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THE MINERALS IN THE CLAY FRACTIONS OF A BLACK COTTON SOIL AND A RED EARTH FROM HYDERABAD, DECCAN STATE, INDIA

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(With Plate XII and Two Text-figures)

Methods for determining the mineral constituents of soil colloids have recently been discussed by Nagelschmidt (1939). These methods were applied to soil samples from a typical black cotton soil (or Regur) and a typical red earth from Hyderabad, Deccan State, India, which have been studied in detail by Desai (1939).

The two soil profiles selected for this study were taken on and near the Government Experimental Farm, Rudrur, Nizamabad. The climate of the district is characterized by cool, dry winters, a rainy season which extends from June to October and a summer season, February to June, during which severe local storms may occur. The total rainfall ranges between 37 and 40 in. per annum.

The black cotton soil (no. P7 in Desai, 1939) was taken from an irrigated area on the farm. It was derived from colluvium over gneiss and consisted of a dark greyish heavy clay loam which was hard and compact to the lowest depth of sampling, 48 in. The fine material contained little calcium carbonate, but some nodules and concretions were distributed throughout the profile; there was no pronounced zone of carbonate accumulation. Its *p*H values increased with depth from 8·0 to 8·4, and the soluble salt content varied between 0·05 and 0·07 %.

The red earth (no. P8 in Desai, 1939) was taken on uncultivated waste land on the slope of a granite hill near the farm. It was a brownish red coarse sandy clay loam, becoming lighter in colour with depth, and containing disintegrating rock material in the lowest sample, 36–42 in. The *p*H values increased with depth from 6·1 to 7·4, no carbonates being present. The soluble salts varied between 0·04 and 0·06%, except for one high value 0·09% at 6–18 in.

MECHANICAL ANALYSIS

The samples of the black cotton soil contained about 5% stones, larger than 2 mm. These were mainly greyish carbonate nodules with a few rock fragments of weathered granite similar to those found in the red soil, and some pieces of vein quartz. The soils of the red earth, P8, had far more (30–40%) stones consisting entirely of weathered fragments of coarsely crystalline granite or gneiss.

Mechanical analyses for six samples of each profile are given in Table I. The data show that there is very little variation within each profile. The black soil has 60–70% silt and clay, whereas the red soil has only 25–40%.

Table I. *Mechanical analyses: oven-dry fractions as percentage of oven-dry soil below 2 mm.*

Depth in.	Coarse sand	Fine sand	Silt	Clay	Air-dry moisture
		Black cotton soil (P7)			
0–6	23·0	13·2	22·6	39·9	6·6
6–12	21·8	14·0	22·8	41·1	6·6
12–18	23·2	13·7	23·6	39·7	6·2
18–24	22·2	12·6	22·8	41·7	6·6
30–36	21·4	12·4	23·2	43·3	6·8
42–48	20·1	11·9	23·1	44·7	6·9
		Red earth (P8)			
0–6	52·2	23·0	5·9	20·0	2·5
6–18	46·4	15·9	6·5	31·8	4·2
18–24	48·8	13·5	7·8	32·0	4·4
24–30	51·7	15·0	7·9	26·8	3·8
30–36	48·0	15·3	9·0	29·0	4·1
36–42	47·0	13·8	8·7	31·3	4·5

Clay fractions were prepared by treating the soils with hydrogen peroxide and acetic acid, washing till the filtrates were free from calcium, and dispersing with ammonia. The clay was separated by repeated decantations at 8·5 cm. after 24 hr.

The clay suspension was subdivided into three fractions, coarse, fine and superfine clay, by repeated supercentrifuging at 23,000 rev./min. with rates of flow of 120 l./hr. and 12 l./hr. The estimated particle sizes of the three fractions were:

Coarse clay	1·4–0·1 μ diameter
Fine clay	0·1–0·06 μ diameter
Superfine clay	Under 0·06 μ diameter

Quantitative results for two representative samples of each profile are shown in Table II. In both profiles the coarse clay forms the smallest and the superfine clay the largest fraction. The proportions of coarse, fine and superfine clay are constant throughout the black profile, but for the red profile the superfine clay increases with depth at the expense of the fine one.

Table II. *Clay subfractions as percentages of total clay*

Soil	Depth in.	Coarse clay	Fine clay	Superfine clay
Black	12–18	10	25	65
Black	42–48	11	22	67
Red	18–24	7·5	43·5	49
Red	36–42	8·5	27·5	64

CHEMICAL ANALYSIS OF CLAY SUBFRACTIONS

Silicate analyses were carried out on all fractions obtained from the two soil profiles. The results show that in each case there is very little variation with increasing depth. As the full data are being published elsewhere (Desai, 1939), it seems sufficient to give results only for one layer from each profile. The data are shown in Table III and include the base exchange capacities determined by the Parker (1929) method, silica-alumina and silica-sesquioxide ratios and the organic carbon determined by the modified chromic acid method (Robertson & Shewan, 1935).

Table III. *Chemical analyses of clay subfractions for one black cotton soil (P7) and one red earth (P8), as percentages of oven-dry clays*

	Black soil, 12–18 in.			Red earth, 18–24 in.		
	Coarse %	Fine %	Superfine %	Coarse %	Fine %	Superfine %
SiO_2	57·30	47·70	49·40	46·39	42·07	45·43
Al_2O_3	16·00	23·00	22·80	25·04	26·01	26·37
Fe_2O_3	10·60	11·90	12·00	11·79	15·48	10·91
TiO_2	2·00	1·39	0·30	1·54	0·94	0·22
MnO	0·05	0·05	0·04	0·05	0·05	0·04
CaO	0·58	0·22	Nil	0·49	0·48	0·53
MgO	2·38	2·30	1·95	1·08	1·03	1·02
Na_2O	0·77	0·39	0·28	0·55	0·55	0·28
K_2O	1·71	1·35	0·71	2·13	1·00	0·67
P_2O_5	0·10	0·14	0·11	0·17	0·24	0·21
Ignition loss	9·04	12·30	13·70	10·93	13·09	14·68
Total	100·53	100·74	101·29	100·16	100·94	100·36
SiO_2/Al_2O_3	6·1	3·5	3·7	3·2	2·8	2·9
SiO_2/R_2O_3	4·3	2·7	2·8	2·4	2·0	2·3
Exchange capacity in mg. equivalent per 100 g. clay	34	75	99	23	36	49
Organic carbon	—	2·08	2·44	—	1·65	1·70

DETERMINATION OF FREE OXIDES

Free silica, alumina and iron oxide were determined by the hydrogen sulphide method of Drosdoff & Truog (1935). The amounts dissolved and the base exchange capacity before and after the treatment were determined on one unfractionated clay sample of each profile and on one fine and superfine clay sample of the red earth. The results are shown in Table IV. A number of samples were subjected to the modified Truog treatment using sodium sulphide and oxalic acid (Truog *et al.* 1937). This method is more drastic and the total loss of material is higher, 40% of the superfine red fraction being dissolved as against 10% with hydrogen sulphide. It is likely that in this process the silicates present are attacked to some extent (cp. Raychaudhuri, 1936; Toth, 1939).

Table IV. *Alumina, iron oxide and silica, as percentage of clay, dissolved by treatment with hydrogen sulphide according to Drosdoff & Truog* (1935), *and base exchange capacities in mg. equiv. per* 100 *g. clay before and after the treatment*

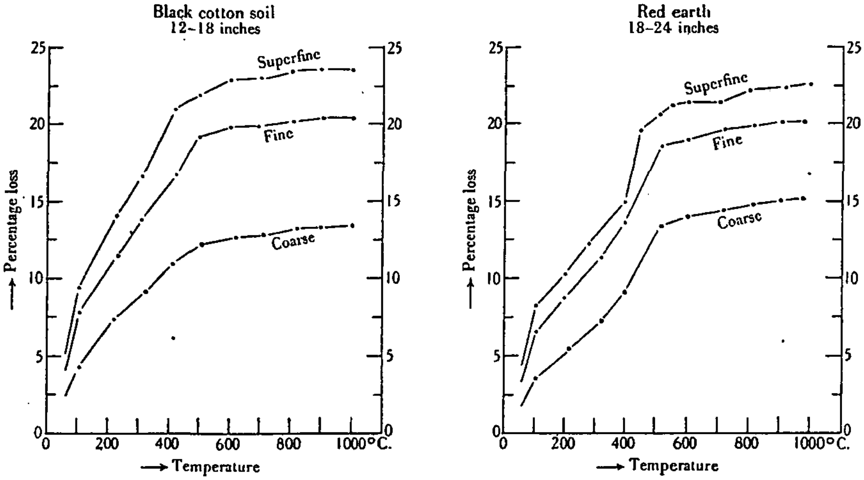
	Black whole clay 42–48 in.	Red whole clay 24–30 in.	Red fine clay 24–30 in.	Red superfine clay 24–30 in.
SiO_2	2·30	3·98	2·37	2·62
Al_2O_3	0·56	1·10	0·57	1·29
Fe_2O_3	4·85	6·98	13·40	5·70
Base exchange capacity:				
Before treatment	83	35	—	—
After treatment	58	30	—	—

DEHYDRATION DATA

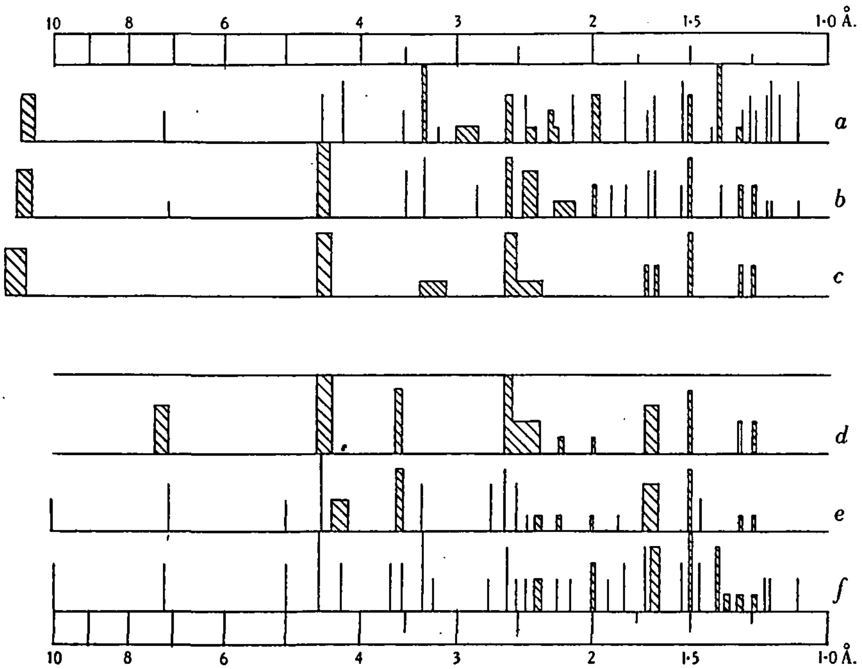
Dehydration curves were taken for three depths in each profile by the method of intermittent heating. Again, there was little or no variation with depth for each profile. Characteristic curves are shown in Text-fig. 1. The water lost at 105° increased rapidly with decreasing grain size for all fractions, and was consistently about 1% higher for fractions from black soils than for the corresponding red ones. The pronounced difference in the form of the curves for red and black soils, especially between 400 and 600°, is discussed in detail later (pp. 647, 650).

X-RAY DATA

Powder and aggregate diagrams were taken for most of the samples and it was found that throughout each profile the clay fractions of equal grain size gave identical diagrams. There were, however, differences between the diagrams from the two profiles and also between the coarse,



Text-fig. 1. Dehydration curves of clay subfractions from black cotton soil and red earth, by the method of intermittent heating. Loss in weight as percentage of air-dry fractions.



Text-fig. 2. X-ray data for black cotton soil (*a*) coarse, (*b*) fine, (*c*) superfine clay and red earth, (*d*) superfine, (*e*) fine, (*f*) coarse clay.

fine and superfine fractions of any one clay. This confirms the chemical data and shows that there is no noticeable variation in the mineralogical composition throughout each profile.

Text-fig. 2 shows the diffraction data in the form described previously (Nagelschmidt, 1939), and Pl. XII shows some of the diagrams. Diagrams were also taken for samples after treatment by the sodium sulphide-oxalic acid method (Truog *et al.* 1937). For all black clays there was no difference between treated and untreated samples, but for most of the red clay samples the diagrams of the treated material contained fewer lines, and, except for one line, the difference could be explained as due to the disappearance of hematite, α-Fe_2O_3. The one line not due to hematite coincided with one of the strong lines of goethite, α-FeOOH, which may have been present in very small amounts. There was no indication of the presence of crystalline aluminium hydroxides.

Diagrams of samples of the black clay at different moisture contents showed the lattice shrinkage and expansion characteristic of a member of the montmorillonite group. The red clays failed to show this effect under the same conditions. Aggregate diagrams of the air-dry black clay showed the basal spacing to be about 12 A.; the corresponding diffraction line was blurred and not very strong. By the method of separation the exchangeable ions of this clay were ammonium and hydrogen, but after the material had been leached with calcium chloride and the excess chloride washed out, new air-dry aggregates showed a stronger basal spacing of 15 A. The replacement of ammonium and hydrogen by calcium would explain this change in the basal spacing at constant relative humidity. Similar results for supercentrifuged bentonite fractions have been reported previously (Nagelschmidt, 1939). The basal reflexions of the soil colloids were, however, less intense than those of the bentonite. The interpretation of the X-ray diagrams is given in Table V.

Table V. *Minerals identified by X-ray diffraction in clay subfractions*

	Black cotton soil, 12–18 in.			Red earth, 18–24 in.		
	Coarse	Fine	Superfine	Coarse	Fine	Superfine
Quartz	Much	Little	Nil	Medium	Trace	Nil
Mica	Trace	Trace	Nil	Little	Little	Nil
Kaolinite or halloysite	Little	Little	Nil	Much	Much	Much
Montmorillonite or beidellite	Medium	Much	Much	Nil	Nil	Little?
Hematite and goethite	Nil	Nil	Nil	Little	Little	Trace

OPTICAL DATA

A petrological examination of the sand fractions from one sample of each profile was carried out by Dr R. Hart, to whom our thanks are due for the following information. "The black soil contained mainly quartz and a few grains of felspar, hornblende and some iron oxide, while the red soil contained the same minerals and, in addition, some brown mica. There was much more felspar and ferromagnesian minerals in the red soil than in the black one, and the quartz was much more heavily stained by iron oxides."

The refractive indices of some of the superfine clay samples were measured in sodium light with a mixture of olive oil, cinnamon oil and bromo naphthalene, as recommended by Correns & Mehmel (1936). The samples were saturated with calcium and measured after they had reached equilibrium weight, at room temperature at 50% relative humidity, and again after drying at 105° C., both before and after sodium sulphide-oxalic acid treatment (Truog *et al.* 1937). The results for $n\gamma$ are given in Table VI. The double refraction of the black samples of the order of 0·013 was not noticeably affected by the drying or by the Truog treatment, and the double refraction of the red samples was not affected by the drying; it was, however, reduced by the Truog treatment from 0·017 to 0·010.

Table VI. *Refractive index $n\gamma$ determined in sodium light for superfine clay fractions before and after Truog treatment and at two temperatures*

	Black cotton soil, 12–18 in.		Red earth, 18–24 in.	
Drying	Superfine	Truog-treated superfine	Superfine	Truog-treated superfine
50% R.H.	1·579	1·577	1·588	1·581
Oven-dry	1·592	1·588	1·600	1·585

CORRELATION OF RESULTS

Although a general knowledge of the minerals present in a soil colloid can be obtained by adequate X-ray diffraction data alone, this knowledge is made more certain and can be refined by using chemical, dehydration and optical data. In this way quantitative statements can be made and the fitting together of the various observations checked. We shall first consider the clay of the black cotton soil (12–18 in.) and then that of the red earth (18–24 in.), in both cases beginning with the superfine fractions.

BLACK CLAY SUPERFINE FRACTION

This fraction shows from the X-ray data only one crystallized mineral, a member of the montmorillonite group. The observed base exchange capacity of 99 mg. equivalent per 100 g. clay is in good agreement with this observation. Its composition (Table III) closely resembles that of beidellite from Beidell, Saguache Co., Colorado (Larsen & Wherry, 1917), as can be seen by comparing the percentages for silica, alumina and iron oxide for beidellite and the superfine fraction, calculated in both cases for ignited material.

	Beidellite from Beidell %	Black superfine clay %
SiO_2	58·6	57·7
Al_2O_3	25·1	26·6
Fe_2O_3	10·8	14·0

In order to see whether appreciable amounts of amorphous material were present in the soil colloid, hydrogen sulphide treatments (Drosdoff & Truog, 1935) were given to the superfine black clay and also to the beidellite from Beidell. The amounts of silica, iron oxide and alumina dissolved were as percentages of the air-dry material.

	Beidellite from Beidell %	Black superfine clay %
SiO_2	3·59	3·02
Al_2O_3	0·23	0·14
Fe_2O_3	5·64	4·06

Both materials were slightly attacked by this treatment, but there was no evidence for the presence of large amounts of amorphous material in the superfine black clay.

A method of calculating isomorphous replacements and base exchange capacities for members of the montmorillonite group has been described by Nagelschmidt (1938). By this method the superfine black clay contains in the silicon layer $Si_{3\cdot49}$ $Al_{0\cdot51}$ instead of Si_4 and in the aluminium layer $Al_{1\cdot38}$ $Fe_{0\cdot62}$, no divalent ions being present, instead of Al_2. The calculated base exchange capacity is 120 mg. equivalent per 100 g. oven-dry material which is somewhat in excess of the observed value of 99 mg. equivalent per 100 g.

Grim (1939) has recently suggested that the mica type material (illite) has negative charges due to isomorphous replacements mainly in the silicon layers, whereas the montmorillonite type with variable basal spacing has these replacements mainly in the aluminium layer. The observations on the black superfine colloid do not seem to bear this out, as there is a variable basal spacing and the replacements are mainly in the silicon layers. It can be argued, however, that the iron oxide determined may include an unknown amount of divalent iron.

The dehydration curve of the superfine black clay differs from known montmorillonite or bentonite dehydration curves in being almost straight up to about 500°, whereas in montmorillonite little water is lost between 300 and 450°. Unfortunately, through lack of material, we were unable to take a dehydration curve of beidellite. It is possible that the iron in beidellite causes its dehydration curve to be different from that for montmorillonite.

The refractive index of the superfine black clay at 105°, $n\gamma = 1{\cdot}592$, is very similar to the refractive index of beidellite from Beidell, taken at 105°, $n\gamma = 1{\cdot}589$, but the air-dry values are somewhat different. This deviation may be due to differences in water content and exchangeable ions.

BLACK CLAY FINE FRACTION

This fraction contains, according to the X-ray data, much montmorillonite, little quartz and kaolinite and very little mica. The estimation of kaolinite and mica is mainly based on the intensities of basal reflexions on aggregate diagrams, the estimation of quartz on reflexions at larger angles of diffraction.

In order to determine the amount of kaolinite present the dehydration curve is usually of great help, as kaolinite loses more than 10% of water between 350 and 500°, whereas montmorillonite or mica lose only 2–3% in this interval. The curve of the superfine black clay is, however, different from montmorillonite curves; it is, therefore, impossible to estimate the kaolinite from these curves. It seems, however, permissible to assume as a first approximation that the base exchange capacity and chemical composition of the Beidellite, which was identified as the only constituent of the superfine fraction, are constant from superfine to coarse clay. With this assumption 75% of beidellite would be a maximum estimate for the fine fraction if the other minerals present had no base exchange capacity at all. Actually the base exchange capacity of kaolinite is low, and could hardly account for more than 10 mg. equivalent %, and mica is only present in very small amounts. 60% of beidellite would therefore seem a minimum and 70% the most likely value. If we now subtract the equivalent of 70% of the superfine fraction from the fine fraction, using the chemical data in Table III, we are left with a residue of 13·1% SiO_2 and 7·1% Al_2O_3, both as percentage of the fine fraction. The aluminium is mainly present in kaolinite and a small proportion in mica. It is therefore possible to state that 17% kaolinite and 5% quartz are maximum estimates under the above assumptions. Actually both percentages should be somewhat smaller, as there is some mica present.

The mica in soil colloids may vary widely in chemical composition, but in comparable materials the potassium content is probably the best guide. The lowest potassium content recorded by Grim *et al.* (1937) for illite is 4·7% K_2O, but earlier data by Denison *et al.* (1929) seem to indicate that much lower amounts, down to less than 1%, can occur in coarse mica in soils. The K_2O content of the fine black clay is 0·64% larger than the K_2O content of the superfine fraction. On the basis of 5% K_2O for the mica in soil colloids in general this would correspond to 13% of mica in the fine fraction. As it seems impossible to isolate the mica from the black clay, there is no proof that this figure is correct, but higher values seem very unlikely from the X-ray data, especially from the intensity of the basal 10 A. reflexion. Recently, Hendricks & Alexander (1939) have suggested that minerals with mixed structures between hydromica and montmorillonite may frequently occur in soil colloids, and although no details about such minerals are known, it seems likely that their basal reflexions would be blurred and weaker than those of the pure minerals; in this way estimates based on X-ray data alone would tend to be too low in comparison with estimates for layer-lattice minerals such as kaolinite, which do not form such mixed structures. For the various reasons given above, it is not possible to determine the various constituents with great accuracy, but the following are the extreme amounts which may be present: beidellite 60–75%, kaolinite 5–20%, mica 5–20%, quartz 2–10%. The most likely composition is beidellite 70%, kaolinite 10%, mica 15%, quartz 5%.

BLACK CLAY COARSE FRACTION

This fraction contains according to the X-ray data much quartz, medium beidellite, little kaolinite and a trace of mica. If the considerations elaborated above for the fine fraction are applied, it is seen that the limiting values for the different constituents are: quartz 25–32%, beidellite 25–35%, kaolinite 10–23%, mica 5–25%. The most likely values are: beidellite 30%, quartz 30%, kaolinite 15%, mica 15%. The analytical data also show that there is too much iron present to be accommodated in beidellite and mica on the assumption that the beidellite has the composition of the superfine fraction. It seems that 4% Fe_2O_3 is present as amorphous or crystalline hydroxide or oxide. As amounts less than 5% of goethite in mixtures with other soil colloid minerals can probably not be detected by X-ray diagrams, this result is consistent with the X-ray data.

The total water content of the coarse fraction is 66% of the water content of the superfine fraction, and if we take all minerals other than quartz together as being hydrated, we get a rough estimate for quartz of 34%, which does not deviate much from the composite estimate of 30% given above.

Red clay superfine fraction

According to the X-ray data, this fraction contains much kaolinite or halloysite, and only a trace of iron oxide or hydroxide. If we assume that all aluminium shown in the analysis of this fraction in Table III represents a kaolinite of theoretical composition, we get a value of 67% kaolinite and are left with a residue of 14·5% SiO_2 and 10·9% Fe_2O_3. The SiO_2 cannot be quartz, as such amounts of quartz would show up on the X-ray diagrams, but it also cannot be amorphous silica, as the Truog treatment dissolves less than 3% of SiO_2, and amorphous silica should be dissolved by that treatment. The presence of a hypothetical iron kaolinite, which would account for the excess silica, seems very unlikely, although it cannot at the present stage of our knowledge be definitely ruled out for soil colloids. It was decided, therefore, to use a sodium sulphide-oxalic acid treatment to remove iron oxides, followed by prolonged heating at 510° to destroy kaolinite. This treatment should destroy all crystalline materials recognized in the original X-ray data. The X-ray diagrams of the treated material showed a number of weak lines corresponding to hk0 reflexions of montmorillonite or beidellite, but no lines corresponding to their basal reflexions. Aggregate diagrams of the heated material showed no clear basal reflexions.

Aggregates of the calcium-saturated original air-dry superfine fraction showed, besides strong kaolinite basal reflexions, only a doubtful trace of a 15 A. line. The presence of beidellite in this fraction is therefore possible but not quite certain. It would account for part of the base exchange capacity of 49 mg. equivalent per 100 g. clay, which is higher than would be expected for kaolinite, and for part of the loss of water below 300° C., which is also higher than would be expected for kaolinite or halloysite in the presence of less than 3% organic matter. The properties of this fraction seem to correspond closely to the data given by Kelley *et al.* (1939) for the Vina colloids.

The dehydration curve of this fraction shows that the bulk of the lattice hydroxyl of the kaolinite is given up below 450° C., which would, according to the dehydration curves of Ross & Kerr (1934), indicate halloysite rather than kaolinite, but it has been shown previously (Nagelschmidt, 1939) that these two minerals cannot be distinguished in soil colloids. The refractive index, even after the sodium sulphide-oxalic acid treatment (Truog *et al.* 1937) is higher than would be expected for kaolinite.

On summarizing our evidence it can only be said that about 60% of the fraction consists of kaolinite or halloysite and less than 10% of iron oxide and hydroxide. Up to 30% of it may be due to a member of the montmorillonite group.

Red clay fine fraction

According to the X-ray data, this fraction also contains much kaolinite or halloysite, and in addition a little hematite, mica and a trace of quartz. From the chemical and dehydration data kaolinite forms 50–60% of the fraction. The amount of Fe_2O_3 dissolved by the hydrogen-sulphide treatment (Drosdoff & Truog, 1935) is 10%, which gives an upper limit for free iron oxide, the remaining iron being partly in the mica and partly perhaps in a member of the montmorillonite group. The quartz content is less than 5%, this estimate being based on the X-ray diffraction data. It again seems that there is slightly more SiO_2 shown in the analysis than can be accounted for as kaolinite, quartz and amorphous silica, but the excess is less than in the superfine fraction. Diffraction diagrams of material after sodium sulphide-oxalic acid treatment and heating to 510° C. showed some quartz and mica lines. In the presence of these lines it is impossible to see whether or not any of the hkO lines of montmorillonite, found on corresponding diagrams of the superfine fraction, are present. If this mineral is present, the base exchange capacity, dehydration and chemical data show that its amount is less than that in the superfine fraction. The composition of this fraction seems to be 50% kaolinite, 15% mica, 10% oxide and hydroxide of iron, 3% of quartz and possibly up to 15% of a member of the montmorillonite group.

RED CLAY COARSE FRACTION

This fraction differs from the fine clay only in having more quartz and slightly more mica. An estimate based on the principles outlined above gives kaolin or halloysite 40%, mica 30%, quartz 10%, iron oxide and hydroxide 5–10%. There is no reason to assume the presence of a member of the montmorillonite group in this fraction.

The results of the estimates for all six fractions are summarized in Table VII.

Table VII. *Minerals present in fractions of clay as percentage of fraction*

	Black cotton soil, 12–18 in.			Red earth, 18–24 in.		
	Coarse	Fine	Superfine	Coarse	Fine	Superfine
Beidellite	30	70	90	—	(?) 15	(?) 30
Kaolinite	15	10	—	40	50	60
Mica	15	15	—	30	15	—
Quartz	30	5	—	10	3	—
Hematite and goethite	5	—	—	8	10	10

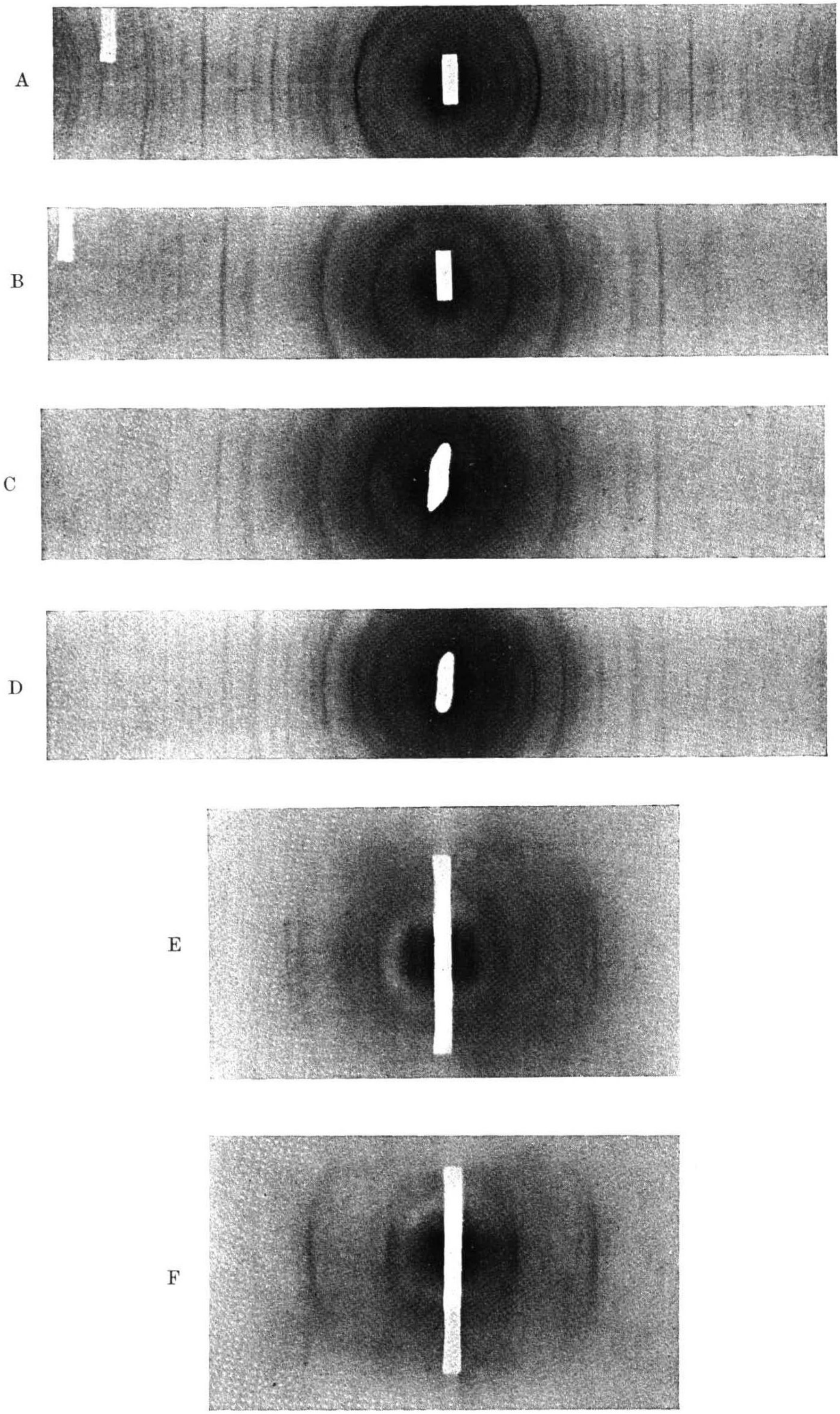
DISCUSSION

The red and the black soils under investigation are derived from the same or from very similar rocks, and as they occur near each other they are exposed to the same climatic conditions. The differences in the mineralogical compositions of the two clays must therefore be due to processes resulting from the difference in the topographical position of the two soils, the red soil occurring on a slope of waste land, while the black soil is found in the plain in an irrigated area. According to Desai (1939) it is a general experience that red soils in the vicinity of black cotton soils are only found on slopes. There are many indications showing that the red soil is eluvial, being strongly leached, whereas the black soil is illuvial, receiving leaching products. The percentage of particles above 2 mm. is very high in the red soil, and the silt and clay contents are comparatively low. Both conditions are reversed in the black soil, and a large proportion of its particles above 2 mm. consist of secondary formations, carbonate concretions. Relatively high proportions of felspar and hornblende are found in the fine sand fractions of the red soil, but these minerals have almost disappeared from the black soil. The red soil has a lower *p*H than the black one, especially in the top layer. The data given in this study show that under such eluvial conditions kaolinite or halloysite is the main constituent of the clay, whereas in the illuvial black soil a member of the montmorillonite group predominates in the clay. Correns & Engelhart (1938) have shown that the weathering of felspar is a molecular process and that the rate at which alumina and silica are dissolved depends within certain limits on the acidity of the leaching solution. Which secondary minerals are formed, and where they are formed in nature will largely depend on the conditions of drainage and on the type and amount of other ions, mainly alkalies and alkaline earths, present.

Kaolin and montmorillonite have been synthesized in hydrothermal bomb experiments and the conditions of their formation investigated. According to Noll (1936) the amount and type of alkalies and alkaline earths present and the *p*H are of greater importance than the relative amounts of silica and alumina, and under appropriate conditions both minerals are formed together. Kaolin formation is favoured by acid or neutral conditions and montmorillonite formation by alkaline conditions. Although hydrothermal bomb experiments are not directly comparable with surface weathering and the formation of clay minerals, it is noteworthy that the montmorillonite and kaolinite occur in soils of types investigated here under just those conditions of reaction under which they have been produced in the laboratory. The simplest hypothesis is that in nature they are produced in a similar manner.

It has been shown in the description of the superfine red clay that kaolin is not the only clay mineral present and that there was possibly 20–30% of a material which may be beidellite or perhaps a silicate not known as a mineral, capable of forming beidellite. This mineral decreases in amount as the particles become larger. Such material would, on account of its small size, be easily transported and might form beidellite under the conditions prevailing in the black soil.

Mica in the red clay decreases rapidly with decreasing grain size, probably indicating its instability under the conditions prevailing in the red soil. In the black soil it is absent from the superfine fraction, but occurs in about equal proportions in the fine and coarse clay. The quartz percentage of the coarse black clay is quite high, but it is impossible to say whether this quartz is residual or newly formed. There is no direct microscopic evidence for secondary quartz in the coarse clay or in the silt fraction of the black soil, which consists almost entirely of quartz. Kaolin occurs in minor amounts in the coarse and fine black clay, but not in the superfine fraction. It seems likely that this kaolin was transported from the red soil and not formed in the black soil, as in the latter case it would probably not decrease in amount with decreasing grain size.



X-ray diffraction diagrams of clay fractions. A to D, powder diagrams, E and F aggregate diagrams.

A. Black cotton soil, coarse clay.	E. Black cotton soil, fine clay.
B. Black cotton soil, superfine clay.	F. Red earth, fine clay.
C. Red earth, superfine clay.	
D. Red earth, coarse clay.	

(For reproduction the blackening in the centre has been reduced by partial shading.)

SUMMARY

The mineral compositions of the clays from a red earth and a black cotton soil from Hyderabad, Deccan State, India, occurring in close proximity in the field are determined. Both soils are derived from the same or from very similar parent rocks, a coarsely crystalline granite or gneiss.

For both soils there is practically no variation in the mineralogical composition of the clay throughout the profile, but for any given clay there is some variation with grain size. The main contrast between the two is that the red clay contains predominantly kaolinite or halloysite, whereas the black clay contains mainly beidellite, a member of the montmorillonite group. The topography appears to be the principal factor associated with this difference in minerals, and the processes of weathering believed to have produced the contrasted clays are discussed with reference to experiments on the leaching of felspar in the laboratory and on hydrothermal synthesis.

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