

SOME NOTES ON SOIL GENESIS IN PULAU PETAK ¹

Tejoyuwono Notohadiprawiro

GENERAL

So far, no studies have been attempted specifically on the genesis of the soils of Pulau Petak. The oldest report is from Polak in 1933, but this only treated the peat, as part of a regional study on peats covering Sumatra, Kalimantan and Java.

The factors of soil formation in Pulau Petak and the origin of the acid conditions in the mineral subsoils have been discussed to a certain extent in the soil survey report of Van Wijk (1951). In a more recent paper of Driessen & Soepraptohardjo (1974) one chapter is devoted to the occurrence, formation, characteristics and reclamation of acid sulphate soils found in Sumatra, Kalimantan and parts of Java. In this report, the Pulau Petak area is presented as a case study.

Postulations on the genesis of soils in Pulau Petak and similar areas can be found scattered in the many soil survey and mapping reports of UGM on tidal swamp areas of Kalimantan and those of IPB on similar areas of Sumatra. The regional geological history of Kalimantan, including the Pulau Petak Delta, is described by Van Bemmelen (1949).

Geological History

In broad terms the geological history of the Pulau Petak Delta may be represented by a series of physiographic changes occurring in Kalimantan since the Lower Tertiary (Van Bemmelen, 1949).

During the Lower Tertiary the present area of Pulau Petak was a sea. By the end of the Lower Tertiary the regression of the sea started and continued during the Upper Tertiary. This was a period of strong sedimentation. By the end of the Upper Tertiary the Pulau Petak Delta was part of a large depression formed between the lowlands in the west and the range of non-volcanic uplift in the east. The uplift effected a compressive settling towards the central axis of the depression. In the Pleistocene the depression

¹ LAWOO Mission Report. No. 18. Research on Acid Sulphate Soils in the Humid Tropics. Wageningen. 1989

became an inland basin, compressed by the gravitational folding from the east. The Barito Basin then came into existence.

According to this history the basement formation of the Pulau Petak Delta is a sea bottom. It has since been covered by marine sediments which aggraded from a marine flat into a terrestrial plain. The aggradation in a terrestrial environment continued during the Lower Pleistocene with an accelerated rate by erosion material from the surrounding higher lying land. A renewed cycle of sedimentation occurred during the later part of the Pleistocene and continued into the Holocene when an increased compression from the east transformed the depression into an inland basin. This basin has become the main debouchment area of the present big rivers of the Barito and the Kapuas.

The Occurrence of Pyrite

Except for a few rare instances, pyrite is always an authogenic mineral because detrital pyrite is chemically and physically very unstable (Berner, 1971). There are three typical iron minerals that occur in reducing environments, namely siderite (FeCO_3), pyrite (FeS_2) and magnetite (Fe_3O_4 or $\text{FeO} \cdot \text{Fe}_2\text{O}_3$). Which of these minerals will be the principal constituent is determined by the relative abundance of total carbonate to total sulphur. A high total carbonate content (IM) and a low content in total sulphur (10^{-6}M) are most conducive to the formation of siderite. In all cases of siderite formation, the pH should be higher than 6. The formation of pyrite is enhanced by a smaller amount of dissolved carbonate and a higher amount of dissolved sulphur. Pyrite may be formed under a high pH of around 10 when it is associated with very low Eh of about -0.4. At the other limit of conditions for the formation pyrite is a pH of 3 and Eh of 0.1. In all cases of pyrite formation the Eh is less than 0.2 volt. Magnetite is the principal iron mineral when both carbonate and sulphur contents are low (Krauskopf, 1979).

Fig. 1 shows the Eh - pS^{2-} diagram for different iron minerals according to Berner (1971). Pyrite is the stable iron mineral under low Eh and low pS^{2-} . Measurements of natural sulphidic marine sediments fall closely along the dashed line drawn across the pyrite compartment. It is true that an environment where pyrite is the stable iron mineral is characteristic of fine-grained marine sediments rich in organic matter, where bacterial sulphate reduction is active. But the diagram in Fig. 1 suggest further that pyrite is not an exclusive product of a marine environment.

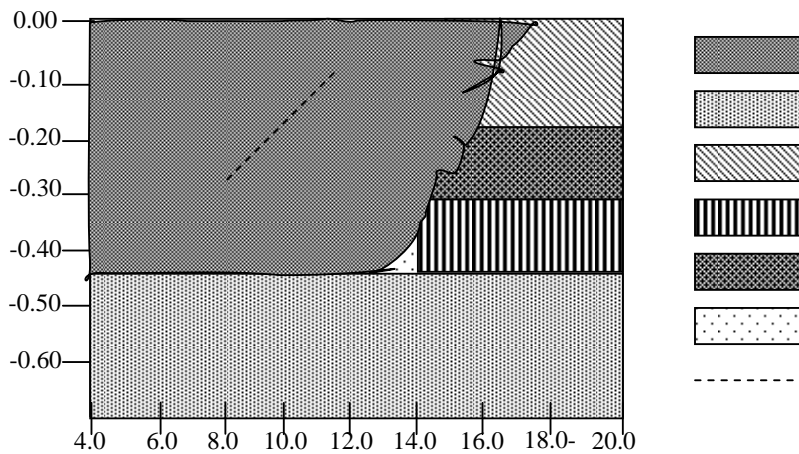


Fig. 1. Eh- pS^{2-} diagram for pyrite, pyrrhotite, hematite, magnetite and siderite ($pH=7.37$; $\log P_{CO_2} = 2.40$; $T=25^\circ C$; $P_{total}= 1 \text{ atm.}$)

Pyrite forms as a result of the reaction of dissolved H_2S with iron minerals. The two major sources of H_2S are microbiologically-reduced sulphate and the decomposed organic sulphur compounds derived from dead organisms. Many lines of evidence have proven that in most sediments dissolved sulphate is a far more important source. This is especially true in marine sediments. Fresh-water sediments that are high in H_2S and/or pyrite, generally occur also in waters high in dissolved sulphate (Berner, 1971).

There are three principal factors that limit the amount of pyrite or any other iron sulphide which may form in a sediment. They are (i) the concentration and reactivity of iron compounds (ii), the availability of dissolved sulphate, and (iii) the concentration of metabolizable organic matter which is utilized by important limiting factor is deficiency in metabolizable organic matter. All marine sediments originally contain some reactive iron compounds and dissolved sulphate. However, many do not contain metabolizable organic matter and as a consequence no H_2S or pyrite forms either (Berner, 1971).

On the source of dissolved sulphate, there are two contradicting opinions in literature. According to Dent (1986), this source will be sea water or brackish tidal water, although occasionally pyrite is associated with sulphate-rich groundwater. Horne (1978) approximately 7.7% while the range in river and lake waters is 8.0-14.9%. The lower limit was found in South America and the upper limit is from Japan. The world and Asian averages in fresh water are 12.1 and 13.0%, respectively. The figures of Horne suggest that fresh waters are more important as sources of sulphate than sea water.

Dent (1986) further states that flushing by tidal movement is an essential condition for the formation of pyrite in removing bicarbonate, renewing sulphate and supplying the limited amount of oxygen that appears to be necessary for pyrite formation. These conditions, in addition to the availability of metabolizable organic matter and active iron compounds, may exist until far behind the brackish-water line like in Kalimantan. In the Pulau Petak Delta it may reach some hundred kilometers inland. Apparently, the current theory of pyrite being an exclusive formation in a marine environment is not as solid as one may think.

Jarosite mottles

Jarosite is one of the products of acid sulphate weathering. Together with (low) pH, jarosite mottles are used as a diagnostic criterion for classifying acid sulphate soils (Soil Survey Staff, 1975, 1987). It forms when pyrite-iron becomes fully oxidized in an acid environment (Ralph, 1979; Van Breemen, 1982; Dent, 1986).

Potassium-jarosite is the most common form, with the general chemical formula of $\text{KFe}_3(\text{SO}_4)_2(\text{OH})_6$. In some cases Na and H_3O may replace K, forming-natron jarosite and hydronium-jarosite, respectively. Al may substitute for Fe (Van Breemen, 1982; Dent, 1986).

As the mineral is stable at lower pH, it precipitates in acid waters or effluents of estuaries, forming straw-yellow mottles. With increasing pH, jarosite becomes metastable and is transformed into goethite, FeO.OH . ultimately it hydrolyzes to ironoxide (Dent, 1986). This hydrolysis is enhanced by leaching, but jarosite sometimes persists for a long time at pH above 4 (Verhoeven cit. Van Breemen, 1982).

This author has investigated jarosite mottles from wet ricefield bunds in the main station of the Barambai Test Farm of the Gadjah Mada University in South Kalimantan. The mottles formed a continuous band between 20 and 60 cm below the rim of the bunds. Its lower boundary was a few centimeters above the surface of the inundating water on the ricefield. The lower boundary was clear with an irregular topography, while the upper boundary was clear to abrupt with a rather smooth topography. The jarosite band consisted of two distinct layers, a brown upper layer and a pale-yellow lower layer. The two layers were analyzed separately and the results are presented in Table 1. The first layer has a lower pH and organic-carbon content and is extremely lower in water-soluble sulphate content as compared to the second layer. Its content in acid-soluble iron, however, is

higher. Free iron and extractable and acid-soluble Al are practically the same in both layers.

Table 1 Chemical properties of jarosite bands in Barambai, South Kalimantan

Layer/ colour	pH-H ₂ O	pH-KCl	Organic carbon %	Water- soluble sulphate ppm SO ₄	Free iron ppm Fe ₂ O ₃	Acid- soluble iron % Fe ₂ O ₃	Extr. aluminum ppm Al ₂ O ₃	Acid- soluble aluminum % Al ₂ O ₃
Upper/ brown	2.5	2.4	1.7	5030	110	2.8	1620	0.2
Lower/ Pale- yellow	3.4	2.6	2.2	21250	115	1.7	1700	0.2

The pH of the first layer suggests the occurrence of reversible reactions of ferric iron precipitation and resolubilization, which have a buffering effect by maintaining the pH in the range of 2.0 - 2.2 (Duncan & Walden cit. Ralph, 1979). It has been assumed that jarosite, being a low-pH mineral, is decomposable in water of near-neutral pH. Therefore, the water-soluble sulphate must include sulphate released from jarosite. Acid-soluble iron and aluminium include free iron and extractable aluminum respectively. The difference between acid-soluble iron and free iron may represent iron in complex compounds. Al in complex compounds may be represented by the difference between acid-soluble Al and extractable Al.

Converting into epm, the first layer contains 105 epm water-soluble sulphate, 4 epm Fe³⁺ as free iron. The acid-soluble iron, and 1050 epm Fe³⁺ in complex compounds. The second layer contains respectively in the same order 440, 4,640, and 640 epm. The stoichiometric combination of Fe³⁺ SO₄²⁻ jarosite is 1.5 to 1. The stoichiometry of water-soluble sulphate and complex iron in the second layer comes very close to that in jarosite, namely 1.4 to 1. In the first layer, however, there is an extreme excess of complex iron. It may be concluded that in this layer the proportion of jarosite is very small. The brown colour of this layer and the pale-yellow colour of the underlying band may support the proposed chemistry.

The high acidity of the upper band of the mottles is most likely caused by the high Al content in association with a decrease in organic matter content which lowers the buffering capacity.

The distribution of water-soluble sulphate in the two layers clearly indicates leaching of sulphate from the upper band. This means that a surface layer of a soil which is now free of acid sulphate material, may have contained this material previously. But in the course of time it may have leached-out. Van Wijk (1951) did observe a similar leaching of toxic compounds from plant ridges which are constructed by piling-up (acid) subsoil in the tidal swamps of south and Central Kalimantan. In digging channels (andils) the people often build ridges (tembokans) from acid subsoil to be planted with palawija. The planting, however, has to wait until the harmful compounds are sufficiently washed out by rain.

These facts show that soils that are now classified as non-acid sulphate soils, may have been real acid sulphate soils previously. The flushing power of very active tidal movement, in addition to the heavy rains falling onto the land, should not be underestimated, especially when assisted by a network of channels in the soils left by dead or decaying roots, or by a high porosity due to incorporated peat material.

References

- Berner, R.A. 1971. Principles of chemical sedimentology. McGraw-Hill Book Company. New York, 240 pp.
- Dent, D. 1986. Acid sulphate soils: a baseline for research and development. ILRI Publ. 39. Wageningen, 204 pp.
- Driessen, P.M. & M. Soepraptohardjo. 1974. Soils for agricultural expansion in Indonesia. Soil Res. Inst., Bogor. Bull. 1. 63 pp.
- Horne, R.A. 1978. The chemistry of our environment. John Wiley & Sons. New York. 869 pp.
- Krauskopf, K.B. 1979. Introduction to geochemistry. Second Edition. McGraw-Hill Kogakusha, Ltd. Tokyo. 617 pp.
- Polak, B. 1950. Occurrence and fertility of tropical peat soils in Indonesia. contr. Gen. Agr. Res. Sta. No. 104. 6 pp.
- Ralph, B.J. 1979. Oxidation reactions in the sulphur cycle. In: P.A. Trudinger & D.J. Swains (Eds), Biogeochemical cycling of mineral-forming elements. Ch. 6.3; p. 369-400. Elsevier Studies in Environmental Science 3. Elsevier Scientific Publishing Company. Amsterdam.
- Soil Survey Staff. 1975. Soil taxonomy. SCS-USDA Agriculture Handbook No. 436. 754 pp.
- Soil Survey Staff. 1987. Keys to soil taxonomy. SMSS Technical Monograph No. 6. 280 pp.
- Van Bemmelen, R.W. 1949. The geology of Indonesia. Vol. IA. Government Printing Office. The Hague. 732 pp.

Van Breemen, N. 1982. Genesis, morphology and classification of acid sulphate soils in coastal plains. In: J.A. Kittrick, D.S. Fanning, and L.R. Hossner (eds), Acid sulfate weathering. SSSA Spec. Publ. No. 10. Ch. 6; p. 95-108. Madison.

Van Wijk, C.L. 1951. Soil survey of the tidal swamps of South Borneo in connection with the agricultural possibilities. Contr. Gen. Agr. Res. Sta. No. 123. 49 pp.

«»