

THE CENOZOIC LEAF FOSSIL AND PALEOCLIMATE AT DOI TON, MAE SOT DISTRICT, TAK PROVINCE, THAILAND

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Abstract

Abundant leaf fossils are preserved as imprinted in sandstone layers at Doi Ton temple, Mae Sot Basin, Tak Province. They were found alongside with branches, tree barks, fossil bivalves, and gastropods. The leaf fossils preservation is rare in the Cenozoic deposit in Thailand; thus, the study site provides a great opportunity for research to solve the paleo-depositional environment and paleoclimate of the region. From primary investigations of leaf morphology, sedimentology, and stratigraphy, Doi Ton deposits were classified into three parts. The lower part is composed of the whitish gray fine-grained sandstone, the middle part is reddish brown to yellowish brown conglomerate and fine-grained sandstone and the upper part is the reddish siltstone. The leaf fossils are abundant in fine-grained sandstone and some plant fragments are also present at the base of the conglomerate. The middle and upper Doi Ton successions show a sign of channel deposits. Bottom sedimentary structures indicated paleocurrent to the northwest direction. The leaf fossils can be classified into 23 morphotypes of dicot leaves with an unlobed and untoothed margin and two of gymnosperm leaves. These dicotyledonous leaves suggest warm and humid paleoclimate.

Keywords: Leaf fossil, paleoenvironment, paleoclimate, Doi Ton, Mae Sot basin

Introduction

Leaves cannot be transported far from the source area with the intact form, so they can be the excellent proxies to indicate the local environment (Maxbauer *et al.*, 2013). In this study, we establish the first leaf fossil morphotypes assemblage and present the interpretation of the paleoenvironment based on the leaf fossil characters and the sedimentology of Doi Ton area.

Leaf fossils also provide important data for ancient terrestrial environment interpretation, especially the paleoclimate (Seyfullah, 2012). Because plants cannot move, they are forced to adapt under the terrestrial conditions to survive, thus, they are good tools for reconstructing the environment conditions. One approach for paleoclimate reconstruction is by using the leaf size, shape and

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type of the margin (leaf anatomy) of the modern flowering plants (Bailey and Sinnott, 1916; Webb 1968; Wolfe; 1979, Wing and Greenwood, 1993; Jacobs, 1999; Royer *et al.*, 2005; Greenwood, 2007). For example, the smooth margin of the leaf is enriched in the wet tropical forests. Whereas the leaves of the temperate vegetation trend to be smaller leaves with tooth margin and/or lobed leaves. Large leaf sizes, which included notophyll, microphyll, and mesophyll size, are a positive correlation with the increasing mean annual precipitation (MAP). This relationship can estimate the temperature and precipitation of habitat condition by the method as known as “Leaf Margin Analysis” or LMA and “Leaf Size Index” or LSI respectively (Bailey and Sinnott, 1916; Webb 1968; Wolfe, 1979; Wing and Greenwood, 1993; Jacobs, 1999; Royer *et al.*, 2005).

The leaf fossils in this study were collected from the outcrops and float rock around Doi Ton temple (16°54'17.12"N, 98°35'56.82"E) Mae Kasa Sub-district, Mae Sot District, Tak Province, Thailand (Figure 1(a)). Doi Ton is a small dome (Figure 1(b)) located in the middle of the Mae Sot's Tertiary Basin. Mae Sot Basin is an intermountain basin that has an extent from Mae Sot District and Mae Ramat District to the east area of Myawaddy, Myanmar. The basin mainly consists of colluvial and alluvial plains, with some small hills of about 200 m-MSL. The Bouguer gravity map represents Mae Sot is formed by elongated two sub-basins, where axis lies on NW-SE direction with the display as a shallow syncline dipping 5°-25°. The southern basin is deeper than the northern basin and the thickness of tertiary rock of the west is thicker than the east. (Piyasin, 1972; Mineral Fuels Division, 1979; Chaodumrong *et al.*, 1983; Thanomsap and Sitahirun, 1992; GMT corporation, 1997; Suwannathong and Khummongkol, 2007).

Materials and Methods

Sedimentology and Stratigraphy

The field observation method is mainly comprised of systematic lithostratigraphy from the west to the south of Doi Ton. The lithology, sedimentary structure, fossil and position of fossils in the outcrop were described. The sedimentary sequence can be subdivided based on their physical characters and their relationship.

Fossil preservation and preparation

Fifty specimens of leaf fossils were photographed by a digital camera (CANNON 60D). The leaf fossils were grouped by their architectures to be the morphotype. The morphotype is no formal

taxonomic identification that used only the appearance of leaf morphology. Morphotype group is not directly related to certain species of plant but it is often equivalent to biological species (Leaf Architecture Working Group, 1999). So, this work does not have purpose to classify the dicotyledonous leaf into their taxonomic affinities. The systematic description and terminology of the dicotyledonous leaf-architecture characters are following by The Botanical Review (Dilcher, 1974), The Manual of Leaf architecture (Leaf Architecture Working Group, 1999; Ellis *et al.*, 2009), the Classification of the Architecture of Dicotyledonous Leaves (Hickey, 1973) and Plant Systematics (Singh, 2010) (Figure 2). The measurements of the leaf area, maximum length and maximum wide were carried out by the software ImageJ (version 1.52a, National Institutes of Health, USA).

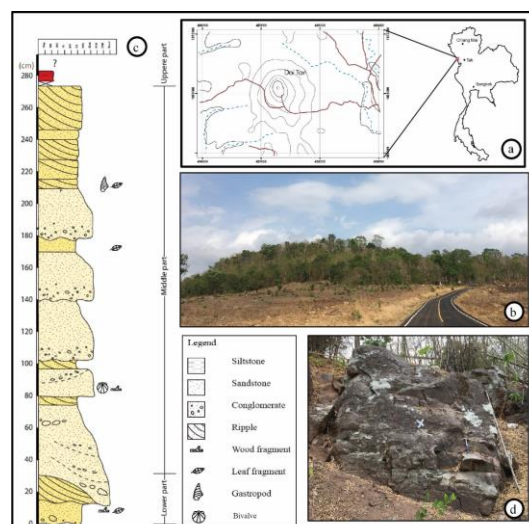


Figure 1. Geographic map and stratigraphic section of the study area. (a) Geographic location of fossil in Doi Ton, Mae Sot, Tak, Thailand. (b) The small hill of Doi Ton surrounded by the undulating plain. (c) Stratigraphic section of Doi Ton. (d) The section of sample collection

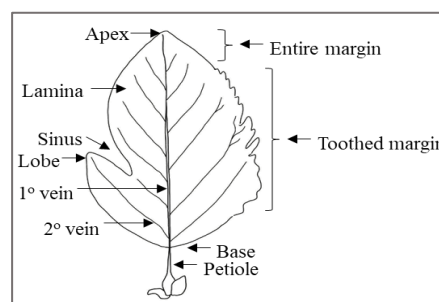


Figure 2. The basic terminology of leaf fossils

Paleoclimate Reconstruction

The interpretation of the paleoclimate conditions of Doi Ton is based on leaf fossil records. Temperature is provided by the Leaf Margin analysis (LMA) approach for mean annual temperature (MAT), which uses the percentage of entire vs toothed dicotyledonous leaf (Webb, 1968; Su *et al.*, 2010; Seyfullah, 2012). This study uses the linear equation of Leaf Margin Analysis of Wolfe (1979) and Wing and Greenwood (1993), whose studying focused on the flora list from East Asia, the nearest the study area. The equation of Peppe *et al.* (2018), who combined the Leaf Margin Analysis data of the world and calibrated for global representation.

Equation (1) from Wolfe (1979) and Wing and Greenwood (1993) (leaf collection from East Asia)

$$MAT_{LMA} = 30.6P + 1.141 \quad (1)$$

Equation (2) from Peppe *et al.* (2018) (leaf data collection from Global distribution sites)

$$MAT_{LMA} = 19.4P + 5.884 \quad (2)$$

where MAT_{LMA} is average yearly temperature estimated using leaf margin analysis and P is defined as:

$$P = \frac{r}{n}$$

where n is the total number of morphotype samples and r is the number of non-toothed margins leaf.

The leaf size is used for climate estimation by the ratio of large leaf class vs. small leaf class, which is compared with the study of the distribution of leaf size and precipitation by Jacobs (1999) and leaf size with vegetation style by Webb (1968). The class of

leaf area (e.g. mesophyll, microphyll, etc.) are based on the category of Raunkiaer (1934) and Webb (1959).

Results and Discussion

Leaf Fossils

The leaf fossil assemblages in this study are well to moderate to low preservation. There are 23 morphotypes of dicotyledonous leaves and two morphotypes of unknown leaves on this site. The 25 morphotypes are systematically described (Table 1) (Figure 3) and the margin and area of leaves analyzed for interpreting climatic conditions in the

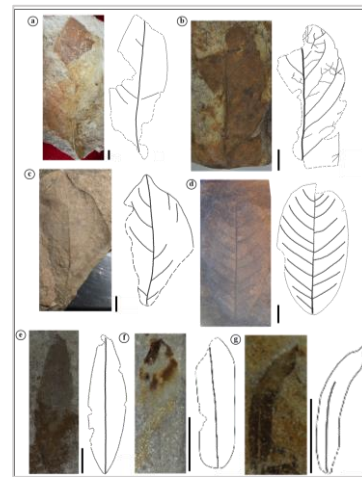


Figure 3. The representative leaf fossils in Doi Ton from large to small respectively. (a) morphotype A, (b) morphotype Y (toothed margin), (c) morphotype C, (d) morphotype, (e) morphotype F, (f) morphotype, (g) morphotype U (scale bar = 1 cm)

Table 1. Compactness of the different automotive radiator designs

Morphotype	Margin	Leaf shape			Venation*		Symmetry		Leaf size	Quantity	Type
		Blade	Apex	Base	1°	2°	Medial	Base			
A	Entire	Narrow oblong			P		✓		Leptophyll	1	Dicot
B	Entire	Narrow ovate			P	EC			Leptophyll	1	Dicot
C	Entire	Narrow oblong	Acuminate		P	PL			Leptophyll	1	Dicot
D	Entire	Narrow oblong		Rounded	P	EC	✓		Megaphyll	7	Unknown
E	Entire	Narrow elliptic	Convex	Rounded	P		✓	✓	Megaphyll	5	Dicot
F	Entire	Narrow elliptic	Straight	Cuneate	P	EC	✓	✓	Megaphyll	3	Dicot
H	Entire	Narrow ovate		Rounded	P	EC	✓	✓	Megaphyll	5	Dicot
I	Entire	Oblong			P	WB	✓		Leptophyll	1	Dicot
J	Entire	Oblate	Convex	Cuneate	P		✓	✓	Megaphyll	3	Dicot
K	Entire	Linear		Rounded	P	EC	×	✓	Megaphyll	2	Dicot
M	Entire	Lanceolate		Rounded	P		✓	✓	Megaphyll	2	Unknown
O	Entire	Oblanceolate	Acuminate		P	EC	✓		Leptophyll	1	Dicot
P	Entire	Lanceolate		Cuneate	P	EC			Leptophyll	1	Dicot
R	Entire	Narrow obovate	Emarginate	Cuneate	P	EC	✓	✓	Megaphyll	3	Dicot
S	Entire	Elliptic			P				Leptophyll	1	Dicot
T	Entire	Narrow obovate			P		✓		Leptophyll	1	Dicot
U	Entire	Lorate	Acuminate		P		✓	✓	Megaphyll	2	Dicot
V	Entire	Elliptic			P		✓	×	Megaphyll	1	Dicot
W	Entire		Acuminate		P		✓		Leptophyll	1	Dicot
X	Entire	Narrow obovate	round	Cuneate	P		✓	✓	Megaphyll	1	Dicot
Y					AC	EC			Leptophyll	2	Dicot
Z	Entire	Narrow ovate		Cuneate	P			✓	Megaphyll	1	Dicot
AA	Entire	Narrow Elliptic	round		P	EC			Leptophyll	1	Dicot
AB	Entire	Oblong			P				Leptophyll	1	Dicot

*Abbreviation: AC: Actinodromous; P: Pinnate; PL: Parallel venation; EC: Eucamptodromous, Q: Quantity.

past. The dicotyledonous leaves morphotypes consist of 22 morphotypes of entire margins and one of the toothed margin and 69% of small leaves with 31% of large leaves.

Lithostratigraphy

From the primary sedimentologic and stratigraphic study, the Doi Ton succession was interpreted to be a fluvial channel deposit (Figures 1(c)-1(d)).

The lower and upper contacts between Doi Ton strata and other rock units could not be observed in the study area. The lithostratigraphic sections were measured and described. Generally, Doi Ton mainly consists of sandstone with minor conglomerate and siltstone. These rocks show red weathered color and whitish gray fresh color. The lower part is made up of the thin to medium bedded sandstone to siltstone couplets. These sandstones are fine to very fine grained, sub angular to sub rounded, medium to poorly sorted and with the erosive base. The cycles demonstrate slightly fining upward from sand to silt size. Each cycle is capped by rippled sand layer. The plant fragments are also found in the sandstone layer.

In the middle part, the lithologic sequence is distinguished by rhythmic fining upward. Each cycle begins with a granule conglomerate, followed by thin to medium bedded, coarse to fine grain sandstone, and topped by fine grain sandstone with ripple marks. The conglomerates have polymictic composition with an abundant of chert, sandstone, mudstone, quartz minor of volcanic and metamorphic clasts. These clasts are 2-6 cm, sub angular to well rounded, moderate to poorly sorted, and matrix to clast supported. The conglomerate shows an erosive base characteristic of a channel on the lower part and was deposited with tree trunks. Most of the plant remains (e.g. leaves, tree barks, and branches), few of the gastropod and bivalve were found together in the sandstone layer in this part. The thickness of each cycle is in the range of 20-60 cm. The primary sedimentary structures, ripple mark and bottom structure, indicate the NW paleocurrent direction. The upper succession mainly includes siltstone in reddish weathered color and greyish black fresh color. These siltstones are highly weathered; thus, the bedding was not observed. The thickness of this part is at least 2 m.

The leaf fossils in this site are imprinted in the sandstone with permineralization preservation thus leaving the original structure still be visible.

Paleoclimate

The character of the leaf margin and size of the leaves were used to reconstruct paleoclimate conditions from leaf fossils. After using the equation

of Wolfe (1979) and Wing and Greenwood (1993) the mean annual temperature is 30.4 ± 1.3 degrees of Celsius and the equation of Peppe, *et al.* (2018) the mean annual temperature is 24.1 ± 0.9 degrees of Celsius. The wider range between the mean annual temperature caused by the difference of database that the scholar used to calibrate the temperature from the modern plant. The equation of Peppe *et al.* (2018) shows a lower temperatures than the equation of Wolfe (1979) and Wing and Greenwood (1993) because they constructed the equation from the modern plant in every area of the earth that are more various climatic conditions.

Besides temperature in the past, the area of leaf fossils can give an estimation of the precipitation character. According to the divisions of 42 leaf size of the dicotyledonous leaves (size category), which were divided into 5 classes for Doi Ton. Small leaf classes are more abundant than large leaf classes. The abundant of small leaf classes are made up of microphyll ($25/42 = 60\%$; area $263.08\text{--}2,185.61 \text{ cm}^2$); 7% ($3/42$) of nanophyll (area $105.33\text{--}208.96 \text{ cm}^2$) and only one of leptophyll leaf ($1/42 = 2\%$; area $<35.87 \text{ cm}^2$). The two classes of large leaves consist of five large mesophyll leaves ($5/42 = 12\%$; area $5,225.42\text{--}5,712.97 \text{ cm}^2$) and one-fifths of notophyll leaves ($8/42 = 19\%$; area $2,027.83\text{--}4,081.02 \text{ cm}^2$).

The sedimentology and stratigraphy evidence of Doi Ton are strongly related to the fluvial environment. That means the leaves were transported from the mother plants grown along the river and deposited in the channel not far from the origin. The rocks in this study can be compared with the fluvatile redbed and grayish green facies of Thanomsap (1983). These facies are also rhythmical sediment deposited with conglomerate and sandstone and laid down in a braided-alluvial way. Moreover, they can be correlated with the Tertiary basal sand near Tichara, Myanmar too.

The relationship between leaf characters and inhabited nature is a powerful tool for paleoclimate reconstruction, using the margin and size of the leaves for LMA and LSI respectively, the methods are the easy but effective result.

Most of the leaf fossils in Doi Ton are a higher proportion of entire margined vs. toothed margined. Only one or four percent of the leaf morphotype shows a toothed margin. This ratio is related to the higher mean annual temperature (Bailey and Sinott, 1916; Wolfe, 1979; Wing and Greenwood, 1993; Royer *et al.*, 2005; Su *et al.*, 2010; Steart *et al.*, 2011). The range of temperature suggests the vegetation in a tropical zone such as a tropical dry forest (Murphu and Lugo, 1986). But the only one leaf in the Doi Ton leaf morphotype as a toothed margin, which is a small sample size, can produce the uncertainty of mean annual temperature.

The size of the leaf is valuable for estimate climate conditions. The larger leaves are enriching in the mesic environment than the dry environment (Webb, 1968; Dolph and Dilcher, 1980; Hall and Swaine, 1981; Givnish, 1984). Following Webb (1968) studied, which is study the leaf size with the margin type of the rain forest in Australia for subdividing the forest type. For Doi Ton, there are 34% of large leaf class (e.g. 13% of mesophyll; 21% of notophyll), 66% of microphyll (small leaf class) and 96% of the entire margin. The leaf size ratio and margin type are well agreed with data of the Semi-evergreen Vine thicket (SEVT) sub formation of the rain forest, the study of the physiognomic classification of the rain forest. This sub formation is abundant of microphyll and smaller leaf size. The canopy level uneven 4.5-9 m, with mixed evergreen, semi-evergreen and deciduous emergent to 9-18 m. This forest is in a subtropical rain forest region with lowland and lower montane. Moreover, the proportion of leaf sizes was used to estimate the rainfall in tropical Africa by Jacobs (1999). The study by Jacobs found that the ratio of the large leaf (notophyll + mesophyll + macrophyll) vs. small leaf (leptophyll + nanophyll + microphyll) has a positive correlation to mean annual precipitation. There are 31% larger leaves and 69% smaller leaves, indicating a relatively dry environment. The proportion is similar to the deciduous forest of the study site of Africa such as the Arabuko-Sokoke Natural Reserve deciduous forest in Kenya, the Lengwe deciduous forest in Malawi.

The average temperature and average precipitation per year of the Doi Ton site can construct the vegetation style based on the Whittaker biomes classification scheme (Whittaker, 1975). The paleo-forest is matched with the seasonal tropical rainforest as known as semi-evergreen forest, tropical mixed or moist deciduous forest by the data of LMA and LAA analysis. This analysis illustrates Doi Ton area in the past is very closed to the present vegetation that widely distributed in the Mae Sot area. Nevertheless, the large number of small leaves must concern, because the large leaf easily broken while transported to deposit. Moreover, the smaller leaves and their character are also associated with the condition of temperature (e.g. altitude or latitude), soil character (moisture, draining, nutrient) and lightness and spaces of the fore (Jacobs, 1999; Royer *et al.*, 2005; Greenwood, 2007).

The taphonomic processes are directly impacted by the leaf character and leaf diversity, so the leaf assemblage is not referred to all the vegetation conditions. Because the leaf is easily to decay than the other part of the plant. The leaf fossils that preserved in fluvial sediments are considered as

par autochthonous. That means the leaves are transported from the mother plant to the deposition place with a short route (Gastaldo *et al.*, 1996; Greenwood, 2005; Kunzmann and Walther, 2007; Su *et al.*, 2010).

Conclusions

The present paper presents a univariable quantitative analysis of paleoclimatic conditions for Doi Ton site in the Mae Sot Basin. More than 80 imprint leaves in sandstone were collected, but there are only 50 leaf samples can be studied the leaf anatomy and analyzed the climate. These leaves subdivided to 23 dicot leaf morphotype and two unknown leaf morphotypes. Compared with the number of leaf samples collected can refer to the high diversity of the plant community, with more than half of the morphotype shown by only one sample.

LMA approach indicates a mean annual temperature range of 24.51°C to 30.52°C. Leaf size reveals that the flora is a warm and wet deciduous forest or semi-evergreen forest in the lower latitude area. Likewise, the results should be critically considered and discussed in terms of taphonomic effects, taxonomic and climatological localization, e.g. some species are tolerant in a wide range of environmental conditions. From the sedimentology and stratigraphy of the Doi Ton site indicate the fossil leaves are preserved in fluvial sandstone with short transported from the source area.

The whole flora was associated with a remained in the tropical domain, which is possibly similar that the early Cenozoic time of Thailand. However, further studies with a larger flora database or collection and accurate taxonomy will be needed to confirm the paleoclimate interpret.

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