Mineralogy and Related Properties of Acid Sulphate Soil from Melaka, Peninsular Malaysia

SHAMSUDDIN JUSOP and TUAN OMAR RAJA SENIK[1]

Department of Soil Science, Faculty of Agriculture, Universiti Pertanian Malaysia

RINGKASAN

Sifat mineralogi, kimia dan fizik tanah asid sulfat dari Kuala Linggi, Melaka telah dikaji. Tanah ini didapati mengandungi mineral montmorillonit, kaolinit, illit, klorit dan pirit. Tidak ada perbezaan dari segi mineralogi diantara lapisan atas dengan lapisan bawah, tetapi kuantiti montmorillonit dan pirit mungkin bertambah ke bawah. Tanah asid sulfat ini mungkin berkeupayaan untuk menghasilkan pengeluaran pertanian yang tinggi; kehadiran montmorillonit meninggikan keupayaan pertukaran kation (melebehi 16 m.e./100g tanah). Walau bagaimana pun, kehadiran pirit yang senang teroksid kepada asid sulfat apabila air disalirkan, menyebabkan potensil pertanian tanah ini rendah. Jumlah sulfat bertambah ke bawah, begitu dengan sulfat larut-air. Sekiranya pirit itu dapat dimusnahkan dengan tidak menjejaskan sifat-sifat fizik dan kimia mineral lain, mungkin tanah ini mempunyai potensil pertanian yang tinggi.

SUMMARY

Mineralogical, chemical and physical properties of acid sulphate soil from Kuala Linggi, Melaka, were studied. The study shows that the soil contains kaolinite, montmorillonite, illite, chlorite and pyrite. There are no mineralogical differences between the top and the lower horizons. Both total sulphate and water-soluble sulphate increase with depth. The CEC of the soil is above 16me/100g soil, probably due to the presence of montmorillonite. However, the presence of pyrite, which is easily oxidizable to acid sulphate on exposure, makes the soil less suitable for agricultural purposes.

INTRODUCTION

Acid sulphate soils are those with a pH < 3.5 (1:2.5) and with a water soluble sulphate content of $> 0.1\%$ within 50 cm of the soil surface[2]. The soil contains a high amount of FeS_2 and is normally low in bases. In Peninsular Malaysia alone, acid sulphate soils probably cover an area of about 141,700 ha, found mainly in the coastal region (Fig. 1) of Melaka, Kedah, Perlis, Kelantan, Selangor, Trengganu, Johor and Pahang (Law and Selvadurai, 1968; Chow, 1968; Kanapathy, 1966; Paramanatham and Law, 1974; Law and Tan, 1975; Kanapathy, 1976) and are largely grown with padi, coconut, oil palm and rubber.

Five soil series namely Telok, Linau, Guar, Sedu and Parit Botak are known to be acid sulphate soils; and are classified at the subgroup level as either sulfic Tropaquept or Typic Sulfaquept (Law and Tan, 1975; Gopinathan *et al.*, 1977). Acid sulphate soils are derived from marine alluvium. Pyrite in the soils is formed under reducing conditions in the areas intermittently flooded with sea water.

Periodic flooding of recent coastal plain soils causes either acidification or deacidification (Breemen, 1975). Acidification results in the formation of FeS_2 and partial loss of alkalinity in flood water during the wet season, followed by oxidation of pyrite during the dry season. Upon flooding Fe^{++} increases at all depths; most strongly in the A horizon. This suggests the occurrence of $SO_4^=$ reduction with accompanying FeS_2 prepitation (Breemen and Harmsen, 1975).

Oxidation of FeS_2 results in the production of acid sulphate and ferric sulphate:-
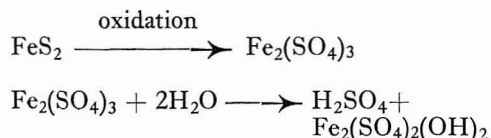
$$FeS_2 \xrightarrow{\text{oxidation}} Fe_2(SO_4)_3$$

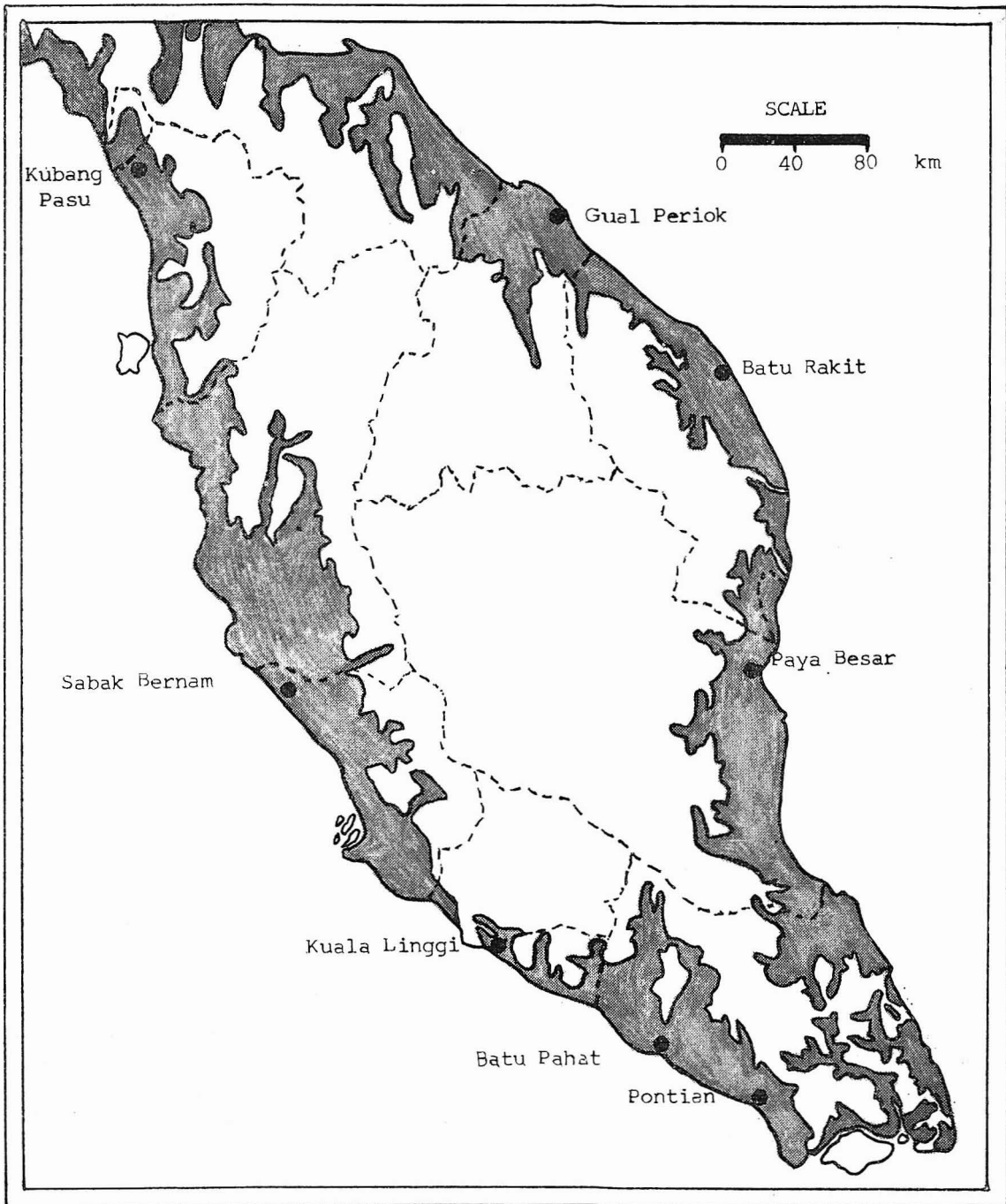$$Fe_2(SO_4)_3 + 2H_2O \longrightarrow H_2SO_4 + Fe_2(SO_4)_2(OH)_2$$

Fig. 1 :   *A map of Peninsular Malaysia showing the distribution of Quaternary alluvial deposits (shaded area).*
The dots denote the places where acid sulphate soils are known to occur (adapted from Stauffer, 1973).

The basic ferrisulphate $Fe_2(SO_4)_2(OH)_2$ so formed can easily be converted to jarosite ($K Fe_3(SO_4)_2(OH)_6$) in the presence of K^+. Jarosite sometimes dehydrates and oxidizes, resulting in the formation of Fe_2O_3. These processes are enhanced by a high pH and a low K concentration (Breemen and Harmsen, 1975).

The object of this paper is to evaluate the agricultural potential of acid sulphate soil in Malaysia by studying mineralogical composition of the soil and physical and chemical properties.

MATERIALS AND METHODS

The samples were taken at three depths, representing A, (B) and Cg horizons (Fig. 2). This particular Linau Series which is found at Kuala Linggi, Melaka, is derived from Quaternary marine deposits (Stauffer, 1973; Sooryanarayana, 1976) and largely covered with "gelam" *(Melaleuca leucadendron)* and or "nipah" *(Nipa fruti-can)*. Taxonomically, the soil is classified as belonging to the clayey, mixed, isohyperthermic family of the Typic Sulfaquept. The ground water table is below 80 cm depth and yellow jarosite mottles are found in the upper layers in dry season. The dried soil is strongly acid. The mean annual temperature of the area is about 26°C and the total annual rainfall is about 2000 – 2500 mm (Dale, 1963).

The soil samples were air-dried and ground to pass through a 2 mm sieve. Soil $pH(H_2O)$ was measured at a 1:2.5 soil. Particle-size analysis was carried out by the pippette method, following the method of Day (1965). Exchangeable cations were extracted by NH_4 OAc at pH7 (Chapman, 1965); Na and K were determined by a flame photometer and Ca and Mg were determined by atomic absorption spectrophotometer. Exchange capacity was determined by the NH_4OAc method at pH7 (Chapman, 1965). Exchangeable aluminium was extracted by 1N KCl (Maclean, 1965). Time requirement was estimated by the titration method of Dunn (1943). Total sulphur was estimated by the method of Jackson (1967), sulphate-sulphur ($SO_4^=$-S) by the method of Hesse (1971) and water soluble sulphate-sulphur by the method recommended by Chow (1968). Organic carbon was determined by the Walkley-Black method (Allison, 1965). X-ray diffraction (XRD) analysis was carried out followig the method of Whittig (1965).

RESULTS AND DISCUSSION

Mineralogical properties

X-ray diffraction (XRD) investigation of Linau Series (Fig. 3) shows reflection at 16.6Å (montmorillinite), 14.0Å (chlorite), 10.1Å (illite) 7.2Å (kaolinite/chlorite), 3.59Å (chlorite), etc
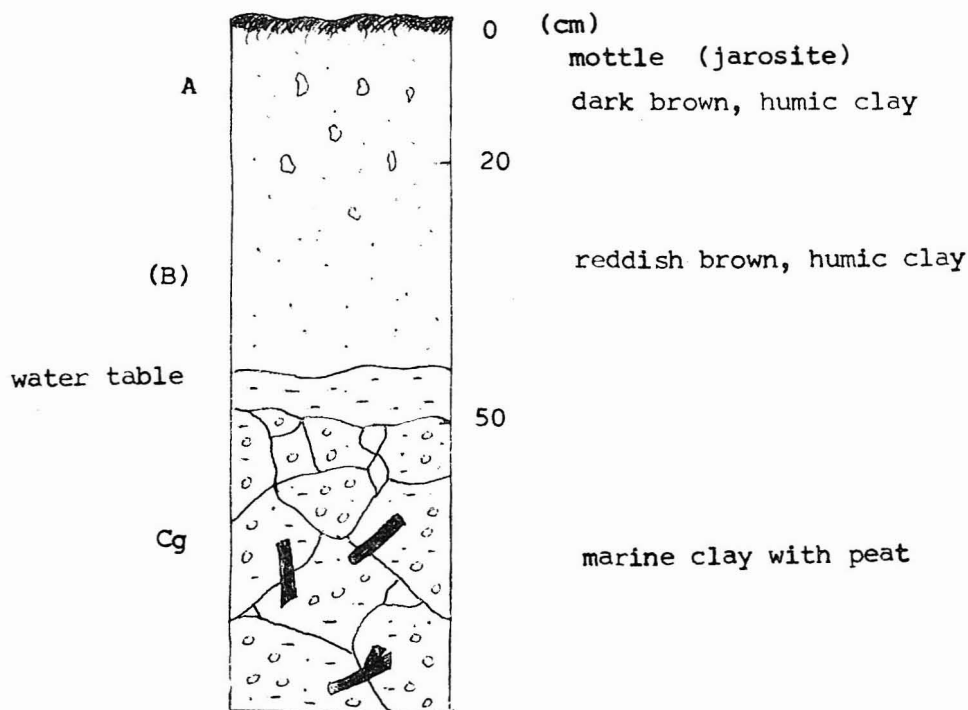

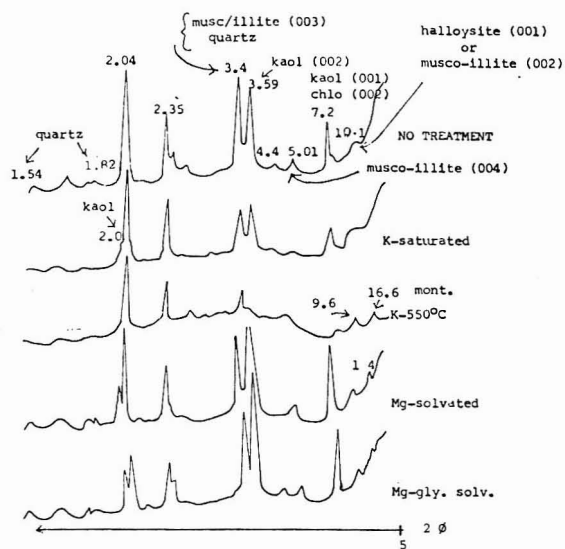*Fig. 2 : A sketch showing the profile of Linau Series from Melaka.*

Fig. 3: *X-ray diffraction pattern of Linau Series saturated with K, K–550°C, Mg and Mg-glycerol solvated.*

All these reflections point to the presence of montmorillonite, chlorite, illite and kaolinite. The presence of pyrite was deduced from the presence of the total sulphur and sulphate-sulphur.

Diffractogram of Mg-saturated and glycerol solvated clay does not manifest reflection at

17 – 18Å. Montmorillonite which may be present in the clay does not expand, probably because of the presence of some cementing material which had not been removed by the deferrating agent (Tsuneo, 1958). This cementing material was probably destroyed when the K-saturated clay was heated to 550°C, as a result of which, reflection at 16.6Å appears. The 16.6Å basal spacing is probably a reflection of montmorillonite. There is no reflection at 10.8Å, thus indicating that halloysite is not present (Whittig, 1965). Treated montmorillonite give reflections at about 15Å; this shows a high order of crystallinity, which may be attributed to the weathering resistivity of montmorillonite itself. Less or low weathering degree is indicated by the occurrence of chlorite.

The intensity of reflection at 7.2Å, 3.59Å and 2.0Å decreased when heated to a temperature of 550°C. This phenomenon proves the presence of kaolinite as heating causes dehydration and dehydroxylation of kaolinite (Fitzpatrick and Roux, 1977). Heating to 550°C does not affect the reflections at 3.4Å (illite) and 2.35Å and 2.04Å (chlorite). There is no clear evidence of the presence of goethite and gibbsite; there are no reflection at 4.86Å and 4.18Å respectively. The XRD pattern of the upper and lower horizons are basically the same, indicating that there is no real mineralogical difference with depth (Fig. 4); but the increase of cation (Na and Mg) and sulphur with depth points to the corresponding
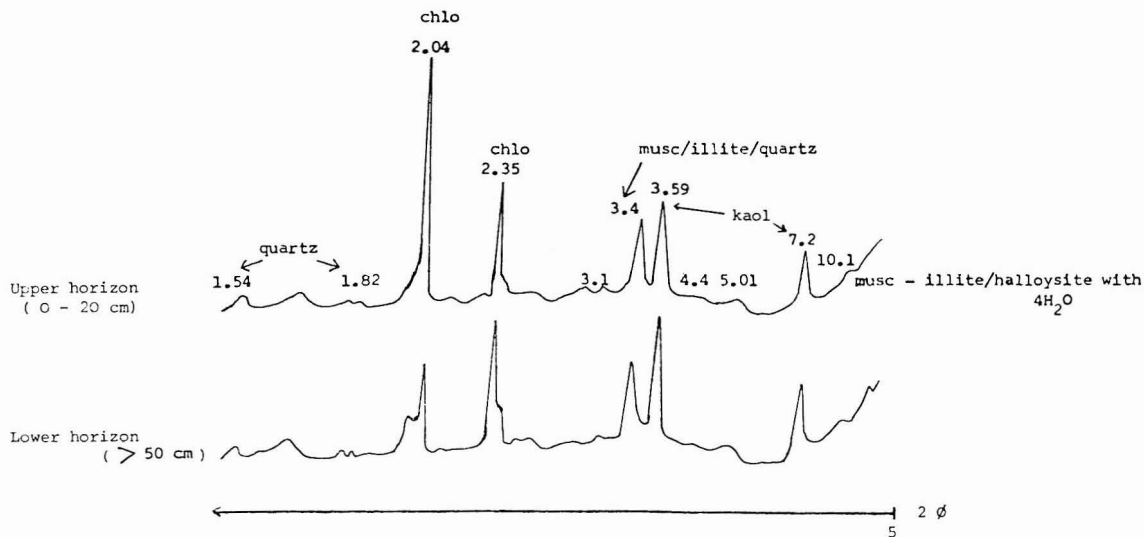

Fig. 4: *X-ray diffractogram of K-saturated clays of Linau Series from Melaka.*

increase of montmorillonite and pyrite with depth (Table 2).

Mineralogically, the soil may have greater agricultural potential than some upland soils in the country. Montmorillonite increases the exchange capacity of the soil substantially, but the presence of pyrite which is easily oxidizable to acid sulphate, makes the soil less suitable for agriculture. The structure of the soil is poor, but it could be improved provided pyrite is absent. If the pyrite can be destroyed without disturbing the composition of the rest of the component minerals, the soil could be one of the best in the country. However, effective practices for achieving such favourable soil conditions are not available. Draining the soil exposes the pyrites to be oxidised to sulphate slowly but steadily over a period of years. Dilution of the acid with large quantities of water and subsequent lime treatment to pH 6.5, is only a short term measure; the remaining pyrite in the soil will eventually be oxidised, rendering the soil unfit for agriculture.

Physical and Chemical Properties

The texture of the soil becomes heavier with depth; it is sandy clay loam in the A horizon, loam in the (B) horizon and clay loam in the Cg horizon (Table 1). pH in $H_2O(1:2.5)$ decreases with depth (Table 2). The decrease in pH is consistent with the increase in sulphate. The acid formed in the A horizon was probably brought down to the lower horizon. Higher pH near the surface may be also due to more water being available in A horizon than in the lower part of the profile. The decrease in pH results in the release of more aluminium into the solution (Table 2). The increase in acidity is subsequently followed by the increase of lime requirement with depth.

The presence of a high amount of K in the A horizon is probably due to the presence of jarosite which is yellow in colour (Fig. 2). Potassium decreases downward because jarosite

does not form below ground water table. The increase of sodium and magnesium with depth is probably due to the presence of montmorillonite and or the nature of the parent material. The high organic carbon content is attributed to the peaty nature of the Quaternary deposits; pieces of wood are frequently spotted in the Cg horizon (Fig. 2).

The CEC of the soil is high, above 16me/100g soil (Table 2). This is probably due to the presence of montmorillonite. Aluminium and hydrogen dominate the exchange sites at low pH. The presence of the excess amount of Al^{+++} and H^+ is undesirable for plant growth. The decrease of pH with depth is small, but the corresponding increase of lime requirement is significantly high. This shows that the soil is highly buffered. High buffering capacity is also shown by the high CEC.

The traditional practice of liming the soil under flooded conditions is currently the best form of management for acid sulphate soil. Growing crops which thrive under such conditions is a more logical step than trying to change the soil by artificial means. Under saturated conditions, the most suitable crop is paddy.

Flooding acid sulphate soil increases its pH significantly (Ting, 1977). The increase in pH is probably brought about by the reduction of hydrous ferric oxide. The pH increase could be due to organic matter which under reduced conditions leads to the accumulation of NH_4^+. Ferrous ions are released near the soil surface just above the pyritic substratum (Harmsen and Breemen, 1975). Ferrous ions and $SO^=$ formed in the substratum move upward by diffusion and mass transport. This explains the presence of Fe^{++} and $SO_4^=$-S in the upper horizon.

Genesis

The parent material of Linau Series has probably been subjected to successive lowering and raising of sea level in the Quaternary (Fig. 1). Evidence of eustatic rise and fall (due to fluctua-

TABLE 1

Physical properties of the soil samples

Horizon	Depth (cm)	Particle-size Distribution			
		C-Sand	F-Sand	Silt	Clay
A	0–20	2.19	48.19	26.3	23.5
(B)	20–50	3.95	50.2	28.8	21.6
Cg	>50	2.77	43.9	23.2	29.6

TABLE 2

Chemical properties of the soil samples.

Depth (cm)	pH (H₂O)	Exchangeable Cation (me/100g)					CEC me/100g	Base Sat(%)	%C	%Total Sulphur	%SO₄-S	%SO₄-S (H₂O)	Lime (ton/ha)
		Na	K	Ca	Mg	Al							
0–20	3.3	2.2	0.33	0.05	0.10	2.80	17.4	15.5	4.23	0.30	0.20	0.04	16.6
20–50	3.1	2.8	0.21	0.03	0.11	2.93	13.8	22.7	3.40	0.65	0.58	0.11	39.9
>50	2.8	4.4	0.19	0.02	0.32	5.30	15.4	31.6	3.20	2.50	1.25	0.70	45.3

tion of Pleistocene glaciation) of sea level in Peninsular Malaysia are recorded in the numerous drowned mangrove swamps, raised beaches, the prograding stream pattern in the continental shelf (Haile, 1970) and punch cores and foraminiferal data (Biswas, 1973). Further evidence of sea level rise is seen in the presence of wave-cut notches and marine beach deposits around the isolated hill of Bt. Kriang, Kedah, which was once probably an offshore rockly islet (Tjia, 1973). It is estimated that the lowest Quaternary sea level was probably about 100 m below and the highest was probably about 40 m above the present one.

When sea level was at its maximum, most of the lowland areas (particularly those of Kuala Linggi) where the present acid sulphate soils mostly occur, were submerged (Fig. 1). These submerged deposits are dominantly clay and sandy clay with intercalated layers of sand and peat (Stauffer, 1973), providing evidence of the existence of both marine and terrestrial deposits. Such a condition was conducive for the accumulation of iron and sulphate, which in reduction resulted in the formation of pyrite when sea level dropped and the deposits were frequently flooded with brackish water. Organic matter provided by 'gelam' and 'nipah' palm helped in the reduction of Fe^{+++} and $SO_4^=$. The presence of a high amount of bases, especially those of Na and Mg, under slow leaching (lowlying areas) resulted in the formation of montmorillonite.

CONCLUSION

The study of acid sulphate soil from Kuala Linggi, Melaka, indicates the presence of montmorillonite, kaolinite, illite, chlorite and pyrite. The pH of the soil is less than 3.5 and the CEC is greater than 16me/100g soil. Total sulphur, $SO_4^=$-S and water soluble $SO_4^=$-S increase with depth.

The presence of montmorillonite and illite followed by high CEC, shows that the soil has great agricultural potential if it was not for the presence of pyrite. Liming is only a short term

solution. The subsequent oxidation of pyrite will eventually cause the soil to revert to unfavourable conditions for plant growth. Keeping the soil under anaerobic condition all the time is probably a logical practice under the present circumstances, even though the choice of crops is limited.

REFERENCES

ALLISON, L.E. (1965): "Determination of Organic Carbon by Walkey-Black method", Methods of Soil Analysis. (Ed.) Black C. A. *Am. Soc. Agro.* **9**. 1367–1378.

BISWAS, B. (1973): Quaternary Changes in Sea-level in South China Sea. *Bull. geol. Soc. Malays.* **6**, 229–256.

BREEMEN, N. (1975): Acidification and deacidification of coastal plain soils as a result of periodic flooding. *Proc. Soil Sci. Soc. Am.* **39**, 1153–1157.

BREEMEN, N. and HARMSEN, K. (1975): Translocation of iron in acid sulphate soil:I. Soil morphology, and the chemistry and mineralogy of iron in chronosequence of acid sulphate soils. *Proc. Soil Sci. Soc. Am.* **39**, 1140–1148.

CHAPMAN, H.D. (1965): "Determination of cation exchange capacity". Methods of Soil Analysis. (Ed.) Black C.A. *Am. Soc. Agro.* **9**, 891–900.

CHOW, W.T. (1968): A preliminary study of acid sulphate soils in West Malaysia. Proc. 3rd. Malaysian Soil Conf. Malaysian Society of Soil Science, Kuala Lumpur. 51–58.

DALE, W.L. (1963): Surface temperature of Malaya. *J. trop. Geogr.* **17**, 57–71.

DAY, P.R. (1975): Particle fractionation and particle-size analysis. Methods of Soil Analysis. (Ed.) Black C. A. *Am. Soc. Agro.* **9**, 545–566.

DUNN, L.E. (1943): Lime requirement of soil by means of titration curve. *Soil Sci.* **56,** 341–351.

FITZPATRICK, R.W. and ROUX, J.L. (1977): Mineralogy and chemistry of a Transvaal Black Clay Toposequence. *J. Soil Sci.* **29,** 165–179.

GOPINATHAN, B., PARAMANATHAN, S., NORDIN DAUD, LIM, S.P., KALSI, M.S. and ESWARAN, H. (1977): Characteristics of some Peninsular Malaysian Soils. CLAMATROPS Conf. Malaysian Society of Soil Science, Kuala Lumpur.

HAILE, N.S. (1970): Radiocarbon dates of Holocene emergence and submergence in the Tembelau and Bunguran islands, Sunda Shelf, Indonesia. *Geol. Soc. Malaysia Bull.* **3,** 135–137.

HARMSEN, K. and BREEMEN, N. (1975): Translocation of iron in acid sulphate soils : II. Production and diffusion of dissolved ferrous iron. *Proc. Soil Sci. Soc. Am.* **39,** 1148–1153.

HESSE, P.R. (1971): A Text Book of Soil Chemical Analysis. London. John Murray Ltd.

JACKSON, M.L. (1967): Soil Chemical Analysis. New Delhi. Prentice Hall of India, Pte. Ltd.

KANAPATHY, K. (1966): Acid swamps and problems in their utilization. Paper presented at 2nd Malaysian Soil Conference. Ministry of Agriculture, Malaysia.

KANAPATHY, K. (1976): Acid Sulphate Soils. Soil and Analylitical Services. *Min. Agric. Malays. Bull* 6. Kuala Lumpur.

LAW, W.M. and SELVADURAI, K. (1968): The 1968 reconnaissance soil map of Malaya. Proc. 3rd Malaysian Soil Conf. Malaysian Society of Soil Science, Kuala Lumpur. 229–239.

LAW, W.M. and TAN, M.H. (1975): Range and properties of Peninsular Malaysia soil. Paper presented at the 3rd ASEAN Soil Conf. Ministry of Agriculture, Kuala Lumpur.

MACLEAN, E.O. (1965): "Determination of exchangeable aluminium." Methods of Soil Analysis. (Ed.) Black C.A. *Am. Soc. Agro.* **9,** 978–997.

PARAMANATHAN, S. and LAW, Y.M. (1974): The taxonomy of Peninsular Malaysian soils – an approximation. Paper presented at the Symposium: Class. Man. Soils in Malaysia, Malaysian Society of Soil Science, Kuala Lumpur.

SOORYANARAYANA, V. (1976): A preliminary study of the soils of Melaka. *Geographica.* **1:** 48–68.

STAUFFER, P.H. (1973): "Cenozoic." Geology of the Malay Peninsula. (Ed.) Gobbett D.J. and Hutchison C.S. New York. Wiley & Sons. pp: 143–176.

TING, C.C. (1977): Some physico-chemical changes on flooding acid sulphate soils. Paper presented at the Annual Fund. Res. Div. Conf. MARDI, Serdang.

TJIA, H.D. (1973): "Geomorphology". Geology of the Malay Peninsula. (Ed.) Gobbett D.J. and Hutchison C.S. New York. Wiley & Sons. pp: 13–24.

TSUNEO, T. (1958): Identification of clay mineral from acid soil. *J. Soil Sci.* **9(5):** 141–147.

WHITTIG, L.D. (1965): X-ray diffraction technique for mineral identification and mineralogical composition. Methods of Soil Analysis. (Ed.) Black C.A. *Am. Soc. Agro.* **9:** 671–697.