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Thorium distribution in the soils of Peninsular Malaysia and its implications for Th resource estimation

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ABSTRACT

As the national electricity consumption peaked over the years, and the reserves of fossil fuels are becoming scarce, interest in thorium fuel-based nuclear energy generation as an alternative energy source for Malaysia is renewed. This paper provides a preliminary investigation of thorium (Th) availability in Peninsular Malaysia. The study is based on assessment of Th contents in soil. Indicated by massive and fertile Th resources associated with granitic belts, 4 series of regional on-ground explorations are implemented in Peninsular Malaysia to obtain the baseline data of Th availability. The geological settings of Th prospect areas and the result of statistical analyses of Th data are discussed. The isoconcentration mapping of Th is developed and the Th prospect areas in Peninsular Malaysia are highlighted. The possibility, availability, production trends and economic issues of Th recovery from tin by-products and heavy mineral products, as well as the potential of black sand placer deposit as a Th resource in Peninsular Malaysia are also discussed.

1. Introduction

Electricity generation in Peninsular Malaysia depends heavily on nonrenewable resources. Natural gas and coal remained the prime fuel sources for electricity generation, each representing 43.7% of the total fuel sources in Peninsular Malaysia (Malaysia Energy Commission, 2014). This is followed by hydropower at 8.7%. The remaining 4% are attributed to the fuel oil, diesel, biomass and other small scale sources (Malaysia Energy Commission, 2014). However, based on long term consumption and production trend of natural gas, the current reserves would last for 24 more years if no new gas fields are discovered (Abdul Rahim and Liwan, 2012). Meanwhile, as the local coal productions are insufficient (2,893,962 metric tonnes) and the consumption amounted to 23,899,128 metric tonnes per year (Malaysia Energy Commission, 2014), most of the coal resources are now imported from countries such as Indonesia, Australia, South Africa and China (Basri et al., 2015). The major challenge of utilization of coal is the capability to conserve the imported supplies as the coal's global price is totally dependent on the suppliers and the raw supplies are limited due to global demands.

Driven by these concerns and other factors such as climate change, security of energy supply and energy mix diversification as well as volatile fossil fuel prices, the government had indicated in the 10th Malaysia Plan (2011–2015), their readiness to incorporate nuclear power as an alternative in their future power expansion (EPU, 2014). Issues of huge current market of U supplies to meet the global energy demands (OECD-NEA, 2014), economic and illegal diversion of nuclear material factors, and the need to secure the long-term nuclear fuel resources as a replacement for the conventional U fuels, have caused many countries explore their Th reserves (IAEA, 1987). In addition, growing awareness of the global depletion of U reserves have also turned Th as an ideal replacement for U-based fuel (Ashley et al., 2015).

For this reason, a preliminary investigation of Th availability in Peninsular Malaysia is conducted. The aim of the study is to establish the baseline data of Th resources based on assessment of Th in soils, as well as from heavy mineral products and other potential sources in Peninsular Malaysia. The established baseline data from this study are essential for identification of Th prospect areas in further Th explorations across the Peninsular Malaysia.

The main approach used in this study is based on e.g., assessment of Th contents in soils. Soil is defined as a mixture of unconsolidated mineral or organic matter on the surface layer of the earth called pedosphere (Henry, 1990). They form due to the weathering processes under the influence of genetic and environmental factors of parent materials or bedrocks (Henry, 1990; Department of Agriculture Peninsular Malaysia, 1993). Generally, soils that formed from their underlying bedrocks are called the sedentary or residual soils. Meanwhile, soils that developed at distant locations from their parent materials are called the

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alluvial or transported soils. Under tropical climate and intense weathering process, sedentary soil is a good indicator for mineral in exploration and prospecting of valuable minerals (Evans, 1993; IAEA, 2003). By only a few ppm of concentration difference, concentrations of U, Th and K in the sedentary soils and their underlying bedrocks are comparable (Dickson and Scott, 1997). Hence, Th content in the sedentary soils can be applied as a direct indicator of Th discoverability in underlying rocks. The importance of sedentary soils has been recognised for a long time in mineral explorations and widely applied by the geologist in geochemical prospecting techniques (Hawkes, 1957).

2. Geological background and soil distribution of Peninsular Malaysia

In order to assess the availability of Th resources in Peninsular Malaysia, the geological settings and soil framework of Peninsular Malaysia are addressed. Peninsular Malaysia comprises two tectonic blocks, the Sibumasu block (Western region) and Sukhothai Arc (East Malaya block) which are separated by the Bentong-Raub suture zone. These blocks assembled in the Late Triassic and formed an integral part of Sundaland continental core of South East Asian (Metcalfe, 2013). The Sibumasu block is derived from the North-West Australia Gondwana block in the late Early Permian while, the Sukhothai Arc terrane (also referred the East Malaya block) is derived from the South China (Indochina) continental block during the Late Carboniferous-Early Permian (Metcalfe, 2013). The Sibumasu block is represented by the north-south extension belt called the Western Belt of Peninsular Malaysia or also referred 'The Main Range Granite'. Meanwhile, the Sukhothai Arc block is represented by the two north-south extension belts namely, the Central Belt and Eastern Belt (Hutchison and Tan, 2009).

Fig. 1 shows the distribution of geological background in Peninsular Malaysia while, the details of age of formations and estimated geological areas are shown in Table 1. The Central Belt is commonly associated with the Triassic marine siliciclastic rocks, volcaniclastic and limestones rocks; and minor occurrences of Permian marine shales, limestones, andesitic-rhyolitic volcanic rocks and granitic plutons. The Eastern Belt contains Carboniferous marine shales, sandstones and limited volcanic bodies; and occasional Quaternary deposits and granitic plutons. The western belt comprises massive granitic bodies; and few occurrences of Carboniferous, Silurian-Devonian and Ordovician phyllites, schists, sandstones and limestone rocks as well as volcanic rocks and marine shales rocks from Carboniferous (Hutchison and Tan, 2009). The Main Range Granite in the Western Belt is formed from the granite batholith series of Peninsular Thailand (Vijarnsorn and Fehrenbacher, 1975) and extends over the southern Peninsular Malaysia (Schwartz et al., 1995). According to Metcalfe (2013), >90% of the plutonic rocks in Peninsular Malaysia are classified as granite and widely distributed across the peninsula. The granitic rocks of Peninsular Malaysia can be subdivided into two types, S-type and I-type granites. The Western Belt granitoids are S-type granitoids while, the Central and Eastern Belts granitoids are both I-type granitoids. The occurrences of volcanic and volcaniclastic rocks in the Western Belt are rare. They occurs most frequently in the Central Belt and Eastern Belt.

In Peninsular Malaysia, the classification of soils is based on the USDA (United State Department of Agriculture) soil taxonomy system (Department of Agriculture Peninsular Malaysia, 1993). Soils in Peninsular Malaysia are characterised into 3 main groups; sedentary soils, alluvium soils and miscellaneous soils based on distinct differences in parent materials, type of formations and geomorphology. Fig. 2 shows the distribution of soil types while, Table 2 lists the details of soil classification in Peninsular Malaysia. Under tropical climate, deep and rapid weathering processes (i.e., heavy rain and intense heat), soils in Peninsular Malaysia have fully formed into mature soils (Wong, 1970; Department of Agriculture Peninsular Malaysia, 1993) and usually persists to great depths before reaching the solid bedrocks (Agocs and Paton, 1958). According to Department of Agriculture Peninsular Malaysia (1993), soil maturity is classified based on soil horizons or subsurface layers. Fully developed soils or mature soils normally tends to have more soil horizons, clearly defined and thick layers in their soil profile.

3. Favourable Th deposits and current world's Th reserves

Th is the second heaviest radioactive metallic element in the actinide series with atomic number 90 and naturally has 6 isotopes. 232Th has the longest life and is the most abundant. Th exists naturally as oxyphile and lithophile. They have an affinity to oxygen and considerably occur in the oxide and silicate minerals. However, Th also exists in the sulphide minerals or as native elements. In short, Th occurs predominantly as oxides, silicates and phosphates mineral, while in some cases it occurs as complex hydrous oxides and hydroxides, vanadate, molybdate, carbonates, sulphates, sulphate-carbonates, arsenates, selenites and tellurites. Th is also substantially associated with the organic compounds such as humus, coal, petroleum, bitumen and thucholite due to its biophile tendency. Thorianite, thoro-uraninite and thorite are the primary minerals (endogene) of Th and it is also a minor constituent for uraniferous, zirconiferous, and other rare earth minerals of brannenite, absite, zircon, monazite and allanite (Boyle, 1982).

Th is widely distributed within the Earth's upper continental crust with an average concentration of 10.5 ppm (Rudnick and Gao, 2003). Previous studies by Eade and Fahrig (1973), Shaw et al. (1976) and Taylor and McLennan (1985) also found comparable results. They indicated that the average values of Th concentration in the upper continental crust were 10.8 ppm, 10.3 ppm and 10.7 ppm, respectively.

According to the most recent estimation by the International Atomic Energy Agency (IAEA), the total world Th reserve is approximately ~6.3 Mt (Barthel and Tulsidas, 2014). The IAEA have classified the placer mineral deposit, carbonatite-hosted and vein-type deposit as the main Th sources, with the total estimated reserves are 2.2 Mt, 1.8 Mt and 1.5 Mt, respectively. It was followed by the alkaline rock-hosted deposits and other or unknown deposits, with the value estimations of 0.6 Mt and 0.1 Mt, respectively (Barthel and Tulsidas, 2014). The OECD-NEA (2014) reported that massive Th reserves (in-situ) were indicated by India (847 kt), Brazil (632 kt), the United States (595 kt), Australia (595 kt), Egypt (380 kt), Turkey (374 kt) and the Commonwealth Independent States (9 states excluding Russia) (1.5 Mt).

Currently, a placer-type deposit is the world's major Th resources (OECD-NEA, 2014). Placer deposit is defined as an accumulation of heavy minerals due to the surface weathering processes of ocean, river, wind, or by gravity separation during sedimentary processes (Haldar, 2014). The placer deposits consist of various types, beach placer, marine placer (offshore), alluvial (stream), eluvial (slope), residual and fossil placer (Hails, 1976). They occur in particular depositional environments and widely distributed across the continents. A considerable number of placer deposits across the globe were listed in a previous report by William (1967), while, a complete compilation map of placer deposits around the world were presented by Hails (1976) and Jackson and Christiansen (1993).

Among the placer deposits, beach placer has received notable attention as the most substantial Th resources (Barthel and Tulsidas, 2014; OECD-NEA, 2014). Beach placer is also referred to as recent placer. They are found throughout the world; Congolone in Mozambique; Beihai, Guangdong, Xun Jiang in China; Westport and Barrytown in New Zealand; Atlantida in Uruguay (Jackson and Christiansen, 1993); Jreida-Lemsid in Mauritania; Djifére and Lompoul in Senegal; the Freetown coast in Sierra Leone (Markwitz et al., 2016); Richards Bay and Gelwaal Karoo in South Africa (Macdonald and Rozendaal, 1995; Jackson and Christiansen, 1993); Bentota and Pulmoddai in Sri Lanka (Rupahasinge et al., 1983; Jackson and Christiansen, 1993); the Sanostee deposit in New Mexico (McLemore, 2015) and the coastal belt of Thanh Hoa to Ba Ria-Vung Tau in Vietnam (USGS, 2013), and