

Pyritization of coastal sediments in the Kelantan Plains as evidence for the sea level rise in the Malay Peninsula during the Holocene

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Abstract: It has been known for years that about 4300 years ago much of the Malay Peninsula was inundated by seawater due the rise of sea level 3-5 m above the present level. Many of the geological features observed throughout the country have been used as evidences to support the notion. As such, during this period of the history of the peninsula, much of the low-lying areas along the coastal plains were pyritized, with some sediments at specific locations having pyrite content of 2-3%. This paper explains how we can use the pyritization of the coastal plains to provide further evidence for the rise of sea level in the peninsula. To do that, the study on the phenomenon of the pyritization in the Kelantan Plains was re-visited and checked in detail. Based on the distribution of pyrite in the sediments of the Kelantan Plains, the plausible shoreline during the height of the sea level rise was delineated. Hence, the presence of pyrite in the sediments mineralized when the plains were inundated by seawater can be used as yet another geological evidence for the rise in sea level in the Malay Peninsula during the Holocene.

Keywords: acid sulfate soil, Malay Peninsula, pyrite, sea level rise

INTRODUCTION

The geology of the Malay Peninsula is very complex. Hutchison & Tan (2009) had summarized the geology of the peninsula in great detail. Besides this, the geological features of the area have also been extensively studied and subsequently published in journals and books as well as discussed in conferences and meetings in Malaysia and abroad. Based on the available information so far, it is generally believed that the Malay Peninsula is tectonically stable since Tertiary (Gobbett, 1973). This notion was shared and confirmed by Woodroffe (2000), Hutchison (2004) and Hutchison (2009) who believed that the South China Sea and Sunda Shelf have been tectonically stable within the last 2 million years. These findings are necessary if we want to explain the phenomenon of sea level rise in Southeast Asia during the Holocene.

Tjia *et al.* (1977) believed that between 3000 and 6000 BP the sea level in Southeast Asia had risen 3-5 m above the present level. Recently, Tjia (2012) confirmed from various geological evidences including the presence of wave-cut notches and the occurrences of sandy beaches ridges in the coastal regions that the highest sea level rise in Southeast Asia during the Holocene was reached some 4,300 BP. This notion was consistent/supported by the study of Shamshuddin (1990) and Roslan *et al.* (2010) on soils occurring in the raised beach ridges of the Kelantan Plains. That means much of the low-lying land in Southeast Asia was inundated by seawater when the sea was its highest level (Figure 1). This paper explains the occurrence of pyrite in the coastal sediments of the Kelantan Plains can be used as evidence for the sea level rise in the Malay Peninsula during the Holocene.

Some explanations on the sea level rise and its effects on the sediments along the coastal plains in Southeast Asia were given by Shamshuddin *et al.* (2014) and Shamshuddin (2014). Their findings are in close agreement with that of Pons *et al.* (1982) who believed that within 1000 years after the last glacier, sea level in the region had risen a few meters above the present level. Additionally, Woodroffe & Horton (2005) who later studied the coastal sediments in Thailand found that the sea level there could have risen about 1.2 m above the present level.

FORMATION OF PEDOGENIC PYRITE IN COASTAL SEDIMENTS

The mineralization of pyrite in the coastal sediments in the Malay Peninsula required the presence of SO_4^{2-} , which

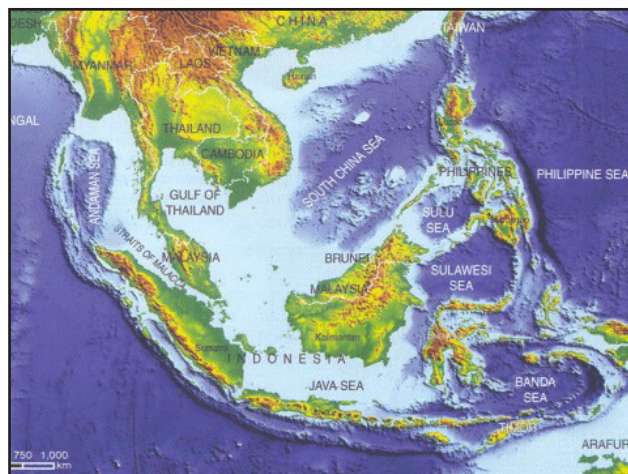
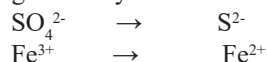
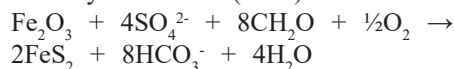


Figure 1: A map of Southeast Asia (Courtesy of the Geological Society of Malaysia).

was supplied mostly by seawater. It needs a lot of sulfate ions; otherwise, we cannot explain the high amount of pyrite present in some coastal sediments in the peninsula. The much needed sulfate ions could only have come from the sea water when the coastal sediments were inundated thousands of years ago. Iron required for the pyritization process was naturally present in the sediments themselves. Under anaerobic condition, both ions were subjected to reduction process, which was expedited by special microorganisms living naturally in the submerged sediments:



Eventually, the Fe^{2+} and S^{2-} in the sediments reacted to form FeS_2 , the so-called pyrite. The overall reaction as described by Pons *et al.* (1982) is as follows:



As mentioned above, the reduction of SO_4^{2-} requires the help of microorganism which thrives under the condition. An example of such microbe that feeds on the organic matter present in the sediments is *Desulfovibrio desulfuricans* (Bloomfield & Coulter, 1973). This process went on without interruption until sulfate ions were no longer available for the reaction, which means after the sea had receded. The pyrite so formed remained stable in the sediments provided that it was continuously under submerged condition. Fresh pyrite crystal as shown in Figure 2 have been found in the sediments some distances away from the present coastline in the peninsula (Shamshuddin & Auxtero, 1991; Shamshuddin *et al.*, 2004; Shamshuddin *et al.*, 2014). Shamshuddin (2006) reported that some coastal sediments in the peninsula contained up to 2-3% pyrite, which could be the result of thousands of years of pyritization process.

Noordin (1980) had proven conclusively that the pedogenic pyrite found in the coastal sediments of the Malay Peninsula was related to the sea. In the study of the acid sulfate soils located in the West Coast states of the

peninsula, Noordin (1980) identified remnants of living organisms usually associated with the seabed, such as diatoms (Figure 3).

Further evidence for the formation of pedogenic pyrite being related to the sea is given in Figure 4. In this figure, a soil profile classified as an acid sulfate soil having pyrite in it is presented as an illustration (Shamshuddin, 2014). The color of the soil profile at the depth below 50 cm was bluish, which was indicative of its origin being related to the sea.

In Kedah-Perlis Plains, which was also located in the West Coast of the peninsula, pyrite was found to occur in some soils planted with rice a few kilometers away from the present coastline (Azmi, 1982). That means part of the areas in the plains would have been inundated by seawater some times in the past in order for the pyrite to be mineralized in the sediments.

PYRITIZATION OF THE KELANTAN PLAINS

Enio *et al.* (2011) studied in great detail the acid sulfate soils in the Kelantan Plains. During the field work for this study, soil samples believed to contain pyrite were collected, placed in plastic bags and brought to the

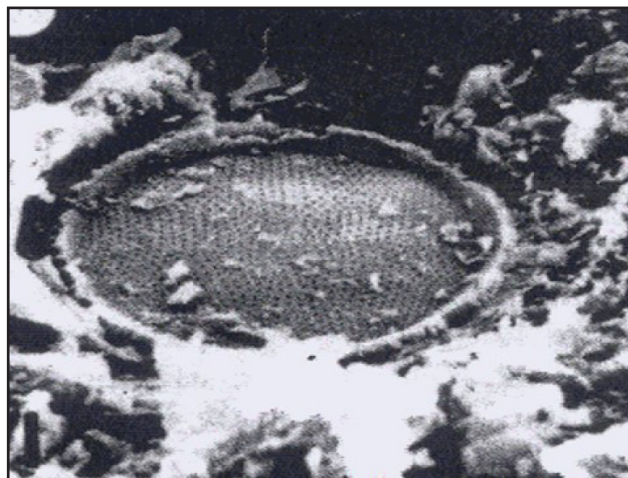


Figure 3: A SEM micrograph of a diatom present in the coastal sediments of Perak, Malaysia (Courtesy of Wan Noordin Wan Daud).

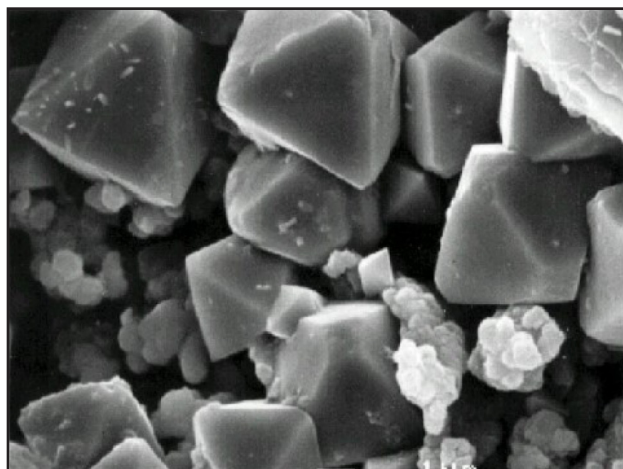


Figure 2: Pyrite crystals found in the coastal sediments of the Malay Peninsula (Shamshuddin *et al.*, 2004).

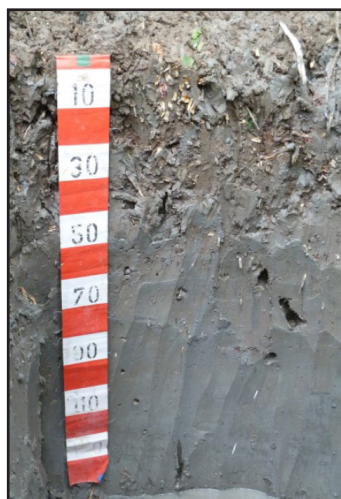
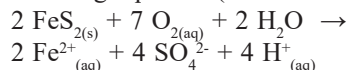


Figure 4: A profile of an acid sulfate soil in the peninsula containing pyrite (Shamshuddin, 2014).

laboratory in Universiti Putra Malaysia for analyses. Using SEM, the presence of pyrite in the sediments was identified and confirmed (Figure 5). Energy dispersive X-ray of the crystals indicated the presence of Fe and S, which was consistent with the formula of pyrite (FeS₂). Note that this pyrite is almost always associated with the presence of its straw yellow counterpart, jarosite [KFe₃(SO₄)₂(OH)₆]. The latter is formed when the pyrite is oxidized due to exposure to the atmospheric condition and the reaction is given by the following equation (van Breemen, 1976):



In this kind of soil profile, jarosite usually occurs in the topsoil or even sometimes in the surface horizon, while pyrite is found under reducing conditions in the area below the water table. That means whenever there is jarosite, there certainly be pyrite occurring below it. Hence, we can say that the presence of jarosite in a soil profile is indicative of the presence of pyrite below it, if not in the present time, it would certainly be in the past.

Based on the afore mentioned argument, Enio *et al.* (2011) set to delineate the areas in the Kelantan Plains (located in east coast state of the peninsula) where pyrite occurred or could have occurred during the history of their existence from those that were free of pyrite. The line separating the areas having pyrite and those without is shown in Figure 6. The researchers believed that the line could represent the shoreline when the sea was at its highest level during the Holocene, which according to Tjia *et al.* (1977) and Tjia (2012) was probably 3-5 m above the present level. If the above argument is true and/or accepted by the scientific fraternity, we can then assume that the pyritization of the Kelantan Plains as yet another evidence for sea level rise during the Holocene. This notion is consistent with the study of Azmi (1982) who believed that much of the rice fields in the Kedah-Perlis Plains was once under the sea as evidenced by the sporadic distribution of pyrite in their top- and subsoil.

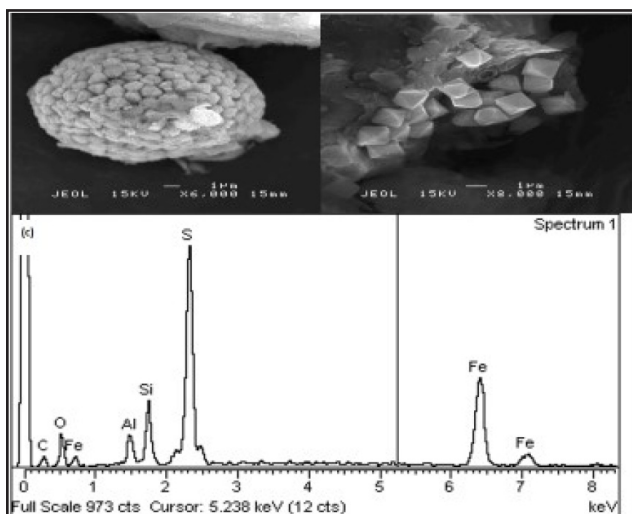


Figure 5: A SEM micrograph showing fresh pyrite (Enio *et al.*, 2001).

Soils in Malaysia containing pyrite and/or jarosite with pH of < 3.5 are classified as acid sulfate soils (Shamshuddin, 2006; Shamshuddin *et al.*, 2014; Shamshuddin, 2014). In the Malay Peninsula, the soils are sporadically distributed along the coastal plains, especially in the West Coast (Figure 7). In the map shown in Figure 7, produced by Department of Agriculture, Peninsular Malaysia (DOA, 2015), three soil series or associations classified as acid sulfate soils (shaded dark) are found in the peninsula. There is no indication in the map of the presence of acid sulfate soils in the Kelantan Plains, which is proven incorrect by the findings of the studies of Shamshuddin (2006) and Enio *et al.* (2011). These researchers had concluded beyond any

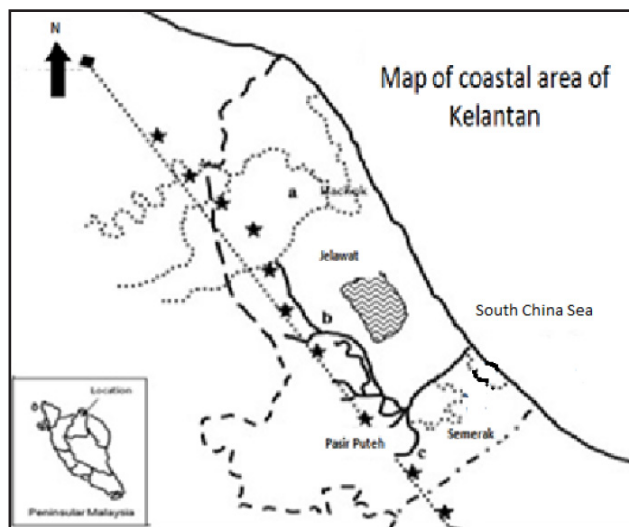


Figure 6: Map showing the predicted coastline in the Kelantan Plains, Malaysia, when the sea level was 3-5 m above the present level (Enio *et al.*, 2011).

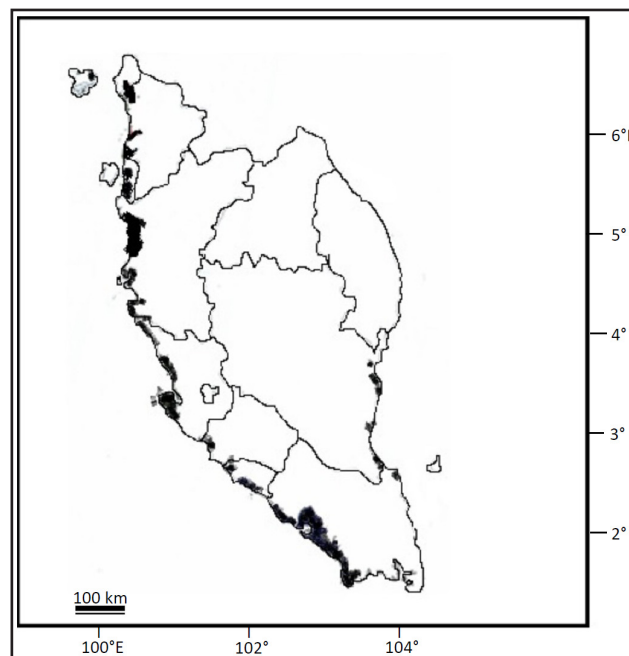


Figure 7: Map of the Malay Peninsula showing the distribution of acid sulfate soils [Modified from Department of Agriculture, Peninsular Malaysia (DOA, 2015)].

doubt that pyrite and/or jarosite did occur in the sediments of the Kelantan Coastal Plains; hence, acid sulfate soils are present in the areas in question.

This paper has proven that it is so. During the field work of a study conducted by Shazana *et al.* (2013), yellowish jarosite was clearly spotted in the soil surface at Tok Bali in the Kelantan Plains (Figure 8). The pH of the topsoil at that particular spot was very low and it was even lower in the subsoil. It was almost certain that pyrite occurred in the subsoil in the zone which was always submerged under water throughout the year. In this layer, it was found that the S content was very high, which was consistent with the presence of pyrite. Hence, it is for certain that acid sulfate soils are present in the Kelantan Plains.

In the West Coast of the Malay Peninsula, some acid sulfate soils were ameliorated via various agronomic practices for the cultivation of oil palm with success (Poon, 1977; Poon & Bloomfield, 1977). The soils are also successfully being utilized for rice cultivation (Shamshuddin *et al.*, 2014; Shamshuddin *et al.*, 2017). The afore-mentioned papers had explained in detail on the formation of acid sulfate soils in the areas under investigation.

CONCLUSION

Some 4300 years ago much of the Malay Peninsula was inundated with seawater due the rise of sea level 3-5 m above the present one. Many geological evidences have been put forward to support the notion of the sea level rise. As such, during this period of the history of the peninsula, much of the low-lying areas along its coastal plains were pyritized. This phenomenon of pyritization of the Kelantan Plains was studied in detail. Based on the distribution of the pedogenic pyrite in the sediments of the plains, the plausible shoreline during the height of the sea level rise was delineated. Hence, the presence of this pyrite in the sediments can be used as yet another geological evidence to support the belief of the rise in sea level during the Holocene.



Figure 8: Jarosite occurring in the topsoil of the Kelantan Plains.

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