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Clay mineralogy of selected alluvial soils from Peninsular Malaysia

J. SHAMSHUDDIN
Soil Science Department, Universiti Pertanian Malaysia
Serdang, Selangor, Malaysia.

Abstract: Some soils sampled from the alluvial plains of Kelantan, Trengganu, Johore, Perak and Kedah-Perlis were studied for their mineralogy. The deposits, believed to be of Holocene age, are termed as T_2 terrace deposits. X-ray diffraction and thermal analyses showed that the clay fractions of these soils contain kaolinite, gibbsite, geothite, mica, chlorite, mixed layers and anatase. The dominance of kaolinite and sesquioxides is reflected by the low cation exchange capacity. The amount of gibbsite and anatase is related to the texture and drainage conditions. Above pH 5.5, kaolinite appears to control the buffering action of the soils. The studied soils are either in the recent or intermediate stage of weathering.

INTRODUCTION

A large acreage of soils in Peninsular Malaysia is derived from riverine alluvial deposits. These deposits are classified as T_1, T_2 and T_3 deposits in terms of age, topography, degree of dissection and elevation (Table 1). Of particular interest to soil scientists are the Subrecent alluvial deposits (T_2), which occur at an elevation of 5–50 m above sea level. This is because of the intensive use of these soils for agricultural production.

The nature of the deposits varies from clayey and silty to sandy. According to Shamshuddin and Tessens (1983), the sandy deposits could have originated from granite as granites occupy about 50% of the land surface of Peninsular Malaysia (Yin and Chung 1968). The silty and clayey ones could have originated from shale, phyllite, schist or other fine grained sedimentary or metamorphic rocks.

TABLE 1

CLASSIFICATION OF QUATERNARY RIVERINE ALLUVIAL DEPOSITS IN PENINSULAR MALAYSIA (GOPINATHAN, 1968; LAW, 1970)

Alluvium	Age	Terrace	Terrain	Elevation
Recent Alluvium	Recent	T_1 (flood plain)	Flat, gently undulating	<15m
Young	Subrecent (<10,000 yrs)	T_2 (intermediate)	Gently undulating weakly dissected	5–50 m
Old Alluvium	Pleistocene (<40,000)	T_3 high	Undulating to rolling, severely dissected	30–70 m

The soils formed on these Subrecent deposits, which are locally described as T_2 terrace soils (Gopinathan, 1968), have been extensively studied (Law, 1970; Paramananthan, 1981). But none of these studies give detail information on the clay mineralogy, which is important for the management of the soils for crop production. The objective of this paper is to study the mineralogy of the soils in relation to their physico-chemical properties.

MATERIALS AND METHODS

18 soil series, derived from Subrecent alluvial deposits, from the Kelantan plain, Trengganu plain, Batu Pahat, Sg. Buloh (Selangor), lower Perak and Kedah-Perlis plains were sampled for this study. The areas of sampling are indicated in Fig. 1. The soils selected for the study, which have been defined by the Department of Agriculture (Paramananthan, 1981), include soils like Nangka (1, 9), Kg. Pusu (2), Bt. Tuku (3), Kerayong, (4, 12), Chg. Hangus (5), Lintang (6), Sg. Buloh (7, 8, 13), Subang (10), Sogomana (11), Rasau (14), Napai (15), Chuping (16), Awang (17) and Holyrood series (18). The soils vary in texture from clayey to sandy.

The samples collected were air-dried, ground and sieved (<2 mm). They were then separated into sand (2000–50 μm), silt (50–2 μm) and clay (<2 μm), using the size classes as defined by USDA (1975). The clay fraction was then analysed by X-ray diffraction (XRD). A complementary analysis by differential thermal analysis (DTA) was also carried out. The amount of kaolinite was estimated by thermogravimetric analysis (TGA), while the amount of gibbsite and geothite was estimated by differential scaning colorimetry (DSC). Surface properties of the soils were determined by potentiometric titration and measurement of charges.

RESULTS AND DISCUSSION

General Properties

Texturally, the soils vary from clayey to sandy, depending on the nature of the rocks from which the deposits were derived from. It is generally believed that parent materials originated from granite or sandstone give rise to sandy (7, 8, 13) or loamy soils (1, 6, 9). In this case granite could be the most likely source of the original rock as it is the most important rock unit in the peninsula; granite occupies 50% of the land surface (Yin and Chung, 1968).

Other soils, which are clayey in nature could have been formed on parent materials originated from shale or other fine-grained rocks. It is also possible that the clayey soils are formed on parent materials deposited in a low energy environment (Reineck and Singh, 1973).

By and large, the soils are acidic in reaction, with pH in water less than 5.5. Cation exchange capacity (CEC) in the top horizons is low to moderate, but at the values decrease with depth. Higher CEC in the top soil is due to the presence of organic matter. The generally low CEC at depth is a reflection of the mineralogy of the soil. Accordingly, one can expect that these soils are dominated by kaolinite, a mineral with low CEC.

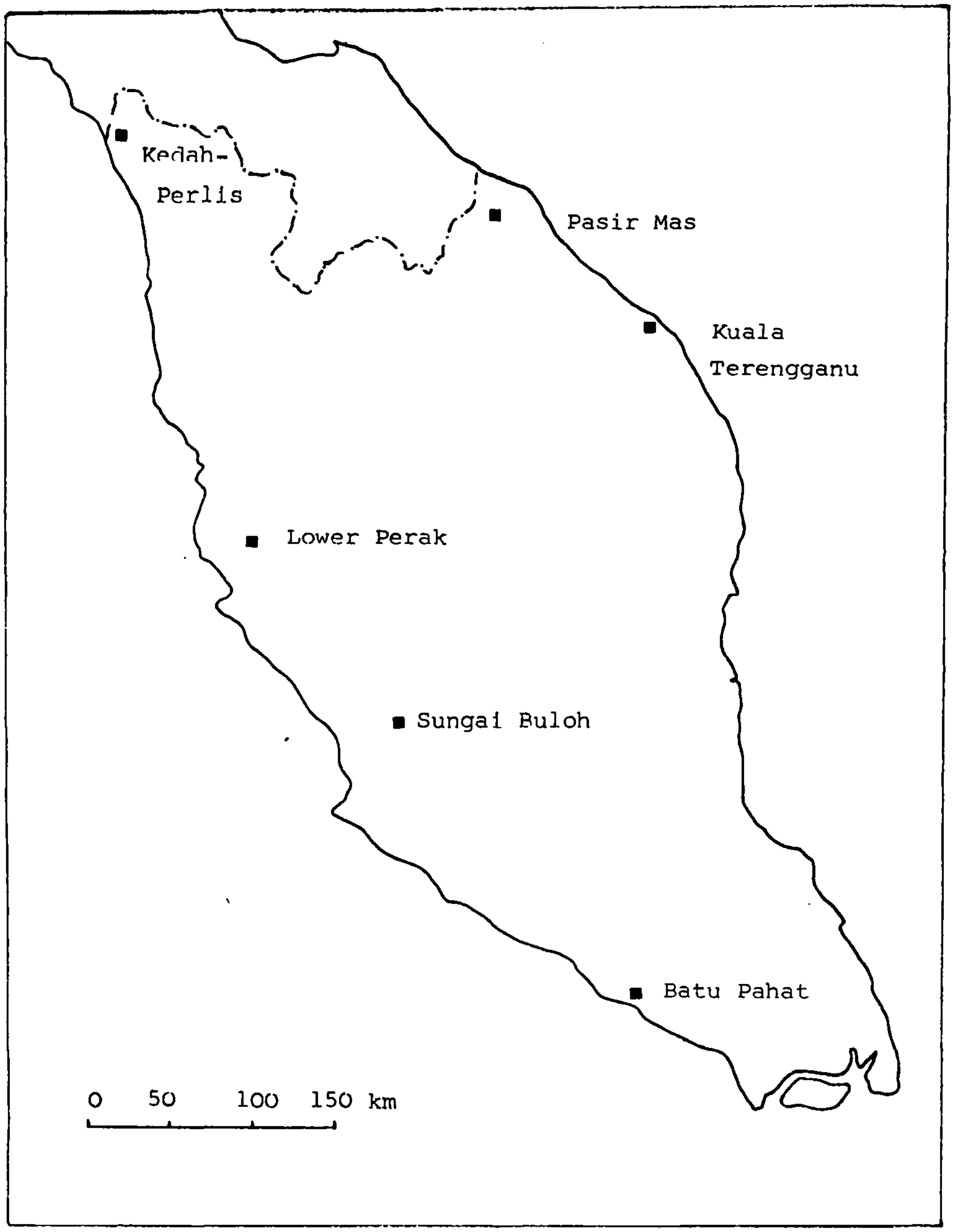

Fig. 1. A map of Peninsular Malaysia showing the areas of sampling.

X-ray Diffraction Analysis

X-ray diffraction analysis was carried out on the clay fraction from both Ap and B horizons. Whenever necessary, the samples were X-rayed after treating with Mg, glycol, K and K-heated at 550°C. These treatments are necessary in order to identify the presence of 14Å minerals (smectite, vermiculite, chlorite) and mica and/or chlorite mixed layers.

Mica, kaolinite, gibbsite, quartz and goethite were identified by the respective presence of XRD peaks at 10Å, 7.2Å, 4.86Å, 4.26Å and 4.18Å. These are well illustrated by the soils of Subang series given in Fig. 2. Mica and quartz did not have any effect on treatment. On the contrary, kaolinite, gibbsite and goethite were destroyed on heating to 550°C. The 14Å minerals as well as mica and chlorite mixed layers were identified on the basis of their response to various treatments. Such responses are shown clearly in Fig. 2.

Referring to Fig. 2, Mg treated sample gave reflections at 14.5Å, 12.5Å and 10Å. The 14.5Å was the reflection of smectite, vermiculite or chlorite, while 10Å and 12.5Å were the reflections of mica and mica mixed layers respectively. When the samples were

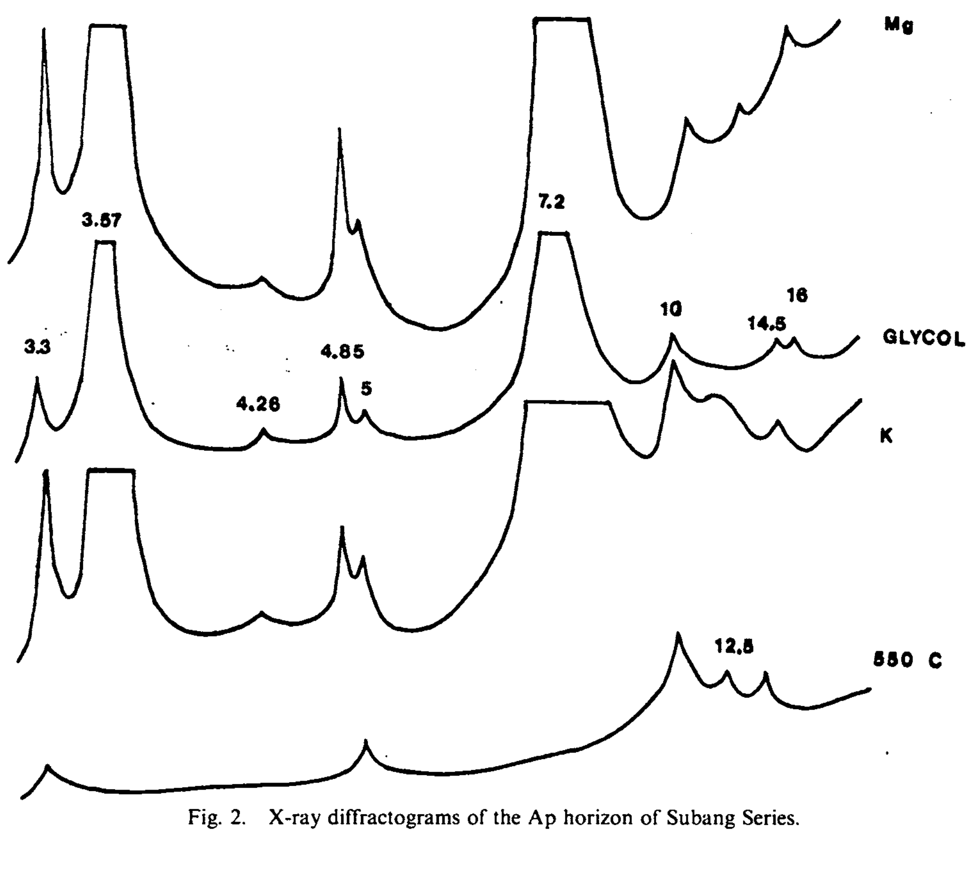

Fig. 2. X-ray diffractograms of the Ap horizon of Subang Series.

glycolated, the 12.5Å expanded to 14.5Å, indicating mica-smectite was present. In the meantime, a 16Å reflection appeared, showing the presence of chlorite mixed layers.

When the sample was treated with K, 12.5Å and 14.5Å appeared. After heating at 550°C, the 12.5Å and 14.5Å remained. The heat and glycol treatments confirm the presence of chlorite (14Å) and chlorite-smectite (16Å) respectively.

Likewise, the clays of other samples were treated, X-rayed and examined in detail. The results of the determinations are given in Table 2. Here, only the results of 5 soil series are given. These are from the soils of Kg. Pusu (2), Bt. Tuku (3), Subang (10), Chuping (16), and Awang Series (17). The results of the others are less interesting. It shows here that T_2 terrace soils of Peninsular Malaysia do contain mica-vermiculite, mica-smectite, chlorite-vermiculite, chlorite-smectite and in one case smectite is present (Chuping series).

TABLE 2

MICA, CHLORITE AND MIXED LAYERS IN SOME OF THE STUDIED SOILS. (M = MICA, VC = VERMICULITE, SM = SMECTITE, CHL = CHLORITE)

Series	Hor.	Depth (cm)	Minerals
Kg. Pusu (2)	B_{22}	40–100	M, M-VC, M-SM, CHL-SM
Bt. Tuku (3)	B_{22}&	58–130	M, M-VC, CHL, CHL-VC
Subang (10)	AC_3	102–145	M, M-SM, CHL, CHL-SM
Chuping (16)	B_{22tcn}	35–63	M, M-VC, M-SM, CHL
Awang (17)	B_3/BC	83–93	M, M-VC, M-SM

Two minerals are examined in greater detail, i.e. anatase and gibbsite. Anatase is a titanium oxide (TiO_2), formed by the weathering of titanium bearing mineral such as ilmenite and sphene. This is known to accumulate in tropical soils (Brown *et al.*, 1978). Anatase was identified by the presence of 3.50Å in the heated samples. On further examination anatase was found to be more abundant in the well drained soils compared to the poorly drained ones. Further, it was found that there was more anatase in the silt than in the clay fraction. The formation of anatase is greatly affected by leaching and weathering.

With regard to gibbsite (Table 3), the amount in the clay fraction was found to be related to the texture and drainage conditions (Table 4). There is more gibbsite in the sandy than the clayey soils. The amount varies in the order: sandy > loamy > clayey. It is also noted that there is more gibbsite in the excessively drained soils than the poorly drained ones. Leaching and weathering in the rock or in the soil play an important role in the formation of gibbsite.

The amount of goethite is not high (Table 3). The highest value is recorded by the soils of Kerayong series (4), with a value of 1.5% for the clay fraction.

TABLE 3

THE AMOUNT OF KAOLINITE, GIBBSITE AND GEOTHITE IN THE CLAY FRACTION OF SOME OF THE STUDIED SOILS.

Series	Hor.	Depth (cm)	Mineral %		
			Kaolinite	Gibbsite	Goethite
Kg. Pusu (2)	B_{22}	40–100	67.0	1.1	0.2
Bt. Tuku (3)	B_{22}	58–130	59.6	0.4	1.0
Kerayong (4)	B_{22}	64–125	48.4	1.9	1.5
Chg. Hangus (5)	Ap	0–20	59.6	1.5	1.2
Subang (10)	Ap	0–33	63.2	2.9	–
Holyrood (18)	B_{23t}	70–90	63.2	–	1.4

TABLE 4

THE EFFECT OF TEXTURE AND DRAINAGE CONDITIONS ON THE FORMATION OF GIBBSITE

Texture	Series	Hor.	Drainage	Gibbsite (% clay)
Sandy	Sg. Buloh (7)	Ap	excessive	63.3
	Subang (10)	B22	poor	4.3
Coarse loamy	Nangka (1)	B22	well	8.6
Fine	Bt. Tuku (3)	Ap	imperfect	1.6
Loamy	Rasau (14)	B24	well	2.9
Clay	Kg. Pusu (2)	Ap	poor	2.2

Thermal Analysis

DTA was employed to supplement the identification of minerals in the clay fraction of the studied soils. This analysis is complementary to X-ray diffraction i.e. to confirm the presence of some mineral identified by XRD. Minerals usually identified by DTA are gibbsite, goethite and kaolinite. In this study, these minerals were respectively identified by the DTA peaks at 260°, 330°C and 500°C. Other minerals, although identified to be present by XRD, are not manifested clearly on the DTA thermograms.

The most important mineral in the clay fraction, expecially for the clayey and loamy soils, is kaolinite. As shown by TGA (Fig. 3), kaolinite is indeed abundant, in most cases it occupies more than 50% of the clay fraction (Table 3).

DSC, which is considered to be 100 times more sensitive than TGA (Tessens and Shamshuddin, 1982), was employed to estimate the amount of gibbsite and goethite.

An example of DSC curve is given in Fig. 3. The area marked (Fig. 3) was compared to the standard curve and the % of gibbsite calculated. This endothermic

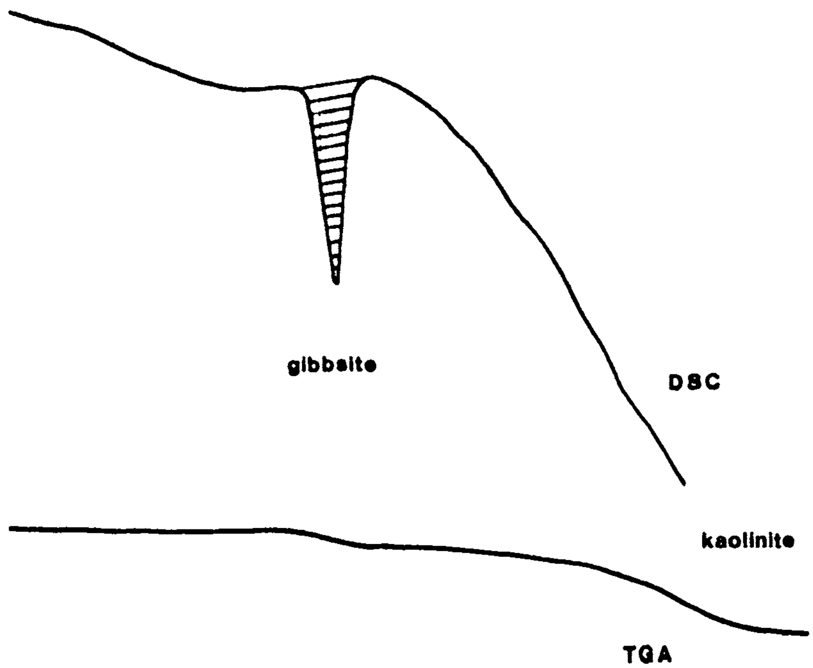

Fig. 3. DSC and TGA curves of the Ap horizon of Subang series.

peak occurred at 260°C. The estimate is given in Table 3. The amount is rather low for the clayey and loamy soils. But in sandy and excessively drained soils, the amount can be high. In the case of Sg. Buloh series, the % of gibbsite is 63.3 in the Ap horizon (Table 4).

Potentiometric Titration

Using an autotitrator and autoburette, 1 g samples were titrated with 0.1N NaOH to pH 9.0 after 2 days of equilibrium in 10 ml 1N KCl. The base needed to raise the pH from 5.5 to 9.0 was estimated from the titration curve. Base needed to raise the pH of the soils from 5.5 to 9.0 was found to be correlated to the clay content. The buffering action of the soils above pH 5.5 is dependant mainly on the percentage of clay. Upon further examination, it was found that the mineral mainly responsible for the buffering action was kaolinite.

Reaction taking place above 5.5 can be described as follows. The pH_o of the broken edges of kaolinite is 7.3 (Rand and Melton, 1975). Thus, below pH 7.3, the broken edges of kaolinite is net positively charged, while above pH 7.3, it is net negatively charged. At pH 7.3 the net charge is zero. Hence, it is expected that strong buffering should take around pH 7.3; i.e. at the pH of kaolinite.

Measurement of Charges

Using the method of Gillman and Uehara (1980), both negative and positive

TABLE 5

WEATHERING STAGES OF SOIL FORMATION BASED ON VALUES OF WEATHERING INDICES (TESSENS AND SHAMSHUDDIN, 1983).

WI	Weathering stage
>75	Recent
75–50	Intermediate
<50	Advanced

TABLE 6

CHARGE PROPERTIES AND WI VALUES OF THE STUDIED SOILS

Series	HOR	– Charge	+ Charge	Net Charge	WI
		meq/100g soil			
Nangka (1)	B_{22}	1.72	0.48	–1.24	72.1
Bt. Tuku (3)	B_{22}	4.21	0.79	–3.42	81.2
Kerayong (4)	B_{22}	7.15	1.25	–5.90	82.5
Lintang (6)	B_{23}	1.51	0.60	–0.91	60.3
Sg. Buloh (13)	AC_3	1.33	0.53	–0.80	60.2
Napai (15)	B_{23tcn}	4.37	0.80	–3.57	81.7
Awang (17)	B_3/BC	2.90	0.56	–2.34	80.7
Holyrood (18)	B_{23t}	2.76	0.60	–2.16	78.3

charges at various pH values were measured. Charges at the soil pH were particularly interesting, as they can be used to determine the stage of weathering; in this study it is called weathering index (WI). Soil pH is the pH (1:1) in 0.01N KC1 solution; 0.01 is considered to be closed to the ionic strength of leached tropical soil.

Weathering index is defined as (Tessens and Shamshuddin, 1983):-

$$WI = \frac{\text{net charge}}{\text{-ve charge}} \times 100$$

Using the values given in Table 5, one can easily determine the weathering stage of any soil if the WI is known.

WI obtained for the studied soils vary from 60% to 80% (Table 6), indicating that the soils are either in the recent or intermediate stage of weathering. This is consistent with the mineralogy of the soil, in which chlorite, mica and their mixed layers are still present. When WI was compared to the mineralogy, it was found as WI decreased, the soils were found to be more weathered, and the amount of oxides increased. In the meantime, silicates decreased.

CONCLUSION

The Subrecent alluvial soils of Peninsular Malaysia contain kaolinite, gibbsite, goethite, anatase, mica, chlorite and mixed layers. The most important mineral is kaolinite, occupying more than 50% of the clay fraction in some cases. This kaolinite controls the buffering action of soils above pH 5.5. The formation of gibbsite and anatase is dependent on texture and drainage conditions.

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