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Some T_2 Terrace Soils of Peninsular Malaysia: II. Mineralogy and Physico-chemical Characteristics*

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Key words: Mineralogy; gibbsite; water dispersible clay; water retention

ABSTRAK

Jumlah gibsit di dalam bahagian lempung tanah teres T_2 *didapati bertambah dengan pertambahan kandungan pasir dan pembaikan keadaan saliran. Kaolinit ialah mineral utama di dalam bahagian lempung tanah yang dikaji. Tanah kurang salir boleh juga mengandungi sedikit mika, klorit, lapisan bercampur dan feldspar. Anatas berkumpul di dalam bahagian kelodak tanah yang baik salir. Kehadiran lempung 1:1 dan/atau seskuioksida digambarkan oleh sifat-sifat fiziko-kimianya. KPK lempung berkurangan dengan pengurangan nisbah kelodak/lempung. % LSA/lempung didapati berkurangan dengan bertambahnya Al dan/atau bahan organik. Nisbah itu juga berkurangan apabila pH menghampiri* pH_o.

ABSTRACT

The amount of gibbsite in the clay fraction of T_2 *terrace soils appears to increase with the increase of sand content and with the improvement of drainage conditions. Kaolinite is the main mineral in the clay fraction of soils. The imperfectly and poorly drained ones may also contain some mica, chlorite, mixed layers and feldspar. Anatase accumulates in the silt fraction of the well drained soils. The dominance of 1:1 clay minerals and/or sesquioxides is reflected in their physico-chemical properties. Apparent CEC decreases with a decrease in silt/clay ration. WDC/clay % appears to decrease with an increase in Al and/or organic matter. The ratio also decreases as the pH approaches* pH_o.

INTRODUCTION

Under the influence of high temperature and high rainfall, tropical soils in the well drained areas undergo physico-chemical weathering readily. The mineralogy of these soils is usually dominated by kaolinite and/or gibbsite. Under impeded drainage conditions, a somewhat different kind of mineralogy is expected. Smectite, vermiculite and mixed layers or even primary minerals can be present. The choice of crops to be grown on these soils should be based on their physico-chemical and mineralogical properties because availability of nutrients and fertilizer requirements of such soils are related to those properties.

This study reports the mineralogy of some T_2 terrace soils in Peninsular Malaysia, and relates it to the physico-chemical properties of

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the soils. The data available from this study can be used for classification purposes as well as for agricultural planning.

MATERIALS AND METHODS

The soils for the study are alluvial soils formed on T_2 terraces (Paramananthan, 1981). The micromorphology and classification of these soils have already been studied (Shamshuddin and Tessens, 1983). The soils selected are those of Nangka (1, 9), Kampung Pusu (2), Bukit Tuku (3), Kerayong (4, 12), Cherang Hangus (5), Lintang (6), Sungai Buloh (7, 8, 13), Subang (10), Sogomana (11), Rasau (14), Napai (15), Chuping (16), Awang (17) and Holyrood Series (18). Data on routine analyses are available from the earlier paper (Shamshuddin and Tessens, 1983).

20 g of soil was put in an end-over-end shaker for 16 hours. The amount of clay dispersed, henceforth referred to as water dispersible clay (WDC), was measured. This is expressed as % of the total clay (WDC/clay %). Moisture retention measurements and bulk density were carried out from core samples. Moisture retention was taken at the suction of 0.001, 0.01, 0.1, 0.33 and 15 bar.

Chloride free samples (clay and silt) from both Ap and B horizons were X-rayed (untreated samples). Whenever necessary, the clay fractions were X-rayed after treatment with Mg, glycol, K and K heated at 550°C. These are repectively referred to as Mg, glycolated, K and heated samples. Interpretation of the diffractograms was done according to DeConink (1978). Selected samples were taken for the study of anatase. These samples were deferrified and X-rayed both before and after heating at 550°C.

Untreated clay samples were also analysed by differential thermal analysis (DTA), differential scanning calorimetry (DSC) and thermogravimetric analysis (TGA), using the Du Pont 990 Thermal Analyser. Transmission Electron Microscopy (TEM) was also employed to identify clay minerals. The VFS fraction, taken from 50 cm depth, was separated using bromoform, into heavy and light minerals. Mounting and counting of the heavy minerals were done according to Stoops (1974).

RESULTS AND DISCUSSION

Mineralogy

General Considerations

The minerals in the clay and the silt fraction were first identified on the diffractograms of the untreated samples. They were subsequently confirmed by DTA. The amount of gibbsite and goethite was estimated by DSC, while the amount of kaolinite was estimated by TGA. Note that the % of mica/chlorite can be estimated by combining TGA and charge studies (Shamshuddin and Tessens, 1985).

Kaolinite and Halloysite

Kaolinite is the most common mineral in the clay fraction. It was identified by XRD peak at 7.2A and 3.57A, and DTA peak at 550 – 550°C. In most cases, kaolinite occupies 40 – 60% of the clay fraction (Table 1), in agreement with the earlier postulated recent and intermediate weathering stage. The presence of significant amounts of kaolinite cannot be regarded as an expression of an advanced stage of weathering as primary minerals, such as mica and feldspar, are also present.

From XRD, DTA, TGA and DSC studies, it is not possible to identify the presence of halloysite. However, looking at TEM micrographs (Plate 1a and b), one can see some tubular minerals present among the kaolinite crystals. These are the halloysite tubes, whose shape are distinctly different from kaolinite, which are hexagonal.

TABLE 1

The % of kaolinite, gibbsite and geothite in the clay fraction

		MINERAL (% clay)		
SERIES	HOR	Kaolinite	Gibbsite	Goethite
Nangka (1)	Ap	48.8	5.8	—
	B_{22}	52.0	8.6	—
Kampung Pusu (2)	Ap	52.0	2.2	—
	B_{22}	67.0	1.1	0.2
Bukit Tuku (3)	Ap	44.6	1.6	—
	B_{22}	59.6	0.4	1.0
Kerayong (4)	Ap	48.4	2.5	—
	B_{22}	48.4	1.9	1.5
Cherang Hangus (5)	Ap	59.6	1.5	1.2
	B_{22}	48.4	4.3	—
Lintang (6)	Ap	55.8	8.6	—
	B_{22}	55.8	8.6	—
Sungai Buloh (7)	Ap	14.9	63.3	—
	C	7.4	50.5	—
Sungai Buloh (8)	Ap	59.6	8.6	—
	AC_3	55.8	10.1	—
Subang (10)	Ap	63.2	2.9	—
	AC_2	44.6	0.3	—
Rasau (14)	A_1	55.8	2.9	—
	B_{24}	59.6	2.9	—
Napai (15)	A_{11}	57.6	—	1.1
	B_{23tcn}	55.8	—	1.2
Chuping (16)	A_1	16.7	0.7	—
	B_{22tcn}	18.6	1.4	—
Awang (17)	Ap	67.0	—	—
	B3/BC	59.5	—	—
Holyrood (18)	Ap	59.6	—	0.5
	B_{23t}	63.2	1.4	

Plate 1: TEM micrographs of the clay fraction from B horizon (mag. X35,000): a. Kaolinite (hexagonal) and halloysite (tubular) in the B22 horizon of Chg Hangus Series (5). b. Kaolinite and halloysite in the B23t horizon of Holyrood Series (18).

Gibbsite

Gibbsite is very common in these soils. It was identified by the XRD peak at 4.86A and DTA peak at 250 – 270°C. The temperature of dehydroxylation is rather low. According to Hsu (1977), this may be due to large size gibbsite, as small crystals normally give a peak at 300 – 330°C.

The amount of gibbsite in the soils appeared to depend on the texture as well as drainage conditions. Light textured soils contain more gibbsite than the heavier textured ones (Table 2), and better drained soils contain more gibbsite than the others.

The formation of gibbsite in soils is found to be controlled by pH and the concentration of Al and Si in the solution (Hsu, 1977). Under slow leaching, Si may gradually accumulate and consequently combine with Al to form kaolinite. Transformation of primary minerals to gibbsite implies intense leaching. Such conditions prevail in the soils of Sungai Buloh Series (7, 8).

Iron Minerals

The most common form of iron oxide in soils is goethite. This mineral is identified by the XRD peak at 4.18A and DTA peak at about 350°C. Hematite is the second most common iron oxide in soils. Under hydromorphic conditions, hematite is converted to goethite (Schwertmann and Taylor, 1977).

Some of the T_2 terrace soils contain goethite. On many occasions, the goethite peak at 4.18A is not clear as it goes together with quartz peak at 4.26A. The amount of goethite, whenever present, was estimated by DSC. The amount of goethite in the soils does not exceed 2%. The highest % is found in the soils of Kerayong Series (4), where the value is 1.5%.

Lepidocrocite is rather rare in tropical soils. It is reported to be found exclusively in hydromorphic soils, generated by oxygen deficiency (Schwertmann and Taylor, 1977; Ross *et al.*, 1979). The colour of lepidocrocite is more reddish than goethite (10YR) and less reddish than hematite (2.5YR) (Schwertmann and Fitzpartrick, 1977). In the T_2 terrace soils, Cherang Hangus Series (5) is the only soil containing lepidocrocite, shown by the XRD peak at 6.26A and by the reddish yellow mottles.

Anatase

Anatase (TiO_2) occurs as an alteration product of titanium-bearing minerals such as sphene and ilmenite, believed to accumulate in weathered tropical soils rich in kaolinite (Brown *et al.*, 1978). To identify anatase in the studied

TABLE 2
The effect of texture and drainage conditions on the formation of gibbsite in T_2 terrace soils

Texture	Series	Hor	Drainage	Gibbsite (clay)
Sandy	Sg. Buloh (7)	Ap	excessive	63.3
	Sg. Buloh (8)	AC_3	excessive	10.1
	Subang (10)	B_{22}	poor	4.3
Coarse	Nangka (1)	B_{22}	well	8.6
Loamy	Lintang (6)	B_{23}	well	8.6
Fine	Bt. Tuku (3)	Ap	imperfect	1.6
Loamy	Rasau (14)	B_{24}	well	2.9
Clayey	Kg. Pusu (2)	Ap	poor	2.2
	Kerayong (4)	Ap	moderate	2.5

soils, silt and clay fractions were selected for XRD. Selection of samples was based on the existence of XRD peak at around 3.5 – 3.6A. These samples were treated with DCB (Mehra and Jackson, 1960) to remove iron oxide and amorphous materials. The Fe-free samples were X-rayed before and after heating at 550°C.

Figure 1 gives the X-ray diffractograms of soils of Lintang (6), Nangka (9) and Sungai Buloh Series (13), both before and after heating at 550°C. One can see that before heating, there are XRD peaks at 3.5A and 3.57A, but after heating only the 3.5A peak remains. This points to the presence of anatase in the samples. Most of the studied soils show this property.

In order to obtain a better understanding of the distribution of anatase, the diffractograms of clay and silt from soils under different moisture regimes were examined *(Figure 2)*. An examination of these suggests:

a. Anatase is more in the sandy than in the clayey soils.

b. Anatase is more in the silt than in the clay.

c. Anatase is more in the well and excessively drained soils (Nangka (9) and Sungai Buloh (8) respectively) than the poorly drained soils (Subang (10) and Sogomana (11) series).

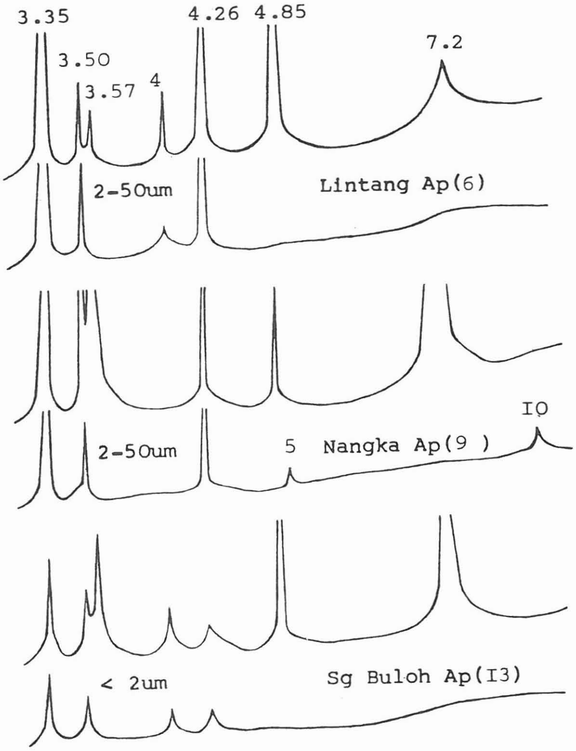

Fig. 1. X-ray diffractograms of Fe free silt and clay before (above) and after heating (below).

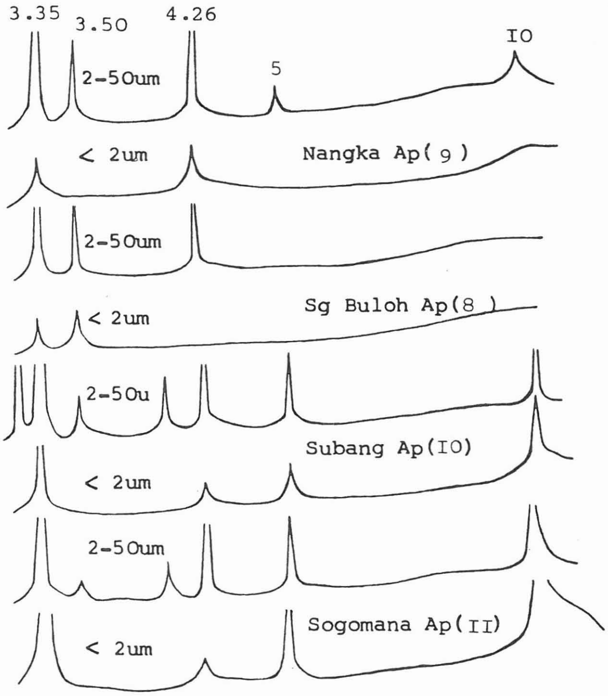

Fig. 2. X-ray diffractograms of the silt and clay (heated) from soils under well (8, 9) and poorly drained conditions (10, 11).

Mica, Chlorite and Mixed Layers

Most of the T_2 terrace soils (Table 3) contain mica and some soils contain chlorite. These minerals are associated with soils in the recent or intermediate stage of weathering, especially under poorly drained conditions. Mica appears as plate-like bodies *(Plate 1c)*, with a size slightly bigger than kaolinite. This mica is mainly muscovite, as evidenced by the study of thin sections.

During weathering, mica is completely or partially converted to secondary minerals. The latter are referred to as mica mixed layers, of which the most commonly reported in soils are mica-vermiculite and mica-smectite (Table 3). In these soils, mica-vermiculite is identified by the presence of XRD peak at 12A in Mg treated and glycolated samples. On the other hand mica-smectite expands to 14.5A on glycolation.

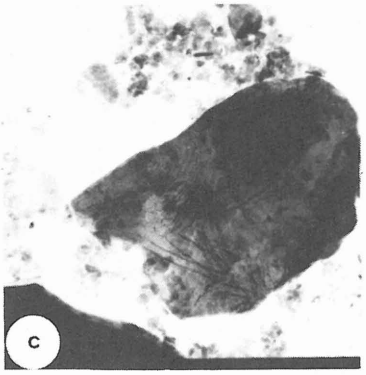

Plate 1c: Mica plate in the B22 horizon at Bt. Tuku Series (3).

Weathering of chlorite wholly or partially leads to the formation of secondary minerals. The former will result in the formation of vermiculite and/or smectite, while the latter results in the formation of chlorite mixed layers. The chlorite mixed layers found in soils are chlorite-vermiculite and chlorite-smectite. The presence of chlorite-vermiculite in these soils was confirmed by the presence of XRD peak of 12A in K saturated and heated samples, while the presence of chlorite-smectite was shown by the presence of 12A peak in K saturated and heated samples, and 16A in the glycolated samples.

In T_2 terrace soils of Peninsular Malaysia, the soils containing chlorite and/or chlorite mixed layers are mostly poorly or imperfectly drained soils. The only well drained soil that contains chlorite mixed layers is the Napai Series (15) (Table 3).

TABLE 3

Mica, chlorite and their mixed layers in T_2 terrace soils of Peninsular Malaysia.
(M = mica, Vc = vermiculite, Sm = smectite, Chl = chlorite)

Series	Minerals (clay)
Nangka (1)	M, Vc
Kg. Pusu (2)	M, M-Vc, M-Sm, Chl-Sm
Bt. Tuku (3)	M, M-Vc, Chl, Chl-Vc
Kerayong (4)	M, M-Vc, M-Sm, Chl-Sm
Chg Hangus (5)	M, M-Vc, M-Sm, Chl
Subang (10)	M, M-Sm, Chl, Chl-Sm
Sogomana (11)	M, M-Vc, Vc
Kerayong (12)	M
Napai (15)	M, M-Sm, Chl-Vc
Chuping (16)	M, M-Vc, M-Sm, Chl-Sm, Sm
Awang (17)	M, M-Vc, M-Sm
Holyrood (18)	M, M-Vc, Chl, Chl-Vc

Silica

The most common silica mineral in soils is quartz, shown by the XRD reflections at 4.26A and 3.34A. Quartz makes up an important portion of the silt fraction of the studied soils. In the study of anatase, XRD peak at 4A *(Figs. 1* and *2)* appears many times in the silt fraction and occasionally in the clay fraction. The intensity of XRD peak does not change with heating at 550°C.

The 4A reflection could either be due to the presence of crystobalite (Wilding *et al.*, 1977) or silica of biological origin (Brown *et al.*, 1978). An examination of the thin sections of the same soils indicates the presence of phytoliths. Phytoliths are opaline silica derived from plants (Stoops, 1978). Thus 4A reflection is believed to be due to the presence of phytoliths.

Heavy Minerals

Checking through the mineralogy of heavy minerals in the VFS fraction of various regions, the following points have been noted (Table 4):

a. Soils of Kelantan. The most important heavy mineral in Nangka (1) and Bukit Tuku Series (3) is zircon, while Kampung Pusu (2) and Kerayong Series (4) are dominated by opaque minerals. Similarity in heavy mineralogy in the Nangka and Bukit Tuku Series suggests that these soils are derived from parent materials of similar origin. The parent material of these soils could have originated from granite.

b. Soils of Trengganu. Soils of Lintang Series (6) contain mostly tourmaline.

c. Soils of Selangor-Johore. Sungai Buloh Series (7) of Selangor contains an important amount of tourmaline. On the other hand, Sungai Buloh (8) and Nangka (9) of Johore contains dominantly zircon in the VFS fraction. The two Johore soils are situated near each other, thus their parent materials could be of similar origin (probably granite).

TABLE 4
Heavy minerals in the VFS fraction of T_2 terrace soils

SERIES	HOR	HEAVY MINERALS VFS (%)		
		Tourmaline	Zircon	Opaque
Nangka (1)	B_{21}	22.5	39.4	38.1
Kg. Pusu (2)	B_{21}	31.5	34.8	34.0
Bt. Tuku (3)	B_{21}	22.3	43.3	34.4
Kerayong (4)	B_{21}	33.1	16.3	50.6
Lintang (6)	B_{21}	51.9	10.7	37.4
Sg. Buloh (7)	AC_1	48.8	36.4	15.8
Sg. Buloh (8)	AC_1	3.4	59.3	37.3
Nangka (9)	B_{21}	8.2	64.4	27.4
Subang (10)	B_{21}	28.1	43.8	28.1
Kerayong (12)	B_{21}	48.2	25.9	25.9
Napai (15)	B_{21tcn}	5.0	6.9	88.1
Awang (17)	B_{21}	96.0	0.3	3.7
Holyrood (18)	B_{22t}	88.7	2.5	8.8

d. Soils of Perak. Zircon is the most important mineral in Subang Series (10), while tourmaline is the most important mineral in the Kerayong (12) and Sungai Buloh Series (13).

e. Soils of Kedah-Perlis. There is a clear dominance of tourmaline in the soils of Awang (17) and Holyrood Series (18). Both of these soils are believed to have been derived from parent materials of granitic origin containing an important amount of tourmaline.

Physico-chemical Properties

General Considerations

Physico-chemical properties of soils are related to their mineralogical composition. Exchange properties, water retention, dispersibility and textural composition are now discussed in relation to the mineralogy of the soils.

Cation Exchange Capacity

The CEC of a soil is related to the amount and type of clay minerals and organic matter. The clay fraction of the soil contributes most of the CEC. 2:1 clay minerals, such as smectite and vermiculite, have isomorphic substitution, resulting in the production of a high amount of negative charges. On the other hand, 1:1 clay minerals and sesquioxides do not show these properties and therefore their CEC is low. CEC, is thus, a good indicator of the stage of soil formation (Sys, 1978).

The CEC of the studied soils is given in the appendix of the earlier paper (Shamshuddin and Tessens, 1983). As these soils are either in the recent or intermediate stage of weathering and contain kaolinite and sesquioxides, with some 2:1 clay minerals and/or mixed layers, the CEC values of the top soils are high; in the subsoils they are high to medium. The values average around 16 meq/100 g soil in the top soil. The A_1/Ap horizons report higher values than the subhorizons due to the presence of more organic matter in the upper horizons. It was also found that the apparent CEC is correlated to the silt/clay ratio, with an R value of 0.819**. The plot of the apparent CEC against silt/clay ratio is given in *Figure 3*.

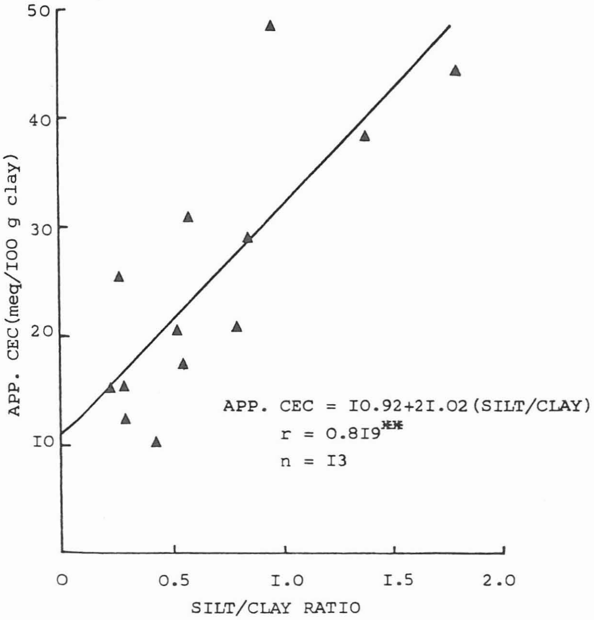

Fig. 3. The relationship between apparent CEC and silt/clay ratio for soil at 50 cm depth.

Water Retention

The amount of water retained in the soil is influenced by the amount and nature of the clay minerals and organic matter present in the soil. Water retained at 15-bar (mm/m) is related to the clay content. To test the validity of these relationships, 15-bar water was plotted against clay content and a regression equation was determined. For A horizons of loamy and clayey soils, the relationship is given by the equation: —

$$\text{Water 15-bar} = 6.08 + 0.47\,(\text{clay }\%)$$
$$r = 0.96^{**},\ n = 12$$

For B horizons, the following regression equation was obtained: —

$$\text{Water 15-bar} = 5.84 + 0.54\,(\text{clay}\%)$$
$$r = 0.97^{**},\ n = 22$$

One can observe that the conversion factor between 15-bar water and % clay is 2, rather than 2.5 as proposed in Soil Taxonomy.

Water Dispersible Clay

Data on WDC for the studied soils are given in Table 5. It is seen that WDC/clay % is higher in the Ap than in the B_{22} horizons. This is well illustrated by the soils of Bukit Tuku (3), Kerayong (4) and Lintang Series (6). The change of WDC with depth is related to the Al and/or organic matter.

To test the validity of this assumption, the correlation between WDC/clay % and Al (foı subhorizons) and between WDC/clay % and organic carbon (for A horizons) were determined. The former is given by the regression equation:—

$$\text{WDC/clay \%} = 45.36 - 14.54 \text{ Al}$$
$$r = 0.67^{**},\ n = 18$$

The latter is given by the regression equation:

$$\text{WDC/clay \%} = 36.02 - 7.13 \text{ O.C.}$$
$$r = -0.62^{*},\ n = 16$$

It is found that the WDC/clay % decreases with the increase of Al and/or organic matter.

Dispersion and deposition phenomena are related to the point of zero charge (pH_0) of the soil in some way. It was found that all these soils are net negatively charged in the pH range of 3 to 6 (Shamshuddin and Tessens, 1985). The point of zero charge of the variable charge colloid (pH_0) is therefore used to characterise the dispersion and deposition phenomena in these soils.

WDC/clay % and pH_0 values for some of the soils are given in Table 5. It is seen that as difference between pH (water) and pH_0 increases, the WDC/clay % increases. The regression equation for the relationship between WDC/clay % and pH (H_2O) − pH_0 is given by the equation:—

$$\text{WDC/clay \%} = -11.75 + 34.89\,(pH - pH_0)$$
$$r = 0.58^{**},\ n = 12$$

This is well illustrated by the soils of Kerayong (4), Awang (17) and Holyrood Series (18). In these soils, WDC/clay % decreases from Ap to B horizon and so is pH − pH_0.

It is considered that WDC approaches a minimum value close to pH_0 because at pH_0 colloids flocculate (Eswaran and Sys, 1979). When the pH of the soil is equal to its pH_0, surface potential and charge is zero (Uehara and Gillman, 1980). The absence of potential and net charge pH_0 results in the flocculation of colloids.

TABLE 5
Flocculation and dispersion phenomena in relation to pH_0

Series	Hor	pH(H_2O)	pH_0	pH − pH_0	WDC/Clay %
Bt. Tuku (3)	Ap	4.8	4.08	0.72	14.0
	B_{22}	5.0	4.20	0.80	3.3
Kerayong (4)	Ap	5.9	4.14	1.76	31.0
	B_{22}	5.2	4.24	0.96	0
Lintang (6)	Ap	5.1	4.18	0.92	46.0
	B_{23}	4.7	4.28	0.42	1.3
Napai (15)	A_{11}	4.9	4.00	0.90	0.7
Awang (17)	Ap	5.2	3.88	1.32	82.9
	B3/BC	4.9	3.70	1.20	17.7
Holyrood (18)	B_{23t}	4.5	4.15	0.35	0

CONCLUSION

Gibbsite dominates the clay fraction of excessively drained, sandy soils. The loamy and clayey well drained soils contain dominantly kaolinite. Mica, chlorite, mixed layers and feldspar are present in imperfectly and/or poorly drained soils. Anatase accumulates in the silt fraction of well drained soils. Apparent CEC decreases with a decrease of silt/clay ratio. Ideal conditions for dispersion are low Al and/or organic matter and a pH far from pH_o.

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