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Research Article

New fossil woods from the Mesozoic Khorat Group of Thailand and their palaeoecological implications

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Abstract- Despite its limited stratigraphical value, fossil wood has been revealed to be of interest to characterize the palaeoenvironment evolution during the sedimentation of the Khorat Group. It helps understand the ecosystems in which the rich Thai Dinosaur faunas evolved. The available Khorat group fossil wood record was, however, mostly from the northeastern Thailand (Isan). New data are presented here, from the southwestern Isan provinces of Chaiyaphum and Nakhon Ratchasima. Although 17 new samples were studied, specific diversity was not increased, which suggests that the taxonomical investigation of the Khorat wood record is quite complete. Fossil wood from the Phu Phan Formation is reported for the first time, and assigned to the genus *Shimakuroxylon*. Despite being sedimentologically similar, the Phra Wihan and Phu Phan formations seem to yield different woods, which suggests that they may have had different palaeoecology or provenance.

Keywords: Fossil wood, Mesozoic, Thailand, palaeobiogeography, taxonomy

1. Introduction

In 2004, a synthesis was published about the fossil woods of the Mesozoic Khorat Group in north-eastern Thailand (Philippe *et al*., 2004). This synthesis focused on the stratigraphy and palaeobiogeography. It revealed a medium-rich record, with four taxa, as well as a wood diversity decreasing over time, from the Phu Kradung Formation upward to the Sao Khua Formation. It also evidenced strong biogeographical affinities with the coeval Indochina (Lao, Cambodia, Vietnam) fossil wood record. The data base for this first synthesis, however, was mostly based on samples collected in central Isan, with most of the samples originating from the Upper Phu Kradung Formation in Phu Phan Range.

We collected and investigated more wood samples from the Mesozoic Khorat group in Chaiyaphum and Nakhon Ratchasima Provinces (southern Isan), and tried to focus on poorly sampled levels. Seventeen samples were studied, including two from the Phu Phan Formation for which no wood data has been reported yet.

These new results are integrated in a reappraised taxonomical framework, as systematical novelties have been published since the 2004 study (Philippe *et al*., 2011, 2014).

2. Material and method

The same stratigraphical framework as in 2004 is used here, apart from the Waritchapum Formation being merged into the Phu Kradung Formation. The Waritchapum Formation is mostly individualised in the Phu Phan Range and in seismic data (Mouret *et al*., 1993), but it is much more difficult, if not impossible, to locate accurately in the field or outside this range (V. Suteethorn, personal communication). All wood data published from the Waritchapum Formation in 2004 has been attributed to the Phu Kradung Formation. The stratigraphical framework is given in Table 1. Wood was collected from six localities (Fig. 1). We tried to focus our sampling effort on those formations that are little-known from the fossil wood point of view.

Fossil wood specimens MP 1925 to 1930 were collected as weathered samples on the surface of a Nam Phong Formation outcrop, at Phu Nokkhien, near Nong Buadang, northwest of Chaiyaphum (E776022, N1780406, Z47Q). Fossil wood pieces are rounded, pebble to gravel-like, and associated with other rounded pieces of hard stones like cherts and quartzite. It is not certain if these pebbles and gravel resulted from the alteration of a conglomeratic layer within the Nam Phong Formation, or if they are alterite residues on the surface and from a remote provenance. They might also have been reworked from underlying formations into the Nam Phong Formation. These are the first fossil woods documented from the Nam Phong Formation. Unfortunately, however, they were found to be deeply recrystallized, with no preserved wood structure. This recrystallization is probably a sign of some reworking.

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At the Petrified Wood Museum in Nakhon Ratchasima we sampled a Nam Phong Formation fossil wood given by villagers, which was found alongside the Chi River, in Ban Nong Ped, Thayai subdistrict (E785248, N1772021, Z47P). This wood, MP1932, was somewhat better preserved but could still only be tentatively identified.

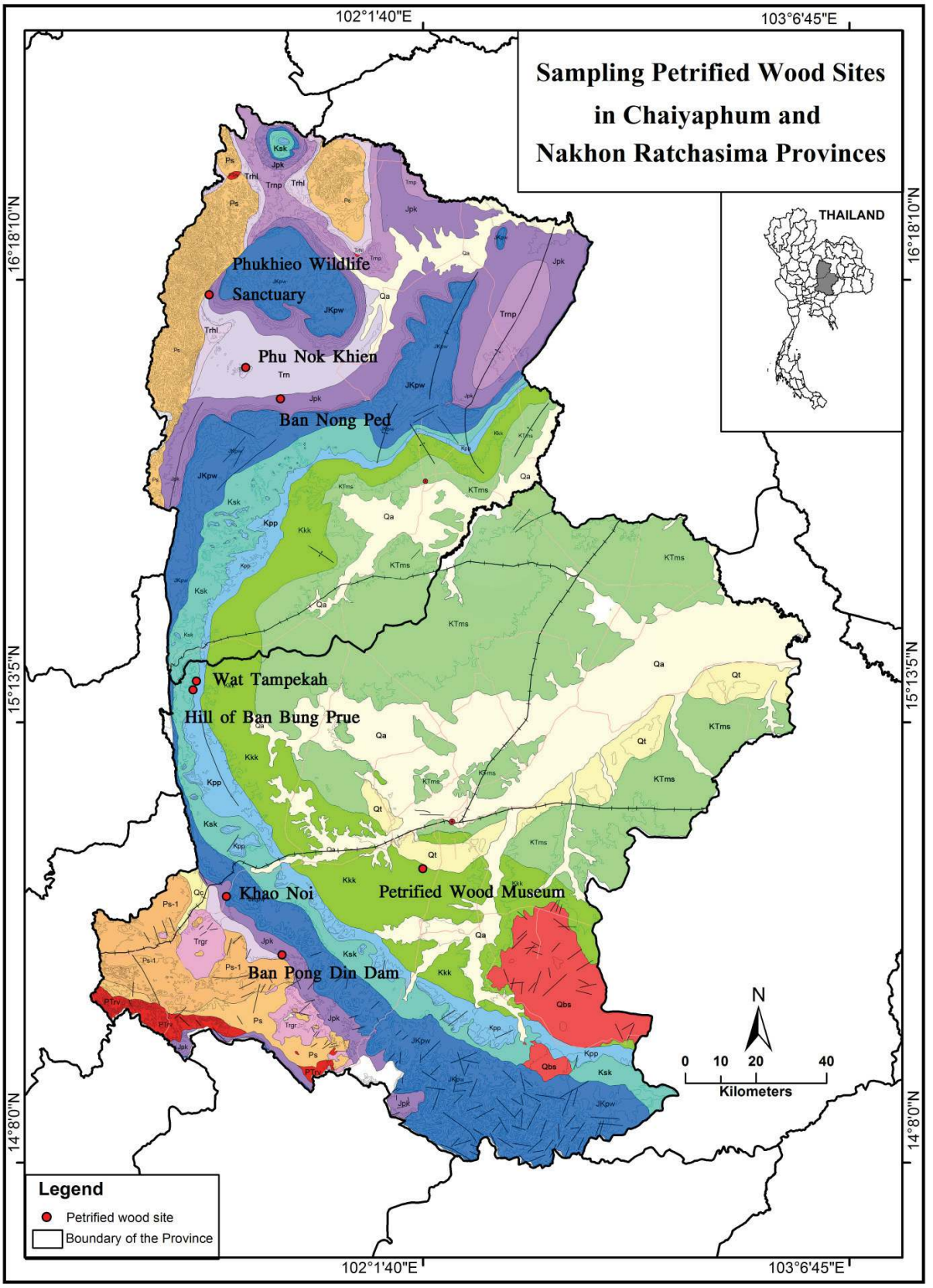

Figure 1. Geological map of Chaiyaphum and Nakhon Ratchasima Provinces, Thailand (Department of Mineral Resources, 2007) with studied petrified wood sites.

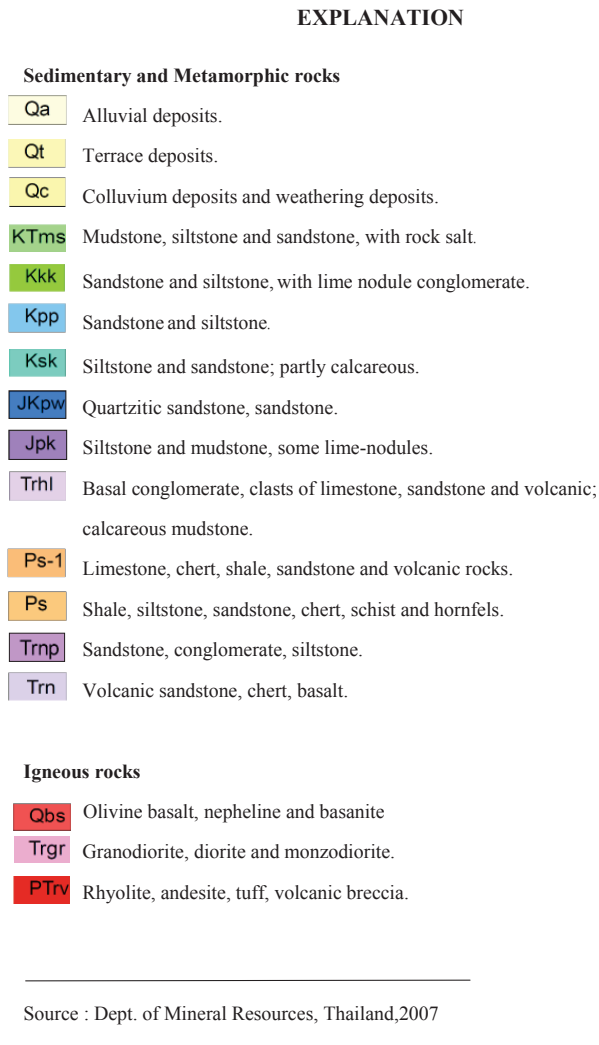

Figure 1. Geological map of Chaiyaphum and Nakhon Ratchasima Provinces, Thailand (Department of Mineral Resources, 2007) with studied petrified wood sites. (Cont.)

In the Phu Kradung Formation, a fossil wood was collected at Khao Noi fossil wood site, near the Lam Takhong Dam, Pakchong District, Nakhon Ratchasima Province (E810953, N1605454, Z47P). The specimen (sample MP1924) is a piece of silicified wood, which was found isolated in the material from a fish pond excavation, about 100 m NW of a shrine that shelters a large fossil log identified as *Agathoxylon* sp. (Songtham *et al*., 2011). At the Northeastern Petrified Wood Museum in Nakhon Ratchasima we sampled fossil woods (samples MP1933 and 1934) that were collected at the Ban Pong Din Dam, Pakchong District, Nakhon Ratchasima Province (E787498, N1620835, Z47P). We collected samples from the base of the southern cliffs of the Phu Khieo Wildlife Sanctuary, Nang Daet Subdistrict, Nong Bua Daeng District, Chaiyaphum Province (E765512, N1799869, Z47P). Fossil wood is abundant there, including large logs and we sampled five specimens: MP 1936-1940 (Fig. 2).

In the Phu Phan Formation, at the temple Wat Tampekah (E762251, N1692708, Z47P), we studied a large fossil wood donated by a villager. The wood was not sampled as a hand-lens revealed that it is a poorly preserved homoxylous tracheidoxyl. On Phu Kao Hill, Ban Bung Prue, Thepharak District, Nakhon Ratchasima Province (E763296, N1695993, Z47P), we studied several wood pieces among which we selected samples MP1931 and MP1935. All these wood pieces apparently originated from a large fossil log that was broken into numerous parts, although it was impossible to be sure that only one log was involved.

For anatomical studies, thin sections were prepared transversely, longitudinally radially and tangentially by standard methods (Hass and Rowe, 1999).

Table 1. Partial stratigraphy of Mesozoic Khorat Group, Northeastern Thailand (adapted from Philippe *et al*., 2014).

AGE			GROUP	FORMATION
Cretaceous	Early	Albian	Khorat	Khok Kruat
		? Valanginian to Aptian		Phu Phan
				Sao Khua
		? Late Jurassic to Berriasian?		Phra Wihan
				Phu Kradung
Jurassic	?Early to Late			Nam Phong

Figure 2. Sample MP1937 from the base of the southern cliffs of the Phu Khieo Wildlife Sanctuary, Chaiyaphum Province. Note that only the darkest part on the left of the fossil wood was cropping out.

3. Results

The results of our xylological investigation are summarized in Table 2. The woods from the Nam Phong Formation are mostly deeply recrystallized. Their xylological features are not preserved, except for the general cross-section pattern. Only in MP1932 could some radial tracheid pitting and cross-fields be observed. They fitted with those of genus *Agathoxylon* Hartig, although not enough pits were observed to make a certain identification. This wood type is a very common one in the fossil wood record from the Palaeozoic upward to the Late Cretaceous (Philippe, 2011). It cannot help, thus, to decipher the origin of these weathered samples on the surface of the Nam Phong Formation outcrops. It is possible that this sample was actually reworked from older strata within the Nam Phong Formation, as quite often happens for silicified wood (Philippe *et al*., 2000).

More interestingly, all the specimens from the Phu Kradung Formation were assigned to the recently described *Shimakuroxylon japonicum* (Shimakura) Philippe, Boura Oh *et* Pons (Philippe *et al*., 2014). It is the same taxon that was determined from the Phu Phan Formation (Fig. 3).

Table 2. Results of taxonomical investigations. Sample numbers are those in the Philippe's collection in the Collections paléobotaniques del'Université Lyon-1, Villeurbanne, France.

Sample	Formation	Identification
MP1924	Phu Kradung	Homoxylous tracheidoxyl
MP1925	Nam Phong	Homoxylous tracheidoxyl
MP1926	Nam Phong	Homoxylous tracheidoxyl
MP1927	Nam Phong	Homoxylous tracheidoxyl
MP1928	Nam Phong	Homoxylous tracheidoxyl
MP1929	Nam Phong	Homoxylous tracheidoxyl
MP1930	Nam Phong	Homoxylous tracheidoxyl, biseriate rays
MP1931	Phu Phan	*Shimakuroxylon japonicum* (Shimakura) Philippe, Boura Oh *et* Pons
MP1932	Nam Phong	cf. *Agathoxylon*
MP1933	Phu Kradung	Homoxylous tracheidoxyl
MP1934	Phu Kradung	Homoxylous tracheidoxyl
MP1935	Phu Phan	Homoxylous tracheidoxyl
MP1936	Phu Kradung	*Shimakuroxylon japonicum* (Shimakura) Philippe, Boura Oh *et* Pons
MP1937	Phu Kradung	*Shimakuroxylon japonicum* (Shimakura) Philippe, Boura Oh *et* Pons
MP1938	Phu Kradung	*Shimakuroxylon japonicum* (Shimakura) Philippe, Boura Oh *et* Pons
MP1939	Phu Kradung	*Shimakuroxylon japonicum* (Shimakura) Philippe, Boura Oh *et* Pons
MP1940	Phu Kradung	*Shimakuroxylon japonicum* (Shimakura) Philippe, Boura Oh *et* Pons

4. Discussion and conclusion

Despite the 17 newly investigated samples, seven of which were assigned to a fossil taxon, the specific diversity has not increase as compared to the 2004 record. This suggests that the taxonomical investigation of the Khorat wood record is quite complete, at least for the Phu Kradung Formation (Table 3).

The report of *S. japonicum* from the Phu Phan Formation has a double interest. First, it is the first identification of a wood from the Phu Phan Formation, which was not xylologically documented up to now. Second, it shows that after an apparent parenthesis this taxon reappeared in the Khorat Basin by the late Early Cretaceous. Although the fossil wood record of the Phra Wihan and Sao Khua is limited, it does not seem to have included *S. japonicum*. If this does not result from a taphonomical bias, then the absence of *S. japonicum* is probably best explained by palaeoecological reasons.

While the Phu Kradung Formation has a relatively diverse wood flora, the Phra Wihan Formation and Sao Khua Formation records are limited to the genus *Agathoxylon*. It was hypothesized that this wood diversity impoverishment was due to a palaeoecological shift towards drier conditions. This, in turn, could have resulted from a decrease in the local rainfall, an increase in the evapo-transpiration rate or a decrease in the external water drainage into the Khorat Basin. Whatever the reason, the occurrence of *S. japonicum* in the Phu Phan Formation points to a return to wetter conditions. Indeed this taxon was bound to year-round warm and at least seasonally wet climates (Philippe *et al*., 2014).

Figure 3. Typical radial tracheid pitting for *Shimakuroxylon japonicum* (Shimakura) Philippe, Boura Oh et Pons. Scale bar is 150 μm.

Table 3. Wood taxa recognized for the Khorat Group (adapted and completed from Philippe *et al*., 2004).

	Phu Kradung Formation	Phra Wihan Formation	Sao Khua Formation	Phu Phan Formation
Agathoxylon saravanensis	+	+	+	
Brachyoxylon orientale	+			
Brachyoxylon serrae	+			
Shimakuroxylon japonicum	+			+

It is speculated that changes in the sedimentary facies between the various formations of the Khorat Group reflect mostly regional climatic variations, and then the wood record of the thick white-sandstone dominated Phu Phan Formation should be similar to that of the Phra Wihan Formation. Indeed there is a striking parallel between the abrupt vertical transition from the Phu Kradung Formation mixed siliclastic red-beds to the Phra Wihan massive white sandstones and the similar transition from the Sao Khua Formation red beds to the white sandstones of the Phu Phan Formation (Booth and Sattayarak, 2011). The discrepancy between the Phra Wihan Formation fossil wood record, which is limited to *Agathoxylon saravanensis*, and the Phu Phan Formation fossil wood record, which is limited to *S. japonicum*, suggests that climatic variations were not the only driver in the sedimentary changes. Changes in the sediment provenance, palaeoecological differences induced by changes in the accommodation space or subsidence as well as more subtle changes in the biosphere may also have played a significant role.

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