Songklanakarin J. Sci. Technol.
43 (5), 1456-1465, Sep. - Oct. 2021

http://www.sjst.psu.ac.th

*Original Article*

# Facies analysis of fluvial deposits of Cenozoic Doi Ton Formation in Mae Sot Basin, Western Thailand

Atiwut Bunlam[1], Yupa Thasod[1*], Rattanaporn Fongngern[1], and Pitaksit Ditbanjong[2]

[1] *Department of Geological Sciences, Faculty of Science,*
*Chiang Mai University, Mueang, Chiang Mai, 50100 Thailand*

[2] *Department of Geotechnology, Faculty of Technology,*
*Khon Kaen University, Mueang, Khon Kaen, 40002, Thailand*

Received: 2 June 2020; Revised: 28 November 2020; Accepted: 30 November 2020

## Abstract

The Cenozoic Doi Ton Formation is outstanding for its leaf fossil deposited in sandstone of which the geologic age is still controversial. This research focuses on stratigraphy and sedimentary facies analyses in order to interpret the paleoenvironment, paleoclimate and identify the geologic age of the study area. Doi Ton Formation can be divided into upper and lower members. The upper Doi Ton member can be divided into five facies including, Sm, Sg, Sr, Sp, and Gm (Gm and Gmg). Furthermore, these facies make up two facies associations, which are (1) channel deposit (Gm, Gmg, Sg, Sr, Sp, and Sm), and (2) sandy bar (Sg, Sr, and Sp) indicating the braided river depositional environment. The lower member is mainly composed of mudstone that suggests the low energy environment. The mineral compositions and leaf fossils indicate the warm and humid climatic conditions during their deposition period.

**Keywords**: lithofacies, fluvial deposit, sedimentology, sedimentary processes

## 1. Introduction

Doi Ton is a small hill in the north of Mae Sot District, Tak Province (Figure 1). The study area is located at UTM Zone 47Q between 457062-457495 E and 1869268-1869207 N (WGS-84 reference for all values) on the 1:50,000 topographic map of Amphoe Mae Ramat’s map sheet L7017-4742 IV (Royal Thai Survey Department, 1999). Mae Sot area is well recognized as one of the most important localities in terms of unconventional natural resources or oil shale deposits (GMT Corporation, 1997). Mae Sot area mainly consists of metamorphic, igneous, carbonate, and clastic sedimentary rocks from the age of Precambrian to Quaternary (Figure 2). Tantiwanit, Raksaskulwong, Bupphasiri, and Khamchoo (1986) named the rocks in Doi Ton area as Doi Ton Formation that consists of conglomerate, gravelly sandstone, sandstone, some with plant fossils and siltstone. There are various literatures describing geology of the Doi Ton area based on the lithology, compared with the adjacent areas, however; they suggested different geologic ages, which can be a Jurassic rock (Department of Mineral Resources, DMR, 2008), Cretaceous rock (Tantiwanit *et al.*, 1986) and Tertiary rock (Brown *et al.*, 1951; DMR, 2007; GMT Corporation, 1997; Saengsrichan, 2007; Sukto, Suteethorn, & Boripatgosol, 1978; Thanomsap, 1983, 1985; Thanomsap & Sitahirun, 1992).

Commonly, fossil leaves usually preserved in fine-grained sediments (Arens, Strömberg, & Thompson, 1998). At Doi Ton, however, an unusual preservation of leaf fossil imprint in sandstone, in good quantity, abundant, and high variation have been reported in recent year. Bunlam, Thasod, Ditbanjong, Fongngern, and Grote (2020) proposed the age of Eocene for Doi Ton area because the paleoclimate and vegetation are comparable with the Eocene climate data in the adjacent areas. In the present study, the lithofacies of Doi Ton Formation were described for sedimentary processes and depositional environment. Moreover, the rocks were examined by petrography, X-ray diffractometer (XRD), and X-ray fluorescent spectrometer (XRF), the mineral composition of the rocks are scrutinized for paleoclimate interpretation.

---

*Corresponding author
Email address: yupa161@gmail.com

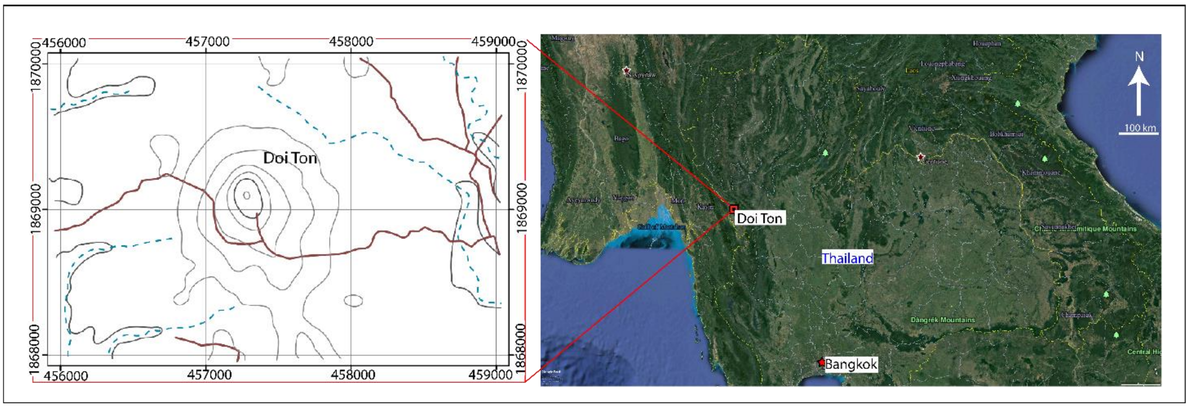

Figure 1. Topographic map of Doi Ton area in the northern part of Mae Sot District, Tak Province (see text for information of the locality)

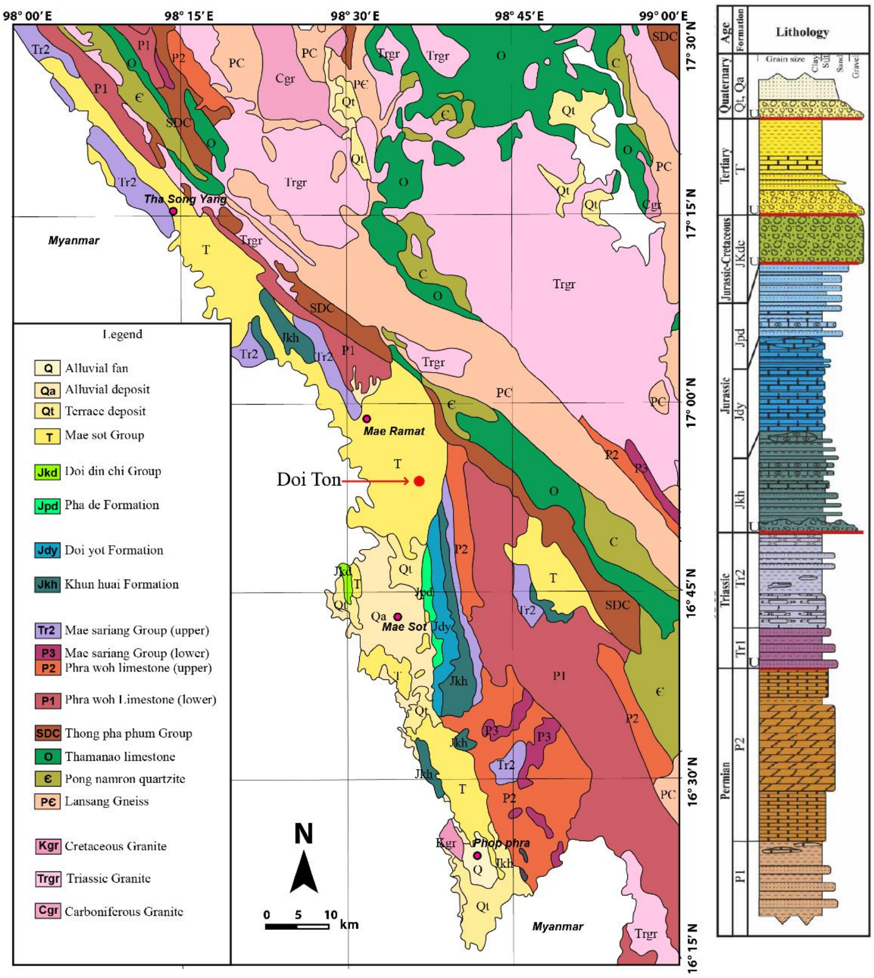

Figure 2. Geologic map and regional stratigraphy of Mae Sot area, Tak Province (modified from Saengsrichan, 2007)

## 2. Materials and Methods

Field mapping, lithostratigraphic study, and rock samples collecting were done during field investigations. The outcrops of Doi Ton Formation are exposed in two areas (Figure 3a): (1) small agricultural pond in the west of Doi Ton hill (47Q 456105 E, 1868911 N), however, the rocks in this pond are not well exposed for facies analysis, and (2) Doi Ton hill (47Q 457304 E, 1869056 N). The facies analysis of this study was carried out by using 11 stratigraphic sections along NW to SE of Doi Ton hill (Figure 3b). Details of sedimentary textures, sedimentary structures, and fossils were illustrated on each stratigraphic section. The facies description and classification are based on Miall (1996).

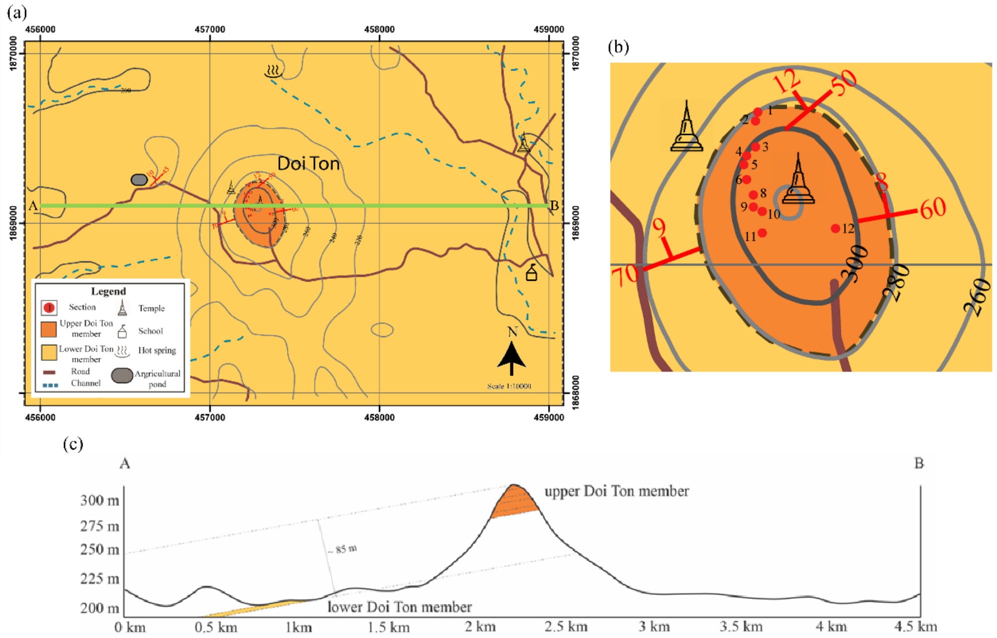

Figure 3. Geologic map and cross-section of Doi Ton area. (a) distribution of the upper Doi Ton member (orange colour) and the lower member (yellow colour); (b) the position of 11 lithostratigraphic sections of the upper Doi Ton member and their orientation; (c) Geologic cross-section of the Doi Ton Formation in this study area showing their total thickness estimation and the relationship between the lower and the upper Doi Ton member.

Twenty-one sandstones and nine siltstones of Doi Ton hill were analyzed by petrographic polarizing microscope, XRD and XRF. The petrographic study provides the content of mineral compositions for plot in the Qt-F-RF diagram (Suttner & Dutta, 1986), this useful for paleoclimate interpretation. The XRD analysis was performed by a Bruker X-ray diffractometer (model D8 Advance) at Department of Geological Sciences, Chiang Mai University with the conditions of room temperature (25 °C) and scanned 2-theta start at 2° to 70°, step 0.04° (Cu-Ka, wavelength of 1.5406). The mineral identification is carried out by a semi-quantitative estimation. Moreover, the whole rock chemical composition of these rock samples was analyzed by XRF analysis (PANanalytical©-XRF spectrometer), which is run for glass bead, to support the climatic interpretation.

## 3. Results

### 3.1 Sedimentology and stratigraphy

The total thickness of Doi Ton Formation in this area is more than 85 m thick (Figure 3c) that can be subdivided into two members, lower and upper Doi Ton members, based on lithology, relationship between rock layers, and fossils.

The lower Doi Ton member is distributed in undulating areas, and usually not exposed. Luckily, we found this member during a farmer dig his area for make an agricultural pond, about 1 km west from Doi Ton hill (Figure 4a) and the thickness of at least 1.5 m. This member is covered by recent sandy and gravelly sediments. The outcrop shows well defined thin to very thin beds that are orientated 045/10 NW (strike/dip angle, dip direction). The sequence is composed of greenish gray mudstone interbedded with fine- to medium-grained gray sandstone. Mudstones show planar lamination and contain a lot of organic plant debris (branch, bark, leaf with cluster deposit) and gastropod fossils. The gray sandstone exhibits erosive base with underlying the mudstone, with ripple cross-laminations and mud clasts along the contact. In the upper part of this member containing, mudstone interbedded with a white crystal layer that should be gypsum. The total thickness of the lower Doi Ton member is estimated not less than 15 m, however, there is no the evidence of contact between the lower Doi Ton member and the upper Doi Ton member because the rocks were highly weathered and formed residue soil along the foothill of Doi Ton.

The upper Doi Ton member (Figure 4b) can be found at the small Doi Ton hill where the in-situ outcrop is well exposed at the top of the hill at the northwest to southeast parts. The lithostratigraphic sections show distinctive rock sequences of approximately 3 to 4.5 m in thickness. The upper Doi Ton member is made up of conglomerates, sandstones, and siltstones, which are orientated in NE-SW (050-080/10 NW). The conglomerates show erosive base, normal grading, and weak imbrication. Moreover, tree trunks with random orientation are found at the base of the conglomerate beds. There are also sandstone lenses with ripple within the conglomerate body. The well bedded sandstones show distinctive sedimentary structure including ripple, planar lamination, load cast, and bottom structure. In the sandstone layers, we found cluster plant fragments, i.e., leaves, tree bark, tree branch together with fossil gastropods, and bivalves. This member is divided into three parts according to their lithological characters presented on 11 measured sections, which are lower, middle and upper as follows Figure 5.

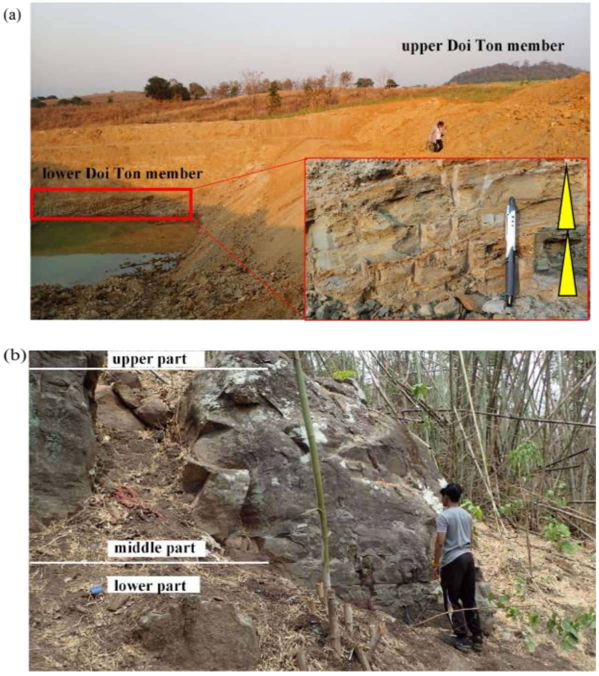

Figure 4. Outcrops of Doi Ton Formation in the study area. (a) Small agricultural pond showing the lower Doi Ton member located at West-side of Doi Ton hill (looking East); (b) Outcrop section number 10 of the upper Doi Ton member (looking Northeast)

The lower part presents slightly fining upward from sandstone to siltstone. Each cycle is capped by the rippled sandstone layer. The sandstones show red weathered color and whitish gray fresh color, fine- to very fine- grained, sub-angular to sub-rounded, moderately to poorly sorted and with erosive base. Plant fragments are also found in these sandstone layers.

In the middle part, the lithological sequence is distinguished by rhythmic fining upward. Each cycle begins with a granule conglomerate bed, followed by thin to medium bedded, coarse- to fine-grained sandstone, and topped by fine-grained sandstone with ripple marks. The conglomerates have a polymictic composition with matrix supported. Most of plant remains (e.g., leaves, tree barks, and branches), few of gastropods, and bivalves are found together in the sandstone layers in this part. The thickness of each fining upward cycle is in the range of 20-60 cm. The primary sedimentary structures, ripple mark and bottom structure indicate NW paleocurrent direction.

The upper part of Doi Ton member consists mainly of thin-bedded sandstone with few sedimentary structures, such as ripple and plant debris and is overlain by siltstone. The siltstone is highly weathered and shows reddish weathered color and dark gray in fresh color with no sign of bedding. This part is thick around 2 m thick in total and exposed only in the section number 12.

## 3.2 Sedimentary facies analysis

Five facies are identified on the 11 stratigraphic sections of the upper Doi Ton member based on their distinctive lithology and paleontology characteristics (Table 1). The facies associations are useful for interpret the depositional environment.

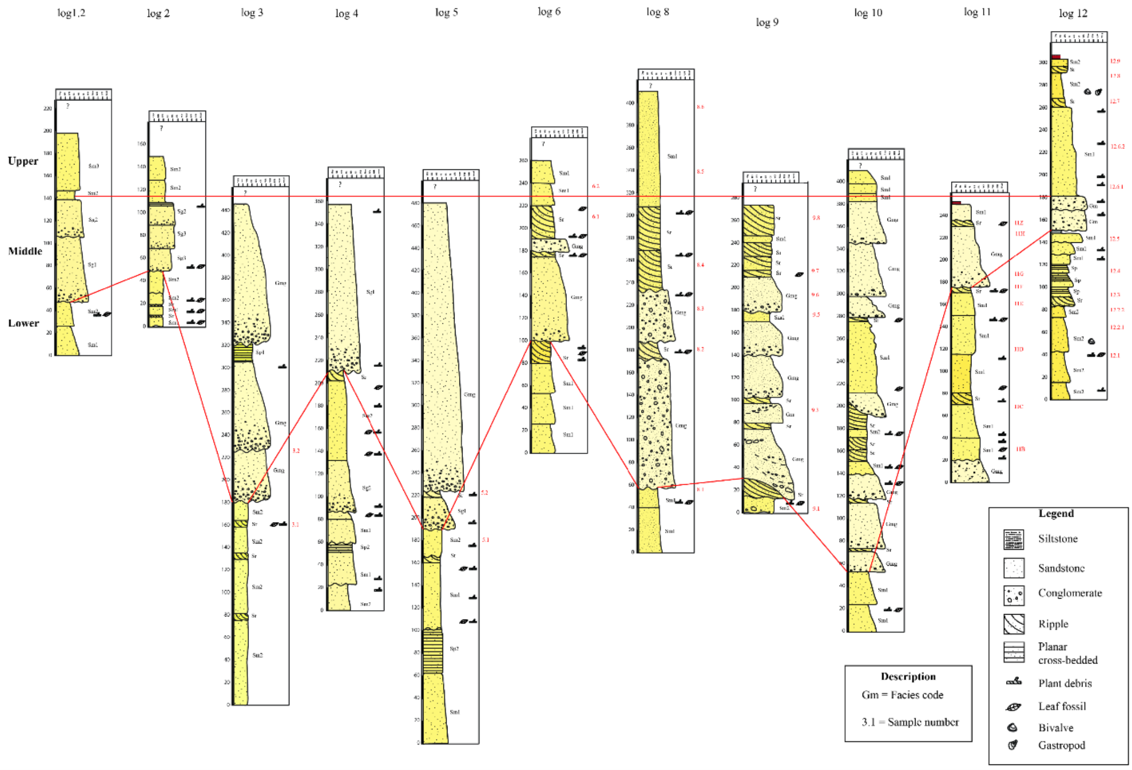

Figure 5. Lithostratigraphic correlation of 11 measured sections of the upper Doi Ton member with details of sample numbers and facies codes

Table 1. Description and interpretation of the lithofacies of the upper Doi Ton member

| Facie code | Facies group | Grain size | Structure | Bed thickness | Fossil | Interpretation |
|---|---|---|---|---|---|---|
| Sm1 | Sm | ms-vfs | massive | thin | leaves, branches, gastropods, bivalves | rapid sedimentation by high concentration rate |
| Sm2 | | fs-vfs | massive | thin | | |
| Sm3 | | ms-vfs | massive | thick | | |
| Sm4 | | ms-vfs | massive | thin | – | |
| Sg1 | Sg | vc-ms | normal grade | medium to thick | – | Decelerating mass flow deposit, from a turbulent currents |
| Sg2 | | cs-ms | normal grade | medium to thick | – | |
| Sr | Sr | vfs-fs | ripple | thin | – | Ripple (lower flow regime) |
| Sp1 | Sp | fs | planar | thin | – | Channel bar |
| Sp2 | | ms | planar | thin | – | |
| Gmg | Gm | granule-vfs | matrix-support, normal grade, erosive boundary | thick | tree trunks, branches | Debris flows |
| Gm | | granule | matrix-support, massive, erosive boundary | thick | | |

### 3.2.1. Massive polymictic conglomerate (Gm, Gmg)

The massive polymictic conglomerate facies consists of matrix supported pebble to cobble conglomerate in sandstone to siltstone matrix (Figure 6a). Clasts have polymictic composition with abundant chert, sandstone, mudstone, quartz, minor of igneous and metamorphic clasts. These clasts are 2-6 cm in diameter, sub-angular to sub-rounded, generally elongate shape, moderately to poorly sorted. This facies is structureless or weakly bedded and absent imbrication. The polymictic conglomerate beds are 40-120 cm thick and commonly situated in the middle part of all sections. This facies can laterally thinner above an erosional surface. Some conglomerate unit grades up into sand size or silt sizes. Sandstones usually occur as isolated lenses within conglomerate bodies or sheet-sand with sharp base (Figure 6b).

This facies is well-matched with the 'Gms' facies of Rust (1978) and might suggest mass transport and debris flow deposits (Miall, 1978). This facies is commonly found under the condition of the arid or semi-arid environment (Miall, 1978). On the other hand, this facies can be rarely found in high rainfall or rainy storm that causes flush debris from the high-land (Collision, 1996, Shettima, Abubakar, KuKu, & Haruna, 2018). That means this facies is generated by in-channel deposition throughout flooding event (Puy-Alquiza, Miranda-Avilés, García-Barragán, Loza-Aguirre, Li, & Zanor, 2017). The weak grading is a sign of reworking of deposits of fast speed downslope movement. Therefore, this facies is occurred in low gradient areas with a shallow depth of water (Mutti, Davoli, Interri, & Zavala, 1996).

### 3.2.2. Normally graded sandstone (Sg1, Sg2)

This lithofacies have fining-upward trends in grain size from very coarse sandstone with granule and pebble to medium grained sandstones, medium to thick bedded. The grains are sub-angular to sub-rounded and low sphericity (Figure 6c). The base of this facies is normally erosion. This facies is mostly found at the middle part of the upper Doi Ton member. It is commonly presented with the sandstone facies (Sm, Sr) but sometimes is existed under the conglomerate facies (Gmg) (Figure 6d). The thickness of this sequence is in the range 20-50 cm. This facies overlies the Sm facies with erosional contact. The characteristics of this facies suggested that it is a product of sediment gravity-flow deposited due to the decelerating of mass flow from turbulence currents (Lowe, 1982). These represent the possession of channel fills or channel bank deposition (Opluštil, Martínek, & Tasáryová, 2005).

### 3.2.3. Massive sandstone (Sm1, Sm2, Sm3, Sm4)

This massive sandstone facies is characterized by moderately- to poorly-sorted, very fine- to medium-grained, sub-angular to sub-rounded, and low sphericity. Sandstones are commonly well and thin bedded, with slightly normal grading and thick between 20-40 cm, commonly absent sedimentary structure or faint planar lamination. The lower part is abrupt contacted with the rippled sandstone (Sr) (Figure 6e). Plant debris, especially leaves and barks, is commonly found clustering in the deposits that shows holes on the weathered surfaces (Figure 6f). Some gravelly rock fragments are also deposited at the base of sandstone-body. This facies might be built under sediment gravity flow (McCabe, 1977; Jones & Rust, 1983) by a short-lived mass flow. It can be interpret as a sand bar that deposited by stream or channel flooding flow (Maahs, Küchle, Scherer, & Alvarenga, 2019; Miall, 1978, 1996, 2010).

### 3.2.4. Ripple laminated sandstone (Sr)

This facies was observed in all three parts of the upper Doi Ton member with a bed thickness of 5–20 cm. It is defined by very fine to fine-grained sandstone, moderately- to poorly-sorted and sub-angular to sub-rounded. These sandstones cyclically overly on Sm facies (Figures 6g and 6h). According to Miall (1978; 1996), Sr facies has originated by current ripples under the lower flow regime or a consequence of receding sheet flood deposit (Handford, 1982; Maahs, *et al.*, 2019; Rust & Koster, 1984; Shettima, *et al.*, 2018).

### 3.2.5. Planar cross-bedded sandstone (Sp)

This facies characteristically takes place over the ripple sandstone (Sr) with a sharp or erosive base, containing fine to medium-grained, and slightly normally graded sandstone, with 10-40 cm thick (Figure 6i). Each foreset bed inclined 10° to 15° in a scale of 0.5-3 cm. This sandstone is generally interbedded with the rippled sandstone and massive sandstone. This lithofacies is suggested to be a transverse bar formed within a lower flow regime (Miall, 1977, 1978, 1985). Moreover, Feary (1984) presented this facies as a product of migration of 2-D dunes or sheet loading (Maahs, *et al.*, 2019; Shettima, *et al*., 2018).

### 3.3 Mineral composition

The petrographic results of sandstones and siltstone show there are subangular to subrounded grained, low sphericity, and poorly sorted. The major component is mainly composed of quartz (38.25%-72.5%), rock fragments (1.25%-12.91%), less of accessory minerals (0.5%-5% of mica, 0%-5% of opaque, 0.75%-3.25% of zircon, and 0%-1.65% of tourmaline) with silica cement. Moreover, the rock fragments are classified as mudstone/shale, silicified rock, sandstone, metamorphic rocks (schist, gneiss, and quartzite), and igneous rocks (plutonic rocks). The mineral contain by XRD analysis trending are quartz, followed by kaolinite and the smallest quantity of mica or illite. Quartz dominates in all sample, with percentages ranging from 64.46 to 91.13%, and 77.45% in average. Kaolinite content shows considerably fluctuation from 6.2 to 27.59% with 14.08% in average. Mica or illite is variable in contents, ranging from 0 to 30.42% with 8.48% in average. Quartz contents show a steady trend throughout the stratigraphic interval. However, kaolinite and illite/mica show varying trends from the lower to uppermost parts.

The result of XRF analysis shows the consistency with the result of mineralogy from petrography and XRD results by showing a high value of $SiO_2$ (68.10%-92.73%), followed by $Al_2O_3$ (4.38%-17.05%), $Fe_2O_3$ (0.18%-5.52%), $K_2O$ (0.22%-2.46%), $TiO_2$ (0%-1.01%), MgO (N.D.-0.45%), CaO (N.D.-0.08%), $Na_2O$ (N.D.-0.62%), $P_2O_5$ (N.D.-0.07%), and MnO cannot be detected. (N.D. means the less amount than detection limit).

## 4. Discussion

### 4.1 Paleoenvironment interpretation

According to the facies analysis at the upper Doi Ton succession, facies associations were grouped along the

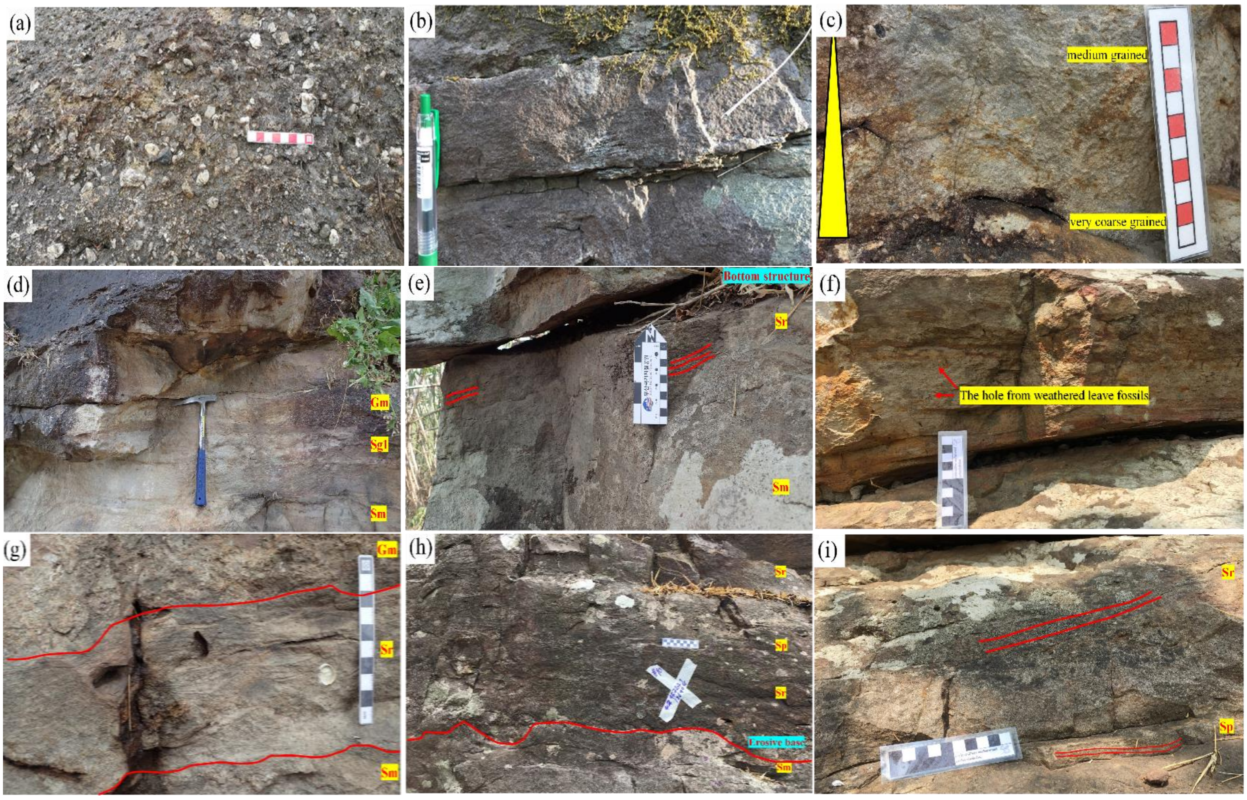

Figure 6. Facies characters: (a) Massive polymictic conglomerate facies (Gm), containing subangular to subrounded, low sphericity, and poorly sorted clasts; (b) Sheet-like sandstone with sharp based and planar cross-bedding sandstone (Sp) within conglomerate body; (c) Normally graded sandstone showing grading from very coarse- to medium-grained (Sg1) with subangular to subrounded and low sphericity grained; (d) Normally graded sandstone facies (Sg1) was deposited below the conglomerate facies (Gm) and overlay the massive sandstone facies (Sm); (e) Massive sandstone facies (Sm) was capped by the rippled sandstone facies (Sr). At the upper part of this figure, the bottom structure indicates the paleocurrent to the NW direction; (f) Weathered surface of massive sandstone facies (Sm) with holes by weathered leaf fossils; (g) Ripple laminated sandstone facies (Sr) covered by the massive polymictic conglomerate facies (Gm) with the erosive base; (h) Ripple laminated sandstone facies (Sr) interbedded with planar cross-bedded sandstone facies (Sp) overlaid on the massive sandstone (Sm) with erosive base; (i) Thin-bedded planar cross-bedded sandstone facies (Sp) interbedded with ripple laminated sandstone facies (Sr).

vertical succession that useful for depositional environments interpretation (Dalrymple, 2010). The upper Doi Ton succession includes gravel dominated facies association (Gm and Gmg) and sand dominated facies association (Sm, Sg, Sr, Sp). These indicate braided channel deposit (Cant & Walker, 1978; Miall, 1977, Opluštil, Martínek, & Tasáryová, 2005; Shettima, *et al*., 2018) (Figure 7). The braided channel deposits have an erosional base with eroded sandy bedforms with elongate lobe geometry. The existence of conglomerates may imply a sudden increase in energy. The Sm and Gm facies also indicate non-cohesive, gravity flow deposition, which is presented within the channel fills and probably a record of channel bank instability and slumping. The sand bodies made up of facies association Sg, Sr, and Sp. They have sharp contact base and sometimes show cut and fill structure. They are record of the intra-channel bar deposition within channel form. Moreover, the Sp facies also shows that the upper Doi Ton member might have been produced by shallow braided river (Miall, 1996; 2010; Shettima, *et al*., 2018).

As braided river system of the upper Doi Ton member, high amount of sediments from nearby areas should be deposit with high rate of erosion and sedimentation in this study area that may cause by the tectonic setting on the high relief of fault rifting basin (Shettima *et al*., 2018). This interpretation is supported by sediments characteristics such as sub-angular to sub-rounded, low sphericity grains indicating near source area transportation. The complete leaf structures from Doi Ton suggested that they were transported in short distance from their mother plants. The leaf deposits in the sandstone layers of each 11 stratigraphic logs together with a few gastropod and bivalve fossils indicate a high deposition rate on the sand bar before the decay process begins (Gastaldo & Demko, 2010).

The lower Doi Ton member that represents by grayish mudstone interbedded with blackish gray sandstone implies a low energy depositional environment such as lake or swamp. Unfortunately, the less outcrop exposed of this member cannot interpret more environmental data. However, more precise paleoenvironment of this member cannot be interpreted due to scarce outcrops. The contact between the lower and the upper members was not observed in the field, however; it is concluded here that they were continuously deposited according to their conformed bedding orientation.

The stratigraphy and lithology of Doi Ton Formation are comparable with the Mae Ramat Formation, of the Tertiary deposit Mae Sot Group (Thanomsap, 1985, Thanomsap & Sitahirun, 1992). Mae Ramat Formation is made up of fluviatile red bed and grayish green sedimentary rocks, interstratified conglomerate, gravelly sandstone, sandstone, siltstone, mudstone, and lignitic shale. Leaf and gastropod fossils were reported. Fossil leaves and gastropods were mentioned in technical reports, but it is not available to compare with the Doi Ton materials. The depositional environment of this formation was interpreted as the braided river (Thanomsap, 1983). The red bed was deposited in an oxygen rich environment and the green sedimentary rock facies was deposited in the channel where oxygen is low. In some areas, this formation unconformable overly the Triassic and Jurassic rocks, and thickening towards the North of the Mae Sot Basin, which shows that the northern part lies downstream deposited, with approximately 240 m thick.

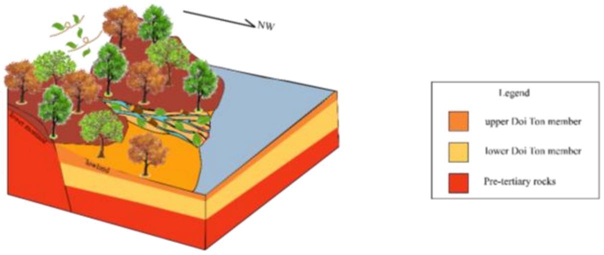

Figure 7. Schematic diagram representing the depositional history of Doi Ton Formation

Furthermore, Doi Ton Formation is also commensurable with Unit A of the Mae Ramat stratigraphic column (Ampaiwan, Charusiri, & Kunwasi, 2003). This unit is composed of fluvial deposits; sandstone, conglomerate, light greenish gray, with more than 100 m thick. Unit A overlies the pre-Tertiary and overlain by mudstone, coal, and pollen-rich Unit B (B1-B4). Result from palynological studies indicated Early Miocene in age and the vegetation was similar to Li and Nong Ya Plong coal mine (Grote, 2005; Sawangchote, 2006). However, the paleoclimatic interpretation from leaf fossil analysis from the upper Doi Ton member suggested that the paleoclimate of this member comparable with the Eocene epoch (Bunlam, Thasod, Ditbanjong, Fongngern, & Grote, 2020).

## 4.2 Paleoclimate interpretation

The paleoclimate of upper Doi Ton member was reconstructed based on the mineral and geochemical composition. The percentage of mineral composition of sandstone from petrographic study was plot on the Qt-F-RF diagram (Suttner, Basu, & Mack, 1981) (Figure 8a). This diagram shows that sandstones of the upper Doi Ton member were derived under humid climate during depositional period.

The XRD analysis (Figure 8b) shows a high content of kaolinite, in the lower part of the upper Doi Ton member which suggested that this part was deposited on the continent under tropical, warm and humid climate with high energy. Kaolinite is a weathering product of feldspar, which is generally derived from the source rock deposited on the continent and grain of sandstone (Weaver, 1989). Moreover, it also implies tropical climate and hot and humid climate in the source area with well-drained soil (Robert & Chamley, 1991). The high content of kaolinite and low content of mica/illite may suggest high depositional energy (Wright & Robinson, 1988). The middle part of the upper Doi Ton member presents high mica or illite content with low kaolinite content represents standing water or low energy or poorly-drained soil situation (Robert & Chamley, 1991). An increasing of mica or illite also suggests the erosion rate may be induced by the cooler weather condition (Akarish & El-Gohary, 2008). The trend of mineral compositions of the upper part suggests hot and humid weather. This means the source rocks had been through intense weathering and yielded kaolinite content. Finally, the mineral content of the uppermost part suggests that this part was deposited in standing water or low energy environment with decreasing weathering of the source rock (Robert & Chamley, 1991). This environment is similar to the middle part, but the grain size and color of the rock are

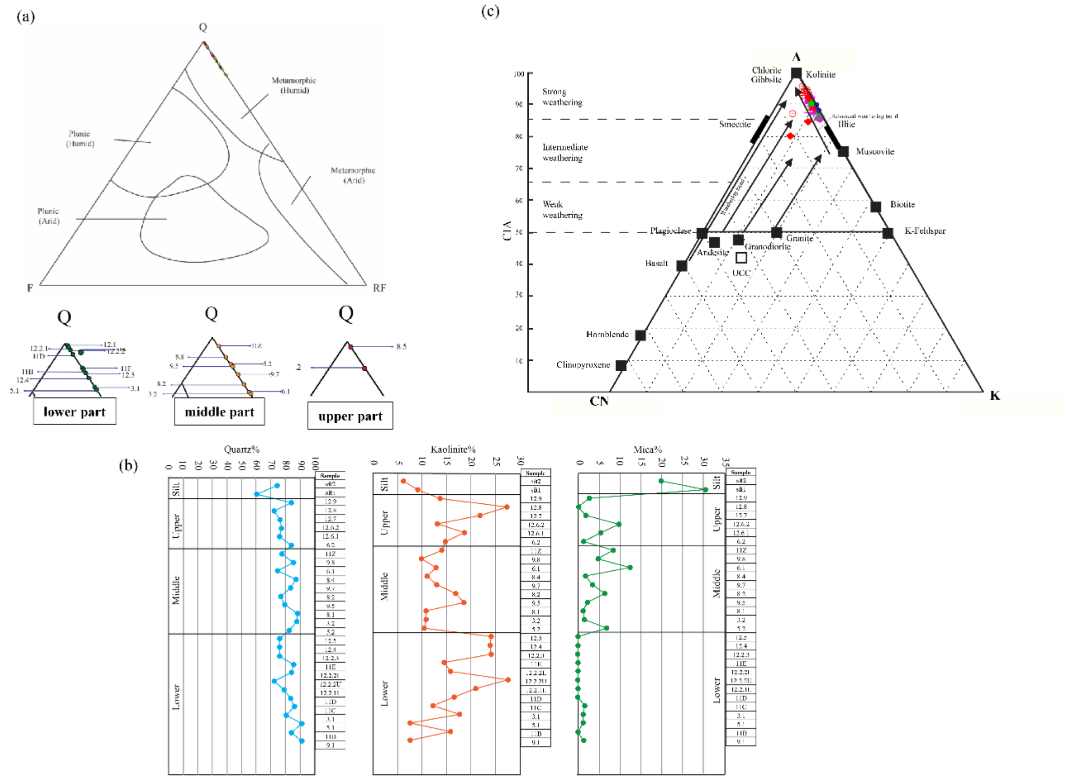

Figure 8. Climatic interpretation based on mineral and geochemical compositions. (a) Q-F-RF ternary diagram plot showing the sandstone from the upper Doi Ton member that are in humid climate (after Suttner et al., 1981); (b) Mineral trending of quartz, kaolinite, and mica (illite) through the stratigraphic succession of the upper Doi Ton member; (c) A-CN-K ternary diagram showing climatic condition during depositional period of the upper Doi Ton member (after Nesbitt and Yang, 1984)

different. This upper part might have been deposited in a calmer environment in order to let silt particle settle out of suspension. The red color of weathered rock shows the presence of ferric oxides in the terrestrial environment. Moreover, the climate interpretation also supports by the weathering condition study based on the geochemical data. The sandstones and siltstones of the upper Doi Ton member show moderate to high intensity of weathering during depositional period (Figure 8c) that presented by high $Al_2O_3$ content when use A-CN-K diagram of Nesbitt & Yang (1984). This means these rocks were derived under hot and humid climatic conditions.

## 5. Conclusions

Base on lithostratigraphy, mineral composition, and fossil association, Doi Ton Formation is probably thicker than 85 m, and can be subdivided in to two members, the lower Doi Ton member and the upper Doi Ton member.

The lower Doi Ton member made of grayish black mudstone interbedded with sandstone. Gastropods and leaf fossils were found. This member was deposited in low energy as lake or swamp. The upper Doi Ton member includes the sandstone, conglomerate, and siltstone. The plant debris, such as trunk, bark, leaf, are plentiful and well preserved in sandstone. Gastropod and bivalve fossils are scattered. The details of lithostratigraphic sections of this member consist of sandstone dominated facies and conglomerate dominated facies. These facies association indicated braided river system.

This braided river flew to the NW direction with high sediment load from nearby source areas. The mineral and geochemical compositions of the upper Doi Ton member suggest these rocks were deposited under the hot and humid climate. The lithostratigraphy of Doi Ton Formation is comparable with the Cenozoic Mae Ramat Formation.

## Acknowledgements

The research was financial supported by the Fossil Management Fund, Department of Mineral Resources, Bangkok. We also appreciated critical comments and suggestions of A. Chitnarin from the Geological Engineering Program, Suranaree University of Technology, and anonymous reviewers, which improved this manuscript.

## References

Akarish, I. M., & El-Gohary, Amr. M. (2008). Petrography and geochemistry of lower Paleozoic sandstones, East Sinai, Egypt: Implication for provenance and tectonic setting. *Journal of African Earth Sciences, 52*, 43-54.

Ampaiwan, T., Charusiri, P., & Kunwasi, C. (2003). Palynology of coal-bearing units in the Mae Ramat Basin, Tak Province, northern Thailand: Implications for the Paleoclimate and the Paleoenvironment. *The Natural History Journal of Chulalongkorn University, 3*(2), 19-40.

Arens, N. C., Strömberg, C., & Thompson, A. (1998) Laboratory mannual "Plant fossils and their preservation". Retrieved from https://ucmp.berkeley.edu/IB181/VPL/Pres/Pres2.html.

Brown, G. F., Buravas, S., Jamchet, C., Nitipat, J., William, D. JR. J., Vija, S., & George, C. JR, T. (1951). Geological reconnaissance of the mineral deposit of Thailand. *Geological Survey of America Bulletin, Geological Investigation of Asia, 4*, 35-39

Bunlam, A., Thasod, Y., Ditbanjong, P., Fongngern, R., & Grote, P. J. (2020). The Cenozoic leaf morphotypes and palaeoclimate interpretation from the Doi Ton Formation, Mae Sot District, Tak Province, western Thailand. *Thai Forest Bulletin (Botany)*, *48*(2), 118-141.

Cant, D. J., & Walker, R. G. (1978). Fluvial processes and facies sequences in the sandy bradied South Saskatchewan River, Canada. *Sedimentology, 25*, 625-648.

Dalrymple, R. W. (2010). Interpreting sedimentary successions: Facies analysis and facies 6 models. In N. P James & R.W. Dalrymple (Eds.), *Facies Models 4* (pp. 3-18). St. John's Newfoundland, Canada: Geological Association of Canada.

Department of Mineral Resources. (2007). *Geological map of Changwat Tak, scale 1: 250,000*. Bangkok, Thailand: Author.

Department of Mineral Resources. (2008). *Geological map of Changwat Tak, scale 1: 250,000*. Bangkok, Thailand: Author.

Feary, D. A. (1984). The Boambolo formation: A Silurian prograding fan delta sequence in southeastern, New South Wales, Australia. *Sedimentology Geology, 39*(1-3), 169-195.

Gastaldo R. A, & Demko T. M. (2010). The relationship between continental landscape evolution and the plant-fossil record: Long term hydrologic controls on preservation. *Topics in Geobiology*, *32*, 249–285. doi:10.1007/978-90-481-8643-3_7

GMT Corporation. (1997). *Evaluation for development and utilization of oil shale, Mae Sot Basin, Tak province* (Executive summary report for board of Mineral Fuels Division, pp. 1-16). Bangkok, Thailand: Department of Mineral Resources.

Grote, P. J. (2005). *Use of leaf architecture and anatomy in the study of plant diversity in the Tertiary and recent Thailand* (Research Report, School of Biology, Insitute of Science, Suranaree University of Technology, Nakhon Ratchasima, Thailand).

Handford, C. R. (1982). Sedimentology and evaporate genesis in a Holocene continental-sabkha playa basin - Bristol Dry Lake, Califonia. *Sedimentology, 29* (2), 239-253.

Jones, D. G., & Rust, B. R. (1983). Massive sandstone facies in the Hawlesbury sandstone, a Triassic fluvial deposit near Sydney, Australia. *Journal of Sedimentary Petology, 56*, 1249-1259.

Lowe, D.R. (1982). Sediment gravity flows: II depositional models with special reference to the deposits of high-density turbidity currents. *Journal of Sedimentary Petrology*, *52*, 279-297.

Maahs, R., Küchle, J., Scherer, C. M. S., & Alvarenga, R. S. (2019). Sequence stratigraphy of fluvial to shallow-marine deposits: The case of the early Permian Rio Bonito Formation, Paraná Basin, southernmost Brazil. *Brazilian Journal of Geology*, *49(2),* 1-21.

McCabe, P. J. (1977). Deep distributary channels and giant bedforms in the Upper Carboniferous of the Central Pennines, north England. *Sedimentology*, *24*, 271-290.

Miall, A. D. (1977). A review of braided river depositional environment. *Earth Science Review, 13*, 1-16.

Miall, A.D. (1978). Lithofacies types and vertical profile models in braided river deposits: A summary. *Memoir Canada, Society Petroleum Geology, 5*, 859-859.

Miall, A. D. (1985). Architectural-element analysis: A new method of facies analysis applied to fluvial deposits. *Earth Science Review, 22*, 261-308.

Miall, A. D. (1996). *The geology of fluvial deposits: Sedimentary Facies, basin analysis and petroleum geology*. Berlin, Germany: Springer-Verlag.

Miall, A. D. (2010). Alluvial deposits. In N.P James & R.W. Dalrymple (Eds.), *Facies Models 4* (pp. 105-137). St. John's, Newfoundland, Canada: Geological Association of Canada.

Mutti, E., Davoli, G., Interri, R., & Zavala, C. (1996). The importance of ancient fluvio-delta systems dominated by catastrophic flooding in tectonically active basins: *Science, Geology Memoir, 48*, 223-291.

Nesbitt, H. W., & Young, G. M. (1984). Prediction of some weathering trends of plutonic and volcanic rocks based on thermodynamic and kinetic consideration. *Geochimica et Cosmo chimica Acta, 48 (7)*, 1523-1534.

Opluštil, S., Martínek, K., & Tasáryová, Z. (2005). Facies and architectural analysis of fluvial deposits of the Nýřany Member and the Týnec Formation (Westphalian D - Barruelian) in the Kladno-Rakovník and Pilsen basins. *Bulletin of Geosciences, 80(1),* 45-66.

Puy-Alquiza, M., Miranda-Avilés, R., García-Barragán, J., Loza-Aguirre, I., Li, Y., & Zanor, G. (2017). Facies analysis, stratigraphie architecture and depositional environments of the Guanajuato conglomerate in the Sierra de Guanajuato, Mexico. *Boletín de la Sociedad Geológica Mexicana, 69(2)*, 385-408.

Robert, C., & Chamley, H. (1991). Development of Early Eocene warm climates, as inferred from clay mineral variation in oceanic sediments. *Global and Planetary Change, 89*, 315-332.

Royal Thai Survey Department. (1999). Topographic map of Thailand, Sheet Mae Ramat (4742IV), scale 1: 250,000. Bangkok, Thailand: Author.

Rust, B. R. (1978). A classification of alluvial channel systems. In A.D. Maill (Ed.),*Fluvial Sedimentology, Volume 5* (pp. 187-198). Calgary, Canada: Canadian Society of Petroleum Geologists, Memoir.

Rust, B. R., & Koster, E. H. (1984). Coarse alluvial deposits. In R. G. Walker (Ed.), *Facies models* (pp. 53-69). St. John's, NL, Canada: Geoscience Canadian.

Saengsrichan, W. (2007). *Sedimeantary facies and stratigraphy of the marine Jurassic Hua Fai Group in Mae Sot-Phop Phra Basin, Changwat Tak, Thailand* (Master's dissertation, Chulalongkorn University, Bangkok, Thailand).

Sawangchote, P. (2006). *Report of surveying and collecting Tertiary plants of peninsular Thailand for biodiversity and paleoecology research* (Research Report, Faculty of Science, Prince of Songkla University, Songkhla, Thaialnd).

Shettima, B., Abubakar, M. B., Kuku, A., & Haruna, A.I. (2018). Facies analysis, depositional environments and Paleoclimate of the Cretaceous Bima Formation in the Gongola Sub – Basin, Northern Benue Trough, NE Nigeria. *Journal of African Earth Sciences, 137*, 193-207.

Sukto, P., Suteethorn, V., & Boripatgosol, S. (1978). *Geology of Moulmein quadrangle (NE 47-14), scale 1:250,000*. Bangkok, Thailand: Department of Mineral Resources.

Suttner, L. J., Basu, A., & Mack, G. H., (1981). Climate and the origin of quartz arenites: *Journal of Sedimentary Petrology, 51*, 1235-1246.

Suttner, L.J. & Dutta, P.K. (1986) Alluvial Sandstone Composition and Palaeoclimate Framework Mineralogy. *Journal of Sedimentary Petrology, 56*, 329-345.

Tantiwanit, W., Raksaskulwong, L., Bupphasiri, W., & Khamchoo, A. (1986*). Geological map of Thailand, Sheet Mae Ramat (4742IV) and Mae La (4643II), scale 1: 250,000*. Bangkok, Thailand: Geological Survey Division, Department of Mineral Resources.

Thanomsap, S. (1983). Stratigraphy sequence and facies distributions in Mae Sot Basins. *Proceeding of Conference of Geology and Mineralogy Resources of Thailand* (pp.366-376). Bangkok, Thailand.

Thanomsap, S. (1985). Petroleum potential of Mae Sot Basin (in Thai). *Proceeding of the 3rd Conference on Geology and Mineralogy resources of Thailand* (pp.91-109). Bangkok, Thailand.

Thanomsap, S., & Sitahirun, S. (1992). The Mae Sot oil shale (in Thai). *Proceeding of the National Conference on Geologic Resources of Thailand: Potential for Future Development* (pp.676-691). Bangkok, Thailand

Weaver, C. E. (1989). *Clays, muds, and shales, developments in sedimentology*. New York, NY: Elsevier.

Wright, V. P., & Robinson, D., (1988). Early Carboniferous floodplain deposits from South Wales: a case study of the controls on palaeosol development. *Journal of Geological Society of London*, *145*, 847-857.