moist)	Texture[1]	Structure[1]	Consistence[1]	Boundary[1]
80-OK-60-18-1	A1	0-10	5YR(3/4)	CL	2mpl	mfr	a
2	B2	10-45	5YR(4/6)	L	1fgr	mvfr	a
3	IIAb	45-82	5YR(3/3)	SiCL	1csbk	mfi	c
4	IIB21	82-127	5YR(3/4)	SiCL	2csbk	mfi	g
5	IIB22	127-155	5YR(4/4)	SiCL	1cpr	mfr	g
6	IIIAb	155-210	5YR(3/2)	SiCL	2msbk	mfr	c
7	IIIB21t	210-278	5YR(3/4)	SiC	2msbk	mfi	d
8	IIIB22t	278-307	5YR(4/4)	SiC	2fsbk	mfi	-

Chemical Data

Horizon	pH[2]	CEC meq/100gm	Exchangeable Cations meq/100 gms					% Base Saturation[3]	% O.M.	ESP	EC25°C mmhos/cm[2]
			Na^{+}	K^{+}	Ca^{+2}	Mg^{+3}	H^{+}				
A1	7.4	15.9	1.1	0.4	10.6	4.3	2.5	86.8	1.1	6.7	0.4
B2	7.5	14.5	1.3	0.3	10.1	4.0	2.7	85.3	1.0	9.1	0.7
IIAb	7.0	23.7	0.9	0.6	11.9	5.1	4.5	80.4	1.8	3.9	0.5
IIB21	6.5	26.3	0.6	0.5	23.2	5.5	4.7	86.4	1.2	2.2	0.2
IIB22	6.4	21.2	0.7	0.4	11.3	5.0	5.0	77.7	1.0	3.1	0.3
IIIAb	6.5	23.5	0.4	0.4	12.5	4.8	4.3	80.8	1.3	1.7	0.3
IIIB21t	7.4	40.0	0.5	0.6	18.2	9.1	1.6	94.7	0.9	1.2	0.4
IIIB22t	7.8	39.0	0.4	0.7	25.2	10.6	1.8	95.3	0.6	1.0	0.3

TABLE IV (Continued)

	Soluble Salts (1:1) meq/100 gms								
Horizon	Na^{+}	K^{+}	Ca^{+2}	Mg^{+2}	Cl^{-}	CO_3^{-2}	HCO_3^{-}	SO_4^{-2}	SAR
A1	0.48	0.01	0.14	0.10	0.65	0.10	0.29	0.20	1.37
B2	0.69	0.01	0.15	0.14	0.81	0.14	0.36	0.20	1.81
IIAb	0.28	0.02	0.16	0.19	0.69	0	0.43	0.16	0.67
IIB21	0.16	0.01	0.14	0.10	0.49	0	0.23	0.16	0.46
IIB22	0.14	0.01	0.14	0.09	0.38	0	0.16	0.16	0.42
IIIAb	0.14	0.01	0.14	0.12	0.42	0	0.22	0.84	0.40
IIIB21t	0.13	0.01	0.39	0.25	0.70	0	0.43	0.96	0.23
IIIB22t	0.08	0.01	0.16	0.25	0.60	0	0.37	0.24	0.17

Physical Data

		Sand Subfraction %					------------%----------		
Horizon	% Gravel	VCS	CS	MS	FS	VFS	Sand	Silt	Clay
A1	----	0.03	0.05	0.05	7.9	16.2	24.2	47.8	28.0
B2	----	----	0.03	0.08	10.6	20.2	30.9	44.6	24.4
IIAb	0.03	0.03	0.05	0.05	4.7	11.2	16.1	50.5	33.4
IIB21	----	----	0.03	0.05	1.1	5.7	6.9	55.9	37.2
IIB22	----	----	0.03	0.03	1.4	6.4	7.9	57.3	34.8
IIIAb	0.03	0.03	0.08	0.13	3.6	12.8	16.6	53.3	30.0
IIIB21t	0.08	0.13	0.05	0.10	1.0	4.7	6.0	52.3	41.8
IIIB22t	5.85	0.36	0.14	0.08	1.0	5.3	6.9	49.8	43.4

[1]Commonly used soil survey abbreviations (Soil Survey Staff, 1951).
[2]pH was determined in the saturated paste, EC in the saturated extract
[3]Base saturation percentage calculated by the sum of exchangeable cations.

leached into the profile. The surface horizon is about 13 cm thick. The light color and the thickness are the reasons for the surface horizon having the characteristics of an ochric epipedon. The profile does not have any mottles, and this shows that the soil is well drained. The level of the ground water was not found within 313 cm of the surface at the time of sampling. The laboratory analyses of the soil samples of this pedon indicate the clay distribution curve (Figure 3) is similar to those of argillic horizons. The particle size distribution of the control section indicates that the pedon fits into the fine-silty textural family. The profile contains more than 1% organic matter in A11 and B1t horizons and also in IIAb and IIB23 (Table I and Figure 4). This profile is affected by the sodium salts. The ESP (Figure 5) is greater that 15% in all the horizons and that caused the pH values to be 8.4 or more in the solum, except in the A11 horizon which has a pH value of 7.9. The exchangeable and soluble sodium together have a maximum value in concert with clay accumulation in the argillic horizon. The electrical conductivity (EC) of the paste-saturated extract was less than 4 mmhos/cm. The high ESP and pH values and the low EC of this soil fit the characteristics of the sodic soils having a natric horizon in the profile. Cl^- and HCO_3^- are the dominant anions in the profile. High amounts of exchangeable calcium were noticed in the profile which prove the existence of $CaCO_3$ accumulation.

Pedon 2 (Table II)

This pedon was located in the area adjacent to the upland area. It is not affected by salt accumulation. The surface horizon is dark in color and has a depth of 25 cm. The dark color and the thickness of

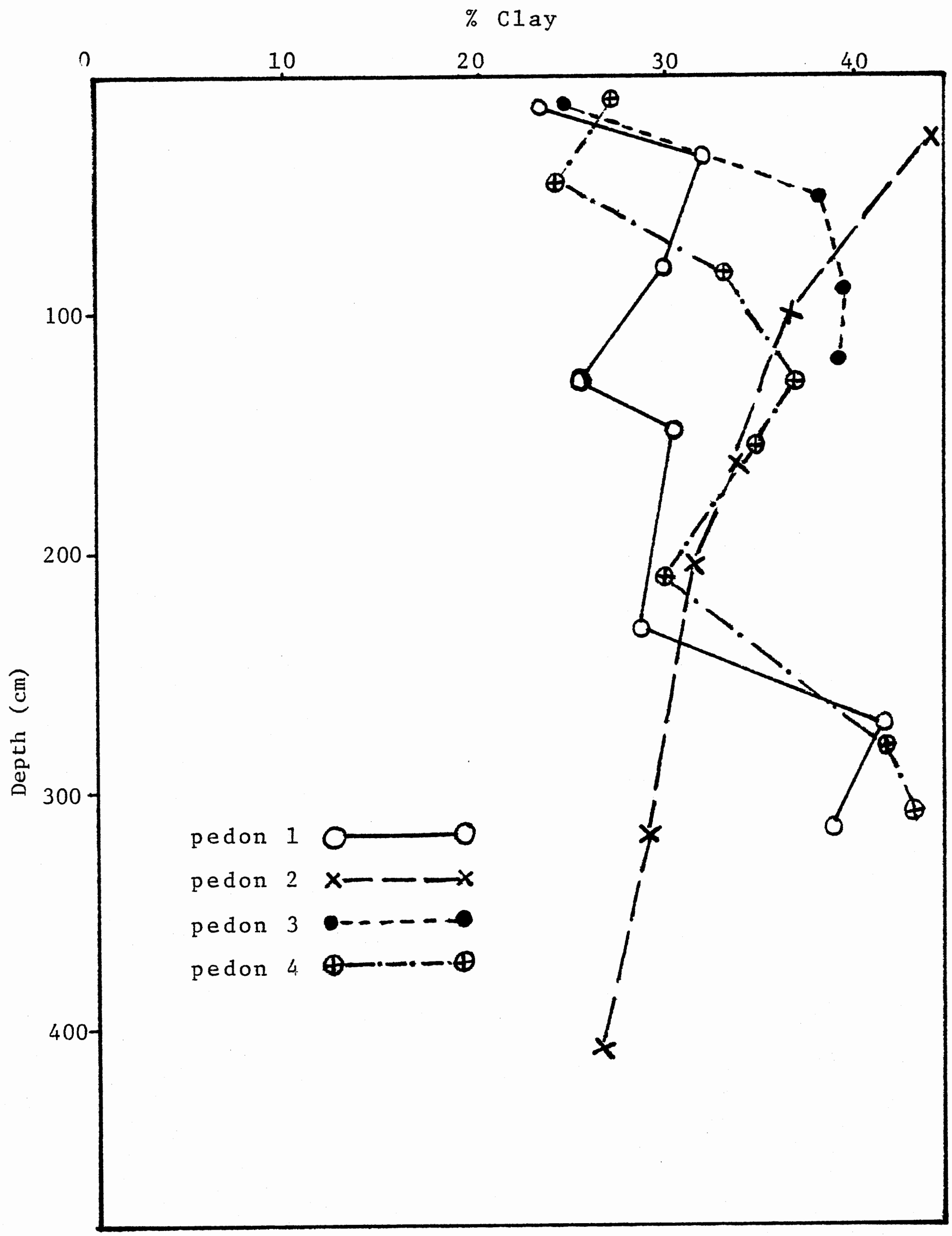

Figure 3. The Clay Content Distribution Curve vs. Depth of the Four Selected Pedons in the Study Area

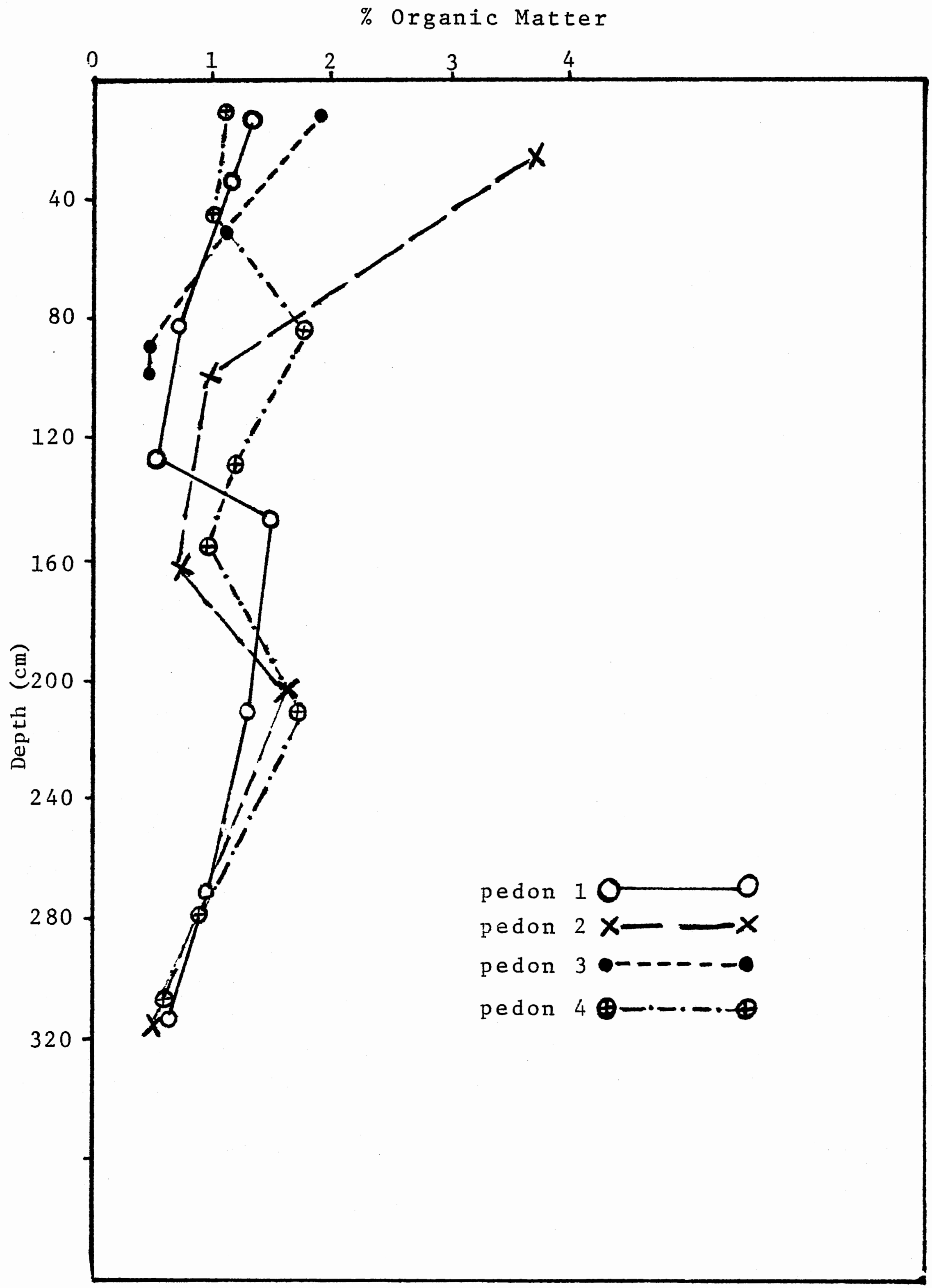

Figure 4. The Organic Matter Content vs. Depth of the Four Selected Pedons in the Study Area

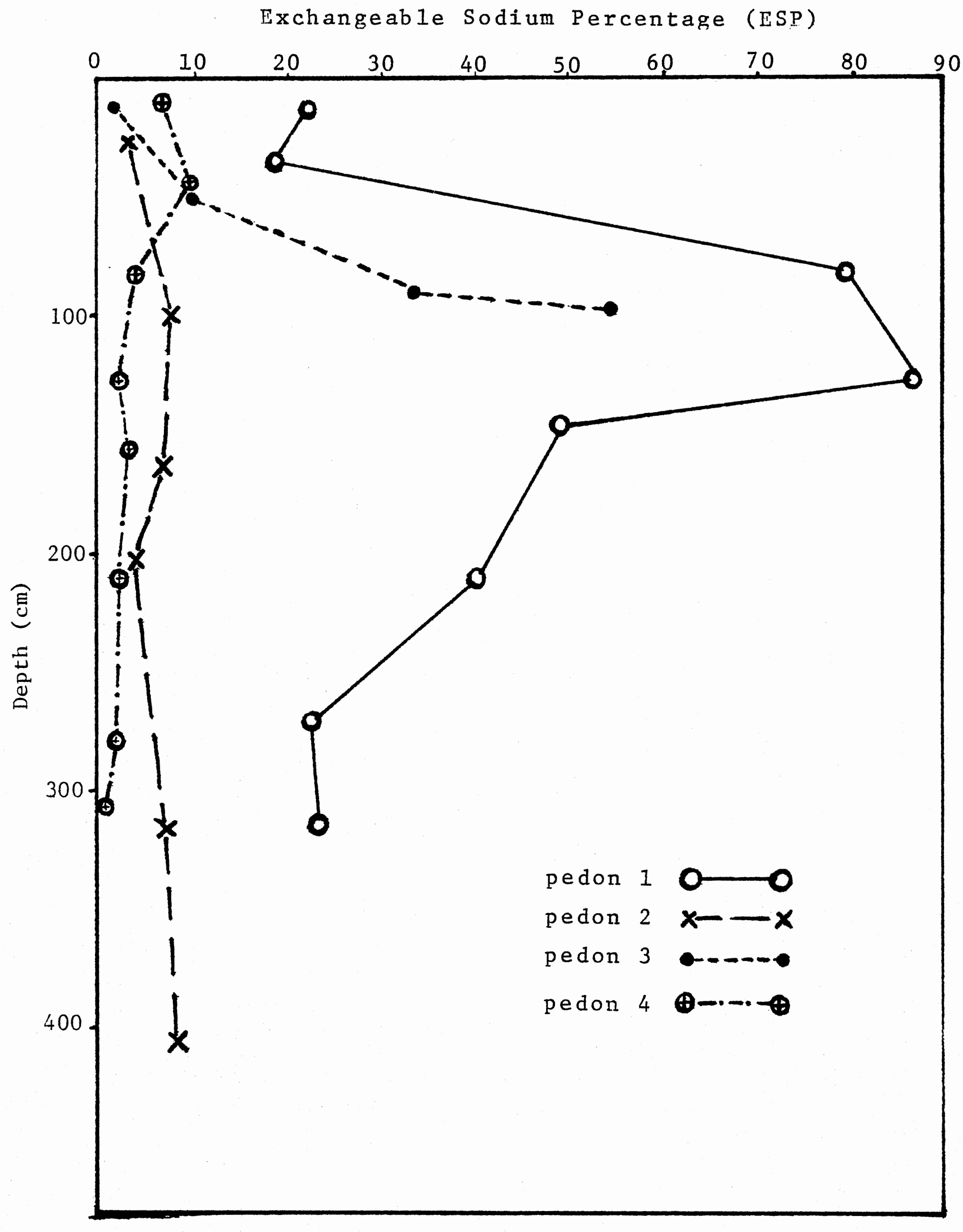

Figure 5. The Exchangeable Sodium Percentage Variations With Depths of the Four Selected Pedons in the Study Area

this horizon and the high base saturation percentage (more than 50%), are characteristics of a mollic epipedon. The area of this pedon also has a well-drained class as in pedon 1. The soil is saturated with a water table at a depth of 375 cm to 440 cm and 468 to 508 cm. The laboratory data indicate that the clay distribution curve (Figure 3) is similar to those of Cambic horizons. The control section has a fine textural family. The surface horizon has an organic matter content of 3.7% (Figure 4) and decreases in the solum with depth. This pedon is not seriously affected by sodium because the ESP (Figure 5) is less than 15% and pH value is less than 8.4 in the profile. The soil also has electrical conductivity (EC) less than 4.0 mmhos/cm in the saturated extract. The low ESP, pH, and EC give the soil the characteristics of non-saline soil. The dominant exchangeable cations are Ca^{+2} and Mg^{+2}. Cl^- is the dominant soluble anion in the soil with maximum concentration of 1.51 meq/100 g soil in the B21 horizon. The base saturation percentage is more than 50% in the profile. This pedon has a weakly calcareous matrix at 133 cm depth and many calcareous bodies are present above that depth.

Pedon 3 (Table III)

This pedon represents the upland area. No evidence of salt effects are noticed. The surface horizon is light in color and thin, about 13 cm thick. The depth and the color of the surface horizon meet the characteristics of the ochric epipedon. The profile does not have any mottles and that means that soil does not have any drainage problem. The profile is strongly calcareous at depth of 12 cm. The solum extends to a depth of 89 cm. The C horizon is made of weatherable calcareous shale materials. The laboratory data showed the clay distribution (Figure 3) as in those of argillic horizons. The control section textural family is fine. Only horizons A1 and B2t in the profile have organic matter more than 1% (Figure 4). The profile is not affected by sodium with depth 0-51 cm, but it is affected in a depth more than that. ESP (Figure 5) increases significantly with depth from value of 1.3 in the surface horizon to 54.6 in the C horizon. The sudden change in ESP caused pH values to increase from 6.9 in the surface horizon to 8.3 in the C horizon. Increasing of ESP and pH values with depth means the existence of the residual sodium in the parent materials. This residual sodium in the upland area might be the source of sodium in the flood-plain areas rather than the deep water table level. EC also increases with depth from 0.34 mmhos/cm in the surface horizon to 3.42 mmhos/cm in the C horizon. According to the ESP, pH, and EC values, this soil can be classified as non-saline soil. The dominant exchangeable cations are Ca^{+2}, Mg^{+2}, and Na^{+}. These exchangeable cations also increase with depth. Soluble salts data show that the Na^{+} and Cl^{-} have the highest concentration in the profile followed by HCO_3^-. The base saturation of this soil exceeds 50%.

Pedon 4 (Table IV)

Pedon 4 is not affected by salt accumulation. The surface horizon has an ochric epipedon because it is thin and light in color. The pedon does not have any mottles and this helps to classify the soil to be well drained. The water table was not found within 307 cm of the surface at the time of sampling. The laboratory analyses indicate that the clay distribution (Figure 3) is as those of cambic horizons. The particle size distribution of the control section indicates that the pedon fits into the fine-loamy textural family. The pedon has more than 1% organic matter in the profile (Figure 4) except in the IIIB21t and IIIB22t horizons. This pedon is not affected by sodium because of the low ESP and pH values (Figure 5). This area is non-saline because the EC is less than 1 mmhos/cm. Exchangeable Ca^{+2} and Mg^{+2} have the highest concentration in the profile and Cl^- is the dominant soluble anion in the solum. The base saturation of the soil is more than 50% throughout the profile.

Classification of the Soils

Soils developed at the study area were classified according to Soil Taxonomy currently in use developed by the soil survey staff, USDA (1975). Soil classification in this system emphasizes diagnostic horizons of the soil pedons. The soils are placed in six categories: order, suborder, Great Group, subgroup, family, and series.

The major differences in morphological characteristics of these soils are the thickness and the color of the surface horizon. These two characteristics, in addition to the base saturation percentage, can determine whether the soil has a mollic or an ochric epipedon. Differences in the curve of the clay distribution through the profile determine the existence of argillic or cambic horizon. ESP must be considered too, because it limits the soil to have a natric horizon or not. All these differences and similarities were discussed and determined in the discussion of the morphology and laboratory data. Other necessary information to help classification were mentioned under the geography of the study area. Classification of these soils, according to the morphological, physical, and chemical properties, are presented in Table V.

Reclamation of the Sodic Soils

Soil properties, amount of exchangeable Na^+ to be removed from the soil complex, and the cost of reclamation are the main factors to be in mind during reclamation. Pedon 1 of the floodplain is the only soil that has the characteristics of calcareous, sodic soils. Sodic soils often have low hydraulic conductivity due to domination of sodium to the soil complex. To reclaim such soils, saline irrigation water must pass through the profile to provide the soil complex with divalent ions (usually Ca^{+2}). The irrigation water usually does not have enough divalent ions to saturate the soil complex (Branson and Fireman, 1960), so chemical amendments to provide soils with Ca^{+2} must be used to reclaim such soils.

The most common amendments are gypsum ($CaSO_4 \cdot 2H_2O$), calcium chloride ($CaCl_2 \cdot 2H_2O$), and sulfuric acid. Gypsum is the common amendment to reclaim such soils because of its low cost, but requires more time and water to become soluble than other amendments (Overstreet et al., 1951). $CaCl_2$ is relatively soluble and produces a high concentration of electrolytes which improve soil permeability and speed reclamation, but it is expensive (Prather et al., 1978). Sulfuric acid is a good amendment to reclaim sodic calcareous soils (as in soil of pedon 1) because it reacts with soil calcium carbonate ($CaCO_3$) producing a soluble source for Ca and $CaSO_4$ (Yahia et al., 1975). Prather et al. (1978) confirmed this in their reclamation study and reported that the H_2SO_4 is superior to either $CaCl_2$ or $CaSO_4 \cdot 2H_2O$, but it is relatively expensive

TABLE V

CLASSIFICATION OF SOILS IN FOUR SELECTED AREAS NEAR STILLWATER CREEK

Pedon No.	Diagnostic Horizons	Order	Sub-order	Great Group	Subgroup	Families	Series
1	Ochric Argillic Natric	Alfisols	Ustalfs	Natrustalfs	Typic Natrustalfs	Fine-silty, mixed, thermic	Oscar
2	Mollic Cambic	Mollisols	Ustolls	Haplustolls	Fluventic	Fine, mixed, thermic	No Series in Oklahoma Three in Texas 1-Bastrop 2-Delwin 3-Mites
3	Ochric Argillic	Alfisols	Ustalfs	Haplustalfs	Vertic Haplustalfs	Fine, mixed, thermic	Grainola
4	Ochric Cambic	Inceptisols	Ochrepts	Ustochrepts	Fluventic Ustochrepts	Fine-loamy, mixed, thermic	No series in the U.S. with this family

(dependent on quality) and needs special equipment to add H_2SO_4 to the soil. They also found that the mixtures of either $CaCl_2$ or H_2SO_4 with $CaSO_4$ reduces time and improves water efficiency rather than using the $CaSO_4$ alone.

The soils of pedons 2, 3, and 4 are non-saline soils and no reclamation practices are needed except good soil and water management to avoid erosion, surface runoff, and salt accumulation hazards.

Interpretations of Soils for Water Management

By using the USDA (1971) Guide for Interpreting Engineering Uses of Soils, the study soils' interpretations for water management can be easily determined according to their properties.

Irrigation

There are many soil features which can determine the suitability for irrigation practices. For example, the soil properties which affect the water movement and drainage must be known. Furthermore, depth of soil, slope, salinity and alkalinity, stoniness, and hazard of water erosion must be considered too. From the characteristics of the study soils, many limitations to irrigation practices in soils of pedon 1 and 3 can be noticed. Pedon 1 has a low rate of water intake and alkalinity problems. Pedon 3 soil has limitations of being droughty and the depth to bedrock problems. The other soils of the floodplain (pedon 2 and 4) do not have any limitation for irrigation practices.

Drainage for Crops and Pastures

Soil features and qualities which determine the suitability for drainage are those that affect installation and performance of surface and sub-surface drainage. The study soils have a well-drained class and very deep water table levels. The floodplain soils (pedons 1, 2, and 4) do not have any layers such as fragipan or claypan, bedrock, sand, etc., that influence the rate of water movement, therefore, no need for drainage in these soils. The upland soil (pedon 3) is shallow to bedrock which influences the rate of water movement.

Pond Reservoir Areas

Factors considered in selecting soils for this use are soil properties that affect seepage rate. Soil permeability, depth to water table, depth to bedrock, and soil slope are the most effective factors on seepage rates. The study soils have slow to moderate classes of permeability and deep water table levels. The floodplain soils (pedons 1, 2, and 4) have slight limitations to be used as a pond reservoir area. On the other hand, the upland soil (pedon 3) has moderate limitation for this use because of the depth to bedrock and slope problems. In addition, the study soils have severe limitation to be used as excavated ponds aquifer fed because of deep water table levels.

Terraces and Diversions

The study of features and qualities that affect stability of the soils, layout, and construction of terraces and diversion, and sedimentation of channels are very important for the upland soil (pedon 3). The upland soil has a 7% slope and moderately deep soils, therefore, hazard of erosion and surface runoff is expected and terraces and diversions are needed. On the other hand, the floodplain soils are deep and slightly level soils, therefore, terrace and diversions are not needed.

Interpretations of Engineering Properties

According to the USDA (1971) Guide for Interpreting Engineering Uses of Soils and the characteristics of the four soils, many problems can be reported which limit the soil uses for many engineering purposes. The soils of pedons 1, 2, and 4 have severe limitations for dwellings, shallow excavations, sewage lagoons, septic tank absorption fields, trench-type sanitary landfills, or local roads and streets because they have flooding problems. The upland soil of pedon 3 does not have the flooding problem, but the depth of the bedrock is 97 cm and this gives the soil a severe degree of limitation.

The study soils can be used successfully for other engineering uses rather than the uses which are limited by flooding or bedrock depth. For example, they are suitable to be used as a source of cover materials for area-type sanitary landfills and as a source of topsoil. In addition, these soils are moderately fine-textured in the control section, well-drained soils, and with total acidity (exchangeable Al^{+3} and H^{+}) less than 8.0 meq/100 g soil, therefore, these soils are moderate in corrosivity to buried uncoated steel materials which are usually used in many engineering purposes. These soils also meet the conditions to have a low potential of corrosivity to concrete materials which are used in many engineering uses. The conditions which control soil characteristics affecting concrete materials in this area are: 1) moderately fine-textured, 2) pH values greater than 6, and 3) containing less than 1,000 ppm of water-soluble sulfate.

Conclusion

The study area was severely affected by the additions, removals, transfers, and transformations of both organic and inorganic soil materials during the time of formation. The topographic sequence had significant differences in the diagnostic horizons of these soils and variations in the total thickness and the colors of the surface horizons occurred. The thickness of the solum of these soils is also decreased as elevation increased as a result of water erosion and surface runoff effects. The laboratory data showed evidence of sodic soil formation in the lowest soil of the floodplain (pedon 1). This pedon was affected by sodium accumulation in the argillic horizon because the exchangeable sodium percentage (ESP) is more than 15% and that caused the pH value to be 9.6. The upland soil (pedon 3) developed on alkali Permian age parent materials with exchangeable sodium percentage (ESP) of 54.6 and a pH value of 8.3. The parent material alkalinity of the upland soil might be evidence of residual sodium existence and may be the source of the sodium in the floodplain soils rather than the deep water table in the area. The electrical conductivity (EC) values never exceed 4.0 mmhos/cm in the soil-saturated extract in the study soils. Soil classification was done according to the diagnostic horizons and other soil properties to get better understanding for both agricultural and engineering uses. In addition, recommendation for land reclamation, water management, and engineering interpretations were also proposed.

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APPENDIX

PEDON 1

Classification: Fine-silty, mixed, thermic; Typic Natrustalfs.

(All colors for moist soils unless otherwise stated)

Horizon	Depth (cm)	Description
A11	0-13	Reddish Brown (5YR 4/4); loam; weak, coarse, subangular blocky parting to weak, fine, granular structure; hard, friable; few vesicular pores; few fine roots; pH 7.9; clear smooth boundary.
B1t	13-33	Dark reddish brown (5YR 3/3); silty clay loam; weak, coarse, platy parting to weak, fine, granular structure; very hard, firm; vesicular pores; common roots; pH 9.5; clear smooth boundary.
B21t	33-81	Dark reddish brown (2.5YR 3/4); silty clay loam; moderate, medium, subangular blocky structure; very hard, firm; common fine random pores; few fine roots, pH 9.6; gradual smooth boundary.
B22t	81-127	Reddish brown (2.5YR 4/4); silty loam; weak, coarse, prismatic parting to weak, medium, subangular blocky structure; common fine random tabular pores; hard, friable; few fine roots; this horizon saturated with water; pH 9.2; clear smooth boundary.
IIAb	127-147	Dark reddish brown (5YR 3/2); silty clay loam; weak, coarse, subangular blocky parting to weak, fine, subangular blocky structure; very hard, firm; few fine random tubular pores; few fine roots; pH 8.4; gradual smooth boundary.
IIB23	147-211	Reddish brown (5YR 4/4); silty clay loam; weak, medium, prismatic parting to weak, medium, subangular blocky structure; very hard, firm; few fine random tabular pores; pH 8.2; clear smooth boundary.
IIB24	211-270	Dark reddish brown (5YR 3/2); silty clay; weak, medium, prismatic parting to weak, medium, subangular blocky structure; very hard, firm; few fine random tubular pores, pH 8.0; gradual smooth boundary.

Horizon	Depth (cm)	Description
IIB25	270-313	Reddish brown (5YR 4/3); silty clay loam; weak, medium, prismatic parting to weak, medium, subangular structure; very hard, firm; few very fine random tubular pores; pH 7.9.

PEDON 2

Classification: Fine, mixed, thermic; Fluventic Haplustolls.

(All colors for moist soils unless otherwise stated)

Horizon	Depth (cm)	Description
A1	0-25	Dark reddish brown (5YR 3/3); silty clay; moderate, medium, subangular blocky and angular blocky parting to moderate, medium, granular and moderate, fine subangular blocky structure; hard, firm; common fine tubular pores; many fine, medium roots, pH 7.4, clear smooth boundary.
B21	25-99	Reddish brown (2.5YR 4/4); silty clay loam; ped faces are dark reddish brown (2.5YR 3/4); weak, fine, prismatic parting to weak, fine, subangular blocky structure; very hard, firm; few fine pores; few fine roots; pH 7.5; clear smooth boundary.
B22	99-163	Reddish brown (2.5YR 4/4); silty clay loam; weak, medium, prismatic parting to moderate, medium, subangular blocky structure; hard, friable; common fine random, tubular pores; few fine roots; water table at 142 cm depth; weakly calcareous matrix at 133 cm depth; spots are calcareous above this depth; pH 7.7; clear smooth boundary.
IIAb	163-203	Very dark gray (5YR 3/1); silty clay loam; moderate, medium, prismatic parting to subangular blocky and strong, medium granular structure; hard, friable; few fine random tubular pores, pH 7.7; gradual smooth boundary.
IIB23	203-317	Reddish brown (2.5YR 4/4); clay loam; weak, medium, prismatic parting to weak, coarse, subangular blocky structure; very hard, firm; few very fine tubular pores; pH 7.9; clear smooth boundary.
IIC11	317-406	Reddish brown (2.5YR 4/4); loam; the soil is super saturated with water at depth of 375 to 406 cm; pH 8.0.
IIC12	406-495	Reddish brown (2.5YR 5/4); clay loam; the soil is super saturated at depth of 406 to 440 cm; pH 7.9.
IIC13	495-584	Dark reddish brown (2.5YR 3/4); fine sandy loam; pH 7.9.

PEDON 3

Classification: Fine, mixed, thermic; Vertic Haplustalfs.

(All colors for moist soils unless otherwise stated)

Horizon	Depth (cm)	Description
A1	0-13	Reddish brown (5YR 4/4); loam; moderate, fine, granular structure; hard, friable; many irregular pores; many fine roots; pH 6.9; abrupt smooth boundary.
B2t	13-51	Reddish brown (5YR 4/4); clay loam; weak, fine, prismatic parting to strong, fine, blocky structure; extremely hard; very firm; very few, very fine roots are mostly on ped surface; pH 7.9; clear smooth boundary.
B3	51-89	Reddish (5YR 4/4); silty clay loam; weak, coarse, subangular blocky parting to weak, medium, subangular blocky structure; extremely hard, very firm; pH 8.2, clear smooth boundary.
C	89-97	Reddish brown (2.5YR 4/4); weathered shale; calcareous; pH 8.3.

PEDON 4

Classification: Fine-loamy, mixed, thermic; Fluventic Ustochrepts.

(All colors for moist soils unless otherwise stated)

Horizon	Depth (cm)	Description
A1	0-10	Dark reddish brown (5YR 3/4); clay loam; moderate, medium, platy structure; friable; very fine horizontal pores; common roots; pH 7.4; abrupt boundary.
B2	10-45	Yellowish red (5YR 4/6); loam; weak, fine, granular structure; very friable; very fine random pores; many very fine roots; pH 7.5; abrupt boundary.
IIAb	45-82	Dark reddish brown (5YR 3/3); silty clay loam; weak, coarse, subangular blocky structure; very hard, firm; very fine vertical pores; many very fine roots; pH 7.0; clear smooth boundary.
IIB21	82-127	Dark reddish brown (5YR 3/4); silty clay loam; moderate, coarse, subangular blocky structure; very hard, firm; very fine horizontal pores; very fine roots; pH 6.5, gradual boundary.
IIB22	127-155	Reddish brown (5YR 4/4); silty clay loam; weak, coarse, prismatic structure; friable; fine horizontal pores; pH 6.4; gradual boundary.
IIIAb	155-210	Dark reddish brown (5YR 3/2); silty clay loam; moderate, medium, subangular blocky structure; firable; very fine horizontal pores; few very fine roots; pH 6.5; clear boundary.
IIIB21t	210-278	Dark reddish brown (5YR 3/4); silty clay; strong, medium, subangular blocky structure; very hard, firm; fine horizontal pores; common very fine roots; pH 7.4; diffuse boundary.
IIIB22t	278-307	Reddish brown (5YR 4/4); silty clay; moderate, fine, subangular blocky structure; very hard, firm; pH 7.8.

VITA

Ghazi Maleh Mutter

Candidate for the Degree of

Master of Science

Thesis: CHARACTERISTICS OF SODIC SOILS IN A TOPOGRAPHIC SEQUENCE IN STILLWATER, OKLAHOMA

Major Field: Agronomy

Biographical:

Personal Data: Born in Baghdad, Republic of Iraq, July 1, 1953.

Education: Graduate from Qutaiba Secondary School, Baghdad, Iraq, in June 1971; received Bachelor of Science degree from the University of Baghdad, Iraq, in June, 1975; completed requirements for Master of Science in Agronomy at Oklahoma State University, Stillwater, Oklahoma, in May, 1982

Professional Experience: Laboratory instructor in the Soil Department, Institute of Agricultural Technology, Baghdad, Iraq, April 1977 - July 1979.