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HYDROMORPHIC SOILS OF TWO INLAND VALLEY SWANPS IN THE RAIN FOREST ZONE OF NIGERIA, I SOME PHYSICAL AND CHEMICAL PROPERTIES

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ABSTRACT

Physical and chemical properties of hydromorphic soils of two inland valley swamps (IVS) in the rain forest zone of Nigeria were studied to assist in predicting water movement and soil management for their effective uses. Soils of Abakaliki swamp are generally silty clay with the silt content ranging from 204 to 562g kg $^{-1}$ in the surface horizons whereas the silt content of pedons on Bende swamp seldom exceed 200g kg^{-1}. Results of particle – size distribution of the soils imply that both soils would have the ability of retaining high amount of water. However, the high silt content of the soils of Abakaliki swamp in addition to clay would enhance much more water retention than the Bende soils. In general, the soils have acidic soil reactions for which high precipitation in the area and leaching effects have been implicated. The effective cation exchange capacity (CECe) values of the soils were generally low: organic carbon content and Bray-1. P values of the surface horizons ranged between 9.3g kg $^{-1}$ and 23.9g kg^{-1} and from 1.0 mg kg $^{-1}$ to 9.0 mg kg $^{-1}$ respectively. The acidic reaction of the surface horizons of the soils could be implicated for low Bray – 1 P. Application of non-acidifying fertilizer would therefore be necessary to ameliorate the poor fertility.

Keywords: Hydromorphic soils, leaching, swamp, active iron ratio

INTRODUCTION

Inland valley swamps (IVS) have been recognized to have great potentials for agricultural development in Nigeria (Moormann *et at.*, 1976), particularly for the production of swamp rice (*Oryza sativa L*). Ayotade and Okereke (1984) estimated that about 75 percent of the total national production of rice in Nigeria is from the lowlands. However, not much research attention have been focused at soils of inland valley swamps despite their potential for sustainable agriculture both in the wet and dry seasons. A collateral of the use of hydromorphic land for producing rice is the gradual development of 'paddies' (bounded and levelled fields) Lagemann (1977), argues that valley bottoms in eastern Nigeria have been ignored because the farming system in the area developed from shifting cultivation hence the principle of ameliorating the land by irrigation/drainage was not part of the cultural heritage.

Generally, soils of IVS have characteristics determined by the influence of parent material, geomorphology and sediment deposition. These soils typically have a seasonally high water table, accumulation of clay and/or silt materials and high exchange acidity.

Their chemistry is dominated more by *Fe* than any other redox element (Brinkman,1970). Formation of horizons with *Fe* accumulation commonly found in seasonally flooded soils has been attributed to the redistribution of *Fe* and *Mn* in the flooded profiles (Pickering and Veneman, 1984). Seasonal fluctuation of water table is responsible for the gray to bluish gray matrix colour of most hydromorphic soils, and mottles may or may not be present depending on aeration.

The main objective of this paper is to examine the physical and chemical properties of soils of two inland valley swamps and to infer from these and from other known processes that can occur, water movement and soil management for their effective uses.

MATERIALS AND METHOD

Two inland valley swamps, one near Abakaliki ($8^0 8^1$E, $6^0 15'$N) and the other at Bende ($7^0 0'$E, $5^0 3/'$N) were used for the study. Both are in the eastern part of Nigeria. The area has a tropical humid climate with mean annual rainfall of about 2000mm and mean air temperature of 27^0C. The Bende area is underlain by Cretaceous feldspathic sandstone and siltstone while geology of Abakaliki area is predominantly mudstone and limestone (Kogbe, 1973). The two sites had been under swamp rice cultivation for many seasons.

The Abakaliki site has an elevation of 100m above sea level while Bende site is on 93.5m. Nine hydromorphic soil profiles were studied: five in Abakaliki (AB-1 to AB-5) and four in Bende (BD-1 to BD-4). The profiles were described according to the soil Survey Manual (Guthrie and Witty, 1982).

Soil samples were air-dried and crushed to pass a 2mm sieve. Bulk density was determined by clod method (Blake, 1965) using paraffin wax melted at 60-70^0C. Particle size analysis was by hydrometer method (Bouyoucos, 1962) and classification by the U.S.D.A system. Soil pH was measured in distilled water (1:1 soil/liquid ratio) using pH meter after equilibration for 30 minutes. Exchangeable bases (Ca, Mg, Na and K) were extracted with neutral 1.0 mol L^{-1} NH_4OAc. Calcium and Mg were analyzed with atomic absorption spectrometry (AAS), but Na and K were determined with a flame photometer. Exchangeable Al and H were extracted by 1.0 mol L^{-1} KCl and titrated according to Yuan's method (Yuan, 1959).

For the measurement of CEC_8,5g sample was treated with 50ml of $BaCl_2$-TEA buffered at pH8.2 followed by 4-time washing with water. Effective CEC (CECe) is the sum of exchangeable Ca, Mg, Na, K, Al and H. The difference between CEC_8 and CECe was calculated to represent the variable charge. Organic carbon was determined by the chromic acid wet oxidation method (Allison, 1965). Total N was by the macro –kjedahi method in Tecator digestor system, with N estimated by Technicon's (AAII) auto-analyzer. Free Fe (Fe_d) was extracted by the dithionite-citrate-bicarbonate (DCB) method of Mehra and Jackson (1960) and determined by AAS. Iron solute in acid NH_4- oxalate (Fe_0) was extracted twice from 1.0g soil sample by 30ml of Tamm- A reagent after 1 hour shaking each in the dark. Fe_0/Fe_d was calculated as the index of activity of iron oxide.

The clay (<2mm) and sand (2-0.05mm) fractions were collected through dispersion, wet and dry sieving and sedimentation method (Jackson, 1956). Silt fraction (.002-, 05mm) separation was by means of sedimentation and decandition from the residues left from the clay separations.

RESULTS AND DISCUSSION

General soil physical characteristics

Field observations indicate that all pedons of the two sites had some mottled horizons either at the epipedon or at the subsoil horizons (Table 1). However, all horizons of pedons AB-2., AB-3 and AB-4 had mottled colours. Table 1 shows the preponderance of Fe/Mn concretions and quartz gravels in some subsoil horizons of all pedons on Abakaliki swamp, which indicates alteration redox conditions. However, in Bende swamp, with the exception of pedon BD-1 all other pedons had horizons that are free of concretions (Table 1).

The particle size distribution in Table 2 shows that pedons BD-3 and BD-4 of Bende swamp generally have higher total sand content than clay and that the silt content of the pedons on the swamp seldom exceed 200g kg^{-1} .Total sand distribution decreases with increase in soil depth in pedon BD-1 while in the other pedons of Bende swamp the distribution is erratic. With the exception of pedon BD-4 which is not far from the upland and has considerably higher sand contents, other pedons of the swamp are clayey. This reflects the influence of transportation and deposition of materials from the upland into the lowland whereby coarse materials are deposited first. Table 2 shows that soils of Abakaliki swamp are generally silty. The soils contain high silt content ranging from 204 to 562g kg^{-1} except in the last two horizons of pedon AB-5 which contain 84 and 88g kg^{-1} silt respectively. In contract to the particle size distribution of soils of Bende swamp, most soils of the Abakaliki site have low sand content. In most cases, the clay content is higher than the sand content (Table2).

The implication of particle – size distribution of soils of the IVS studied on water movement is that the soils would have the ability of retaining high amount of water. Therefore cultivation of swamp rice in paddies in the IVS should not be of much problem.

However, the Abakaliki soils appear more promising because the high silt content of the soils (Table 2) in addition to the high clay content (especially of the surface horizons) would enhance much more water retention than in Bende soils. Relative accumulation of clay at the surface horizons of all pedons of Abakaliki site is a reflection of good land and water management of fairly good 'paddies'- levelled and bounded rice fields. Variations in particle size distribution appear to be of land and water use reflection rather than of geological factors because of the importance of sediment deposition in valley swamps.

Results of the fractionation of sand indicate that the fine sand (0.25-0.1) seems to be the dominant fraction in all pedons studied. This was followed by the medium sand (0.05 – 0.25) and very fine sand (0.1-0.05) fractions. Bulk density of the soils ranges between 0.80 and 2.09 mg m^{-3} No definite pattern of bulk density within the profile was observed. Generally, the surface horizons of pedons sited at Abakaliki had higher bulk density values than those of Bende site. This, in a way, is similar to clay and silt distribution in the pedons.

Chemical Characteristics:

Table 3 shows the chemical characteristics of the pedons. Soils of Abakaliki swamp generally have acid surface horizons (4.5-5.1, pH in H_2O) while their subsurface samples were slightly neutral to alkaline except pedon AB-5 which has acid subsoil. All pedons in Bende site have more acidic soil reactions. High amount of rainfall and leaching are suspected to be responsible for the type of soil reactions observed in the pedons. Calcium and magnesium dominate site complex of the soils followed by K and Na. The low exchangeable bases (Ca, Mg,and K) generally observed in the soils could be associated with the soil mineralogy and geology of the area. Low activity kaolinite clay mineral dominates in these soils. Relatively high exchangeable bases obtained in the subsoil horizons of pedons AB-1, AB-2, AB-3 and AB-4 seem to be residual. Generally, the exchange acidity (Al^{3+} + H^{+}) content of the soils is dominated by Al^{3+} more than H^{+} with the more acidic soils of Bende swamp having higher values.

The effective cation exchange capacity (CECe) values of the soils were low ranging from 0.87 to 14.64cmol (+) kg^{-1} soil. This is related to the low activity clay mineralogy of the soils which implies that the soils plant nutrients retention is low. Cation exchange capacity CEC_8) values follow similar trend as CECe except in the saprolitic horizons of pedons AB-2 (109-150cm) and AB-3 (100-158cm) which contain some smectite. Also, horizons of pedons BD-1 and BD-2 contain higher CEC_8 values (Table 3) which is due to the presence of some degraded mica minerals and high clay contents in them.

The difference between CEC_8 and CECe, i.e (CEC_8- CECe) (ΔCEC) is hereby referred to as variable charge. The value is positive for all horizons ranging from 0.80 to 24.62cmol (+) kg^{-1}soil. This is indicative of presence of high amounts of pH-dependent changes which could not be determined at the pH of the extract for CECe. This study shows that pedons containing some degraded mica minerals (pedons AB-2, AB-3, BD-1 and BD-2) have higher values of CEC_8- CECe than the other pedons which are mainly kaolinitic. Organic carbon content of the surface horizons of the pedons ranged between 9.3 and 23.9g kg^{-1} and decreased generally with soil depth (Table 3). The total nitrogen distribution followed similar pattern with organic carbon. However, its values ranged between 0.2 and 2.3 g kg. The surface horizons of the soils contain low Bray-1 values of between 1.0 and 9.0mg kg^{-1}. The acidic reaction of the surface horizons of the soils may account for low Bray-1 P. In order to ameliorate the poor fertility levels of the soils, the use of non-acidifying fertilizer becomes imperative.

Data on active Fe ratio, (Fe_o/Fe_d) are shown in Fig.1. Active Fe ratios in the pedons are generally low and decrease with soil depth. This indicates that higher proportions of Fe are in more crystalline forms in the lower horizons which corroborates the presence of Fe concretions in the subsoil horizons of Abakaliki soils and in pedons BD-1 (Table1). In hydromorphic soils, a zone of Fe accumulation may indicate the zone of fluctuating water table (Okusami et al., 1987). Oils of Abakaliki swamp and pedons Bd-1 and BD-2 had perched water tables whereas pedons BD-3 and BD-4 owe their hydromorphism mainly to high groundwater tables.

Exchange acidity and Al saturation could be useful indices of horizon development of some soils of the tropics sometimes obscured by subtle differences in morphological features. Ragland and Coleman (1959) reported that Al saturation has been found to be generally higher in hydromorphic pedons. The relatively high Al saturation obtained in pedons AB-2, AB-3, AB-4, BD-4 (Fig. 2) would seem to support the ferrolysis concept of Brinkman (1970) and the hypothesis of Buol *et al* (1980), who proposed that clay mineral lattice destruction results in the release of Al ions. Differential accumulation of Al, especially in hydromorphic soils with perched water table e.g pedon AB-4 (Fig.2) may indicate the active weathering zone of the solum because exchangeable Al is not considered mobile in the soil.

CONCLUSION

Soils of Abakaliki swamp are generally silty clay with the silt content ranging from 204 to 362g kg^{-1} in the surface horizons. In contrast to the particle size distribution of soils of Bende swamp, most soils of the Abakaliki site have low sand content, which in most cases is less than the clay content. The silt content of pedons on Bende swamp seldom exceed 200g kg^{-1}. Pedons BD-1 and BD-2 are clayey but pedons BD-3 and BD-4 generally have higher total sand than clay. The implication of particle size distribution of soils of the inland valley swamps (IVS) studied on water movement is that the soils would have the ability of retaining high amount of water. However, the high silt content of soils of Abakaliki swamp in addition to clay would enhance much more water retention than in Bende soils. Soils of Abakaliki swamp generally have acid surface horizons (pH 4. 5-5.1) but pedons in Bende site have more acidic soil observed. The effective cation exchange capacity (CECe) of the soils was generally low. Organic carbon content of the surface horizons ranged between 9.3 and 23.9g $kg^{-1}$and decreased generally with soil depth. The acidic reaction of the surface horizons of the soils might be responsible for low Bray-1 P. In order to ameliorate the poor fertility levels of the soils, the use of non acidifying fertilizer becomes imperative.

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Table 1: Morphological Properties of the Soils

Horizon	Depth (cm)	Colour (moist) Matrix	Mottle	Texture*	Structure*	Consistence g*	Concretions (abundance) kg^{1}	Boundary
Pedon	**AB-1**							
Ap	0 – 20	10YR6/4	10YR6/8	Sicl	3m sbk	Fr shs shp	-	As
A$_2$	20-40	10YR7/3	-	Sil	3m sbk	Fl shs shp	-	As
Bwg^2	40-81	10YR7/2	-	Cl	3m sbk	Fl shs shp	>150Fe/Mn	As
Bwg^2	81 – 111	10YR7/2	-	Sil	4m sbk	Fl vs vp	>100Fe/Mn	Gs
Bwg^3	111-170	10YR7/2	5Y2/1	Sil	4m abk	Fl s p	<100Mn	Cs
Bcg	170 – 194	10YR7/2	10YR6/8	1	3m sbk	Fl s p	>200Mn + quarts gravel	-
Pedon	**AB-2**							
Ag	0-26	2.5Y5/1	7.5YR5/6	Sicl	2f sbk	fr shs shp	-	cs
A$_{2g}$	28-47	10YR8/2	7.5YR5/6	Cl	3f sbk	fr shs shp	-	Cs
2Bwg	47-74	2.5YR3/6	10YR5/2	Sicl	3m sbk	fr shs shp	150Fe/Mn	As
2Bg	74-109	7.5YR5/1	10YR6/6	Sic	3m sbk	fr s p	<100Mn	Ds
2Bcg	109-194	7.5YR5/1	10YR6/6	Sicl	3m sbk	fr shs skp	>150Mn	-
Pedon	**AB-3**							
Apg	0-28	7.5Y7/1	10YR5/8	C	2f sbk	fr shs shp	-	as
A$_{2fcg}$	28-54	7.5Y7/1	10YR5/8	1	nd	Nd	>800Fe	cs
Big	54-100	7.5YR4/8	7.5YR2/1	C	nd	Nd	00Fe/Mn	as
B2g	100-158	7.5Y7/1	10YR5/8	C	3m sbk	fi s p	quarts gravel	-
Pedon	**AB-4**							
Apg	0-30	2.5Y5/1	7.5YR5/6	C	2m sbk	fr shs shp	-	cs
Bwg^1	30-50	10YR8/2	7.5YR5/6	sicl	3m sbk	fr shs shp	-	cs
Bwg^2	50-98	2.5YR4/6	10YR5/2	sicl	3m sbk	fr shs shp	>150Fe/Mn	as
Bcg	98-148	7.5YR5/1	10YR6/6	sicl	4c sbk	fr shs shp	<100Mn	-
Pedon	**AB-5**							
Ap	0-20	7.5YR4/4	-	sicl	2f gr	fr shs shp	-	ds
AB	20-50	7.5YR4/4	-	sicl	2f sbk	fr shs shp	-	as
2Ew	50-76	10YR5/2	-	sl	3m sbk	fr shs shp	-	
2B$_{wfcg}$	76-95	7.5YR4/8	10YR5/6	1	nd	nd	>800Fe	
3BCg	95-135	7.5Y5/1	10YR5/8	ls	3m sbk	fi s p	-	gs
3Cg	135-170	7.5Y5/1	10YR5/6	sl	sm sbk	fi s p	-	-

Horizon	Depth (cm)	Colour (moist) Matrix	Mottle	Texture*	Structure*	Consistence g*	Concretions (abundance) kg[1]	Boundary
Pedon	**AB-1**							
Ap	0 – 21	5YR3/2	-	Scl	2m sbk	fr s p	-	cs
BW[1]	21-50	5YR4/3	7.5YR6/1	c	3m sbk	fl vs vp	-	cs
Bwg[2]	50-85	7.5YR5/1	2.5YR3/4	c	4m sbk	vfl vs vp	>100Mn	gs
Bwg[3]	85 – 100	7.5YR5/1	2.5YR4/8	c	4cabk	vfl vs vp	>150Mn	cs
Bcg	100-158	7.5YR5/1	10YR5/8	c	4cabk	fl s vp	<150Mn	-
Pedon	**AB-2**							
Ap[1]	0-20	7.5YR3/2	-	c	2f sbk	fr shs shp	-	cs
Apg[2]	20-52	7.5YR5/6	10YR5/2	Sc	3f sbk	fr s p	-	as
Bwg[1]	52-89	2.5YR8/8	2.5Y6/2	c	4m sbk	fi vs vp	-	as
Bwg[2]	89-120	2.5Y6/2	10R3/4	c	4m sbk	fi s p	-	cs
BCg	120-165	2.5YR4/8	2.5Y6/1	Scl	3f sbk	fr s p	-	-
Pedon	**AB-3**							
Ap	0-20	7.5YR3/2	7.5YR4/6	Sc	3f sbk	fr shs shp	-	cs
Bw[1]	20-73	7.5YR6/1	7.5YR4/6	Sc	3m sbk	fi s p	-	cs
Bwg[2]	73-100	7.5YR6/1	-	scl	4m sbk	Fi vs vp	-	gs
BCg	100-152+	7.5YR6/2	-	sl	3m sbk	fi vs vp	-	-
Pedon	**AB-4**							
Ap	0-18	10Y3/2	5YR4/3	Sl	3f sbk	fr shs shp	-	Cs
Bw[1]	18-30	10YR5/2	5YR4/8	scl	3m sbk	Fi s p	-	cs
Bw[2]	30-75	7.5YR6/1	7.5YR5/6	Scl	4m sbk	Fi vs vp	-	aw
BC	75-144	7.5YR6/1	-	sl	2f cr	Vfr shs shp	-	-

* Abbreviation according to Soil Survey Handbook (Soil Survey Staff, 1962).

Table 2: Soil Particle size distribution

Horizon	Depth (cm)	Bulk density mg m^2	Very Coarse sand	Coarse sand	Medium sand	Fine sand g kg^{-1}	Very fine sand	Total sand	Silt .05-.002	Clay <.002m
Pedon	**AB-1**									
Ap	0-20	1.65	-	17	29	62	36	144	500	356
A_2	20-40	0.93	13	30	51	116	50	260	562	178
Bwg1	40-81	0.93	20	2	34	130	134	340	420	240
Bwg^2	81-111	0.99	-	25	36	73	70	204	506	290
Bwg^3	111-170	1.16	-	25	30	79	70	204	506	290
BCg	170-194	1.71	-	8	25	36	51	120	420	460
Pedon	**AB-2**									
Ag	0-28	1.43	-	21	32	46	47	146	534	320
A_{2g}	28-47	1.19	27	33	38	160	82	340	385	275
2Bwg	47-74	1.05	-	26	20	33	41	120	515	365
2Bg	74-109	1.68	47	48	31	43	31	200	400	400
2Bcg	109-150	1.41	-	21	32	46	46	145	515	340
Pedon	**AB-3**									
Apg	0-28	2.04	-	07	10	20	11	48	400	552
A_{2feg}	28-54	1.22	39	36	62	110	113	360	440	200
B1g	54-100	1.04	16	20	55	103	111	305	275	420
B2g	100-158	1.70	34	33	40	121	72	300	200	480
Pedon	**AB-4**									
Apg	0-30	1.53	35	50	68	124	63	340	201	456
Bwg^1	20-50	1.74	-	26	33	52	31	142	520	338
Bwg^2	50-98	1.50	-	27	40	66	49	182	518	300
Bcg	98-148	1.51	-	24	31	101	44	200	500	300
Pedon	**AB-5**									
Ap	0-20	1.93	-	47	49	34	50	280	438	382
AB	20-50	1.93	-	58	30	45	41	182	440	378
2Ew	50-76	1.11	52	53	181	122	126	534	324	142
$2B_{wfeg}$	76-95	1.13	76	86	44	100	74	380	360	260
3BCg	95-135	0.85	113	164	210	191	133	816	848	100
3Cg	135-170	0.83	124	140	212	144	140	760	88	152

Horizon	Depth (cm)	Bulk density mg m^{-3}	Very Coarse sand	Coarse sand	Medium sand	Fine sand g kg^{-1}	Very fine sand	Total sand	Silt .05-.002	Clay <.002mm
Pedon	**BD-1**									
Ap	0-21	0.94	100	124	226	180	122	642	40	318
Bw1	21-50	2.03	74	93	39	84	50	340	196	164
Bwg2	50-85	2.87	-	50	68	88	54	260	200	540
Bwg3	83-100	2.01	-	60	64	93	41	258	162	580
BCg	100-168	1.82	63	66	38	80	53	300	168	532
Pedon	**BD-2**									
Ap^1	0-20	0.89	45	52	90	134	79	400	143	257
Apg^2	20-52	0.91	38	76	73	201	77	475	140	385
Bwg^1	52-89	1.36	89	52	46	103	80	380	100	520
Bwg^2	90-120	2.06	56	97	40	55	34	282	118	600
Bcg	120-165	0.80	40	224	182	221	93	700	80	220
Pedon	**BD-3**									
Ap	0-20	0.94	47	76	110	164	124	521	106	373
Bw^1	20-73	2.04	29	103	82	201	65	480	100	420
Bw^2	73-100	0.96	45	114	84	192	202	635	62	303
BC	100-152+	0.80	66	142	119	298	141	760	62	176
Pedon	**BD-4**									
Ap	0-18	0.73	136	152	301	86	99	774	44	182
Bw^1	18-30	0.92	80	131	245	160	84	700	60	240
Bw^2	30-75	1.01	96	139	199	124	122	680	43	277
BC	75-144	0.85	76	124	322	161	140	822	38	140

Table 3: Selected Chemical Characteristics of the soils

Depth (cm)	PH-H_20	Ca^{2+}	Mg^{2+}	Na^+	K^+ c mol(+) kg^{-1}	Al^{3+}	H^+ soil	CECe	CEC_s	Change in CEC	O.C	T.N g kg^{-1}	Bay 1-p $mgkg^{-1}$
Pedon	**AB-1**												
0-20	4.9	1.27	0.54	0.13	0.24	1.78	0.80	4.76	14.32	9.66	9.7	1.3	2.4
20-40	6.1	1.08	0.71	0.05	0.93	0.56	0.2	3.55	11.40	7.85	9.3	0.3	1.8
40-81	8.0	1.56	1.88	0.12	3.53	0.10	0.02	7.21	19.64	12.42	9.3	0.4	1.8
81-111	9.0	1.81	2.34	0.24	4.72	0.34	0.13	9.58	20.16	10.58	8.3	0.3	1.8
111-170	7.7	2.81	3.70	0.11	3.71	0.19	0.04	10.56	26.01	15.45	8.2	0.2	2.7
170-194	9.1	3.78	2.48	0.11	3.77	0.06	0.01	10.21	24.92	14.71	7.6	0.2	2.7
Pedon	**AB-2**												
0-28	5.1	0.46	0.30	0.06	0.32	2.81	0.17	4.19	11.00	6.81	9.3	0.4	1.4
28 – 74	4.2	9.89	0.40	0.14	0.318	2.92	0.37	4.90	12.24	7.34	20.8	1.3	2.1
47 – 74	6.0	1.81	2.14	0.09	2.04	1.90	0.57	7.47	17.11	9.64	9.5	0.4	0.9
74-109	8.9	2.74	3.23	0.24	4.85	0.10	0.02	11.18	25.23	14.05	7.8	0.2	1.0
109-150	8.3	3.97	3.90	0.03	4.91	0.25	0.05	13.11	36.74	23.63	2.8	0.3	1.8
Pedon	**AB-3**												
0-28	4.7	0.43	0.39	0.35	0.18	2.94	0.36	4.65	8.53	3.88	14.1	0.7	9.0
28-54	4.8	1.18	1.77	0.11	0.17	2.40	0.59	6.21	13.70	7.49	13.6	0.8	1.5
54-100	6.3	5.91	5.09	0.13	0.50	0.56	0.07	12.26	25.04	12.78	9.1	0.4	1.2
100-158	7.4	8.92	4.69	0.13	0.77	0.10	0.03	14.64	28.28	24.62	13.6	0.3	1.7
Pedon	**AB-4**												
0-30	4.5	0.53	4.95	0.08	0.17	2.98	0.32	9.03	21.33	12.30	15.7	0.8	3.3
30-50	4.6	0.24	0.31	0.05	0.18	2.98	0.59	4.35	7.95	3.60	10.5	0.4	1.8
50-98	5.6	0.38	0.63	0.06	0.62	2.93	0.63	5.24	8.24	3.00	10.3	0.4	1.3
98-148	7.3	1.49	2.33	0.07	3.29	0.27	0.10	7.55	11.08	3.51	7.8	0.3	1.0
Pedon	**AB-5**												
0-20	5.0	0.86	1.14	0.10	0.13	1.10	0.15	3.39	7.21	3.82	11.8	0.5	3.6
20-50	4.9	0.80	0.71	0.09	0.15	1.99	0.83	4.57	7.87	3.30	11.7	0.5	1.6
50-76	4.7	0.62	0.57	0.08	0.18	2.80	0.82	5.07	9.44	4.37	11.9	0.6	1.4
76-95	5.4	0.27	0.21	0.02	0.14	0.20	0.03	0.87	1.67	0.80	6.8	2.0	1.8
95-135	5.5	0.22	0.14	0.02	0.13	0.66	0.07	1.24	4.01	2.77	6.9	2.3	1.5
135-170	4.6	0.30	0.34	0.07	0.18	3.25	0.65	5.79	10.59	4.80	10.9	0.6	3.1

Depth (cm)	PH-H_2O	Ca^{2+}	Mg^{2+}	Na^+ cmol	K^+ (+)kg^{-1}	Al^{3+} soil	H^+	CEC e	CEC_8	CEC	O.C	T.N g kg^{-1}	Bay Ip mgkg^{-1})
Pedon	**BD-1**												
0-21	5.0	4.90	0.53	0.12	0.20	2.73	1.10	11.59	28.16	16.04	20.1	1.8	2.7
22-50	4.9	3.42	2.10	0.10	0.16	2.89	1.31	9.56	24.00	14.04	15.9	1.2	1.8
50-85	5.0	4.97	3.07	0.24	0.21	3.14	1.66	13.29	33.94	20.65	11.6	0.9	1.5
85-100	4.9	3.16	2.06	0.14	0.18	3.25	1.70	11.03	27.48	16.48	9.8	0.7	1.5
100-158	5.1	3.70	2.93	0.24	0.22	2.03	1.27	10.31	26.11	15.72	9.2	0.5	0.6
Pedon	**BD-2**												
0-20	4.9	6.44	3.19	0.22	0.21	1.97	0.80	12.83	27.98	15.15	23.9	2.3	3.2
20-52	4.7	4.77	2.59	0.14	0.20	2.46	0.17	10.87	24.90	14.03	13.9	0.7	1.2
52-89	5.0	3.46	2.47	0.15	0.20	2.02	1.10	9.40	24.21	14.81	9.9	0.6	10.8
89-120	5.0	3.64	2.43	0.22	0.19	2.15	1.17	10.10	25.01	14.91	9.5	0.5	1.6
120-165	4.8	3.62	3.01	0.25	0.20	2.60	1.72	11.34	26.39	15.01	9.4	0.5	0.06
Pedon	**BD-3**												
0-20	5.2	0.61	0.49	0.09	0.17	2.63	1.70	5.69	8.79	3.10	20.2	1.2	1.0
20-73	5.8	0.66	0.74	0.08	0.17	2.95	1.75	6.29	10.33	4.04	13.4	0.1	1.8
73-100	4.7	0.71	0.91	0.10	0.17	2.72	1.81	6.42	11.16	4.74	13.1	0.7	0.6
100-152+	5.0	0.63	0.60	0.25	0.19	1.98	1.29	4.94	8.57	3.63	11.5	0.5	1.8
Pedon	**BD-4**												
0-18	5.5	0.6	0.23	0.04	0.15	2.85	0.98	4.85	7.93	3.08	19.0	1.4	2.1
18-30	5.3	0.51	0.32	0.04	0.16	2.24	1.29	4.56	7.10	2.54	4.2	0.4	1.6
30-75	5.1	0.54	0.51	0.06	0.14	2.82	0.94	5.02	9.04	4.02	10.0	0.5	1.2
75-144	5.1	0.34	0.26	0.05	0.15	2.56	1.87	4.83	8.00	3.17	8.2	0.3	10.2

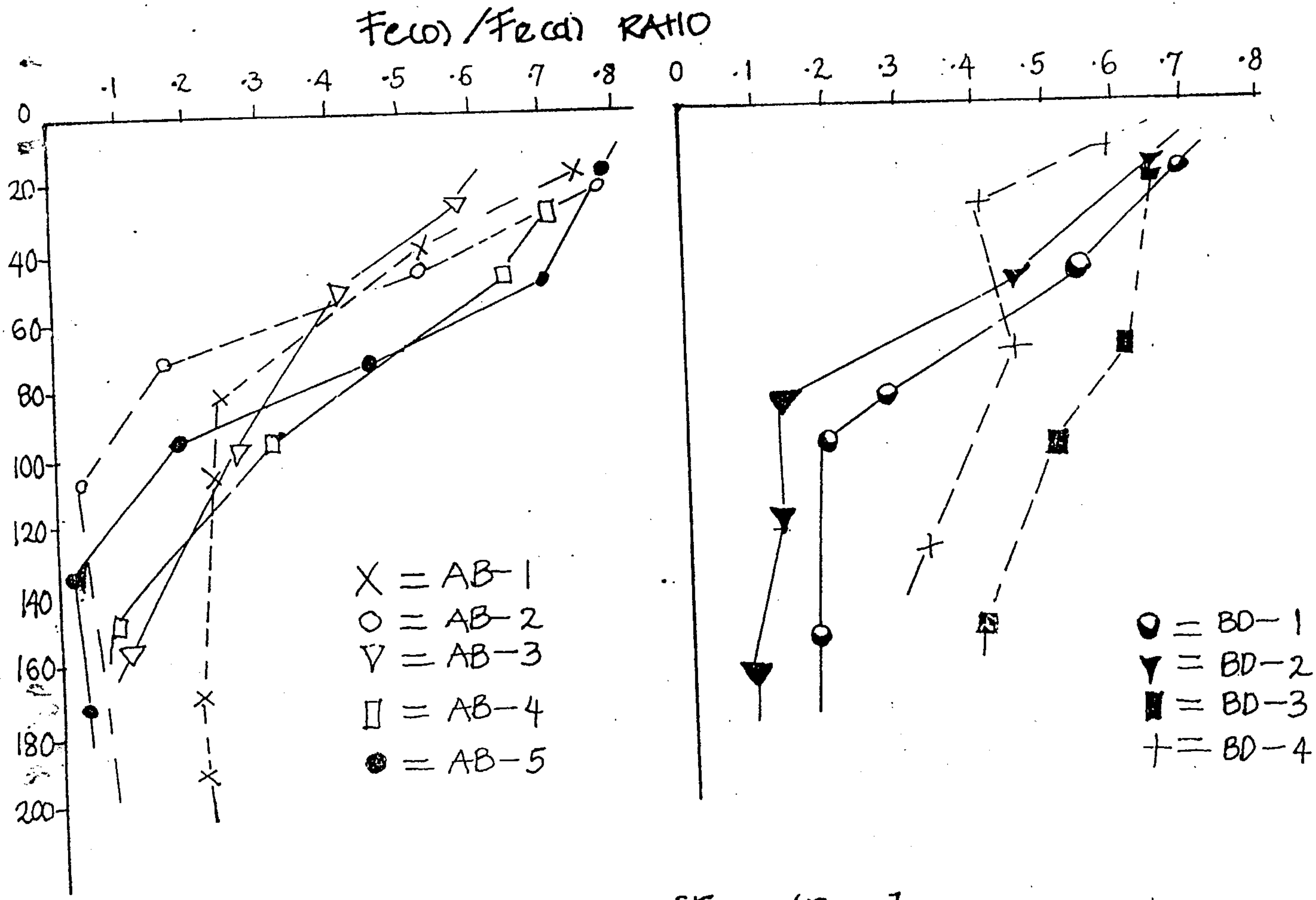

Fig 1: ACTIVE Fe RATIO [Fe(o)/Fe(d)] DISTRIBUTION IN THE SOILS.

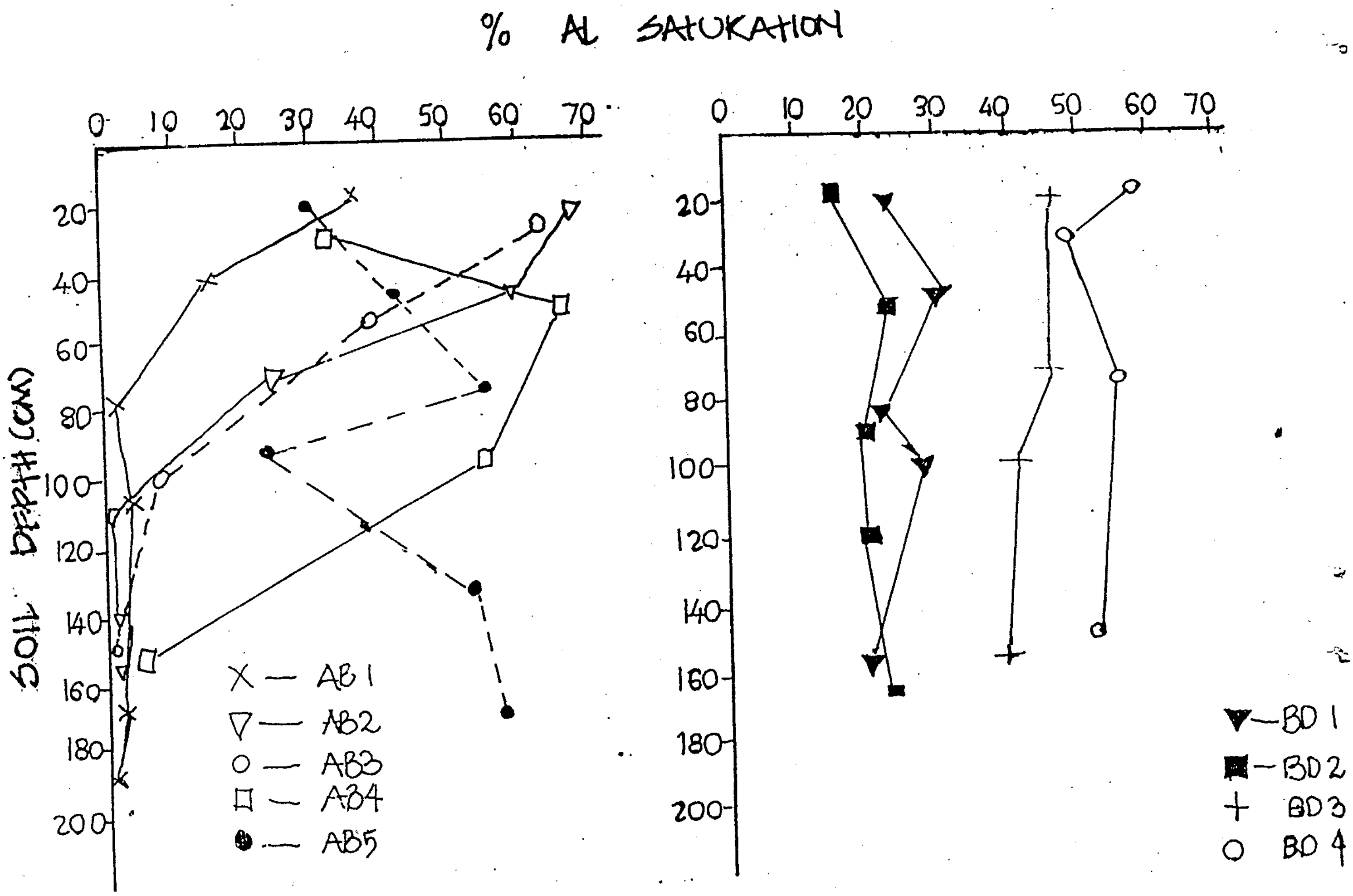

Fig 2: PERCENT AL SATURATION OF THE PEDONS.

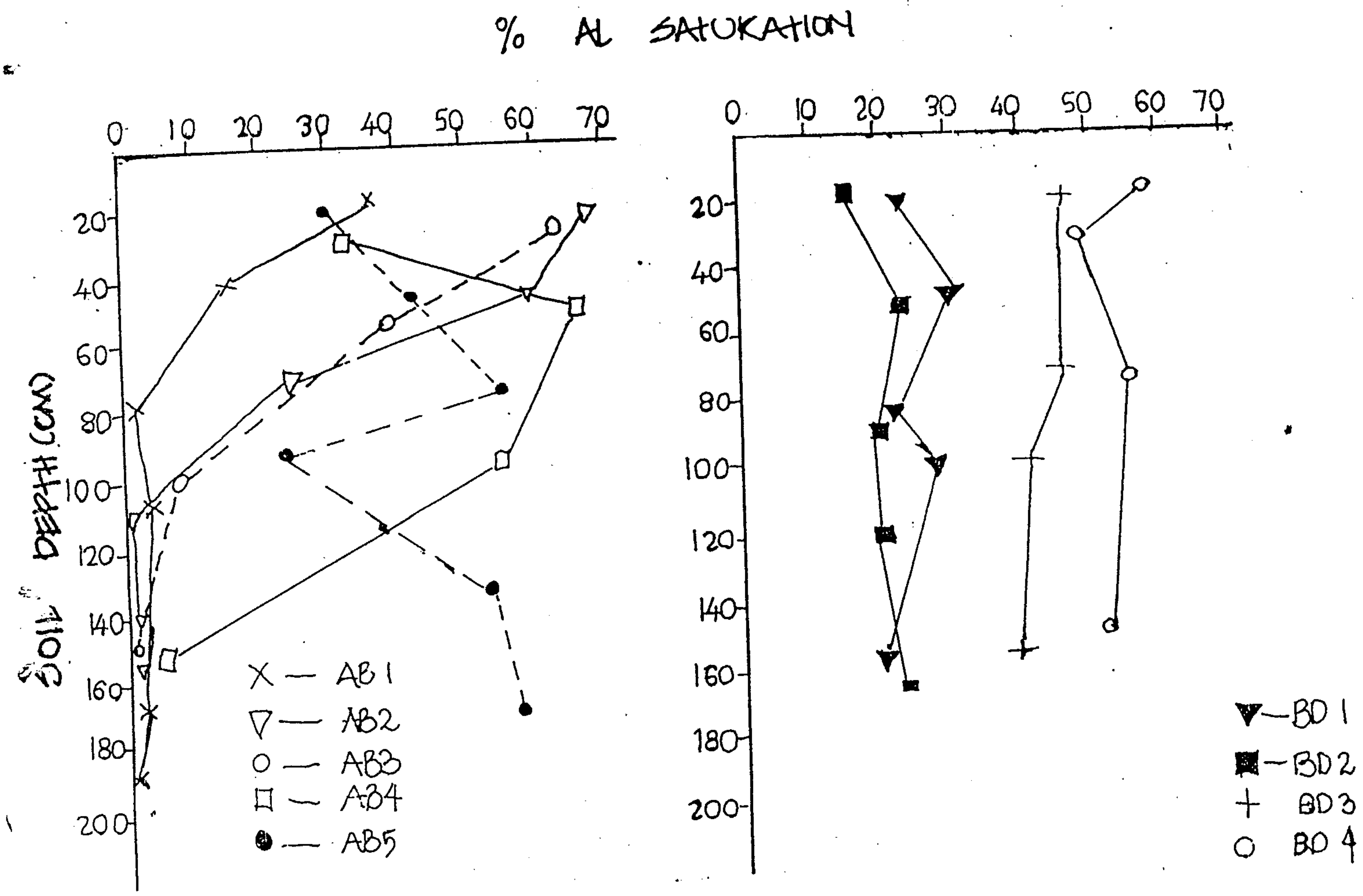

Fig 2: PERCENT AL SATURATION OF THE PEDONS.

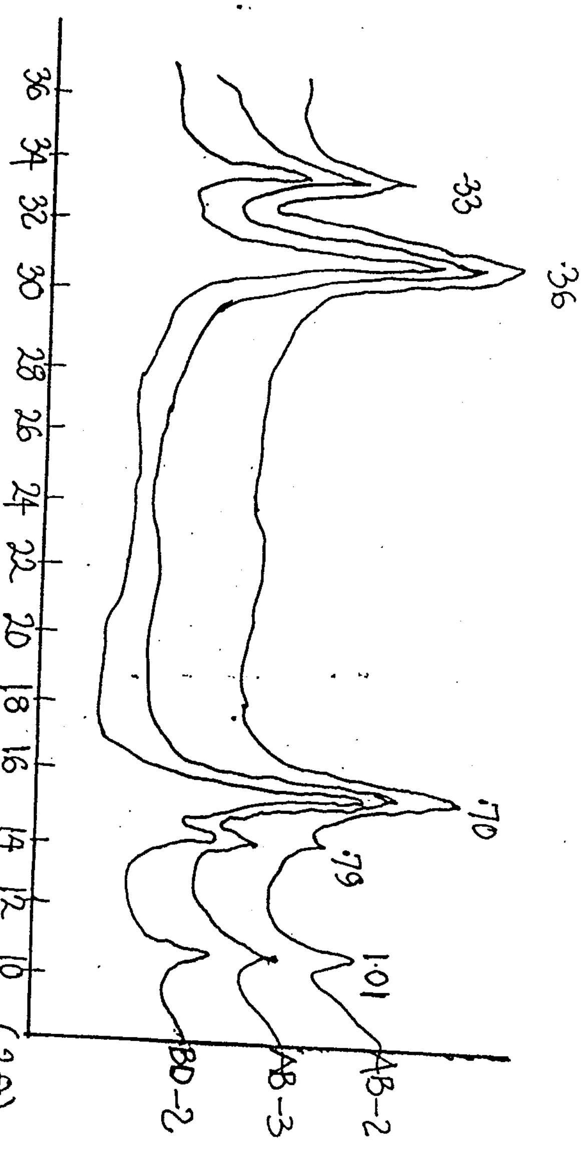

Fig.1: X-RAY DIFFRACTOGRAMS OF Mg-SATURATED CLAY SAMPLES OF PEDONS AB-2, AB-3, AND BD-2.

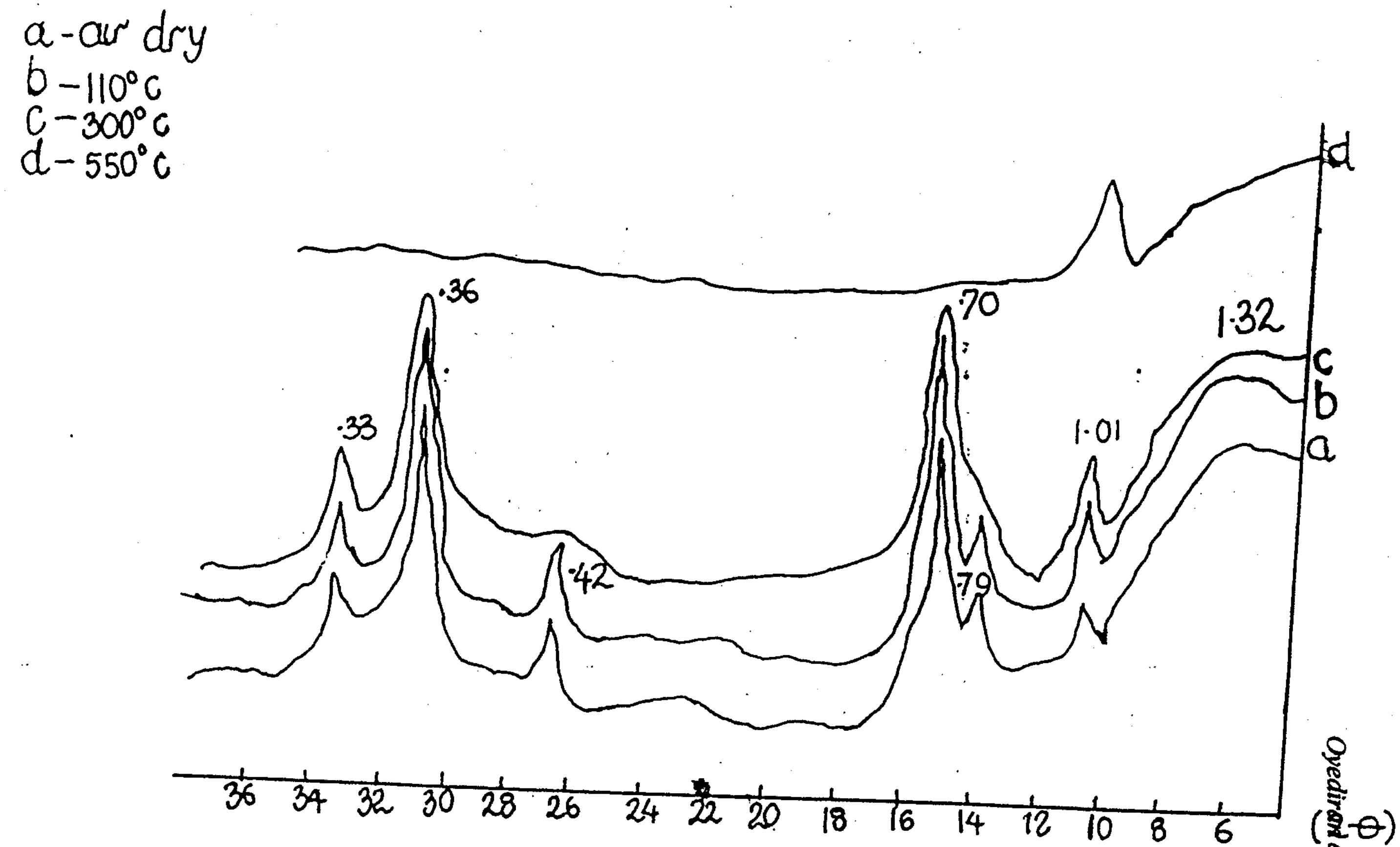

Fig 3: X-RAY DIFFRACTOGRAMS OF PEDON BD-1, K-SATURATED CLAY WITH HEAT TREATMENTS.