

# SOME CHEMICAL, PHYSICAL, AND MINERALOGICAL FEATURES OF SOIL COLLOIDS

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## SYNOPSIS

The -1 micron portion of several diversified soils were separated by sedimentary fractionation. Physical properties were evaluated on the -1 micron portion, the +1 micron portion, and on the original -40 sample. The -1 micron portion was analyzed for clay mineral identity by X-ray diffraction, and analyzed chemically for associated materials such as the oxides of Iron, Aluminum, Calcium, and Magnesium.

These data present several possibilities and trends as to the inter-dependency of the involved variables. Other considerations have been devoted to the geologic origin of several samples and to various physico-chemical relationships.

Each component or ingredient in a natural soil mixture embraces a series of variables of a physical and chemical nature. Combinations, either natural or synthetic, of these ingredients accordingly involve a multitude of variables which may contribute in part or in whole to the resultant physical properties of a soil.

The physico-chemical phenomena associated with soil colloids and near-colloids have been under exploration by investigators since the discovery of the crystalline nature of soil colloids by Hendricks and Fry (1)<sup>1</sup> in 1930. Although cation exchange in soil colloids had been observed as early as 1850 by both Thompson (2) and Way (3), the work was generally predicated on the misconception that soil colloids were of the character of hydro-gels of silicic acid, and of oxides of iron, and aluminum. The results of this early work are now manifest in modern concepts of clay mineralogy and associated cation exchange. The problem of ascribing properties beyond a definite crystalline structure to an unknown clay is, even today, a laborious and tedious task complicated by isomorphic replacements and uncertainty as to the purity of the specimen under study. However, it has been shown by recent investigators (4) that clays which were once described under various names are actually isomorphs of one of the mineralogical "families" of clays. These families are characterized by discrete ranges with respect to cation exchange capacity, height of the unit cell as determined by X-ray diffraction, silica-sesqui-

oxide ratios as determined by chemical analyses, and their accommodation for water. Of these families, the names Kaolinite, Illite, and Montmorillonite have been widely accepted and applied to those most frequently associated with soils.

These clay minerals represent only one portion of soils, and in any study attempting to define the physical or engineering properties of soil, it is necessary to examine all constituents and variables, both individually and collectively. There must be at least one of these variables which can be held accountable for the difference in physical properties of any two random samples. Further, by exhaustive analysis of all constituents, it should be possible to determine the relative dependencies of these variables on the resultant physical properties. Only by a thorough understanding of these mechanisms will it ever be possible to prescribe the most favorable stabilizing treatment for soil categories.

These problems have been under study in Kentucky for two years. The first report (5) on this work was presented at the 28th Annual Meeting of the Highway Research Board in 1948. That report described in detail a fundamental method of investigation and a limited tabulation of data. During the past year the method of investigation was modified in favor of simplicity and adaptability to survey work. Results reported previously indicated the possibility of soils derived from Ordovician formations in Kentucky being characterized by containing only Illite as the clay mineral ingredient. Kelley (6) in-

<sup>1</sup> Italicized figures in parentheses refer to the list of references at the end of the paper.

dicates that even the random occurrence of a single clay mineral in a soil is not only rare, but highly improbable. The possibility of such occurrence has been further investigated and reported in this paper.

Endell, Loos, and Breth (7) prepared synthetic mixtures of clays and quartz sand which demonstrated the effect not only in percentage of clay present but of differences in type of clay plus the effect of the exchangeable cation in the clay with respect to the Atterberg Limits. It was shown that by increasing the clay content, an increase in the Atterberg Limits resulted, but the increase was not linear. These results were obtained from the use of relatively pure clays, whereas soil colloids are generally mixtures of clays or of a clay and other colloidal materials.

Were soils composed of inert granular material and a pure clay, positive correlation could most certainly be obtained, as in the experiment by Endell, et al.; however, in natural soils, such variables as mixtures of clays, organic impurities, soluble salts and colloidal sesquioxides, variations in gradation, silicic acid gels, and cation exchange introduce multiple complexities. Further, with respect to the exchangeable cations, it cannot be stated with certainty that a clay contains only one type of cation even in a relatively concentrated environment of any single cation. Although the equilibrium may be shifted, in complex colloids of soils the assumption of complete replacement must be treated with caution.

The purpose of this study was to make an objective investigation of these colloidal constituents and their effect upon the engineering properties of soils through analyses for clay mineral content and identification of the mineral suite, analyses for associated sesquioxides and other so-called impurities, and by the performance of physical tests on the composite soil species as well as on the individual fractions

#### MATERIALS AND PROCEDURES

Thirty-two of the soils were selected from samples obtained in a study of the pumping action of rigid pavements in Kentucky (8). These samples were selected on the basis of variety of physical characteristics and geologic distribution. In addition 16 miscellaneous samples of unknown origin, all but two of which represented unusual features in other

states and some foreign countries, were included.

Because of limitations in the amount of soil available, no attempt was made to determine physical characteristics other than the Atterberg Limits of the sixteen special soils. Results of classification tests on the 32 Kentucky soils are tabulated in Table 1.

*Recovery of -1 micron Fraction.* Two hundred to five hundred grams of soil passing the No. 40 sieve were taken as a sample from which the -1 micron fraction was extracted by gravity separation as described in the previous report on "Separation Fractionation and Mineralogy of Clays in Soils."<sup>2</sup> The -1 micron material was recovered from the accumulated suspension by precipitation with sodium chloride. The amount of this salt added was just enough to bring about complete flocculation and precipitation in 24 hours.<sup>3</sup> The -1 micron material was recovered after precipitation by decantation and dried by evaporation under mild heat and air. On drying, the soil had occluded salt crystallized on the surface, but this could be washed away without disturbing the material. This dried material was pulverized in a mortar to pass the No. 200 sieve.

Sodium chloride was selected as the precipitating agent in view of its relative inability to replace natural cations other than potassium and lithium. The actual effect of the NaCl on the natural cations is not definitely known, and it is not known whether the concentration of Na<sup>+</sup> necessary to bring about precipitation is in excess of the concentration necessary to produce appreciable shift in the replacement equilibrium of the natural cation whether monovalent or divalent. In any case, it must be conceded that the possibility of alteration of the natural clay is very high, and it may be further stated that any other electrolyte used would produce a similar alteration unless the natural cation were identifiable in

<sup>2</sup> See *Proceedings*—Highway Research Board, Vol 28, p 470 (1948).

<sup>3</sup> Some soils required considerably more salt than others, yet in most cases the supernatant liquid rarely tasted salty. It was also observed that many soils which were initially reluctant to go into suspension, invariably entered into suspension after several successive washings with distilled water.

advance and the electrolyte to be added were a soluble salt of the same cation.

Kelley, (8) in a discussion of the effect of NaCl saturation on a clay, indicates that Na<sup>+</sup> saturated soils tend to be more impermeable than Ca<sup>++</sup> saturated soils; whereas, Ca<sup>++</sup> saturated soils tend to be more granular due to the binding together of the clay particles. Na<sup>+</sup> soils are more dispersed. He also infers that when large numbers of soils are compared,

was the case, the NaCl altered the electrolytic condition of the suspending medium without replacing the exchangeable cation of the clay.

*Chemical Analysis.* After essentially all of the material -1 micron in size had been separated from the -40 soil, a 0.5 g. sample of the -1 micron material was extracted with dilute HCl with mild heat and the extract analyzed gravimetrically for R<sub>2</sub>O<sub>3</sub>, CaO and MgO.

TABLE 1  
PHYSICAL PROPERTIES OF 32 KENTUCKY SOILS

Sample Number	Gradation					Atterburg Limits				Proctor Compaction		Specific Gravity	Highway Research Board Classification
	Sieve	Hydrometer				Liquid Limit	Plastic Limit	Plasticity Index	Shrinkage Limit	Optimum Moisture Content	Maximum Density		
		% -5μ		% -1μ									
		% -40	Natural	-40 <sup>a</sup>	Natural								
212	98	24	24.5	14	14.3	29	20	9	22.6	15.8	111.4	2.68	A-4(8)
213	87	60	68.5	40	45.0	64	25	39	16.9	26.0	96.2	2.76	A-7-5(20)
225	38	18	45.8	10	29.8	27	21	6	20.0	16.8	108.6	2.64	A-2-4(0)
226	100	29	29.0	14	14.0	30	23	7	22.1	17.5	106.9	2.66	A-4(8)
238	98	66	67.8	33	32.6	68	33	35	18.5	27.0	91.9	2.68	A-7-5(20)
243	39	18	48.0	10	26.0	39	20	19	12.8	17.3	111.2	2.72	A-2-6(1)
247	89	50	56.2	24	27.0	38	20	13	11.2	18.1	109.2	2.72	A-6(8)
271	94	51	56.0	30	32.8	50	24	26	19.3	24.2	95.4	2.69	A-7-5(16)
274	85	48	58.0	32	38.8	52	23	29	18.9	22.3	101.4	2.75	A-7-5(18)
289	94	58	61.6	25	26.6	52	28	24	16.8	21.4	99.7	2.75	A-7-5(16)
297	95	37	40.0	15	17.9	25	14	9	22.7	14.2	115.8	2.68	A-4(8)
300	97	21	21.7	10	11.1	21	16	5	19.4	12.8	116.9	2.65	A-4(8)
301	62	36	46.8	16	16.1	31	19	11	26.1	15.6	114.5	2.69	A-6(4)
302	82	26	32.1	11	13.0	32	21	7	17.4	14.8	115.0	2.70	A-4(6)
305	90	32	32.4	10	12.2	25	20	5	21.1	14.2	115.0	2.69	A-4(2)
310	64	18	28.5	8	6.4	28	17	6	19.9	12.8	117.8	2.72	A-4(1)
337	82	20	39.2	8	15.4	30	20	10	23.0	15.1	110.0	2.63	A-6(2)
341	84	48	57.8	17	19.3	44	28	16	19.4	21.1	104.1	2.76	A-7-5(11)
350	87	51	56.2	22	25.3	37	22	15	18.0	18.2	107.9	2.75	A-6(10)
359	76	36	47.3	16	21.0	37	21	16	18.4	17.3	109.8	2.71	A-6(10)
377	63	25	39.7	9	14.3	40	20	20	17.0	14.8	108.3	2.71	A-6(8)
382	78	28	38.4	15	20.6	38	22	13	18.0	15.6	108.5	2.72	A-6(7)
383	78	31	40.2	13	16.9	29	18	11	17.1	17.1	110.4	2.69	A-6(7)
386	45	15	33.3	4	8.9	21	13	8	17.2	12.4	118.0	2.68	A-2-4(0)
389	92	36	40.6	10	12.1	31	19	12	26.1	15.3	108.2	2.69	A-6(9)
390	63	38	60.3	10	17.5	63	24	38	19.7	27.0	95.8	2.72	A-7-5(15)
391	78	40	51.3	25	35.9	42	19	23	27.4	24.5	98.6	2.70	A-7-5(12)
392	57	24	40.3	10	17.5	38	16	22	18.9	17.0	97.4	2.68	A-6(6)
394	78	34	44.0	20	25.8	32	24	10	18.0	17.7	110.9	2.74	A-4(7)
395	61	25	40.0	10	16.6	32	24	8	25.0	17.6	105.3	2.67	A-4(3)
398	49	16	32.7	9	14.3	34	24	9	25.0			2.70	A-4(7)
410	78	38	47.8	17	20.6	35	20	15	22.4	19.4	105.2	2.72	A-6(8)

<sup>a</sup> Refers to percentage of total material passing 40 mesh sieve (soil mortar)

the correlation between percentage of Na<sup>+</sup> saturation and physical properties is often found to be poor. It can be shown by the data in Table 2 that in each sample of the -1 micron fraction, almost without exception, a sufficient amount of Ca<sup>++</sup> and Mg<sup>++</sup> was present to satisfy the adsorbed cation capacity. In that connection, it is possible that the NaCl served primarily to reduce the Zeta-potential of the double layer (9) and consequently to reduce the hydration of the adsorbed cation, thus bringing about coagulation without involving appreciable cation exchange. If that

Volumetric determinations for Fe<sub>2</sub>O<sub>3</sub> were made by reduction of the iron with stannous chloride and titrating with KMnO<sub>4</sub> solution. The percentage of Al<sub>2</sub>O<sub>3</sub> was estimated by subtracting the percentage of titrable Fe<sub>2</sub>O<sub>3</sub> from the percentage of R<sub>2</sub>O<sub>3</sub>. Aliquot portions of the extract are being held in reserve for determinations of Na<sup>+</sup> and K<sup>+</sup>, and it is not possible to present those data in this report.

The residues from the extractions were dried and weighed. These results are reported in Table 2 as "Approximate Percentage Clay by Extraction." The sums of all the determina-

tions subtracted from 100 percent is also reported in Table 2 as the "Approximate Percentage Other Material." Attempts were made to estimate the amount of organic material

That, of course, is very indicative of organic impurities. Only after treatment with 30-percent  $H_2O_2$  was it possible to obtain clear patterns, indicating that the extraction of the

TABLE 2  
RESULTS OF CHEMICAL AND MINERALOGICAL ANALYSES ON THE -1 MICRON FRACTIONS

Sample Number	Chemical Analysis % by weight							Calculated Ratios and Equivalents						Mineralogical Analysis (X-Ray Diffraction)				
	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	R <sub>2</sub> O <sub>3</sub>	CaO	MgO	Clay <sup>a</sup> by Ex-traction	Other <sup>a</sup> Materials	% MgO % CaO	% R <sub>2</sub> O <sub>3</sub> % Clay	m eq 100 gm. -1u		m. eq 100 gm Clay		Approximate Percentage				
										Ca++	Mg++	Ca++	Mg++	Kao-lin-ite	Illite	Mont-morillonite		
212	6.00	11.30	17.30	94	2.17	79	59	2.31	220	34	212	43	269	40	60	20		
213	11.86	6.24	18.10	74		75	7.16		243	27		36		10	90			
236	1.56	2.80	4.36	1.08	0.46	58	36.10	43	075	39	45	67	78	100				
238	15.64	8.46	24.10	1.06	1.62	50	23.22	1.53	482	38	158	76	316	40	100			
243	4.60	7.48	12.08	1.54		66	20.38		.183	51		77			100			
247	2.60	7.83	10.43	1.78		38	49.79		.285	63		166			100			
271	13.20	7.78	21.00	16.60	1.32	60	1.08	.08	593	128		990	214		100			
274	18.90	3.32	22.20	1.56	0.33			.21	56	32				40	60			
289	5.29	11.98	17.27	1.24	0.87	60	20.62	.70	290	45	85	75	141	40	60			
297	8.48	6.72	15.20	1.04	2.44	74	7.32	2.35	205	37	238	50	322		100			
300	3.80	3.18	6.98	1.46	0.62	92	0.00	43	076	82	61	57	66	40	60	b		
301	7.27	2.14	9.41	0.70	0.89	28	61.00	1.27	336	25	87	89	310	70	30			
302	10.82	4.18	15.00	2.14					77					50	50			
305	7.20	4.60	11.80	2.76		56	31.44		211	27		48		50	50			
310	11.30	13.70	25.00	3.98	0.72	75	0.00	0.18	333	142	70	189	93	50	50			
337	12.02	5.88	17.90	1.28	1.17	70	9.05	0.91	255	46	114	66	163	50	50			
341	3.62	3.80	7.42	1.32	0.63	70	20.63	0.48	106	47	61	67	87	80	20			
350	26.30	4.97	33.30	11.50	2.20	36	17.40	0.19	935	410	214	1150	600		100			
359	11.79	5.11	16.90	1.48	1.81	83	0.00	1.22	.204	53	177	64	214		100			
377	10.26	3.21	13.50	5.2	2.03	79	4.95	3.90	.171	19	119	24	151		100			
382	16.60	9.65	26.20	2.20	2.04	49	20.56	.93	.535	79	119	161	242		100			
383	13.27	4.83	18.10	.46	1.74	76	3.70	3.78	238	17	90	22	118	80	20			
386	16.24	7.16	23.40	.94	1.70	31	42.96	1.81	755	34	166	110	534	30	70			
389	0.36	5.70	6.06	1.04	.08	30	62.82	.08	202	37	8	122	27	60	40			
390	11.00	7.66	18.70	1.88	0.56	60	19.86	0.64	312	32	54	53	90	50	50			
391	1.12	10.10	11.22	1.64	0.58	55	31.56	0.35	204	59	55	107	100	50	50	b		
392	4.36	4.32	8.68	.58	0.74		41.80	1.28		21	72			50	50			
394	14.90	7.96	23.90	.42	2.26	72	2.42	5.38	818	15	221	21	308	30	70			
395	9.50	7.46	17.00	.50	1.42	82	0.00	2.84	207	18	139	22	170	40	60			
398	12.30	7.34	19.64	.74	.70	72	6.96	.95	272	27	69	38	96	50	50			
399	3.62	3.12	6.74	1.24	0.17	24	67.85	0.14	280	45	16	187	67					
410	1.68	3.12	4.80	1.18	.64	70	23.38	.54	.069	42	62	60	89	50	50		b	
D-59	6.27	1.37	7.64	1.24	4.10	66	21.02	3.31	.113	45	400	68	605					
21	18.19	4.71	22.90	.98	0.34	66	9.78	.35	347	35	34	53	52	33½	33½			33½
48-B	16.40	9.58	26.00	.50	1.16	63	19.34	2.32	491	18	114	34	215	50	50			
P-4	9.66	5.76	15.42	0.20	2.43	48	24.95	0.26	.321	329	236	685	490					
H-104	29.10	3.38	32.50	0.30	0.58	66	0.62	1.93	.492	11	56	16	85	60		40		
F-39	20.70	1.94	22.60	1.64	1.39	16	58.37	.85	.413	59	136	369	850		100			
F-37	13.60	7.01	20.60	.71	1.10	72	5.59	15	286	26	107	38	148		100			
D-153-1	3.20	4.12	7.32	3.61	0.42	90	0.00	12	081	108	42	120	47		100	b		
B-144-C	21.20	1.82	23.00	1.76	6.11	50	20.13	8.04	460	27	595	54	1190	10	90			
B-30	5.92	6.20	12.12	1.28	1.92	56	26.68	1.50	216	46	187	82	334	40	60			
B-3-C	9.10	6.32	15.42	1.50	2.10	54	27.00	1.40	.286	54	205	100	218					
78-A	12.30	6.89	19.20	.58	1.14	62	17.08	1.97	310	21	110	34	178		50		50	
1-A-B	9.20	5.98	15.18	2.88		17	64.94		.893	103		606		10	90			
50	6.49	11.89	18.38	1.02	1.39	72	7.21	1.36	.255	37	136	61	189		100			
28	1.87	2.25	4.12	4.53	2.22	42	47.13	0.49	.099	162	216	386	515		100			
18	11.50	4.90	16.40	1.32	2.48	54	25.80	1.87	304	47	242	87	450	100				

<sup>a</sup> Approximate percentages calculated

<sup>b</sup> Indication of Quartz

remaining in the residue from the extraction by further extraction with organic solvents, and in several instances appreciable quantities could be recovered by evaporating the solvent from the extract; but after extraction by this method, it was not possible to obtain clear X-ray diffraction patterns on the residue.

organic materials by solvents was by no means complete.

**Mineralogical Analysis.** After extraction by HCl and organic solvents followed by treatment with  $H_2O_2$  to oxidize the remaining organic material, X-ray diffraction patterns were

made on the purified residue from each sample. These patterns were used for identification of the clay mineral groups present. Samples of one clay identified as an Illite-Kaolinite mixture by X-ray diffraction methods were analyzed by the differential-thermal method.

**Physical Tests.** Physical characteristics were defined mainly by the Atterberg Limits on the composite -40 sample, the -40 to +1 micron fraction, and the -1 micron fraction. In some cases an insufficient quantity of sample made it necessary to omit some of the limit tests. Sieve and hydrometer analyses and Atterberg limits tests on the -40 material had been made in previous investigations pertaining to the 32 Kentucky soils. None of the 16 special samples was tested for grain-size distribution; therefore, in any of the graphical presentations of results involving percentages of material finer than certain size, these 16 samples are not represented. The same is true, of course, for any particular relationship involving any sample when one of the tests for that relationship was necessarily omitted because of insufficient material.

#### RESULTS AND ANALYSES

Essentially all of the pertinent data resulting from these tests and analyses are shown in Table 1 through Table 3. Graphical presentations of the data are supplemented in many instances by statistical evaluations of the resulting relationships. Only those relationships worthy of discussion are considered in this report.

**Natural Soil -40.** Relationships resulting from physical tests on the soils finer than the 40-mesh sieve were not unusual with respect to the amounts of material finer than 5 microns; nor was there any significant effect of the type of clay mineral. This is demonstrated in Figure 1 where it is indicated that the liquid limit increases in a manner exceeding a direct proportionality with increases in the percentages of -5 micron material. Both this and the relation shown in Figure 2 conform generally with accepted and established concepts of the influences from these fine portions of the soil mortar. However, the significance of extrapolation of the curves back to the ordinate intercepts or origin should not be overlooked. In the case of Figure 1, it is indicated that, if the percentage of -5 micron material is

reduced to zero, the average soil would be expected to have a liquid limit of zero; and the possibility for variation from this trend is limited by the grouping of the plotted points as well as by the average conditions represented by the curve. When Figure 2 is considered in the same light, on the extrapolation

TABLE 3  
PHYSICAL PROPERTIES OF FRACTIONS

Sample Number	-1 Micron				-40 to +1 Micron			
	L.L.	P.L.	P.I.	S.L.	L.L.	P.L.	P.I.	S.L.
212		53 5		20 4				25 0
213	90 2	27 8	62 4	20 5	26 4	13 0	13 4	16 0
235	57 2	29 7	27 5	24 0				
236	103 0	29 6	73 4	11 0				
238	85 2	31 9	53 3	23 0	36 3	22 8	13 5	23 5
243	41 1	20 2	20 9	13 7				
247	81 9	34 9	47 0	35 0				
271	95 8	30 9	64 9	10 0	30 9	26 1	4 8	23 0
274	100 0	32 8	67 2	24 5				
289	88 2	28 5	59 7	22 0	33 3	26 6	6 7	22 0
297	34 1	18 9	15 2	18 7				
300	36 7	20 83	15 9	39 0				
301	79 6	30 48	49 1	21 0				
302		25 1		44 2				
305		51 27		24 3				
310		23 6		27 5				
337		29 4						
341								
350	68 5	30 7	37 8	25 8	32 4	26 3	6 1	26 0
359	76 2	30 97	45 2	44 5				
377		37 9		19 6	24 0	18 1	5 9	19 0
382	71 0	38 9	32 1	26 8				
383	81 0	33 88	47 1	24 0				
386		18 8		44 6				
389	75 6	31 93	43 7	28 1				
390	79 2	30 6	48 6	9 5	20 0	17 5	2 5	17 0
391	82 2	35 6	46 6	22 0				
392	97 5	34 7	62 8	23 0	25 8	18 3	7 5	21 0
394		34 4		26 3				
395		33 1		43 4				
398		23 0		37 9				
410	44 0	25 0	19 0	24 7				21 0
D-59	68 5	49 63	18 9	22 0				
21		37 4		17 6				
48-B	124 0	48 3	75 7	15 0				
P-4		34 2						
H-104	67 2	37 4	29 8	24 0				
F-39	52 4	30 8	21 6	16 1				
F-37	87 4	31 15	56 2	24 0				
D-153-1	51 5	29 1	22 4	8 0				
B-144-C	68 3	34 3	34 0	23 4				
B-30	80 4	52 8	27 6	29 1				
B-3-C								
78-A	85 9	33 03	52 9	4 0				
1-A-B	81 8	26 45	55 3	23 0				
50	75 9	34 67	41 2	15 5				
28	96 3	31 1	65 2	17 0				
18		45 2						

of the curve to the intercept, a certain value for the liquid limit is retained after the amount of -1 micron material is reduced to zero.

Perhaps the most significant feature resulting from these and similar plots relative to other properties is the absence of any characteristic which can be consistently ascribed to the influence of clay minerals. The highly Kaolinitic clays usually have lower values of plasticity, but mixtures of Illite and Kaolinite

exhibit random distribution which cannot be held to account by any of the information obtained thus far. It must be considered, however, that these influences in certain natural soils may be obscured by other variables such

capacity factor, intensity representing the reactivity of the ingredient and capacity representing the amount of material contributing, all of which must be evaluated by differentiation of the individual components.

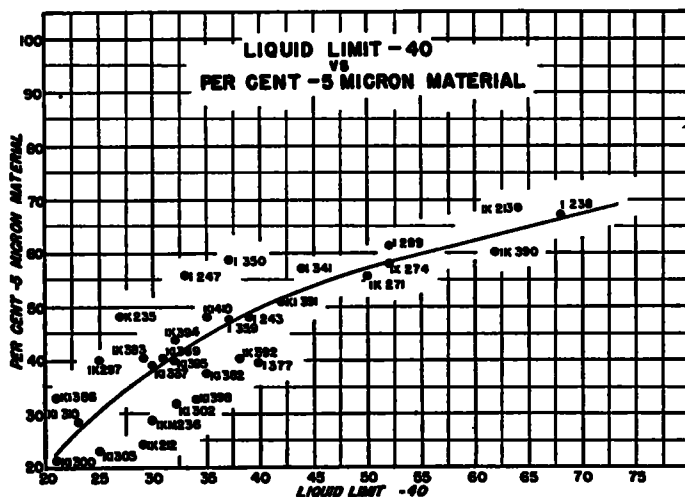


Figure 1

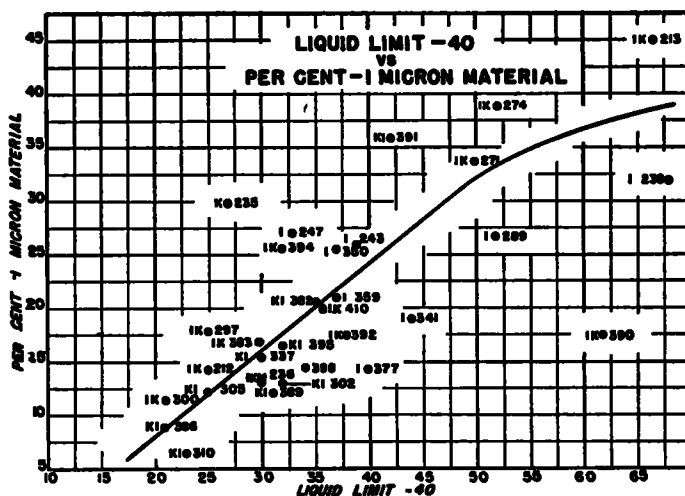


Figure 2

as sorting and the so-called contaminating ingredients, and that the physical properties shown are, in fact, summations of all influences. In a general way, the influences of any particular component should probably be described in terms of an intensity factor and a

-40 to +1 micron Fraction. That part of the soil between the 40-mesh sieve and 1 micron in size was generally more erratic than the soil as a whole, insofar as relationships between different physical properties are concerned. The limited number of tests performed on

this size material does not permit extensive evaluation of any individual property, but from general inspection of the limits for this size-range in Table 3 as compared to the equivalent values for the -40 soil in Table 1, it must be concluded that the manifestations of plasticity have been all but eliminated by the extraction of the -1 micron fraction. This, of course, does not imply that plasticity of a soil can be explained by such a simple observation as this, but it does emphasize the dependency of granular soils—and even soil mortars—on the colloid and near-colloid sizes for its plastic qualities.

cally in Figure 3. A statistical test of these data yields a relationship of 0.940 for Pearson's linear correlation coefficient, whereas a coefficient of unity would indicate a perfect linear correlation between the two variables.

The relationship between liquid limit and plastic limit shown in Figure 4, is a matter of further interest and should probably be considered the more fundamental relationship. The inference made here may be better understood from consideration of the proportionality between liquid limit and plastic limit up through values of approximately 65 percent and 32 percent respectively; and then, the

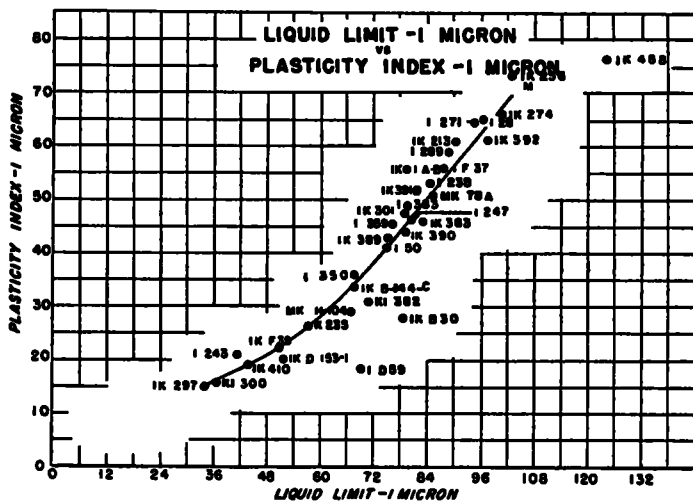


Figure 3

In all but two of eight cases represented, the liquid limit, plastic limit and shrinkage limit were nearly equal, and in those two cases the amount of material finer than the 5 micron size was unusually large

**-1 micron Fraction.** When the -1 micron fraction is separated from the coarser material of the natural soil, the properties of these colloidal plasticizers may be tested independently of the coarser materials. Also, by virtue of greater homogeneity with respect to size, the relationships between the Atterberg limits may be defined more precisely. All the results from physical tests on this fraction are reported in Table 3.

The resulting relationship between liquid limit and plasticity index is illustrated graphi-

caly in Figure 3. A statistical test of these data yields a relationship of 0.940 for Pearson's linear correlation coefficient, whereas a coefficient of unity would indicate a perfect linear correlation between the two variables. The inference made here may be better understood from consideration of the proportionality between liquid limit and plastic limit up through values of approximately 65 percent and 32 percent respectively; and then, the

absence of any further increase in plastic limit for further increase in liquid limit. In view of these considerations the plot of liquid limit versus plasticity Index (Fig. 3) in the lower range describes the proportionality mentioned while in the upper range it is essentially a description of the liquid limit plotted against itself, the abscissa being measured liquid limit values and the ordinate being values of liquid limit after subtraction of the relatively constant plastic limit.

It may be noted that samples D59, B30, and 48B had exceptionally high plastic limits—around 50 percent—which might be expected for a Na-Montmorillonite; but by X-ray diffraction analysis, B30 and 48B were shown to be Illite-Kaolinite mixtures. There are no significant features shown in Table 2 by which





of iron and aluminum is of no minor concern. Such a factor should be considered in any attempt to evaluate the properties of soil colloids where iron and alumina appear as accessory ingredients to clays.

minerals have been found and it appears to be the exception for a single clay mineral to be in existence in a soil.

Attempts have been made to show that the mode of origin of a soil or its parent materia

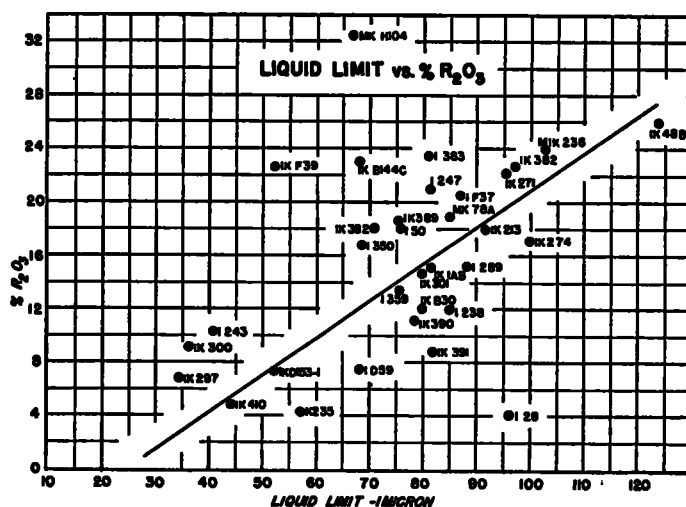


Figure 5

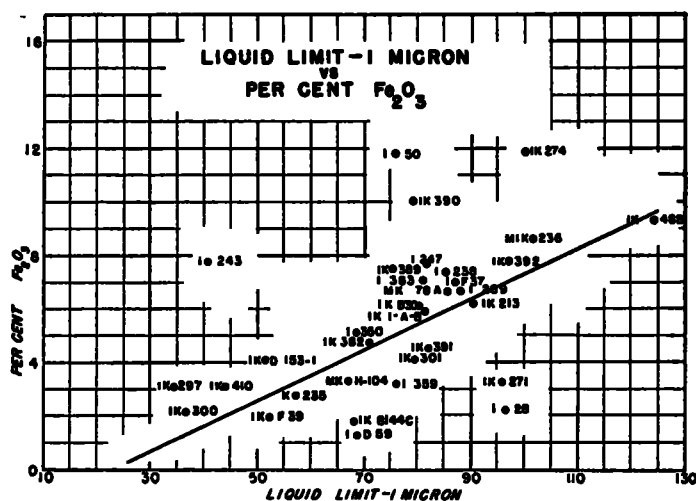


Figure 6

*Clay Mineralogy and its Areal Aspects.* Fifty-four different Kentucky soils have been analyzed for their clay minerals. These samples were chosen to represent a spread geographically, geologically, topographically and pedologically. Diverse combinations of clay

has a tendency to produce a characteristic clay mineral. Thus far, only the soils in the Blue Grass Region of Kentucky—derived principally from Ordovician limestone and shale formations—have borne this out. Sixteen soils from this region all contained Illite ex-

clusively, and only one other soil sample analyzed showed this feature. However, soils derived from younger formations have shown no tendency to be characterized by clay minerals. It can be shown that the Blue Grass

Efforts were made to detect possible areal variations of iron, aluminum, calcium and magnesium oxides that were determined. Iron and calcium oxide content was shown to be relatively constant in the Blue Grass Area

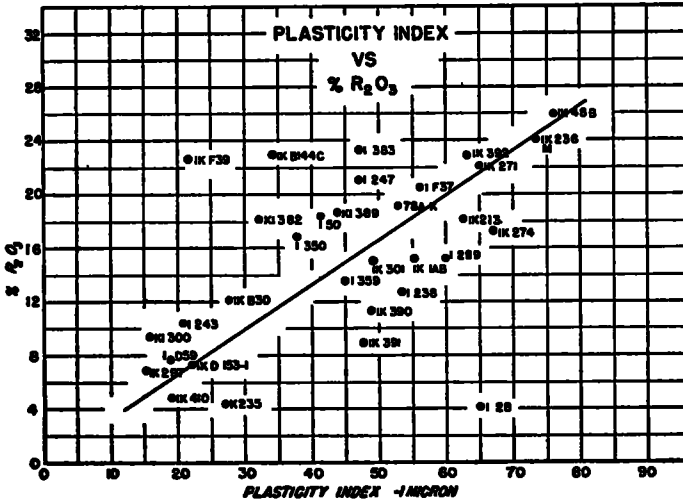


Figure 7

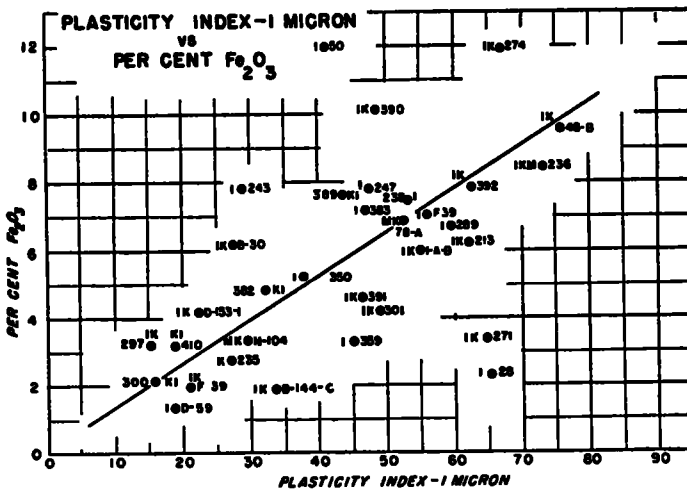


Figure 8

Region contains no exclusive features other than age of formations and their structural aspects. Although general geologic regions of Kentucky have not been covered completely, there is evidence suggesting a unique situation in the Blue Grass area.

but varied without regard to any known aspects outside this region.

No soil-area differentiated pedalogically, showed exclusive clay mineral content but this aspect was not explored with the detail thought necessary. Future work might well

include a more specific analysis of this type. These observations are in anticipation of substantiating data, but are nevertheless interesting points worthy of discussion.

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