

Influence of Clay Minerals and Iron Oxides on Selected Properties of Two Lateritic Soils

by

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Introduction

The term-Lateritic soils, is used to describe all red coloured residual and non-residual soils which are products of tropical weathering. They genetically form a chain of materials ranging from decomposed rock through clay to sesquioxide rich crusts (Gidigas, 1976). In India such soils, first recognised in the Malabar Plateau of Kerala, occur widely over most of the Panninsular shield, Deccan Traps and some Coastal Sedimentary rocks. The characteristic property of this type of soil is the remarkable hardening on exposure to air. The reason for such behaviour has been traced to the dehydration of iron oxides and halloysite type of clay minerals occurring in the soils. An understanding of engineering properties of lateritic soils would thus be incomplete without a systematic study of the type of clay minerals and iron oxide phases present.

In this paper the authors summarise a detailed investigation of two typical lateritic soil samples with particular emphasis on the effects of iron oxides on selected engineering properties. One sample comes from Kottamparamba, about 50 km. west of Calicut, Kerala and the second sample from near Rajahmundry town, Andhra, Pradesh.

Method of Study

The field samples were collected from a depth of about 1.5 m below ground surface avoiding the root zone and packed in polythene bags. No water content was determined in the field. However, the Calicut soil collected after heavy rain was water saturated, whereas the Rajahmundry soil was relatively dry.

After transporting the samples to the laboratory, both these were exposed to laboratory air for 10 days before further testing. The water content of the Calicut soil at this stage ranged from 25 to 30 per cent, whereas the value for the Rajahmundry soil fell between 15 to 20 per cent. No further control on water content was maintained.

The following additional soil properties were determined for both the samples (1) Grain size distribution by Indian Standards Procedure, (2) Soil

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pH by using a precision *pH* meter in an 1 : 1 suspension in distilled water (3) Atterberg limits by Standard Casagrande apparatus (4) Organic matter content from weight loss after heating to 80°C and treatment with 30 per cent H_2O_2 , (5) Cation Exchange Capacity by saturation with potassium acetate, exchange with ammonium acetate and determination of exchangeable potassium by Flame photometry. The mineralogy of the clay fraction (less than 2 micron size) was investigated by *X*-ray Diffraction, Differential Thermal Analysis, Election Microscopy and Mossbauer Spectroscopy. The selected engineering properties were re-determined after removal of "free iron oxides" by the Sodium dithionite-citrate-bicarbonate method (Black, 1965). Important results of this work are summarised in Table 1 and discussed below :

TABLE 1
Results of Tests on Lateritic Soils

	Calicut Laterite	Rajahmundry Laterite				
General	Over Pre-cambrian Charnockites, biotite gneiss, bright red, wet, coarse grained, <i>pH</i> 6.1	Over Middle Miocene Sandstones, clays, dark red, dry, fine grained, <i>pH</i> 6.9				
Mineralogy	Intermediate halloysite (2+ <i>XH</i> ₂ O) tubes, poorly crystalline kaolinite, gibbsite and quartz.	Intermediate halloysite (meta halloysite), well developed kaolinite, gibbsite, goethite and quartz.				
Water content (per cent) after air drying for 10 days.	25 to 30	15 to 20				
Clay content (per cent)						
Natural	18	39				
Iron removed	25	86				
Organic matter per cent	6.8	10.3				
Atterberg limits (per cent)						
	<i>LL</i>	<i>PL</i>	<i>PI</i>	<i>LL</i>	<i>PL</i>	<i>PI</i>
Natural (Air dried)	72.00	38.54	33.46	62.00	24.00	38.00
Oven dried	67.51	34.55	32.96	59.63	21.82	37.81
Iron removed	49.00	19.00	30.00	59.00	22.00	37.00
Activity						
Natural		1.858			0.982	
Iron removed		1.212			0.435	
CEC m.e/100g						
Natural		31.27			28.77	
Iron removed		17.78			51.14	

Mineralogy

Although both the samples represent lateritic soils, there are subtle differences in mineralogy and engineering properties which are all the more significant in terms of the effect of iron oxides.

The Calicut laterite has developed over Precambrian Charnockites and biotite gneiss country rock. It has a bright red colour and is relatively coarse grained. X-ray Diffraction, D.T.A. and Election Microscopy revealed the presence of halloysite with intermediate hydration ($Al_2O_3 \cdot 2SiO_2 \cdot 2 + xH_2O$), poorly crystalline, kaolinite, goethite, gibbsite and quartz. Halloysite shows characteristic tubular crystals under election microscope (Figure 1). Presence of goethite was confirmed by its Mossbauer spectrum.

The parent rocks for Rajahmundry laterite are Middle Miocene sandstones and clays. The soil is dark red in colour due to its higher organic matter content (Table 1). This is relatively fine grained. Although the general mineralogy is similar to the Calicut soil, election microscopy showed well developed kaolinite crystals and tubes of hydrated halloysite were conspicuously absent (Figure 2). X-ray spacings (8.01, 8.67 and 4.44°A) indicated that the halloysite in Rajahmundry laterite was closer to metahalloysite ($Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$) in composition. Another important difference is the near absence of crystalline goethite in the Rajahmundry sample. The iron oxides obviously occur in colloidal form in this soil. The parent rock of Calicut, on the other hand, contains silicate minerals rich in iron which may have contributed to a general abundance of



FIGURE 1 Electron micrograph of tube shaped halloysite of Calicut soil (X 88,000 magnification)

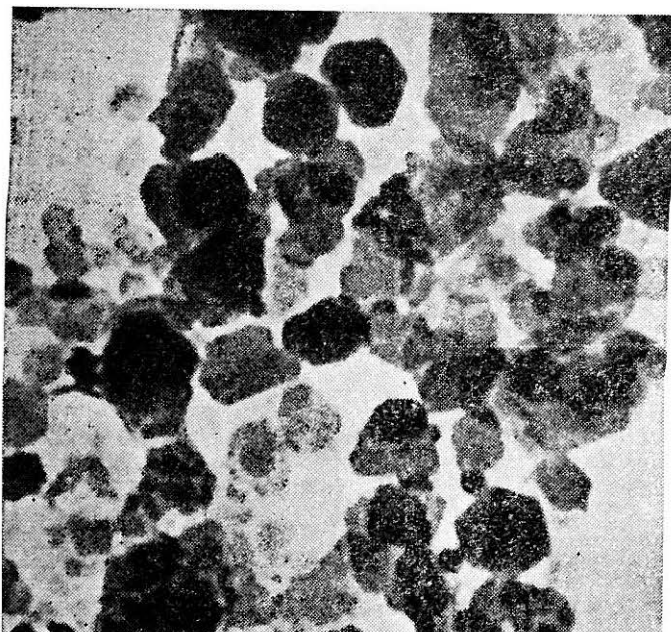


FIGURE 2 Electron micro graph of well developed Kaolinite crystals Rajahmundry soil ($\times 68,000$ magnification)

crystalline goethite. The occurrence of more hydrated halloysite in the Calicut soil also points to a more humid environment of soil formation.

Figures 3 and 4 clearly show that the peak intensities of clay minerals in X-ray Diffraction sharply increases after removal of iron oxides in both soil samples. This suggests that the iron oxides occur as coatings on clay minerals and thereby suppress the surface properties. Similar effects were also observed for D.T.A. peaks. Moreover, the goethite peak disappeared after iron removal from the Calicut sample and the organic matter peak became sharper in the D.T.A. pattern of Rajahmundry sample (Figures 5 and 6).

Grain Size Distribution

The distribution of sand, silt and clay fraction in Calicut soil is 50,32 and 18 per cent respectively, whereas the corresponding values of Rajahmundry soil are 30, 34 and 39 per cent. (Figure 7). On the basis of the scheme of classification of decomposed rocks discussed by Gidigas (1976), the relative proportion of clay fraction with respect to the total of silt and sand fraction approximately represents the degree of decomposition of the primary rock. By this criterion, the Rajahmundry soil is in a more advanced stage of weathering. The presence of well crystalline kaolinite supports this conclusion.

For both soils, removal of iron oxides drastically increased the clay content (Table 1). This appears to be due to the fact that the iron oxides coat the clay mineral surfaces and bind them into coarse aggregation.

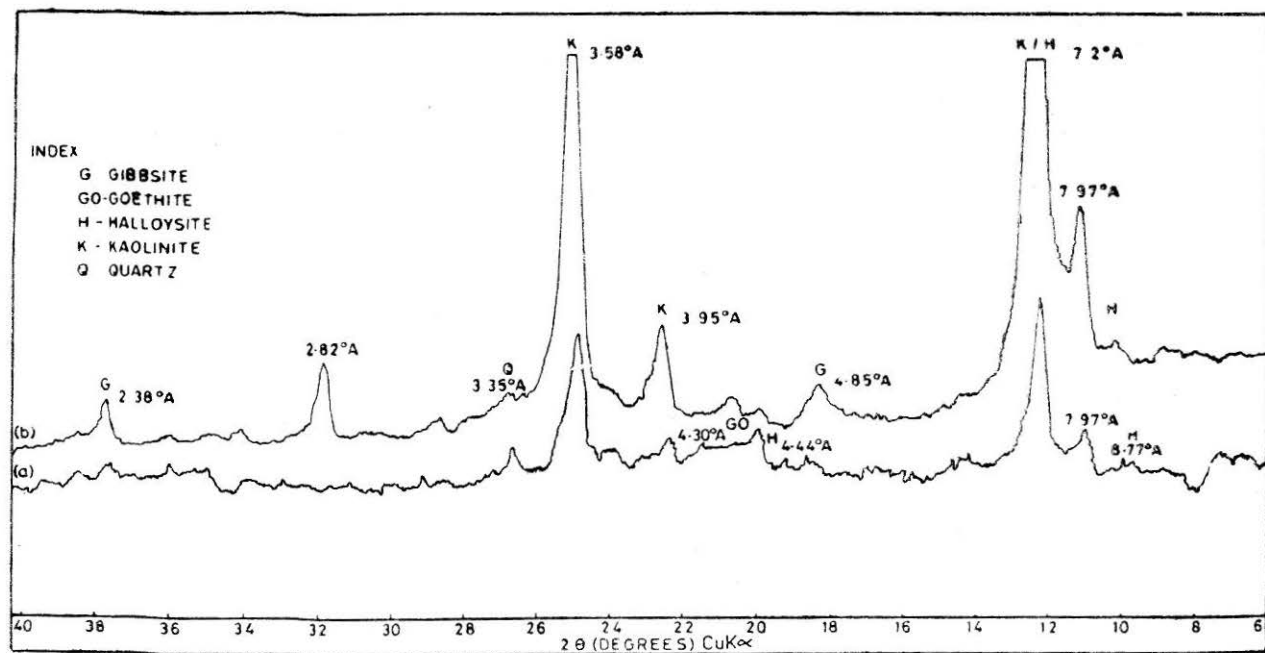


FIGURE 3 X-ray diffraction patterns of calicut laterite (a) Natural soil (b) Iron free

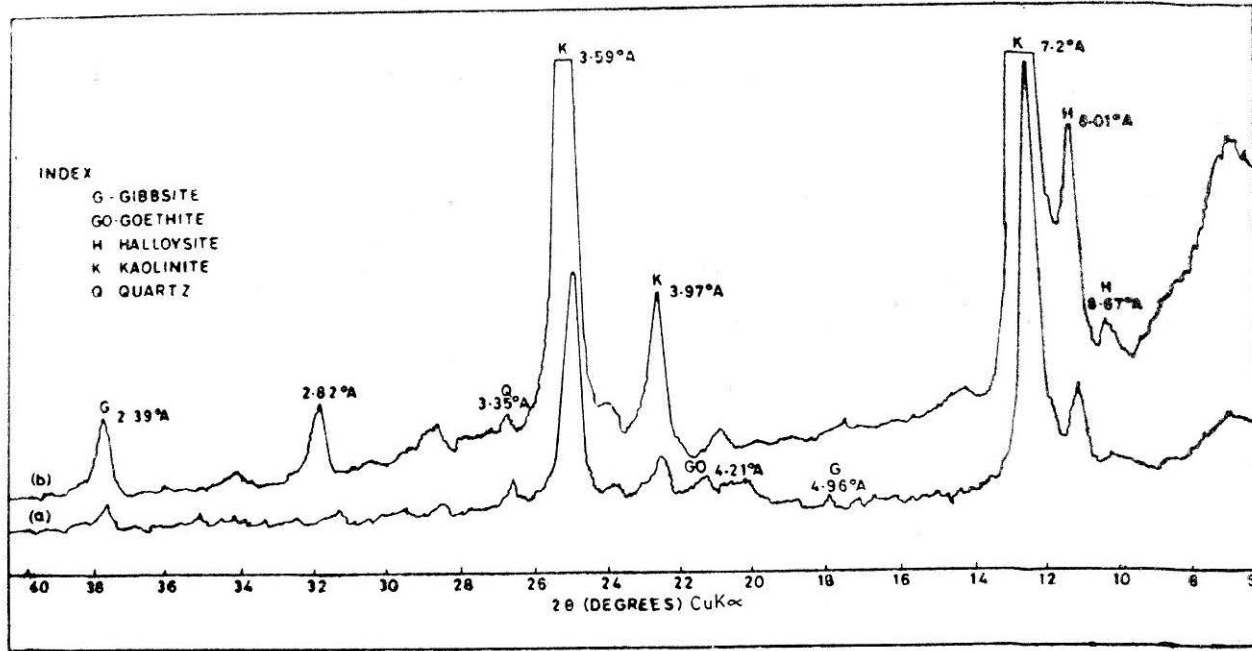


FIGURE 4 X-ray diffraction patterns of Rajahmundry laterite (a) Natural soil (b) Iron free soil

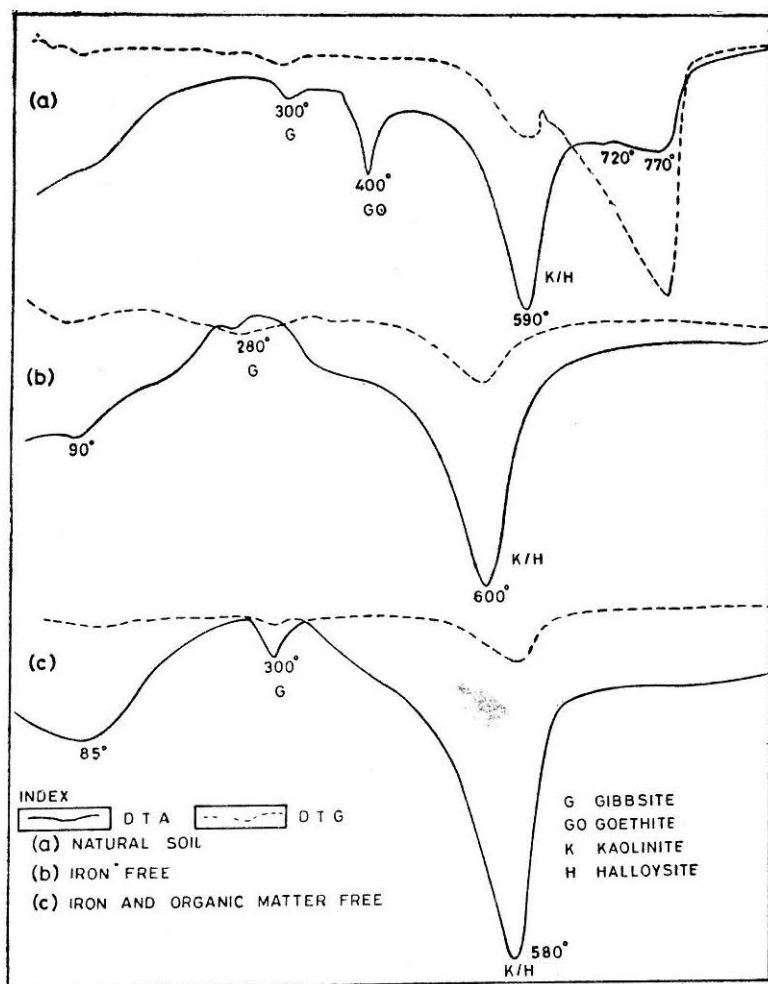


FIGURE 5 DTA and DTG patterns of calicut laterite

Iron removal breaks up the clusters and increases the clay size fraction. The relatively larger effect on the Rajahmundry soil is possibly due to its higher organic matter content, as it is well known that the soil organic matter accumulates in the clay size fraction (Carroll, 1959; Gidigas, 1976).

Plasticity Characteristics

The standard plasticity chart (Figure 8) shows that the halloysite bearing Calicut soil plots below the A-line, whereas the kaolinite rich Rajahmundry soil plots above this line. Gidigas (1976) noted that halloysite is a common material in laterities which plot below A-line. Data on halloysite bearing Sasumua and Kabete red soils of Kenya (Newill, 1961) have been super imposed on Figure 8 for comparison.

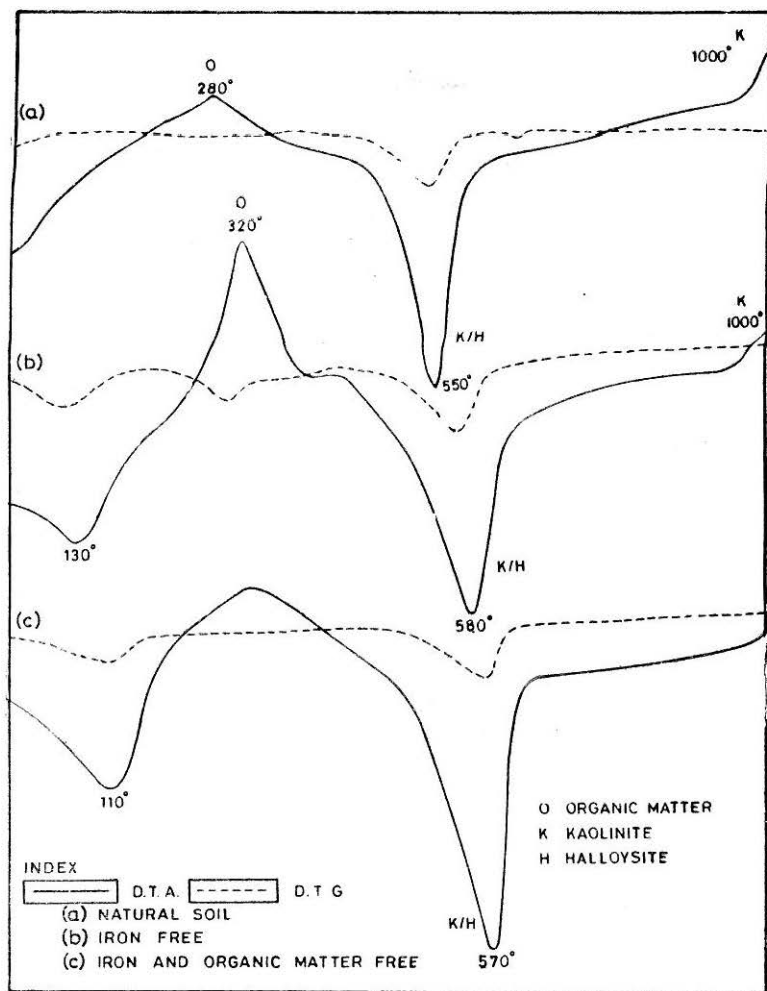


FIGURE 6 DTA and DTG patterns of Rajahmundry laterite

The higher plastic and liquid limit values for Calicut soil are apparently due to the presence of poorly crystalline minerals which are known to have higher limits than well organised particles (Grim, 1962). Another reason for these higher limits could be the presence of intermediate halloysite. It is known that halloysites in an intermediate state of hydration show higher values of limits and PI compared to the halloysite, $4H_2O$ variety and more so when compared to meta-halloysite, $2H_2O$ (Grim, 1962). This is due to the non-equilibrium condition that develops when all the surface of the halloysite units are not coated by a uniform thickness of water layer. In an intermediate state, when the thickness of the water layer is not the same between all particles, the particles are more easily separated.

According to Skempton's colloidal activity classification (activity = $PI/\text{clay content}$), Calicut and Rajahmundry soils are classified under

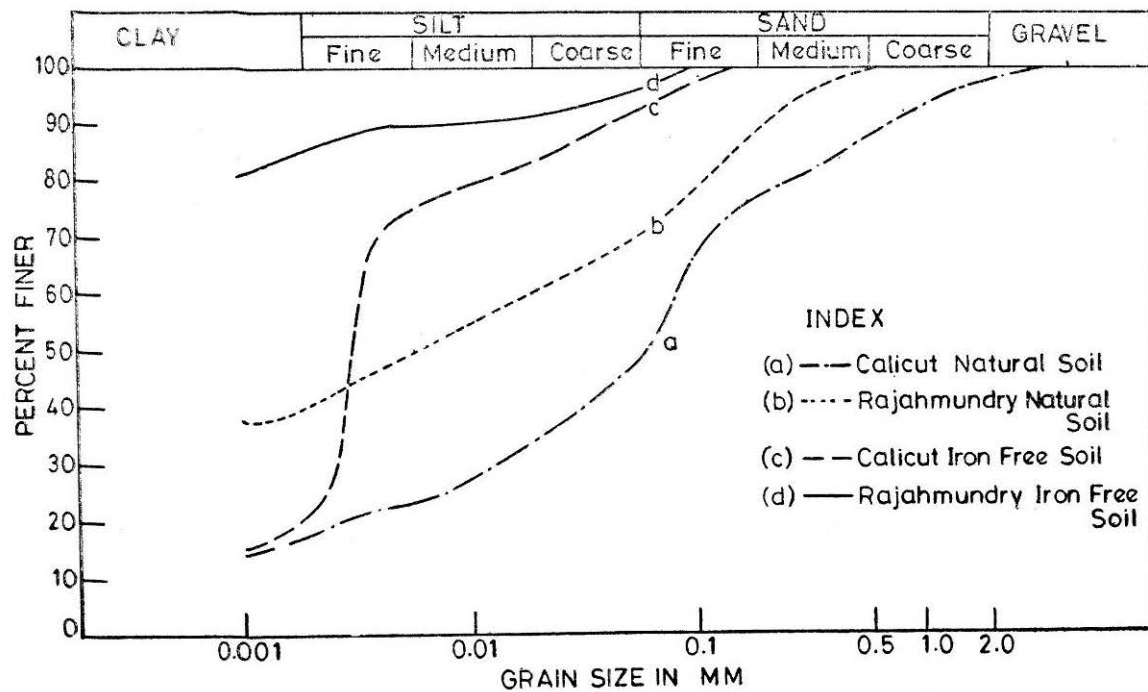


FIGURE 7 Particle size distribution curves

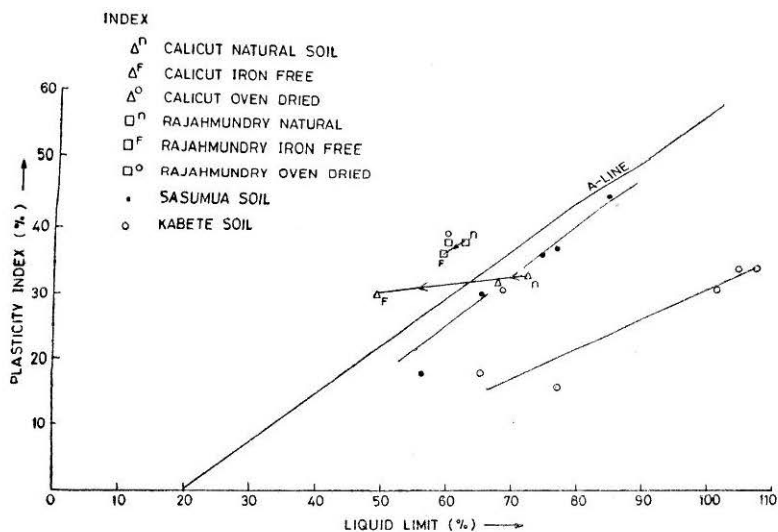


FIGURE 8 Plasticity chart

'Normal Activity' class, (Table 1). The Calicut soil has higher activity value than the Rajahmundry soil, which reflects its high plastic and liquid limits. The increase in clay content after iron removal results in a decrease in Activity of both soils.

After oven drying at 105°C both the soils showed a decrease in the limit values (Table 1). Such decrease in limits on drying has been attributed to aggregation of organic matter and iron oxides into clusters (Yudhbir, 1978). At the same time, the pronounced effect on the Calicut soil is undoubtedly because of partial dehydration of intermediate hallosite.

Although clay content increased and Atterberg limits decreased on removal of iron oxides (Table 1), no systematic pattern emerged from the behaviour of the two soils. It is known that various factors like degree of weathering, sampling and storage methods and sample preparation strongly affect the variation of Atterberg limits (Gidigas, 1976). The present data are too limited to reach a firm conclusion.

Cation Exchange Capacity

It is clear from Table 1 that although the two soils have similar CEC values in the natural state, they behave quite differently on iron removal. The Rajahmundry soil showed a tremendous increase from 28.77 to 51.14 m.e/100 g on removal of iron oxides. This should be considered in the context of an increase in clay content from 39 to 86 percent. As mentioned earlier, there is a significant proportion of organic matter in the clay size fraction. Thus the increase in CEC may be caused by two factors namely (1) a larger clay surface, free of coatings and (2) occurrence of organic matter which by itself is known to have high CEC values (Carroll, 1959; Helgason, 1968; Gidigas, 1976).

The Calicut soil, on the other hand, showed a decrease in CEC from 31.27 to 17.78 m.e/100 g although the clay content increased from 18 to

25 per cent on iron removal. Although the clay content of this soil did not increase as much as in the Rajahmundry soil, this behaviour is unusual and must be due to the specific mineralogy of the soil. Carroll (1959) has pointed out that the relationship between iron oxide coatings and kaolinitic clay minerals depends on the nature of the clay surface. For example, in *H*-kaolinites, iron forms a disordered and porous complex and is absorbed almost indefinitely on the surface. This is in contrast to kaolinite with alkaline ions in exchange position where excess iron oxide occurs as discrete particles on the surface. The Calicut soil has a relatively acidic *pH* (6.1 Table 1). It is possible that ferric ion is part of the exchangeable cations on the clay surface. The presence of Fe^{+3} iron is also supported by the Mossbauer spectrum. Therefore, removal of iron by chemical method probably results also in the removal of exchangeable Fe^{+3} ion, thereby lowering the CEC value.

Conclusions

The main objective of this study was to compare the mineralogy and selected engineering properties of lateritic soils developed in the type area around Calicut with the same parameters in a different geological environment near Rajahmundry. It was concluded that the iron rich parent rocks of Calicut, weathering under relatively humid environment, give rise to a lateritic soil rich in halloysite and crystalline goethite. The soil profile near Rajahmundry, on the other hand, is at a more advanced stage of development. The major minerals in this soil are crystalline kaolinite and metahalloysite along with iron in *X*-ray amorphous colloidal state. The halloysite in Calicut laterite, present in the intermediate hydrated form is apparently responsible for the relatively high Atterberg limits and a sharp decrease in these limits after oven drying.

The influence of iron oxides on soil properties was studied by chemically removing this material. This treatment broke up the soil clusters and resulted in an increase in the clay size fraction along with a decrease in Skempton's colloidal activity. For the Rajahmundry soil, increase in clay content was accompanied by a significant increase in the CEC value, whereas the CEC value of the Calicut soil decreased after iron removal, probably because Fe^{+3} ions are part of the exchangeable cations.

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