Advancing
PALEONTOLOGICAL RESEARCH
& SPECIMEN CONSERVATION in Southeast Asia
Bangkok, Thailand
December 17th -19th 2019

Final Report

AC21 Special Project Fund (SPF) 2019: Advancing Paleontological Research and Specimen Conservation in Southeast Asia

Funded by: Academic Consortium 21 & The Department of Mineral Resources, Thailand

Hosted by: North Carolina State University, USA; Stellenbosch University, South Africa; Kasertsart University, Thailand; Suranaree University of Technology & The Department of Mineral Resources, Thailand.

Additional Participating Institutions: Mahasarakham University; Chulalongkorn University; Khorat Fossil Museum (Nakhon Ratchasima Rajabhat University), Chiang Mai University, Thammasart University, Rama IX Museum, Thailand; & Fukui Prefectural University, Japan; & Western State Colorado University, USA.

Academic Consortium 21
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Background

The Cretaceous Period (145-65 million years ago) was a dynamic time in the co-evolution of life and planet. During this time, Earth's inhabitants endured climate changes that mirror our modern challenges, including a global temperature spike attributable to increased atmospheric CO_2 and dramatic sea-level rise that flooded coastal areas, dividing continents into island refugia. As a result, many species went extinct, redefining the composition of terrestrial ecosystems on a planetary scale. Over a century of paleontological explorations in North America document the impact of these events regionally; however, little is known about how climate change affected plants and animals inhabiting Southeastern Asia during this time. The Khorat Plateau, connecting Thailand, Laos, and Cambodia, contains one of the richest Cretaceous rock records in the region, offering the potential for scientists to make key discoveries that extend our knowledge of these effects across the Northern Hemisphere. However, reconstructing paleoclimate and biodiversity trends requires a multidisciplinary team of experts and mastery of the latest approaches for synthesizing palaeontological, sedimentological, stratigraphical, geochronological & geochemical data. With the generous support of an AC21 Special Project Fund award, paleontologists, geologists, and paleoclimatologists from North Carolina State University [NCSU, USA], Stellenbosch University [SU, South Africa], and Kasetsart University [KU, Thailand], collaborated with regional and international partners including Western Colorado University [WCU, USA], the North Carolina Museum of Natural Sciences [NCMNS, USA], Suranaree University of Technology [Thailand] and the Department of Mineral Resources [Thailand] to co-host the first international symposium directed toward this effort.

Summary of Symposium Activities

The three-day meeting was held at the Berkeley Hotel in Bangkok, Thailand, December 17th-19th and included 80 participants. The symposium opened with a full-day of research presentations summarizing the current state of knowledge about southeastern Asian geology and paleontology including keynote presentations focusing on the challenges and opportunities for research in the region. Talks were followed by three workshops that provided hands-on training in the latest methodologies. Workshop I: Reconstructing Ancient Ecosystems: Application of Detrital Zircon Geochronology and Isotope Geochemistry was led by Dr. Ryan Tucker (SU) and Dr. Ethan Hyland (NCSU). The workshop provided hands-on experience in using detrital zircon geochronology as a provenance tool for tectonic and paleogeographical reconstruction, landscape evolution, and refining the age of terrestrial floras and faunas, as well as the application of stable isotope techniques for creating high-resolution records of climate in deep time, and correlating ecosystem impacts with major climate events. Workshop II: Mitigating deterioration of fossil specimens due to pyrite oxidation explored various methods for conserving fossil specimens at risk for destruction by pyrite decay (a serious and widespread concern with many Thai fossils) and was led by Lisa Herzog (NCMNS). Participants included museum curators and collection managers who performed hands on mitigation with Thai fossils. Finally, Workshop III: Digitizing Dinosaurs: how to use advanced visualization techniques to conserve and study fossil specimens was led by Dr. Ryan King (WCU) and Dr. Lindsay Zanno (NCSU) and explored the use of rapid, high-resolution, 3D imaging technology to capture and model paleontological and geological data as well as different options for data archiving as a means for museum and universities to increase visibility of their research collections. Each workshop accommodated thirty participants.

Participants and host committee members of the symposium: Advancing Paleontological Research and Specimen Conservation in Southeast Asia, December 2019.

The symposium opened with 15 presentations at Kensington Ballroom, 5th Floor, Berkeley Pratunam Hotel.

Participants study geochronology techniques during the workshop: Reconstructing Ancient Ecosystems: Application of Detrital Zircon Geochronology and Isotope Geochemistry led by Dr. Ryan Tucker and Dr. Ethan Hyland.

Participants practice constructing photogrammetric models of fossils with Dr. Ryan King during the workshop: Digitizing Dinosaurs: how to use advanced visualization techniques to conserve and study fossil specimens.

Participants learn fossil conservation methods with expert Lisa Herzog during the workshop: Mitigating deterioration of fossil specimens due to pyrite oxidation explored various methods for conserving fossil specimens at risk for destruction by pyrite decay.

Pre-Symposium Field Excursion

Prior to the symposium, members of the host committee conducted two weeks of joint fieldwork in the Cretaceous Sao Khua Formation on the Khorat Plateau with four undergraduate students. Students were trained in collecting fossils materials and gathering sedimentological and stratigraphic data for independent research projects. The project team collected the partial remains of a dinosaur skeleton as well as data for future paleoclimate reconstructions of the region and geochronology of sediments of the Khorat Group. During the fieldwork, members of the host committee engaged in public outreach with community stakeholders and local politicians about identifying and protecting fossil resources in their area. The host committee also had several successful meetings to outline future research efforts and collect preliminary data for upcoming grants proposals to support future collaborative research.

The symposium project team trained four undergraduate students from Kasetsart University in field methods for paleontological and geological data collection in a pre-symposium field excursion.

Project team spent time conducting public outreach with community leaders, and project planning in the field.

DEPARTMENT OF MINERAL RESOURCES

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Advancing PALEONTOLOGICAL RESEARCH & SPECIMEN CONSERVATION in Southeast Asia

Ichnogenus *Eubrontes* isp. at Tha Uthen quarry.
Photo by Dr. Shohei KOZU

17th-19th December 2019
@The Berkeley Hotel Pratunam
Bangkok, Thailand

The International Symposium and Workshop

Advancing PALEONTOLOGICAL RESEARCH & SPECIMEN CONSERVATION *in Southeast Asia*

Bangkok, Thailand
December 17th -19th 2019

Berkeley Pratunam Hotel, Bangkok Thailand

Kensington Ballroom 5th Floor

Organizers

UNIVERSITEIT STELLENBOSCH UNIVERSITY

NC STATE UNIVERSITY

PREFACE

The Royal Thai Government, through the Department of Mineral Resources, Ministry of Natural Resources and Environment and North Carolina State University, in collaboration with Stellenbosch University, Kasetsart University and Suranaree University of Technology organize the International Symposium and Workshop on "Advancing Paleontological Research and Specimen Conservation in Southeast Asia". Between 17th and 19th December 2019 at the Berkeley Hotel Pratunam, Bangkok, Thailand.

Three-day activities comprise of one day symposium and two days workshop. The symposium provides an opportunity for more than 80 participants from Thai government organization and universities to share knowledge and expertise in paleontology and geology, in particular advancing geological research and extend networking for future research collaboration. The workshop provides a modern technology for fossil conservation and application of Detrital Zircon Geochronology and Isotope Geochemistry.

On behalf of the organizers, we would like to warmly welcome you all to the symposium and workshop. We hope that this event can lead our geoscientist colleagues' attention to the major role that the paleontology can play for a society. We wish the symposium and workshop all success and wish you all a pleasant time in the beautiful city of Bangkok.

The International Symposium and Workshop
"Advancing Paleontological Research and Specimen Conservation in Southeast Asia"
17th -19th December 2019, Kensington Ballroom, 5th Floor
Berkeley Pratunam Hotel, Bangkok, Thailand

International Symposium

Tuesday 17th December 2019

08.00-08.30	Registration
08.30-09.00	Opening ceremony at Kensington Ballroom, 5th Floor, Berkeley Pratunam Hotel
09.00-09.30	**Keynote Speaker 1: Mr. Nares Sattayarak** "What Would Geologists Like to See More in Paleontological Research in Thailand"
09.30-10.00	**Keynote Speaker 2: Dr. Terry Gate** The dynamic exchange of dinosaurs between Asia and North America"
10.00-10.30	**Keynote Speaker 3: Prof. Dr. Punya Charusiri, Thailand** "Updated U-Pb Age data: Its significances for provenances and tectonic settings"
10.30-10.45	Coffee break
10.45-11.15	**Speaker 1: Assoc. Prof. Dr. Thasinee Charoentitirat, Chulalongkorn University** "Geotectonic evolution of Thailand during Upper Paleozoic time"
11.15-11.45	**Speaker 2: Dr. Pradit Nulay, Department of Mineral Resources** "Geology and stratigraphy of the Khorat Plateau"
11.45-12.05	**Speaker 3: Dr. Pitaksit Ditbanjong, Chiang Mai University** "Sedimentology and stratigraphy of the Jurassic continental deposit "ms Group" from Sukhothai Fold Belt, Northern Thailand"
12.05-13.00	Lunch
13.00-13.20	**Speaker 4: Dr. Chalida Laojumpon, Thammasart University, Bangkok** "Triassic-Jurassic boundary vertebrate fossils from Thailand: a Review"
13.20-13.40	**Speaker 5: Dr. Phonphen Chanthasit, Department of Mineral Resources** "Biodiversity of the Late Jurassic/Early Cretaceous Phu Noi, Phu Kradung Formation, Kalasin, Thailand"
13.40-14.00	**Speaker 6: Dr. Duangsuda Chokechaloemwong**, **Nakhon Ratchasima Rajabhat University** "Theropod of the late Early Cretaceous Khok Kruat Formation, Ban Saphan Hin, Nakhon Ratchasima"
14.00-14.20	**Speaker 7: Dr. Masateru Shibata, Fukui Prefectural Dinosaur Museum, Japan** "Iguanodontian dinosaurs of the Khok Kruat Formation, Nakhon Ratchasima"
14.20-14.40	Coffee break

14.40-15.00 **Speaker 8: Miss Sasa-on Khansubha, Department of Mineal Resources**
"Giant Sauropod Remains from the Early Cretaceous Khok Kruat Formation, Ban Phanang Sua, Nongbua Rawe, Chaiyaphum"

15.00-15.20 **Speaker 9: Dr. Ryan T. Tucker, Stellenbosch University, South Africa**
"A refined temporal framework for the upper Cedar Mountain Formation (Mussentuchit Member), Mussentuchit Wash, Central Utah"

15.20-15.40 **Speaker 10: Dr. Ladda Tangwattananukul, Kasetsart University**
"An ancient petrified wood in Ban Tak Petrified Forest, Tak Province,Thailand"

15.40-16.00 **Speaker 11: Dr. Wipanu Rugmai, Nakhon Ratchasima Rajabhat University**
"Jurassic-Cretaceous palynofloras from Thailand"

16.00-16.20 **Speaker 12: Dr. Rattanaphorn Hanta, Suranaree University of Technology**
"Baby sauropod of the Nam Phong Formation, Nong Bua Daeng, Chaiyaphum"

Workshop

Wednesday 18th December 2019

09.00-10.30 Workshop: "Reconstructing Ancient Ecosystems: Application of Detrital Zircon Geochronology" by Dr. Ryan T. Tucker

10.30-10.45 Coffee break

10.45-12.00 Workshop: "Reconstructing Ancient Ecosystems: Application of Detrital Zircon Geochronology" (continue) by Dr. Ryan T. Tucker

12.00-13.00 Lunch

13.00-16.30 Workshop: "Reconstructing Ancient Ecosystems: Application of Detrital Zircon Geochronology and Isotope Geochemistry" (continue) by Dr. Ethan Hyland

Thursday 19th December 2019

09.00-10.30 Workshop: Mitigating deterioration of fossil specimens due to pyrite oxidation" by Lisa Herzog

10.30-10.45 Coffee break

10.45-12.00 Workshop: Mitigating deterioration of fossil specimens due to pyrite oxidation" by Lisa Herzog

12.00-13.00 Lunch

13.00-16.00 Workshop: Digitizing Dinosaurs: How to use advanced visualization techniques to conserve and study fossil specimens by Dr. Ryan King and Dr. Lindsay Zanno

16.00-16.30 Closing Workshop

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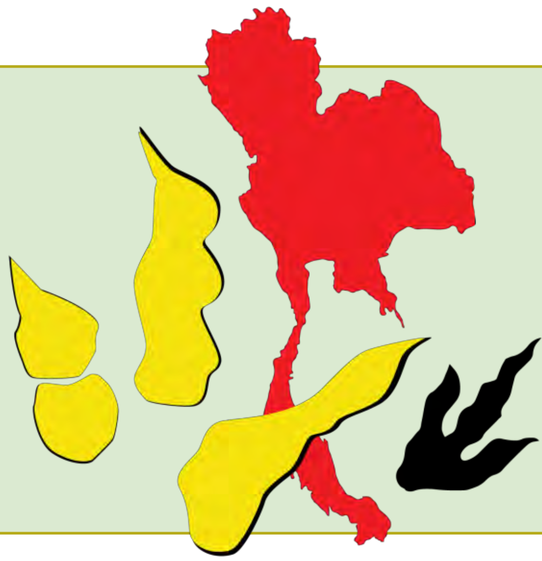
ABSTRACT



A refined temporal framework for newly discovered fossil assemblages of the upper Cedar Mountain Formation (Mussentuchit Member), Mussentuchit Wash, Central Utah

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EXTENDED ABSTRACT

Detangling the pace and structure of biotic turnover between the late Early and early Late Cretaceous within the Western Interior of North America requires refined stratigraphic controls of fossiliferous sediments; however, to date, many key mid- Cretaceous strata remain understudied and only tenuously or coarsely correlated. Intensified data collection in the uppermost Cedar Mountain Formation (Mussentuchit Member) suggests preservation of an undervalued volcanilithic archive that can provide key insight into this enigmatic period in North America’s geological history. Radiometric age dating of its individual members, along with samples from the overlying Naturita Sandstone (Dakota Sandstone of older literature), placed the depositional interval into the Late Albian to early Cenomanian (100-96 Ma) age and identified numerous disconformities and unconformities within the Cedar Mountain Formation (Lawton et al., 2010; Hunt et al., 2011; Arens and Harris (2015); Kirkland et al., 2016; and references therein). The earliest radiometric dates derived from the Mussentuchit Member of the Cedar Mountain Formation were published by Cifelli et al. (1999) in the area of Mussentuchit Wash. Cifelli et al. (1999) recovered age of 98.2 Ma using 40Ar/39Ar chronometry, which have since been recalibrated by Garrison et al. (2007) to be between 98.2-96.7 Ma. Interestingly, the middle ash layer of the three reported by Garrison et al. (2007) is out of temporal sequence. The lowermost ash horizon is age dated at 98.2 Ma with the uppermost age dated at 97.2 Ma; however, the middle ash bed is age dated to be emplaced at 96.7 Ma, possibly indicating reworking (Rossignol et al. 2019; Tucker et al., *In Review*). Therefore, many linkages across the Cedar Mountain Formation, and more specifically, the Mussentuchit Member remain tenuous.

Between 2008 and the present, extensive surveys of the dinosaurian fauna of the Mussentuchit Member have been undertaken in the region of Mussentuchit Wash (here defined as the region of Mussentuchit outcrop spanning from the cliffs flanking the western margin of Last Chance Desert north to Mesa Butte). This decade of work has resulted in the discovery of several new vertebrate species and specimens (Zanno and Makovicky 2013, 2016; Makovicky et al. 2014, 2015; Herzog et al. 2015; Driebergen et al., 2017; Zanno et al. 2019; Avrahami et al. in press) and a dramatic increase in the number of localities preserving identifiable remains. Despite this importance, tenuous linkages both lithostratigraphically and geochronologically render many of these discoveries enigmatic. With this in mind, this study sought to 1) refine the depositional age and the duration of sedimentation of the Mussentuchit Member within this particular depo-centre; 2) determine if the recovered volcanilithics are suitable to generate a robust temporal framework while simultaneously determining if these are non-coval or coeval inputs; thus, providing reliable YMDA’s; and 3) determine if the multiple, newly recovered Mussentuchit

fossil assemblages represent a temporally single assemblage or may, in fact, represent multiple, temporally distinguishable assemblages.

The combination of both LA-ICP-MS and CA-TIMS Data, along with seven numerical methods and additional provenance tools, provides a confident assessment of the youngest maximum depositional ages for the upper and lower sediments of the Mussentuchit Member in this area. We find that the sediments surrounding Mussentuchit Wash were deposited no earlier than the upper Cenomanian, spanning an age interval of 96 to 94 Ma. Furthermore, by coupling well- established K- S Test with novel methods for assessing contemporaneity between sedimentation and volcanism, we identify at least two pulses of sediment input into Mussentuchit Wash depo- centre. The first coeval volcanic input occurs in very basal portions of the lower Mussentuchit Member, accompanied with a non- coeval recycling phases. The second coeval volcanic input occurs in very basal portions of the upper Mussentuchit and a repeated non-coeval volcanism and epiclastics. Therefore, this two phase depositional cycle preserved in the uppermost Cedar Mountain Formation occurred no later than the terminal phase of the Cenomanian, likely linked to the onset of the next phase of thrusting to the west. It is likely that the later- phased sedimentation in the Mussentuchit can be linked to embryonic development of the Last Chance Delta, but occurs before Turonian thrusting of the westerly lying Sevier Belt. Finally, our data indicates that two temporally separable fossil assemblages may be preserved within the lower and upper Mussentuchit Member. Testing this hypothesis will require refined stratigraphic occurrence data for all vertebrate localities within the Mussentuchit recovered to date, as well as detailed anatomical investigations of taxa known from multiple skeletal remains spanning upper and lower sediments of the Member. Our future investigations will seek to broaden and re-examine the findings of this study in a regional context, along with testing broad-scale correlations including those recently published from the Cloverly Formation to the Northeast in Wyoming (D’Emic et al., 2019).

Acknowledgements:

We thank staff, students, and volunteers of the 2015– 2019 expeditions for repeated explorations of the Mussentuchit Member; M. Leschin, S. Foss, G. McDonald, R. Hunt-Foster, J. Kirkland, M. Hayden, J. Krishna, R. Irmis, staff of the Price Field Office, the Bureau of Land Management Utah State Office, Natural History Museum of Utah, and Utah Geological Survey for permitting and expedition support. Special thanks go to Rossouw, R and Bracciali, L of the Central Analytical Facility at Stellenbosch University and Huang, H., at the Advanced Analytical Centre at James Cook University during preparation and data reduction of LA- ICP- MS data, along with Crowley, J., at the Department of Geological Sciences at Boise State University for CA- TIMS analysis and data reduction. Financial support was provided by Stellenbosch University's Department of Earth Sciences, North Carolina Museum of Natural Sciences, the Canyonlands Natural History Association, and the DRD.

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An ancient petrified wood in Ban Tak Petrified Forest, Tak Province Thailand

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Abstract

Petrified wood deposit in Ban Tak District, Tak province, is protected under Fossil Protection Act B.E. 2551 and registered as petrified forest on March 31st, 2016. The Petrified wood deposit is precipitated in Ban Tak – Sam Ngao basin of Pleistocene age. The Petrified wood deposits are distributed on both side of the Ping and Wang Rivers. The characteristics of fossil woods are close to *Koompassia malaccensis* and *Afzelia xylocarpa*. The petrified woods are reddish brown and light brown color composed of 70% quartz, hematite and illite minerals and 30% empty space with no crystallization of mineral. The reddish brown of petrified woods mainly consist of quartz and hematite precipitated between quartz crystals. The light brown fossilized woods predominantly consist of quartz and illite. Quartz can be separated into two textures: mosaic and saccharoidal textures. The saccharoidal quartz is characterized by fine-grained, anhedral to subhedral crystals, and crystals resembling grains of sugar texture. The mosaic quartz is characterized by fine-grained, equivalent crystal size, and jigsaw-like interlocking pattern. Most of quartz formed in the petrified wood are mostly opal-A. The oxygen isotope of quartzes range from 18.1 to 19.4 per mil suggesting silica solution from meteoric water. The petrified woods were preserved in gravel and soil. Age of fossilized woods range from 120,000 to 129,000 year, while soils range from 124,000 to 129,500 year based on thermoluminescence dating. The petrified wood in Tak province was formed by transported of stream and river become buried in the floodplains and the silica mobilization of infiltration must have originated from meteoric water including weathering and soil formation of silica mineral in the age of 120,000 to 129,000 year

Keywords: Petrified wood, Tak province, oxygen isotope, age dating

Introduction

The largest pertified wood of Thailand is cover about 30 km^2 in Ban Tak Petrified Forest, Tak Province, Thailand. There is a longest of petrified wood in SE Asia approximately 72.2 m (Fig. 1). Recently, seven logs of petrified wood were excavated in 2004-2005 and shelter by roofs. Based on the preliminary xylological studies of these petrified wood suggested that these trees are belong to *Koompassioxylon elegans* Kramer of 6 logs and 2 logs of *Afzelie xylocarpa* (Songtham et al., 2011) (Fig. 1). Geology of the study are is composed of mica-schist, gneiss of Precambrian age exposing in the western flank of the area. These Precambrian rocks were intruded by granite, granodiorite of Triassic age (208 to 212 Ma) (Teggin, 1994). These metamorphic and igneous rocks were covered by sedimentary rock of Pleistocene age. These fossil is deposit in Quaternary sedimentary layer, which is gravel of the Ping River (Fig.1) (Kyriazi et al., 2015).

Figure 1 (A) Petrified wood no. 1 is *Koompassioxylon elegans* and the longest fossil wood in Thailan (B) Petrified wood no. 7 is *Afzelie xyocarpa*.

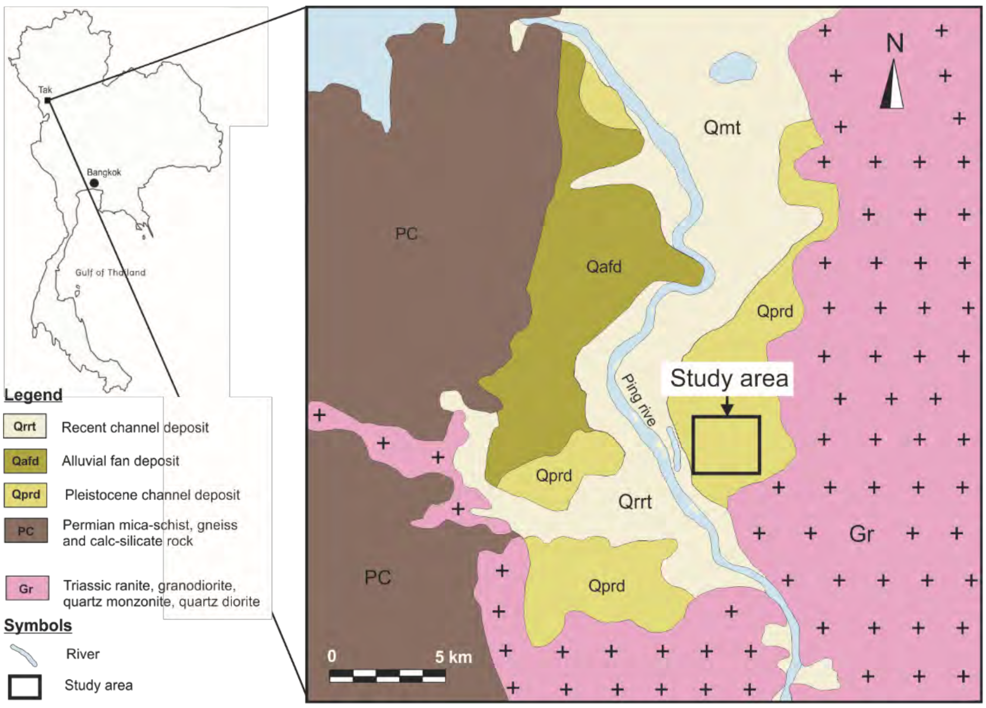

Figure 2 Geologic map of Ban Tak District, Tak Province, Thailand. (modified from Songham et al., 2010).

Result and discussion

The petrified woods are characterized by reddish brown and light brown color which are composed of 70% quartz, hematite and illite minerals and 30% empty space with no crystallization of mineral (Fig. 3). The reddish brown of petrified woods mainly consists of quartz and hematite precipitated between quartz crystals. The light brown fossilized woods predominantly consist of quartz and illite. Quartz can be separated into two textures: mosaic and saccharoidal textures. The saccharoidal quartz is characterized by fine-grained, anhedral to subhedral crystals, and crystals resembling grains of sugar texture. The mosaic quartz is characterized by fine-grained, equivalent crystal size, and jigsaw-like interlocking pattern (Fig.4).

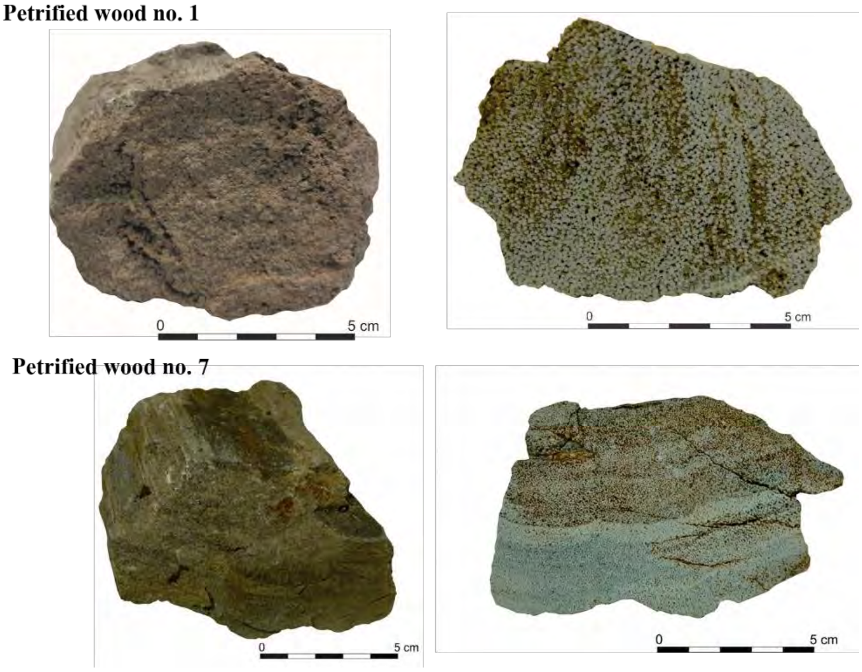

Figure 3. Fossil wood of logs no. 1 and 7 show permineralized of silica, kaolinite, hematite and remain of holes.

Opal-A, Opal-CT and quartz can be classified using reliable characterization by absence of diffraction peak. The samples were analyzed using X-ray diffraction. Quartz and chalcedony can be recognized by the diffraction peaks that the peak is different with Opal-A. Based on the pattern of diffraction peaks by x-ray diffraction of 30 samples of logs no. 1 to 7 are composed of microcrystalline quartz and opal-A. The samples were composed of a large amount of silica polymorph forms of SiO_2 that have different crystallinity such as opal-A (amorphous), opal-CT (cristobalite and tridymite), chalcedony (micro-fibrous quartz), microcrystalline quartz and quartz. The petrified wood samples consist of a large amount of silica polymorph with small amounts of kaolinite and hematite. Quartz and microcrystalline quartz are 50 to 300 μm in diameter that are showing mosaic and saccharoidal textures (Fig. 5). Chalcedony are 20 to 30 μm in diameter with fibrous texture. Microcrystalline quartz and chalcedony filled in the lumina of individual tracheid while quartz fill in larger vessels.

The age of petrified wood and sediment were analyzed by thermoluminescence dating (TL) and optically stimulated luminescence (OSL) dating. Seventeen sample for TL and OSL dating of sediment and petrified wood. Based on the TL and OSL dating can interpret the age of ancient trees grew for a lone time (120,000 – 130,000 years ago) before subversion and deposited during 53,000 – 124,000 year ago.

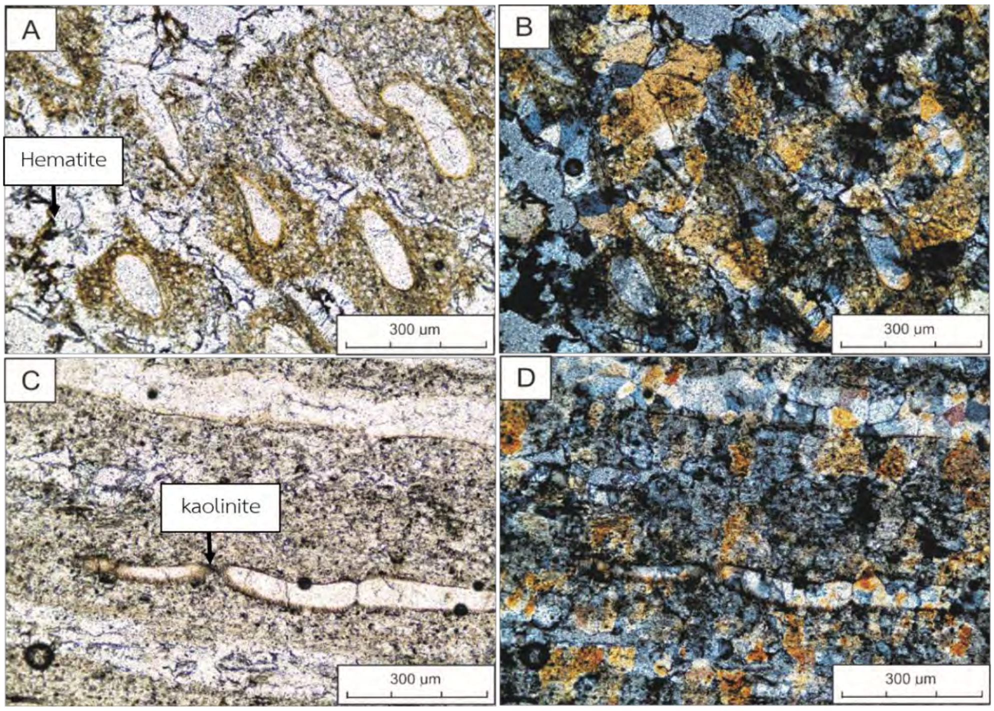

Figure 4. Microphotograph of fossil wood no. 1 (A and B) and fossil wood no. 7 (C and D) are composed of a large amount of microcrystalline quartz, quartz with rare of kaolinite

Summary

Petrified wood in Tak forest was deposited in ancient river by transportation of stream and river. The petrified wood was permineralized by opal-A, chalcedony, quartz with trace amount of kaolinite and hematite. The age of sediment in range of 124,000 to 129,500 years ago, while petrified wood was permineralized in ranging of 120,000 to 129,000 years ago.

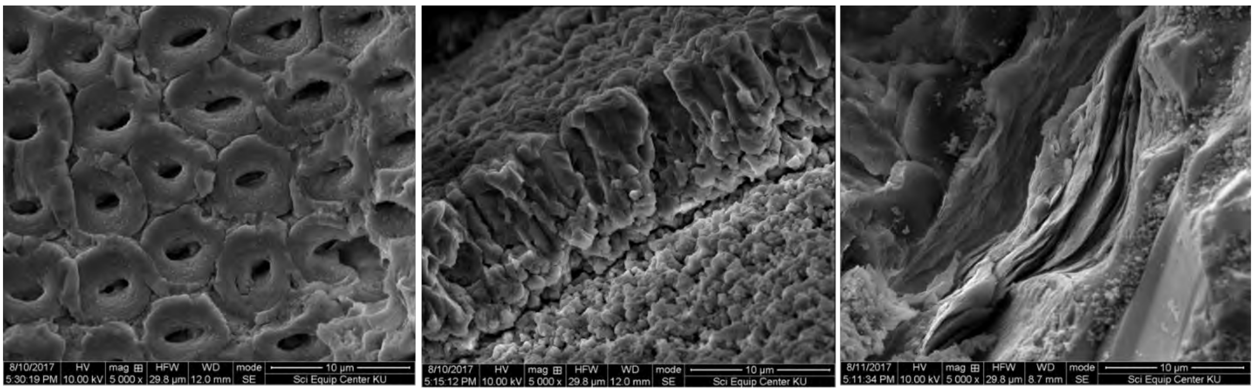

Figure 5. SEM image of opal-A from petrified wood no. 1 and 7.

Acknowledgement

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Baby sauropod of the Nam Phong Formation, Nong Bua Daeng District, Chaiyaphum, northeastern Thailand

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EXTENDED ABSTRACT

An early form of a sauropod has been discovered from the Nam Phong Formation in Nong Bua Daeng District, Chaiypahum Province and has been named as *Isanosaurus attavipachi*. Later more sauropodan specimens were uncovered from nearby the type locality of *Isanosaurus* and other areas that comprised at least two taxa of unknow basal sauropod from this formation. Here we report the baby remains of basal sauropodan remains, a rare material of basal sauropod group, which is crucial for the study of growth development. The studied material was discovered from Thung Sawang village, Wang Chomphu subdistrict, Nong Bua Daeng district, Chaiyaphum province since the year 2007. The material was prepared and stored at the Northeastern Research Institute of Petrified Wood and Mineral Resources. The material was totally covered with the rock matrix and identifiable after years of preparation. The studied material was comprised of two individuals, early-stage and late-stage juveniles. Individual number one, late-stage juvenile, composed of the cervical centrum, femoral shaft, vertebral neural arches (cervical, anterior dorsal, mid-dorsal, and posterior dorsal) and fused anterior caudal vertebral; and individual number two, early-stage juvenile comprise three posterior dorsal vertebral neural arches. The baby sauropods showed that the vertebral laminae form an incipient and simple ridges in the early stage of growth that unrecognized for diagnostic traits. Then the marked complex vertebral laminae were developed in early growth development, in the late-stage juvenile. The complex vertebral laminae of the neural arch suggest that it clearly be unincluded in the basal sauropodormorph (traditionally known as 'prosauropod'). Besides, it shares a number of complex vertebral traits with Tazoudasaurus, a well-known basal sauropod that having a complete skeleton from Morocco. However, its size and proportion cannot be compared due to its early stage of growth which is subjected to change during growth development. In conclusion, the baby sauropod belongs to a basal sauropod, though unable to clarify its taxon to those sauropoda of the Nam Phong Formation and its flat dorsal neural spine implied the capability of the head uplift in early life and probably co-developed with a quadrupedal walking gauge.

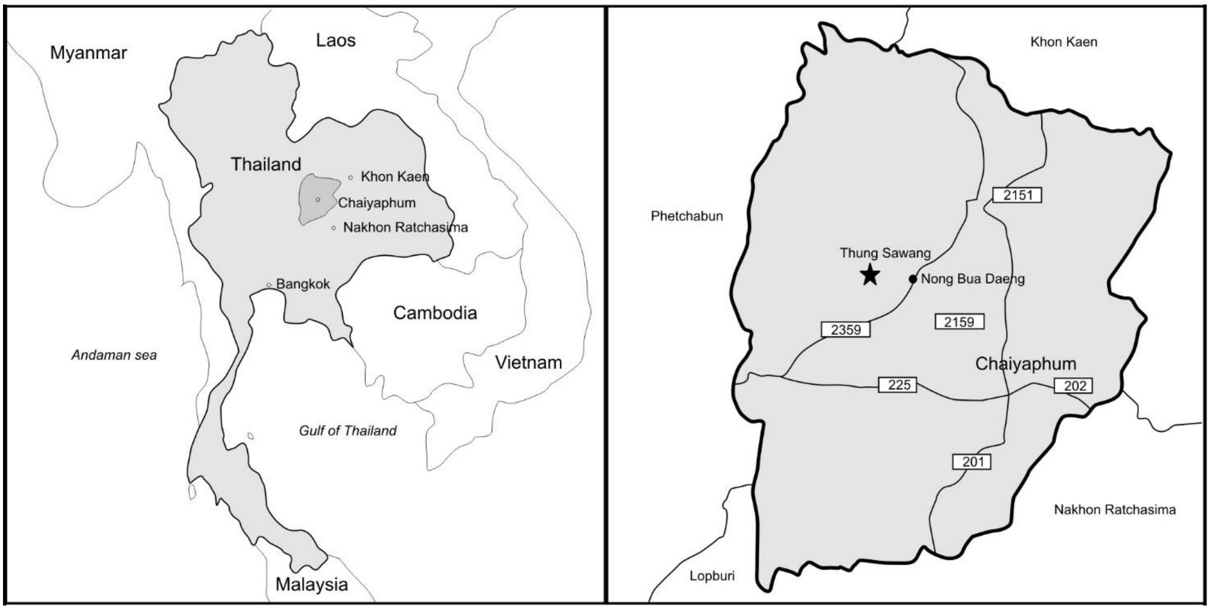

Figure 1. Fossil locality (star mark) in Nong Bua Daeng District, Chaiyaphum Province.

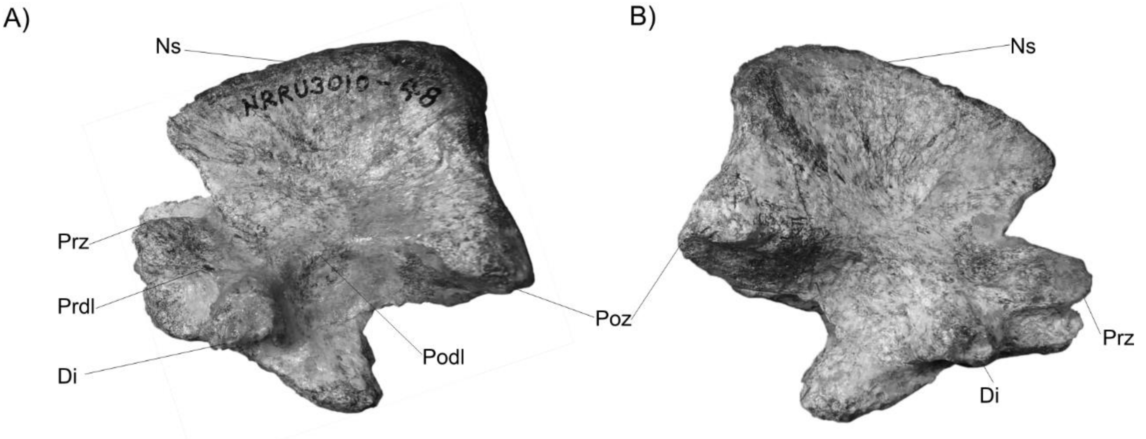

Figure 2. The neural arch of the axis of the individual no. 1, 5 cm in length. Lateral views.

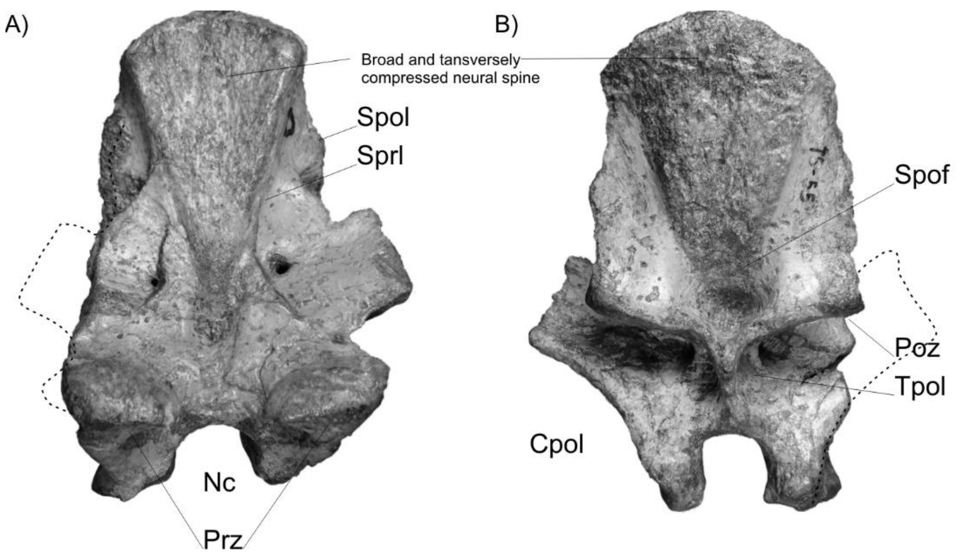

Figure 3. The mid-dorsal neural arch of the individual no. 1, 10 cm in height. Anterior and posterior views.

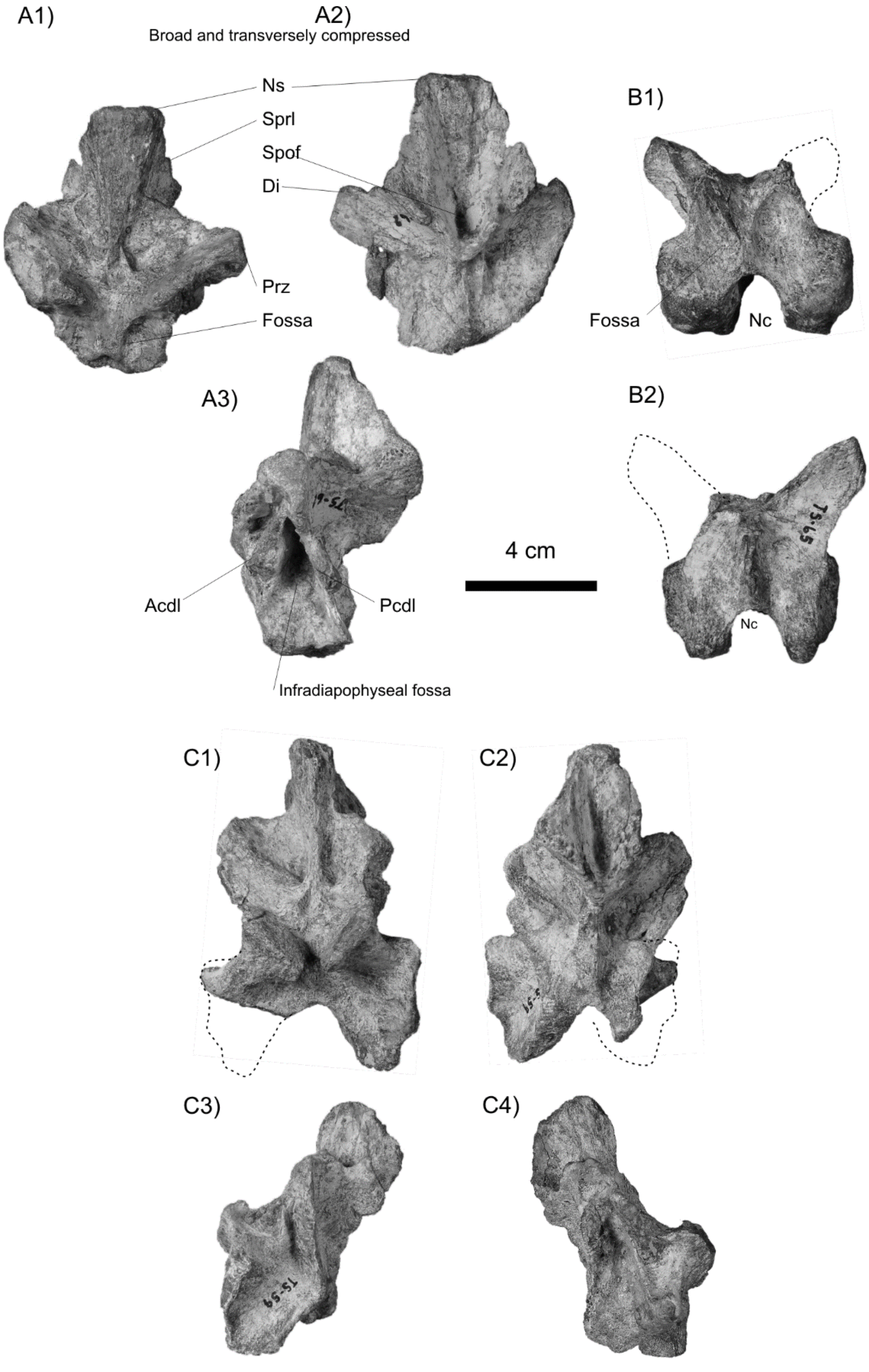

Figure 4. The posterior dorsal neural arch of the individual no. 2.

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For years, the painstaking preparation of material was carried out by the laboratory staff, S. Ruenjangreed. RH thanks to Haruo Saegusa and highly appreciated for several guidance and critical point of views. RH and PJ were grateful to Dong Zhiming for suggestions during visited Yunnan. The study was accomplished by kind help of Yoshikazu Noda and Masateru Shibata of Fukui Prefectural Dinosaur Museum and Hiroshi Nishi of The Center for Academic Resources and Archives, Tohoku University Museum. This study is financially supported by the National Research Council of Thailand.

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Biodiversity of the Late Jurassic/Early Cretaceous Phu Noi, Phu Kradung Formation, Kalasin, Thailand

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ABSTRACT

Phu Noi, a small hill, located in Dinchi Sub-District, Kham Muang District, Kalasin Province (Fig.1), is known as one of the richest Mesozoic vertebrate fossil locality in Thailand. Phu Noi fossils have been discovered from reddish to maroon siltstone and conglomerate of Phu Kradung Formation (Late Jurassic-Early Cretaceous) of the Khorat group which is mostly distributed in northeastern Thailand (Fig.1a). The paleontological excavation at Phu Noi was started in 2008 and has been continuing to the present day by the cooperation between Sirindhorn Museum under the Department of mineral resources and the Palaeontological Research and Education Centre, Mahasarakham University. Thus far, Phu Noi site has distributed almost five thousand pieces of vertebrate fossils and shown a high biodiversity of those fossil assemblages.

The conglomerate of the lower part of Phu Noi contains small fossil remains including actinopterygian scales and teeth, fragments of lungfish toothplates, turtle shell fragment and crocodile teeth. In addition, different fresh water shark taxa have been described from this layer based on characteristic teeth and dermal denticles. They include *Hybodus* sp., *Jiaodontus* sp., *Lonchidion* sp. a new fresh water shark “*Acrodus kalasinensis*” (Cuny et al., 2014) (Fig.2a). In the middle part of Phu Noi, the rich-fossil bearing bed have been uncovered with about 1,200 square metres of excavated area. A new actinopterygian “*Isanichthys lertboosi*” (Cavin et al, 2014), two new xinjiangchelyid turtles: “*Phunoichelys teerakhupti*” (Tong et al., 2014) and “*Kalasinemys prasarttongosothi*” (Tong et al., 2019) and a new freshwater teleosaurid “*Indosinosuchus potamosiamensis*” (Martin et al. 2019) were described (Fig.2b-e). Moreover, an azhdarchoid pterosaur has been reported by Buffetaut et al. (2015) and later discussed by Unwin & Martill (2017). This Phu Noi bone bed has yielded as well as numerous fossils which are currently under study. They include teeth and partial skull roof of lung fish, an almost complete skull and several intercentra of a temnospondyl and several dinosaur remains.

The dinosaur remains are the majority (70%) of Phu Noi fossils with at least three groups of dinosaur taxa: large Sauropodomorph, large Theropoda, and small ornithischian. According to preliminary studies of cranial and postcranial sauropod material, they possibly belong to Mamenchisauridae with probably 2 different forms. The maxillae of Phu Noi theropod show a complex of accessory opening which is the characteristic of the Sinraptoridae (Curries & Zhao, 1993). However various sizes and shapes of theropod teeth have been found and probably suggest the diversity of the group. A lower jaw of a small ornithopod from Phu Noi was briefly described by Buffeteaut et al. (2014). It shows a combination of characters suggesting that it belongs to a new taxon. Recently, a well preserved partial articulated skeleton of a small ornithischian was found and prepared. Although, this dinosaur association can be comparable to the dinosaur assemblage from the upper member of the Middle Jurassic Shaximiao Fm. and Chuanjie Fm. in the Sichuan-Yunnan Basin of China, the dinosaur assemblage dominated by *Mamenchisaurus* is also present in the Upper Jurassic Suining Fm. and Penglaizhen Fm. of Sichuan Basin. Furthermore, according to morphological studies, the sinraptorid specimens from

Phu Noi are comparable to *Sinraptor dongi* from Upper Jurassic Shishugou Fm. of the Junggar Basin in northwestern China and *Yangchuanosaurus* from the Middle Jurassic Shaximiao Fm.

As mentioned above, Phu Noi fossils from Phu Kradung Formation shows a remarkable biodiversity and reveals a close relationship with Chinese Jurassic vertebrate assemblage. However, the detail description and phylogenetic analysis of several taxa are necessary in the approaching studies to better define the Phu Noi fauna and their paleobiogeography. In addition, the future results will clarify the scenario of Late Jurassic to Early Cretaceous ecosystem of the Indochina terrane and Asia before it was replaced by a totally different faunal assemblages and paleoenvironment in the younger Early Cretaceous period.

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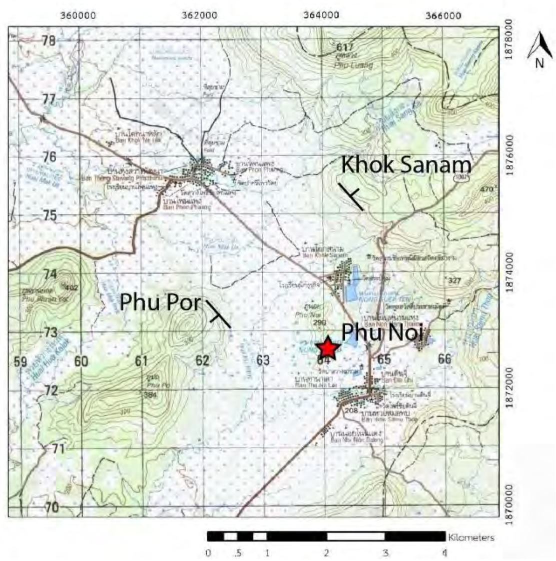

Fig. 1 The distribution of Phu Kradung Formation (above) and the Phu Noi fossil site located by red star.

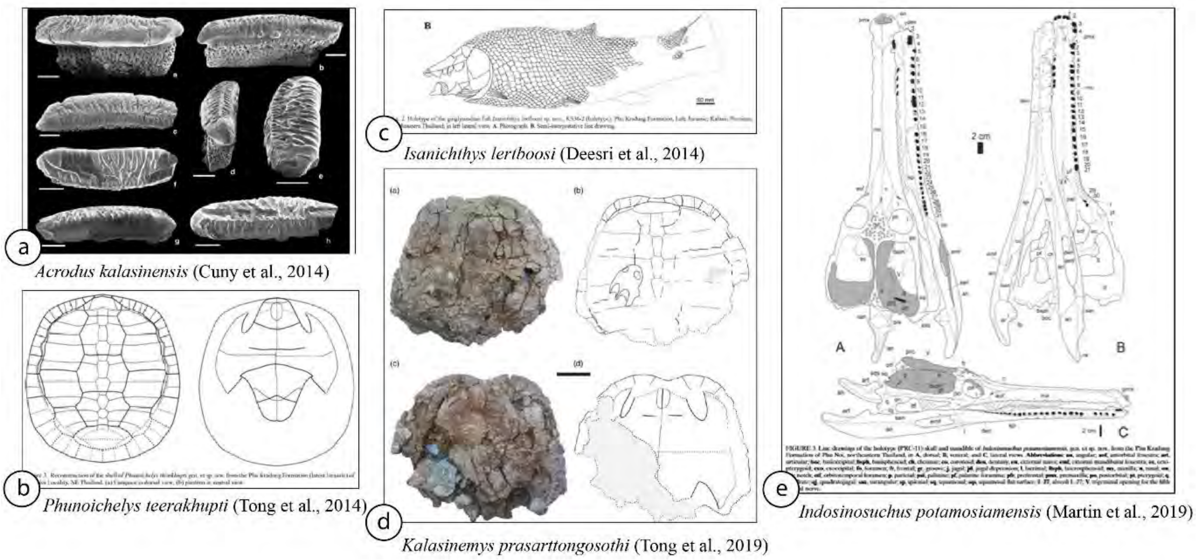

Fig. 2 New vertebrate taxa from the Phu Noi Locality, Kalasin Province, Thailand.

Geology and Stratigraphy of the Khorat Plateau

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EXTEND ABSTRACT

The geology of the Khorat Plateau or the northeastern of Thailand has long been studied more than forty years ago by Thai and foreign geologists based mainly on the surface mapping program of the Department of Mineral Resources (DMR). According to the geologic map of the DMR on the scale 1:2,500,000, the Khorat Plateau has a long history of the rock unit since the Silurian to the Cretaceous period. In this paper a review of each time-rock unit are briefly described.

According to Mantajit (1997) and Bunopas (1994) the Middle Paleozoic rocks (Silurian-Devonian) of the northeastern of Thailand comprise the Na Mo and Pak Chom Formations. The Na Mo and the Pak Chom Formations are possibly the oldest rocks in the northeastern of Thailand. They are well exposed in a north-south mountain belt in the eastern border between Loei and Nong Khai, Udon Thani, Nong Bua Lam Phu Provinces. The Na Mo Formation is low-grade metamorphic rocks. It consists of phyllite, chlorite, politic schist, metatuff and quartzite which are overlain unconformably by the Devonian-Early Carboniferous Pak Chom Formation (Chairangsee et al., 1990). The Pak Chom Formation is composed mainly of shale, limestone, minor tuff and occasional chert in which radiolarian banded chert is a main constituent in the upper sequence. Paleontological study on radiolarian and coral indicates that the Pak Chom Formation is the Devonian-Early Carboniferous in age (Udchachon et al., 2011; Shasida et al., 1993; Saesaengseerung et al., 2008).

The Upper Paleozoic rocks (Carboniferous-Permian) are broadly exposed in all regions of the country. The Carboniferous Wang Saphung Formation was reported in northeastern of Thailand. The Wang Saphung Formation underlies conformably the massive Permian limestone. Generally, it has been informally called by petroleum geologists as the "Lower Clastics or the Si That Formation" of the "Saraburi Group" (Racey, 2011). It is delineated from the seismic profiles and occupies a section between the base of the Permian massive limestone and the Mid-Carboniferous Unconformity (Booth and Satayarak, 2011).It is composed mainly of sandstone, shale with some thin limestone beds and conglomerates. In the Permian period, the rocks in Thailand are predominantly limestone but their age and facies characteristics vary from place to place. In northeastern Wiclchowsky and Young (1985) subdivided the Permian rocks in this region into three sub-regions, i.e., western carbonate platform (or the Khao Khwang Platform), a central mixed siliciclastic - carbonate basin (or the Nam Duk Basin) and an eastern mixed carbonate - siliciclastic platform (or the Pha Nok Khoa Platform). The Khao Khwang Platform consists mainly of shallow marine fossiliferous limestone and dolomite. The Nam Duk Formation is proposed by Chonglakmani and Sattayarak (1978) for the rocks sequence in this region. It is composed of the succession of pelagic sediment of deep marine in the lower part (e.g. chert, shale and allodapic limestone) grading up into flysh facies in the middle part (e.g. grawackes sandstone alternated with shale) and shallow marine molasses in the upper part (sandstone and shale) (Helmcke and Kraikhong, 1982). The Pha Nok Khoa Platform is composed of two main facies rocks including carbonate and silisiclastic. Fossils assemblages are included fusulinids and corals that indicate the Early to the Middle Permian in age (Ueno and Charoentitirat, 2011).

The Mesozoic rocks are widely exposed in Thailand. It can be categorized into two main facies, i.e., marine and non-marine facies. In northeastern Thailand only the non-marine facie have been found. It consists of the Upper Triassic to the Upper Cretaceous rocks. The Upper

Triassic rock is composed of the Huai Hin Lat Formation which is overlain by the Nam Phong Formation. The Huai Hin Lat Formation overlies unconformably on the Permian rocks and older strata. Chonglakmani and Sattayarak (1978) divided the formation into five members in ascending order, i.e., the Pho Hai Member (mainly volcanic rock), the Sam Khaen Member (chiefly of conglomerate with some intercalations of finer sediment), the Dat Fa Member (gray to black carbonaceous shale), the Phu Hi Member (Clastic Sedimentary rock, mainly sandstone) and the I Mo Member (Clastic sedimentary rock associated with intermediate volcanic rocks). The Huai Hin Lat Formation was considered to be of the Late Triassic (Norian) on the basis of its faunal and floral assemblages (Chonglakmani, 2011). The Nam Phong Formation overlies unconformably on the Huai Hin Lat Formation in place and elsewhere the Permian or older rocks. It consists of conglomerate, carbonaceous sandstone, siltstone and mudstone. According to the subsurface geological data, the Nam Phong Formation can be separated into the lower member and the upper member, which are well defined by seismic profile (Booth and Sattayarak, 2011). In general, the Nam Phong Formation is considered to be the Late Triassic (Rhaetian in age) based on the occurrence of palynological evidence and prosauropod dinosaur bones associated with stratigraphic relation (Chonglakmani and Sattayarak, 1978; Buffetaut and Suteethorn, 1998; Racey et al., 1996)

In the Jurassic to the Cretaceous the rock sequences of the northeast are represented by the red beds of the Khorat Group (Ward and Bunnag, 1964). The Khorat Group is composed of six formations of the alternated braided and meandering fluvial sandstone facies. It consists of the Nam Phong, Phu Kradung, Pha Wihan, Sao Khua, Phu Phan and Khok Kruat Formations (Racey and Goodall, 2009). The Khorat Group overlies unconformably on the Permian, Triassic Pre-Khorat and the older rocks. The thickness of the Group is approximately more than 4000 m. Traditionally, the Khorat Group has been interpreted to be deposited since the Late Triassic to the Late Cretaceous without any breaking time (Ward and Bunnag, 1964). This age dating has been based on plant macrofossil and vertebrate studies. However, according to palynological evidence Racey and Goodall (2009) believed that the Khorat Group was initiated to deposit not older than the Late Jurassic (the upper Nam Pong Formation) and continue to the late Early Cretaceous (Aptian age; the Khok Kruat Formation) (Racey and Goodall, 2009). Based on Racey and Goodall (2009), they proposed the hiatus in the Early to the early Late Jurassic in the northeastern part of Thailand. After the termination of the Khorat Group, the Maha Sarakham Formation began to deposit overlying unconformably on the top of the Khorat Group. It was considered as the Mid-Cretaceous (Albian - Cenomanian) (Sattayarak and Polachan, 1990) which consists of lower red-beds, lower salt, lower clay, middle salt, middle clay and upper salt units (Sattayarak and Polachan, 1990)

In turn the Maha Sarakham Formation is overlain conformably by the Late Cretaceous Phu Tok Formation (Raksasakulwong, 2002). The Phu Tok Formation is composed of three informal members in ascending order; the Nawa (mainly claystone), Kham Takla (fine sandstone interbedded with siltstone and claystone) and the Phu Tok Noi (aeolian sandstone) (Meesook, 2011). In the Nakhon Thai region west of th Khorat Plateau, an aeolian sandstone was named as the Khao Ya Puk Formation by Kosuwan (1990) rather than the Phu Tok Formation. Furthermore, Kosuwan (1990) and Heggemann (1994) reported the finding of conglomerate and sandstone sequences overlying on the Khao Ya Puk Formation. Kosuwan (1990) also proposed the new informal name for this sequence as the Phu Khat Formation. Due to the fact that the Phu Khat Formation overlies on the Khao Ya Puk Formation (or the Phu Tok Formation) it is, therefore, supposed to deposit in the Late Cretaceous to the Early Paleogene.

Geotectonic Evolution of Thailand during Upper Paleozoic Time

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In past two decades, many attempts have been examined and use microfossils for reconstruct the geotectonic evolution in Thailand and adjacent areas. Recently, Ueno and Charoentitirat (2011) has clearly explained tectonic evolution of Thailand during Upper Paleozoic time based on various geological data especially on foraminiferal biostratigraphy. This research has firstly clarified some of the vague Upper Paleozoic stratigraphic names and their correlations.

Well-exposures Late Paleozoic carbonate-dominant shallow marine strata yielding abundant and variable fusulinids are widely distributed all parts of Thailand except in the Khorat Plateau. Over four decades, many works have been devoted to the biostratigraphy, taxonomy and classification of Late Paleozoic fusulinids (*e.g.* Toriyama, 1944; Pitakpaivan 1965; Igo 1972; Toriyama 1975; Kanmera *et al*., 1976; Toriyama&Kanmera 1977, 1979; Ingavat & Jumnongthai 1988; Ueno&Sakagami 1993; Igo *et al*., 1993). These works are mainly composed of basic framework on fusulinid study of Thailand and other SE Asian countries. Bunopas (1981) was the first Thai geologist who has introduced geotectonic to Thai geological society. Firstly, two microcontinental blocks named Shan Thai and Indochina were essential parts to explain about geotectonic subdivision of Thailand. It was believed that the Gondwana-derived Shan Thai and Indochina Blocks were collided and the collision zone was represented by the Nan-Uttaradit-Sa Keao Suture (e.g. Buopas 1981; Metcalfe 1996, 1999; Hada *et al*., 1997, 1999). Later, Ueno (1999); Ueno&Hisada (1999) have firstly revised and purposed the new geotectonic subdivision of Thailand based on concrete data of Late Paleozoic foraminiferal distribution and paleogeographic characteristics. They recognized two other geotectonic units between the Indochina (carbonates with high diversity and abundant of Cathaysian faunas) and "revised Sibumasu" (previous Shan Thai) Blocks namely the Sukhothai Zone (of volcanic arc origin) and Inthanon Zone (representing remnant of Paleotethys). And they also mentioned that the Nan-Uttaradit-Sa Keao Suture has been interpreted as a closed back arc and neither the Gondwana/Tethys divide nor the boundary between Sibumasu and Indochina Blocks. Their 'revised Sibumasu" is characterized by Gondwana glacio-marine strata and low diversity fauna assemblages. Ueno and Charoentitirat (2011) also stated that the Sibumasu Block (or "revised Sibumasu" Block by Ueno 1999; Ueno&Hisada 1999), extending in north, west and peninsular Thailand is composed of two domians: the Sibumasu (glacio-marine and Cimmerian faunas) and Inthanon (remnant of Paleotethys) domains. The Inthanon domain (or Zone) is considered as a part of Paleo-Tethyan and later collided and emplaced as napped upon Sibumasu basement where the evidences can be observed in north Thailand but in the south. Although, there are still many unclarified subjects on geology and geotectonic of Thailand, microfossils have become a powerful clue that helps us explain or find lacking detail parts.

Giant Sauropod Remains from the Early Cretaceous Khok Kruat Formation, Ban Phanang Sua, Nong Bua Rawe, Chaiyaphum

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ABSTRACT

Phanang Sua dinosaur site, located at the bank of public reservoir of Ban Phanang Sua, Nong Bua Rawe District, Chaiyaphum province. This site has been informed to the Department of Mineral Resources since April 2016 under Fossil Act 2008, due to Mr. Thanom Luangnan, a local villager who first discovered sauropod sacrum here in early March, 2016. Later, geologists from Division of Fossil Protection and Office of Mineral Resources Regional 2 have started the paleontological investigation at Ban Phanang Sua dinosaur site since then so far.

Lithostratigraphic study at Ban Phanang Sua dinosaur site can be divided the sequence of the Khok Kruat Formation into nine units i.e., Units 1-9, having totally 3.96 m thick. Dinosaur bones and fragments are detected in the lower part of the sequence comprising mainly of reddish-brown sandstones and siltstones with noticeable climbing ripple lamination of Units 1-3. Unit 4 consists of a thin layer of calcrete paleosol at the top of this part. In Units 5-9, sandstones appear various directions of cross bedding and the bones are absent. The upper part of the sequence is represented by the sandstones of the channel and channelized sandstone. And the dinosaur bones are found in the crevasse splay layers. The rocks are interpreted as having been deposited by the meandering rivers for Khok Kruat Formation in semi-arid to arid paleoclimate.

Under Paleontological Investigation, Phanang Sua fossils have been recorded on the tremendous sauropod remains from the Early Cretaceous Khok Kruat Formation including post-cranial specimen from an individual sauropod , for instance an axial skeleton (isolated dorsal vertebrae and a large sacrum) and an appendicular skeleton (a complete well-preserved giant right humerus, 1.78 m in length, large dorsal ribs, partial small ribs, partial and nearly complete right femur, pelvic girdle and many bone fragments), unearthed with associated fossils such as several isolated teeth which belong to allosaurid and spinosaurid theropods. Other associated faunas include a hybodont shark *Heteroptychodus* sp. and crocodilian teeth. While, the bivalves *Trigonioides* sp. and *Plicatounio* sp. are also usually found.

According to a preliminary study on humeral morphological features proposed that this new finding probably belong to a new taxon and one of a colossal titanosauriform sauropod dinosaur from the Khok Kruat Formation of Northeastern Thailand. More information on anatomical and phylogenetic studies and further excavations are principal to complete and compare with other vicinity sauropods.

The lithostratigraphic section and faunal assemblage from Ban Phanang Sua dinosaur site are not only useful for lithostratigraphic and biostratigraphic correlations to other vertebrate sites. This new dinosaur locality will shade light and figure out more understanding on sauropod evolution, distribution and paleoenvironment in this region, and also suitable for promoting as one of the fossil sites and one of the GeoSites for promoting GeoPark in Chaiyaphum Province.

Key Words:

Giant Sauropod, Khok Kruat Formation, Early Cretaceous, Chaiyaphum

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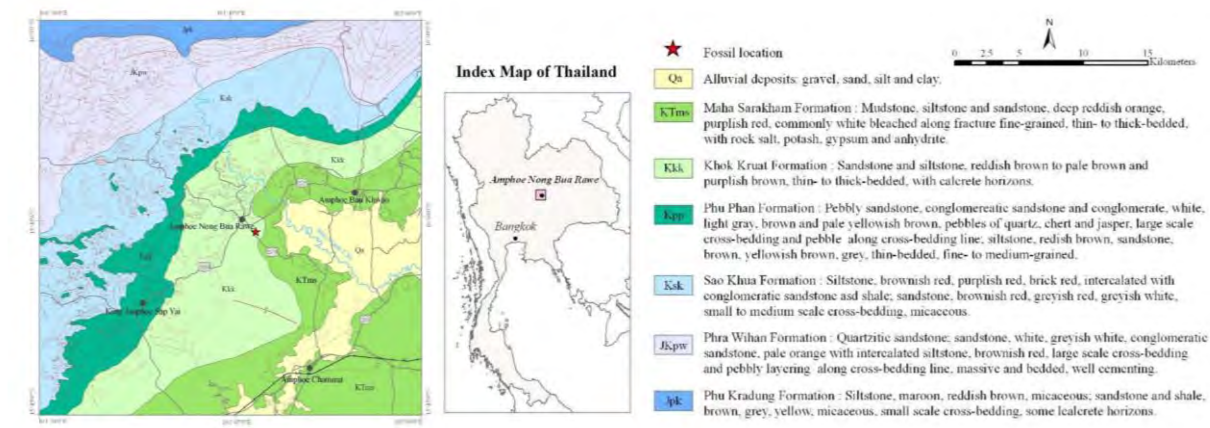

Fig. 1 Geological map of the Nong Bua Rawe area, Chaiyaphum Province and adjacent areas including the locality of the giant sauropod remains as shown in red star (adapted from Meesook, 2016) at Ban Phanang Sua dinosaur site, Nong Bua Rawe district, Chaiyaphum province.

Fig. 2 First discovered sauropod sacrum at the bank of public reservoir of Ban Phanang Sua, Nong Bua Rawe district, Chaiyaphum province by Mr.Thanom Luangnan in early March 2016 as shown the location in red arrow. Later, geologists from the Department of Mineral Resources have investigated and started systematic palaeontological excavation during April-June 2016, and continued done further since then so far.

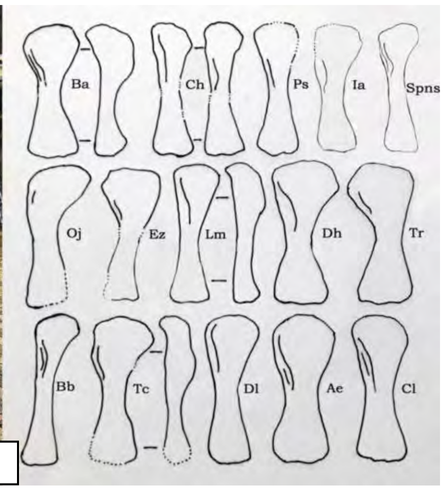

Fig. 3a Two replicas of the right humerus specimen from Ban Phanang Sua dinosaur site, Nong Bua Rawe district, Chaiyaphum province, display in both anterior and posterior views with 178 centimeter in length.

Fig. 3b Simplified drawing of outline shape of the right humerus specimen from this locality compare to those humeri of other sauropod dinosaurs (anterior and medial views). (Adapted from Martin *et al*., 1994) Ba: *Barosaurus africanus* (Janensch, 1961); Ch: *Cetiosaurus humerocristatus* (Hulke, 1869); Ps: *Phuwiangosaurus sirindhornae* (Martin *et al*., 1994); Ia: *Isanosaurus attavipachi* (Buffetaut *et al*., 2000); Spns: Sauropoda indet. (Phanang Sua); Oj: *Omeisaurus junghsiensis* (Young, 1937); Ez: *Euhelopus zdanskyi* (Young, 1935); Lm: *Lapparentosaurus madacascariensis* (Ogier, 1975); Dh: *Dicraeosaurus hansemanni* (Janensch, 1914); Tr: *Torneria robusta* (Janensch, 1961); Bb: *Brachiosaurus brancai* (Janensch, 1914); Tc: *Tienshanosaurus chitaiensis* (Young, 1937), Dl: *Diplodocus longus* (Osborn & Granger, 1901); Ae: *Apatosaurus excelsus* (Osborn & Granger, 1901); Cl: *Camarasaurus lentus* (Marsh, 1889). Drawings not to scale.

Iguanodontian dinosaurs from the Khok Kruat Formation (Khorat Group), Nakhon Ratchasima Province.

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EXTENDED ABSTRACT

Since 2007, Fukui Prefectural Dinosaur Museum has had collaborative works on the Khok Kruat Formation in Nakhon Ratchasima Province with the Khorat Fossil Museum (or Northeastern Institute of Petrified Wood and Natural Resources, Nakhon Ratchasima Rajabhat University). Our collaborative work, called Thailand-Japan Dinosaur Project (TJDP) has been successful to discover variable vertebrate fossils, such as fishes including chondrichthyans, crocodilyforms, pterosaurs and dinosaurs. Recently, our team reported new large-bodied charcarodontosaurian theropod named *Siamraptor* (Chokchaloemwong et al., 2019). However, the most abundant dinosaur bones found from our sites are iguanodontians.

Three iguanodontians have been reported from this formation; *Siamodon nimngami, Ratchasimasaurus suranareae,* and *Sirindhorna khoratensis* (Buffetaut and Suteethorn, 2011; Shibata et al., 2011, 2015). Although limited body parts have been known in the former two genera, *Sirindhorna* includes majority of skull parts and undescribed postcranial skeletons from the Ban Saphan Hin site. According to discovered braincases, at least four individuals were known. The holotype was assigned into a well-preserved braincase with frontals, postorbitals and squamosals. The extended sagittal crest reached for the frontoparietal suture was recognized as an autapomorphy in this genus. Brief descriptions of other characters are following: relatively straight frontoparietal suture, caudodorsally faced supraoccipital, no participation of the supraoccipital in the foramen magnum, antorbital fossa of the maxilla not visible, slightly rostrally deepening dentary ramus, simple troughs for dentary alveoli with vertical walls and tooth crown-shaped base, vertical coronoid process expanded along rostral and caudal margins, and dentary teeth with primary and secondary ridges but no accessory ridges.

The osteological features, especially those in the oral and cheek regions, such as the transversely wide and edentulous premaxilla, divergent vascular grooves on the rostral surface of the predentary, and wear facets on the dentary consisting of one functional tooth crown, suggest *Sirindhorna* to be a typical non-hadrosaurid styracosternan (Norman, 2015). Although several basal styracosternans with well-preserved cranial material from North America, such as *Hippodraco scutodens* and *Theiophytalia kerri* (Brill and Carpenter, 2007; McDonald, et al., 2010) are known, their morphological traits, including the existence of the antorbital fenestra, the largely exposed angular in lateral view and so forth, are totally different and distinguishable from those of *Sirindhorna* and other Asian taxa. Our phylogenetic analysis resulted in settling Thailand iguanodontians in the basal hadrosauroid, closely related to other Asian taxa with exception of *Fukuisaurus* positioned in more basal Styracostarna.

Thailand iguanodontians provided additional information into the chronological and paleobiogeographical distribution patterns of this group in the Early Cretaceous. The most basal iguanodontians, such as dryosaurs and camptosaurs, were limited in North America, Europe and Africa before Hauterivian. Iguanodontians probably invaded into the Asian region after Hauterivian. During late Early Cretaceous, derived taxa, hadrosauroids, had been diversified all over the Asian region to the Southeast Asia
meanwhile primitive taxa had survived in North America. Interestingly, *Fukuisaurus*, which had lived in far-eastern Asian continent, shows the most primitive condition in its skull among late

Early Cretaceous Asian taxa. Appearance of hadrosauroids in North America had not occurred until Cenomanian.

Iguanodonitans were the most common and diverse herbivorous dinosaurs in Early Cretaceous, and their fossil records had a widespread distribution in all continents. Therefore, understanding the distribution pattern of iguanodontians in the Early Cretaceous would help to recover paleoenvironmental transitions with floral changes during this period. In addition, recent analysis of dinosaur diversity suggest that distribution patterns of dinosaurs are closely related with paleogeography, and tectonic events had a major role to give place and timing of immigrations for particular dinosaur groups (Upchurch et al., 2002; Dunhill et al., 2016).

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Jurassic – Cretaceous palynofloras from Thailand

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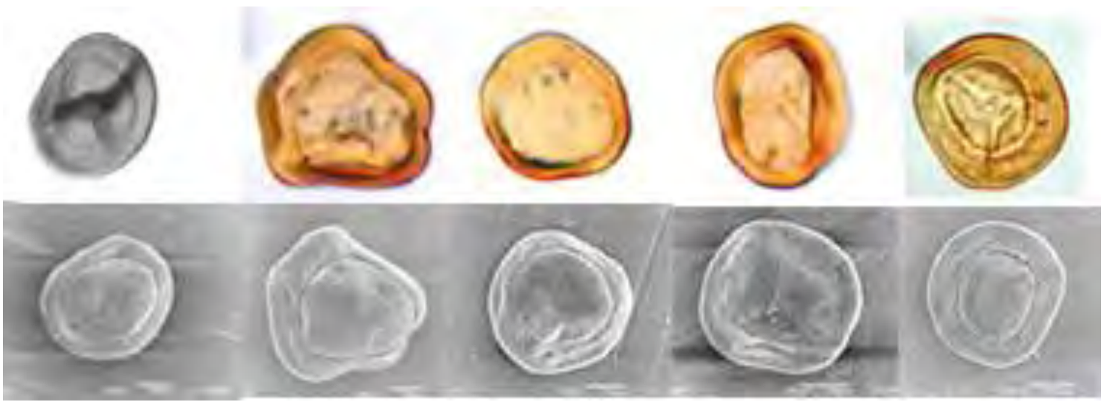
EXTENDED ABSTRACT

This study presents palynomorphs retrieved from sediment samples of two localities, Krabi province in southern Thailand and Kalasin province in northeastern Thailand. The sediment samples are from Khlong Min Formation of Shan-Thai block and Phu Kradung Formation of Indochina block, respectively. Both formations are considered to be of Late Jurassic to Early Cretaceous based on vertebrate, plant and palynological studies.

Palynomorphs from both localities are generally rather low in abundance and diversity. *Classopollis* pollen morphotypes are the dominant group (>80%) with low proportion of other Gymnosperm pollen and Pteridophyte spores in the assemblages. The observation of pollen under the light microscope and scanning electron microscope showed diversity of *Classopollis* with different morphological characteristics in size, sculpture, triradiate scar, rimula, internal equatorial striae, and cryptopore. *Classopollis* is pollen of the conifer in extinct family Cheirolepidiaceae. This pollen was found earliest in Upper Triassic then increased variety during the Jurassic and Cretaceous. They existed worldwide at low and middle paleolatitudes (Watson, 1988).

Another important pollen in family Cheirolepidiaceae is *Dicheiropollis etruscus*, though very few gains were found in these two locality assemblages. The occurrence of *D. etruscus* indicates a Berriasian to early Barremian, making it an Early Cretaceous marker. Racey and Goodall (2009) and Lei (1993) also found this pollen species in samples from Phu Kradung and Khong Min Formations, respectively, from which Racey and Goodall (2009) discussed the ages of the formations and suggested to be of Early Cretaceous.

Predominance of *Classopollis* pollen may represent the mesophilic to xerophilic plants, which can grow in well-drained uplands to coastal lowlands or even saline habitats (Alvin, 1982). The pollen types also suggest a hot and dry climate. Similarity of Palynofloras found in both localities of Phu Kradung and Khlong Min Formations also suggest similar environments and age.



Picture presents various morphological characteristics of *Classopollis* pollen.

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Non Marine Triassic-Jurassic boundary vertebrate fossils from Thailand: a Review

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ABSTRACT

The Late Triassic to Early Jurassic was one of the most important events in the history of the vertebrate animal. At that time, the first dinosaurs and pterosaurs arose like most major groups of recent continental vertebrates. In several years of vertebrate palaeontological studies in Thailand, Palaeontologist has been found many vertebrate fossils from the Late Triassic to Early Cretaceous in several localities around Thailand. However, scientific reports of vertebrate fossils from Triassic are still rare and necessary to improve. Here we review vertebrate fossils from The Late Triassic to Early Jurassic of Thailand since 1980 when first report of this topic published until recently discovery from field survey. Our results show that in the Huai Hin Lat Formation (Canian-Norian) following these vertebrate fossils were found: Hybodont shark, bony fishes; palaeoniscids, semionotid, ginglymodians and lung fish *(Fergatoceratodus* sp.), Amphibian; *Cyclotosaurus* cf. *posthumus,* metoposaurid and Plagiosauriod, Phytosaur and coprolites. Whereas, in the Nam Phong Formation (Late Triassic-Early Jurassic) Prosauropod and basal sauropod; *Isanosaurus attavipachi* and Theropod footprints were found. Our results implied that, vertebrate animal in Thailand from The Late Triassic to Early Jurassic rather diverse. We hope our results to be a starting point for more interesting about The Late Triassic to Early Jurassic vertebrate fossils from Thailand. Moreover, these studies helped to better understand Triassic-Jurassic transition in Thailand and better understanding of the vertebrate biogeography of South East Asia.

Key words: vertebrate fossils, Late Triassic to Early Jurassic, Thailand

EXTENDED ABSTRACT

Thailand is among the regions in the world where continental sedimentary rocks spanning the Late Triassic-Early Jurassic transition are found. The non-marine Mesozoic sedimentary rocks of Thailand range in age from the Late Triassic to the Early Jurassic period consist of Huai Hin Lat and Nam Phong Formations (Racey and Goodall, 2009).

The Mesozoic sedimentary rocks of Thailand range in age from the Late Triassic to the Early Jurassic consist of Huai Hin Lat and Nam Phong Formations (Racey and Goodall, 2009). The Huai Hin Lat Formation is unconformably overlies Permian limestones. Outcrops of the Huai Hin Lat Formation were found in the western part of Khorat Plateau in Loei, Khon Khaen, Chaiyaphum and Phetchabun Provinces. The Huai Hin Lat Formation is unconformably overlied by the Nam Phong Formation. The seismic analysis divides this formation into two sections: The Lower Nam Phong Formation and the Upper Nam Phong Formations (Racey, 2009). The Lower Nam Phong Formation consists of continental rocks formed in alluvial fans and floodplain. Based on palynology and vertebrate data, the age of this unit can be constrained to the Late Triassic (Rhaetian). Whereas, the Upper Nam Phong was deposited in a lacustrine dominated alluvial floodplain environment (Racey, 2009). Palynological data suggested that the age of this unit is not older than Plienbaschian (Late Early Jurassic). This result is in accordance with seismic analysis which indicated that the upper part of the Nam Phong Formation is possible of Jurassic age (Racey, 2009; Racey and Goodall, 2009).

Studies on the Triassic vertebrate fossils from Thailand started in the 1980s when the Thai-French palaeontological team began its activities. At that times were published the first scientific reports about vertebrate fossils in the Triassic of Thailand. Most of vertebrate fossils were found in the Huai Hin Lat Formation (Canian-Norian). These include; a tooth of *Ferganoceratodus szechanensis* (Martin and Ingavat, 1982), the turtle *Proganochelys ruchae* (Broin, 1984), the amphibians *Cyclotosaurus* cf. *posthu*mus and a plagiosauroid (Ingavat and Janvier, 1981), and phytosaurs (Buffetaut and Ingavat, 1982). All of them were found at an outcrop near Chulaborn dam in Chaiyaphum Province.

Several years later, more vertebrate fossils also found in several localities of Huai Hin Lat Formation including a hybodont shark denticle (Cuny et al., 2007), a *Hybodus* tooh, aff. Paleoniscidae and semionotid fish scales (Laojumpon et.al., 2014), probably ginglymodians fish (Cavin et.al., 2014), a metoposaurid temnospondyl (Nonsrirach et.al., 2019), Archosaur trackways were discovered at Tad Huai Nam Yai, near Nam Nao in Phetchabun Province (Le Loeuff et al., 2007; 2008 and 2009) and numerous of coprolites from Chaiyaphum province (Laojumpon et al., 2012). All of the results above indicated that Huai Hin Lat Formation has yielded a lot of vertebrate fossils.

Vertebrate fossils were also found from the Nam Phong Formation. These include: the sauropod *Isanosaurus attavipachi* from Phu Nok Khian, Chaiyaphum Province (Buffetaut et al., 2000, 2002), at least 2 more taxa of sauropod were found (Laojumpon et.al., 2017), prosauropod specimen from Phu Khuang (Buffetaut et al., 2008) and theropod footprints from Tha Song Khon close to the town of Phu Kradung, Loei Province (Le Loeuff et al., 2009). Most of the dinosaur specimens in this formation similar to dinosaurs in the Early Jurassic more than Late Triassic dinosaur. Therefore, most of them deposited in the Upper part of Nam Phong Formation.

Our results implied that, vertebrate animal in Thailand from The Late Triassic to Early Jurassic rather diverse. Moreover, these studies helped to better understand the Triassic-Jurassic transition in Thailand and a better understanding of the vertebrate biogeography of South East Asia.

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Sedimentology and stratigraphy of the Jurassic continental deposit “ms Group” from Sukhothai Fold Belt, Northern Thailand

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EXTENDED ABSTRACT

The non-marine Jurassic deposit in Northern Thailand is widely exposed in Sukhothai Fold Belt including Chiang Rai, Phayao, Nan, Phrae and Lampang provinces (Fig.1). It approximately extends with at least 80-100 km wide and 250 km long and generally rests unconformably either on marine Triassic of Lampang Group or upper Paleozoic rocks. Locally, it lies conformably on Triassic rocks. The continental Jurassic strata in Sukhothai Fold Belt were deformed and dominantly presented by anticline and syncline. They were firstly named as J1-J5 by Baum et al. (1970). After that, ms1-ms5 were used to replace J1-J5 by Hahn (1976) for Nan-Phayao basin. The succession, with 1,750-2,000 meters thick, is dominated by micaceous reddish siltstone, sandstone and conglomerate. Pyroclastic and volcanic rocks unit also present within the succession. Ms group was reviewed by Sattayarak (1983).

From the older to younger, ms1 is composed of reddish siltstone, sandstone and minor conglomerate. Conglomerate clasts including limestone, chert, sandstone and shale were probably derived from Paleozoic rocks. At the top of ms1, where it is covered by volcanic of ms2, fresh water carbonate rock is found. Stratigraphically, ms1 was considered to be Norian to Rhaetian in age (upper Triassic) by Hahn (1976), Hahn and Siebenhuner (1982) and Drumm et al. (1993).

Ms2 is pyroclastic and volcanic rocks which consists of rhyolite, andesite, spherulite and tuff. In general, it overlies on ms1 and it is capped by ms3 at the middle of basin (Nan-Phayao area). However, on the flank of basin, ms2 rests unconformably on marine Triassic or upper Paleozoic rocks. Ms2 is well exposed and shows characteristic irregular topography in the field. Last decade, several works focusing on U/Pb zircon age dating of ms2 indicate Norian to Pliensbachian age (Early Jurassic) (Ruenthon, 2010; Srichan et al., 2010; Wipakul, 2012; Ditbanjong et al., 2018; Srichan, 2019; Srichan et al., 2019).

Ms3 is dominated by reddish siltstone interbedded sandstone. Locally, conglomerate have been found especially at flank of basin or at the lower part of ms3. Drumm et al. (1993) founds palynomorph such as *Carolina sp. (Classiopollis)* which indicated Early Jurassic in age. Hinthong et al. (1999) reported about the blackish water bivalve and identified as *Modiolus* sp. from ms3 formation of Nan Province. This fossil occurrence suggests marine incursion during Jurassic period. In 2002, dinosaur bones were discovered from micaceous reddish siltstone and sandstone of ms3 at Doi Phu Nang National Park Protection Unit (Dinosaur), Chiang Muan District, Phayao Province (Wongko, 2003). Geological map of Chiang Muan sheet has been revised by DMR and the new formation names have been proposed; there are Jdk (Doi Kui Kaem Formation), Jv (Jurassic Volcanic Formation), Jnp (Nam Phi Formation) and JKtw (Thawa Formation) which are equivalent to ms1 to ms4 respectively (Imsumut and Krawchan, 2005). However, Chaing Muan Dinosaur site is the only one that dinosaur bone was found in northern

Thailand until now. The result of paleontological study suggests that the bones belong to a primitive sauropodomorph. The dinosaur bearing bed overlies on the Kang Luang rhyolite (ms2) which is Sinemurian- Pliensbachian in age. Therefore, the dinosaur site of Chiang Muan is late Early Jurassic (Toarcian) or younger (Ditbanjong et al., 2018).

Ms4 can be well distinguished in the field by forming a high resistance bedding cliff. It overlies conformably on ms3 and it is covered by ms5. It is quartzitic, medium to thick bedded sandstone with cross-bedding (Praditwan, 1980). Fresh water fish and pelecypods, plant remains were reported by Baum et al. (1970). After that, Heggemann et al. (1990) discovered fossil plants and arthropods within ms4. Palynomorphs include *Apiculatisporis ovalis*, *Araucaritites australis*, *Baculatisporites comaumensis*, *Concavissimisporites* sp., *Carolina* sp. *(Classiopollis)*, *Cyathidites minor* and *Laevigatosporites* sp. are also reported by Drumm et al. (1993). Paleontology results from previous works indicate Middle Jurassic in age.

Ms5 shares more and less similar facies to ms1 and ms3. It overlies conformably on quartzitic sandstone with cross-bedding of ms4. Rock salt presented in Bo Klua (northeastern of Nan province) indicated evaporite rocks intercalations in ms3-ms5 formation (Hahn, 1976; Hinthong et al., 1999).

At the present, we can conclude that ms2-ms3 rock units with distributed in the Sukhothai Fold Belt (Fig.1), northern Thailand are Jurassic in age. As we have not had the precise age of ms1, we assume that either lower or upper boundary of ms1 probably representing Triassic-Jurassic boundary. The JK boundary is still in doubt. Ms3 which contains sauropod bones is probably late Early Jurassic or younger age. Consequently, Chiang Muan dinosaur site from ms3, northern Thailand is hypothetically older than dinosaur sites from Phu Kradung Formation of the Khorat Group. Moreover, it can be noticed that ms Group is found restrictedly in Sukhothai Fold Belt while Khorat Group is distributed in the Indochina terrane which deposited during the amalgamation or post collision of Indosinian orogeny. Although ms group and Khorat group from two different tectonic terranes show more and less similarity in lithology, it is still difficult to correlate stratigraphically.

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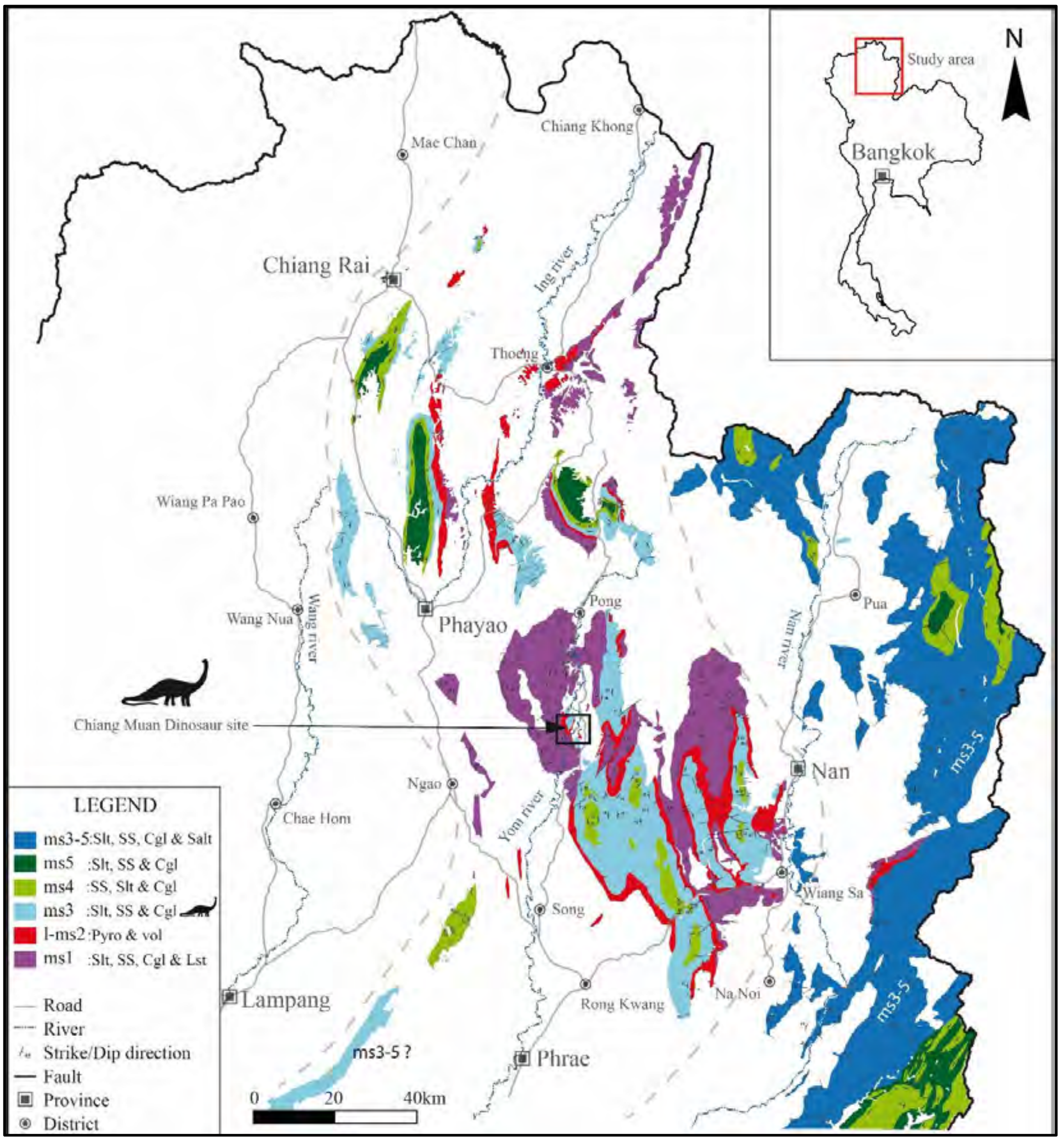

Fig.1 Compiled geologic map (1:250,000) of ms Group in the study area (including Phayao, Chiang Rai, Nan, Phrae and Lampang province). (Modified from Baum and Hahn, 1976.; Braun and Hanh, 1976.; Hess and Koch, 1975.; Charoenprawat et al., 1994.

The dynamic exchange of dinosaurs between Asia and North America

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Global biodiversity is shaped by repeated intermittent mixing of organisms from one continent to another followed by diversification during continental isolation. Occasionally throughout the Mesozoic, after the break-up of Pangea, Asia and North America coalesced through a land bridge across Siberia and Alaska, which allowed for dinosaurs to migrate from one continent to another. These immigrations affected the evolution of endemic species either through direct competition with extinction or providing the seeds of lineages that would grow into iconic species over millions of years.

Three important Late Cretaceous lineages exemplify the process of immigration, diversification, and emigration. During the Early Cretaceous a land bridge opened through which the ancestors of tyrannosaurids, hadrosaurids (duck-billed dinosaurs), and ceratopsids (horned dinosaurs) left their ancestral home of Asia and traveled to North America. Each of these three dinosaur clades diversified into a wide range of species that includes some of the most recognized genera such as *Triceratops*, *Parasaurolophus*, and *Tyrannosaurus*. Each of these lineages increased in body size, gained dietary specializations, and cranial ornamental features.

Arrival of the Late Cretaceous brought a new land bridge across which these three lineages traveled back to Asia in their new forms. Eventually the North American lineages became common features of Asian dinosaur faunas in China and Mongolia. South East Asian dinosaurs at the end of the Cretaceous are largely unknown, however, leaving a hole in our understanding of dinosaurian evolutionary dynamics.

The Early Cretaceous record of South East Asian dinosaurs is much better known, with Thailand offering the vast majority of named species. Further discovery of dinosaur species in this region will help paleontologists determine the diversification patterns of each of these three lineages and thereby be better able to propose models that explain the rate, direction, and magnitude of Laurasian dinosaur evolution.

The first carcharodontosaurian theropod of the late Early Cretaceous, Khok Kruat Formation, Ban Saphan Hin, Nakhon Ratchasima, Thailand

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EXTENDED ABSTRACT

It is very well known that Allosauroidea and Megalosauroidea are the basal tetanuran clades, appeared by the Middle Jurassic and were soon represented by large-bodied taxa. These two clades are key to understanding Middle Jurassic-early Late Cretaceous dinosaurian ecosystems, in which they comprised almost all large predators over a span of approximately 85 million years. Although large theropod records from Early Cretaceous are scarce in Asia (Holtz et al., 2004), some important specimens have been recovered in recent years (Benson and Xu, 1964; Buffetaut et al., 1996; Buffetaut et al., 2005; Currie and Azuma, 2006; Ji et al., 2009; Li et al., 2010; Brusatte et al., 2010; Xu et al., 2012; Mo et al., 2014) Allosauroidea, a clade of large-bodied theropod dinosaurs that ranged from the Middle Jurassic until the Late Cretaceous, has been the subject of extensive phylogenetic study (e.g. Brusatte et al., 2008; Benson et al., 2010; Carrano et al., 2012; Porfiri et al., 2014). Among them, Carcharodontosauria is the most inclusive clade, comprising *Carcharodontosaurus saharicus* and *Neovenator salerii*, but not *Allosaurus fragilis* or *Sinraptor dongi* (Benson et al., 2010). However, Asian carcharodontosaurs have been exceptionally poorly known so far in the Early to mid-Cretaceous of Asia (Holtz et al., 2004; Benson et al., 2010).

The Khok Kruat Formation is the uppermost of the non-marine Mesozoic Khorat Group of northeastern Thailand, whose age has been referred to the Aptian age based on palynological data and other fossil occurrences. In the last decade, Thailand has yielded a huge number of Mesozoic non-marine fossil vertebrates, ranging from the Late Triassic to the late Early Cretaceous (Suteethorn et al., 1995). Nevertheless, dinosaur remains from the Lower Cretaceous Khok Kruat Formation have hitherto been scarce, and only iguanodontian ornithopods have been described based on isolated remains (Buffetaut and Suteethorn, 2011; Shibata et al., 2011; 2015). For the first time, a definitive carcharodontosaurian theropod is established on a series of autapomorphies among allosauroids from the Lower Cretaceous Khok Kruat Formation in Thailand. A new theropod taxon is described based on extensive cranial and postcranial materials collected in a locality of the Khok Kruat Formation (Shibata et al., 2015; Figure 1).

Siamraptor suwati, is described based on isolated cranial and postcranial remains from Ban Saphan Hin (Dinosaur excavation site), the Lower Cretaceous Khok Kruat Formation. It is considered as a member of Allosauroidea in this study based on several features of extensive skull elements, axial material, ischium, tibia, manual ungual, and a pedal phalanx (Figure 2). The osteological description of this taxon shows a notorious skeletal pneumaticity in the skull and axial elements, which presents some features that are similar to those observed in derived allosauroids such as *Aerosteon* (Sereno et al., 2008) and *Murusraptor* (Coria and Currie,2016) and some particular features, like the presence of pneumatic foramina in the surangular, camerate structures in the cervical vertebrae, or foramina in the base of cervical and dorsal neural spines.

And a reduced and oblique ridge of suprastragalar buttress for the astragalus in the tibia. The remarkable pneumaticity in cranial and axial bones of *Siamraptor* is also characterized, which is comparable with those observed in several other carcharodontosaurians, although those taxa could have another phylogenetical interpretation as tyrannosaurids. The results of the phylogenetic analysis indicate that the new taxon is a new basal member of Carcharodontosauria from the Early Cretaceous of Southeast Asia. Although other carcharodontosaurians have also been reported from Asia such as *Fukuiraptor* (Azuma and Currie, 2000) *Shaochilong* (Brusatte et al., 2010), *Kelmayisaurus* (Brusatte et al., 2012), and an indeterminate and fragmentary carcharodontosaurid from Thailand (Buffetaut and Suteethorn, 2012). This is the first report of the presence of a more basal carcharodontosaurian theropod in this area. In combination with the presence of carcharodontosaurian materials in the Upper Jurassic of Portugal (Malafaia et al., 2018) and Tanzania (Rauhut, 2011; Carrano et al., 2012), this study also indicates the wide distribution of Carcharodontosauria during the Upper Jurassic and Early Cretaceous, which is consistent with previous paleobiogeographic studies about Mesozoic faunal interchanges (Ezcurra and Agnolín, 2012; Dunhill et al., 2016). Both phylogenetic analyses using two independent datasets locate *Siamraptor* as the most basal member of Carcharodontosauria, which also means that this taxon is the first definitive carcharodontosaurian theropod from Southeast Asia. The presence of *Siamraptor* in this area indicates an extension of the record in the Laurasian landmasses during the earliest stage of the evolutionary history of Carcharodontosauria.

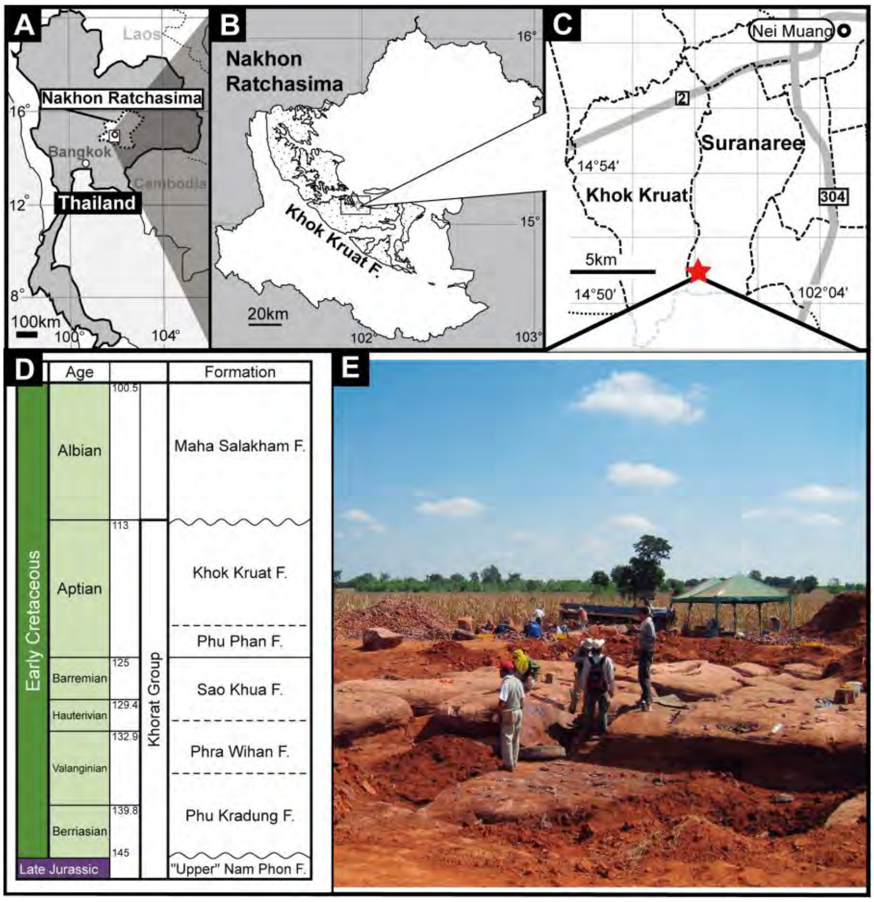

Figure 1. Locality map of *Siamraptor suwati* material and stratigraphy of Khorat Group.

Figure 2. Skeletal reconstruction of *Siamraptor suwati*. Cranial elements were scaled to fit in with the holotype (surangular). Scale bar equals 1 m.

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Updated U-Pb zircon ages: Constraint for provenances and tectonic History of Thailand and nearby regions

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Abstract

Previous and recent data on U-Pb zircon dates from Thailand and nearby regions have been compiled and updated with the aims to visualize geologic and tectonic history of the country. In this study, three kinds of data have been identified and grouped including, those of detrital, magmatic, and metamorphic zircons.

The detrital ages of zircons from several stratigraphic positions can be largely grouped into those of Precambrian (Archaeozoic < Proterozoic), Paleozoic (Early > Late), and Mesozoic (Early > Late) ages, suggesting their various and contrasting provenances. The magmatic zircons show distribution of dates and ages mainly from Middle Paleozoic down to Mesozoic ages, particularly equivalent to Indosinian I, II, and III tectono-magmatic episodes. On the other hands, several dates of metamorphic zircons which seem to be the most difficult to interpret seem to display Precambrian inherited ages. Many metamorphic zircons yield the dates ranging from the majority of Permo-Triassic to the minority of Early Paleozoic and Neogene times.

The old detrital/metamorphic zircon ages are well concordant to Pan African tectonic (or deformation) zone. By comparison with those of the detrital zircon ages outside Thailand, it is visualized that those zircons may have been derived from the western part of South China continent block which denote similar age patterns. Besides the detrital zircon data can constrain the probably oldest age of sedimentary rocks.

It is further recommended that the U-Pb dates of zircon are quite significant clue for deciphering tectonic evolution. Additionally, data on isotopic, trace and RE elemental analyses are required and can give rise to origin and formation of zircon-carrying rocks in Thailand and nearby regions in the near future.

Key words: *U-Pb zircon, geochronology, provenance, tectonics, Thailand*

What Would Geologist Like to See More in Paleontological Research in Thailand

Nares Sattayarak

Geological Society of Thailand

Conceivably, many unidentified objects had been found in the world since the pre historic time. They were thought to be the remains of life forms and the evidence of mythological creatures such as dragons or creatures made by the devil or of a higher power and having a special curative or destructive powers. Later on, Georgius Agricola (1494-1555) coined the term "Fossil" from the Latin word "fossus" that literally means "having been dug up". Today, fossil refers to the remains or traces of an organism that lived in the past. Some said, to be considered a true fossil, a specimen must be at least 10,000 years old.

Recognition of fossils as remnants of once-living organisms became well-known by the study of some early polymaths such as Leonardo da Vinci and Nicholas Steno, since then, paleontology has become an interesting science throughout the world particularly after the discoveries of dinosaurs.

In early day, the study of fossil and paleontology in Thailand were conducted by foreign scientists. For example; the first fossil known to Thai people which is Carboniferous Brachiopods from Phatthalung, south of Thailand was found by Cowper-Reed in 1920. In addition, the first fossil collected at Thai Department of Mineral Resources as TF 1 (Thai Fossil no. 1) in 1922, is also Carboniferous Brachiopods found by an American geologist. Moreover, Japanese paleontologists also discovered various species of fossils and published a large number of reports about fossils they found in Thailand.

Paleontology study by Thai scientist probably started in 1950's on Invertebrate animals. Subsequently, paleontology become popular in Thai society, not surprisingly, after the finding of Dinosaur remains in the Northeast in early 1980's. Nowadays, studies on paleontology in Thailand are extending into both animal and plant kingdom, varying from Cambrian to Recent. More universities that teach or include the courses related to paleontology leading to the increase of number of Thai paleontologist. Moreover, new tools and technologies have been used in the studies and researches resulting in more precisely, attractive, stunning and interesting works.

Although paleontological studies and researches in Thailand is expanding and developing satisfactorily, there are still some missing link in some studies between paleontologists and geologists, e.g., various genus and/or species of fossils were reported in the same location without any stratigraphic section. To achieve more fulfill and accomplish findings, and to the benefit of the country, geologist would love to see, if possible, some comment related to geological aspect will be included in future paleontological research and studies in Thailand.

Workshop Descriptions

Wednesday, 18 December 2019
Workshop I – Reconstructing Ancient Ecosystems:
Application of Detrital Zircon Geochronology and Isotope Geochemistry

Dr. Ryan Tucker, *Lecturer*, Department of Earth Sciences, Stellenbosch University, South Africa
Dr. Ethan Hyland, *Assistant Professor*, Department of Marine, Earth & Atmospheric Sciences, North Carolina State University, USA

Time: 9.00 to 17.00

Overview

The integration of paleontological and geological data is essential for understanding how changing climate and the timing of geophysical events (e.g., tectonic and eustatic alterations) shaped the evolution of terrestrial ecosystems through time. The rigor of modern approaches necessitates synthesizing palaeontological, sedimentological, stratigraphical, geochronological & geochemical data. This workshop will focus on introducing attendees to the current methodologies of dating the fossil record, palaeoenvironmental/paleoecological reconstruction, palaeobiogeographical hypothesis testing, taphonomic investigations of floras/faunas, and a range of other topics that link geological context to palaeontological research.

Part I: Detrital zircon geochronology

Detrital zircon geochronology has traditionally been used as a provenance tool for reconstructing landscape evolution and tectonics by tracing known age populations of zircons back to their metamorphic or igneous (and in some cases recycled sedimentary) points of origin. Over the past decade sedimentary provenance analysis has evolved significantly due to numerous advances in U–Pb geochronology that have made it possible to rapidly and economically date large populations of detrital minerals, in particular zircon. This has been particularly beneficial in provenance studies focused on tectonic and paleogeographical reconstruction and landscape evolution. Although a number of studies have recently focused on the application of detrital zircons and other minerals for maximum depositional age constraint, it is noteworthy that in palaeontology, a field for which this approach has great potential, there has been little application of this technique to date. Within the field of palaeontology, particularly continental ecosystems, detrital zircon geochronology has major potential for refining the age of terrestrial floras and faunas, which are often notorious for their poor temporal and stratigraphic controls due to ambiguous biostratigraphy. Detrital zircons are nearly ubiquitous in continental clastic sediments, commonly sourced from syndepositional or closely contemporaneous volcanic rocks (located within or even outside of the basin), which can often provide more precise temporal constraints than through biostratigraphy alone.

Part II: Isotope and bulk geochemistry

Geochemical techniques have been used to describe and quantify geologic processes for decades, but have only now become an integral part of understanding past environments and providing context for paleontological findings and questions. Recently, the development of stable isotope techniques and the introduction of “clumped” isotope systems has begun to allow researchers to create high-resolution records of climate in deep time, and to correlate ecosystem impacts with major climate events. This explosion of techniques has also allowed isotopes to be applied directly to paleontological questions, such as evaluating characteristics of organism diets, life habits, and migratory patterns. The related development of portable geochemical tools (e.g., pXRF) and the application of bulk element measurements to the description of sedimentological systems and their role in recording climate/ecosystem processes (e.g., paleosol climofunctions) has further opened the door to explaining and classifying climate-environment-ecosystem interactions at a variety of scales and through many periods of Earth history. Novel geochemical techniques like these can prove to be a crucial tool when combined with paleontological data in a holistic approach to understanding past ecosystems and environments, particularly in terms of generating quantitative data which can be compared both to modern systems and to a wide set of paleo-systems and timescales.

Workshop outcomes

- Participants will acquire basic knowledge and understanding of the origin of detrital zircons, their characteristics and their cycling through geological systems;
- Participants will create a process-oriented conceptual framework for interpretation of geologic features related to detrital zircon geochronology coupled with sedimentary geology;
- Participants will learn the mechanisms of sediment erosion, transport, deposition and alteration in a broad variety of geological environments (facies analysis and architectural analysis);
- Participants will acquire basic knowledge of isotope and bulk element geochemistry, and discuss applications of these techniques to describing past habitats and climates
- Participants will gain experience with portable geochemical equipment, and have the opportunity to use generated data to describe fossil contexts
- Participants will experience an extensive hands-on application of standard field and laboratory techniques used in the science of sedimentology and stratigraphy (field excursion only)

Dr. Ryan T. Tucker, an emerging paleo-scientist and *Lecturer based at Stellenbosch University in Stellenbosch South Africa*, is principally a field-based geologist with strong interests in the fossil record and the tectonics of sedimentary basins. Dr Tucker has focused on contextualizing Mesozoic strata and entombed fossil assemblages therein. In particular, this research expertise draws upon a background in sedimentary environments, chemical tracers of sedimentary provenance (e.g., detrital zircon geochronology; Lu-Hf isotopes), and palaeontology, to address questions about the fossil record and the evolution of sedimentary basins, in particularly: 1) development of new strategies for improving the depositional age of clastic stratigraphic successions through the application of detrital mineral geochronology, 2) timing and pattern of basin development in Gondwana during the Late Paleozoic to Mesozoic, 3) vertebrate taphonomy, and 4) vertebrate palaeontology.

Dr. Ethan Hyland, a paleoclimatologist/geochemist and *Assistant Professor in the Department of Marine, Earth and Atmospheric Sciences at North Carolina State University in the United States,* spends most of his time reconstructing paleoenvironments during major climate transitions, and is particularly interested in providing geological context for paleontological sites. Hyland has significant experience in field expeditions working on a variety of Mesozoic and Cenozoic projects in places such as Argentina, Saudi Arabia, Italy, Arctic Canada, and the American West. His Paleo^3 Lab at NCSU includes facilities for paleobotanical, stable and “clumped” isotope geochemical, and bulk element geochemical analysis, allowing his research group to tackle important questions related to developing high-resolution spatiotemporal records of climate change during “greenhouse” periods and tracking the impacts of such changes on major global ecosystems during these turbulent times.

Thursday, 19 December 2019
Workshop II - Mitigating Fossil Specimens With Pyrite Decay

Lisa Herzog, *Operations Manager*, Paleontology Unit, North Carolina Museum of Natural Sciences, USA

Time: 9:00-12:00

Overview

Pyrite decay (oxidation) is a recognized conservation issue for fossil material, particularly in high humidity environments. The process of mitigating pyrite decay in fossil specimens is not well understood and myths and misinformation are pervasive. Publications detailing protocols for reducing pyrite oxidation provide conflicting practices making the process of determining best practices difficult. Although some recommendations have proven to be effective, others fail to meet the standards of scientific rigor. This workshop will explore various methods in use and their individual merits. Participants will have a chance to perform hands on mitigation with specimens and materials. Associated chemical reactions and molecular properties will be reviewed.

North Carolina Museum of Natural Sciences Pyrite Mitigation Protocol

In 2016, the North Carolina Museum of Natural Sciences (NCSM) received a collections improvement grant from the National Science Foundation to develop a protocol for conserving fossils deteriorating from pyrite oxidation. Over a two-year period we applied this approach to treat pyrite oxidation in multiple specimens (NCSM Paleobotany, Invertebrate Paleontology, and Vertebrate Paleontology collections), including one of the museum's most scientifically significant vertebrate specimens, the theropod dinosaur *Acrocanthosaurus* (NCSM 14345). Specimens were identified by the presence of pyrite-oxygen-water redox reaction byproducts. This includes rust and/or yellow or white powder residue. At this workshop, participants will receive hands-on instruction in best-practices derived from this effort.

Pyrite decay by-product will be cleaned from bone surfaces. Specimens will be thoroughly dried, then stabilized with archival consolidant (Paraloid B-72, or Polyvinyl Acetate PVA). Specimens will be assessed for any needed support system, including custom plaster cradles, or ethafoam cavity mounts. Once the long-term stability of a specimen is secured, it will be stored within a custom made oxygen and moisture barrier film bag (FilmPak). Each bag will contain a sachet of blue indicating silica desiccant beads and an indicating oxygen scavenger packet. Custom cradles will be made for all large elements to ensure proper support and mitigate breakage due to rolling, or weight. Participants will then discuss the proper form of cabinetry and associated materials to create a control for humidity – the primary concern for pyrite decay.

Workshop Outcomes

- Participants will acquire basic knowledge and understanding of the mineral Pyrite and its polymorph Marcasite.
- Participants will gain hands on experience removing pyrite decay by-product and understand basic stabilization techniques
- Participants will learn safety standards for handling and dealing with associated chemicals and compounds.
- Participants will be taught paleontological importance of specimen conservation and mitigation for long-term storage and stability.
- Participants will be able to identify the steps needed to implement their own strategies to deal with associated collections under their care.

Lisa Herzog is the *Operations Manager of Paleontology at the North Carolina Museum of Natural Sciences* and *Past President of the Association of Materials and Methods in Paleontology*. Lisa has over 20 years of experience in the field of paleontological conservation. In that time, she has had the opportunity to prepare specimens from all over the world and has developed new techniques and strategies for enhancing the scientific value and long-term conservation of fossil specimens. She is especially interested in the long term affects of pyrite decay and has overseen the conservation and care of the NC Museum of Natural Science's iconic specimen *Acrocanthosaurus atokensis*.

Thursday, 19 December 2019
Workshop III: Digitizing Dinosaurs
Using advanced visualization techniques to conserve & study fossil specimens

Dr. Ryan King, *Adjunct Professor*, Western State Colorado University
Dr. Lindsay Zanno, *Associate Professor*, Biological Sciences, North Carolina State University & *Head of Paleontology*, North Carolina Museum of Natural Sciences

Time: 13:00 to 17:00

Overview

Issues of data preservation and accessibility pose significant challenges for those who collect, study, and manage fossil resources. The recent explosion in 3D technologies and online resources allows researchers to conserve, store, and share three-dimensional data rapidly and inexpensively with other scientists and with public audiences. Three-dimensional digitization of specimens has three main areas of benefit: 1) specimen conservation and preservation; 2) increasing the accessibility of collections to promote active research and public interest; and 3) research applications such as advanced visualization.

Specimens suffering from conservation problems and those that may be damaged by traditional methods of duplication (i.e., molding/casting) can be studied without handling or reproduced through 3D printing techniques. Three-dimensional digital records are also valuable for long-term archives of specimen morphology in the case of accidental damage or catastrophic loss (such as the recent fire at the Museu Nacional Brasil). Three-dimensional technologies can be used to capture specimen data in the field (such as trackways) improving our ability to preserve contextual data for fossils, or study fossils that cannot be moved to a collection.

The high cost of research travel can be a barrier to specimen access. Digital data archives such as 3D scans can be easily shared and thus promote research and collaboration.

Three-dimensional fossil specimens have historically been illustrated in 2D. The production of 3D specimen models creates opportunities to apply leading research applications to ancient specimens, such as topographic profiling of morphology or dimensional comparison analysis. Representing fossils in 3D is especially critical for research on tracks and trackways. Unlike body fossils, track morphology is dependent on the substrate, so depth is an important component that must be captured for adequate study. Finally, data archiving is becoming a standard requirement for scientific publication and 3D models can meet this need.

Description

In this workshop we will explore the use of rapid, high-resolution, 3D imaging technology to capture and model the morphology of extinct organisms. This technology can be used to output 3D quantifications of fossil specimens rapidly, inexpensively, and objectively. We will gain hands-on practice with constructing 3D models out of: 1) surface scanning technology; and 2) photogrammetry methods. We will also explore different options for open and closed access data archiving, including 3D databases of scientific specimens as a means for museum and universities to increase visibility of their research collections.

Workshop Outcomes

- Participants will understand the value in generating 3D data
- Participants will review new technologies in 3D digitization of fossil specimens
- Participants will compare/contrast available options for storing 3D data and making it publicly accessible
- Each participant will have access to the presentation file and receive a 3D guidebook summarizing the information presented.

Ryan King, an *Adjunct Professor at Western Colorado University*, has documented vertebrate tracks for 18 years. Dr. King has worked with conservation of body fossils for the past 15 years. His research focus mainly on taphonomic and toponomic aspects of fossil preservation. King has extensive experience in the field working on geological and paleontological research projects in Pennsylvanian to Cretaceous age strata from multiple basins across North America (e.g., Appalachian Basin, Western Canada Sedimentary Basin, and Sevier Basin as comparison). Currently, Dr. King is working on ichnological photogrammetry projects regarding dinosaur tracks, turtle swim traces, and large batoid feeding/burial structures in the Cretaceous. Additionally, King is utilizing three-dimensional modeling for fracture mapping in Jurassic sauropod bones from Colorado to enhance and build understanding of taphonomic preservation related to regional stress.

Lindsay Zanno is *Head of Paleontology at the North Carolina Museum of Natural Sciences* and *Associate Research Professor in the Department of Biological Sciences at North Carolina State University*. Despite over 20 years of global expedition experience in places such as China, Mongolia, Thailand, and Mexico, Zanno has a soft spot for the American West from where she has described many new species. Her lab uses active field explorations and next-generation visualization approaches to gather new data on life during the Cretaceous—a time period experiencing hot-house temperatures and rising seas. Zanno's research garners worldwide media attention. She was recently featured as Science Advocate for the Walking With Dinosaurs Arena Spectacular and currently serves as President of The Jurassic Foundation, a non-profit, grant funding organization supporting dinosaur research. Zanno leads several citizen science and STEM education projects including co-editing *The Complete Dinosaur*, an upcoming crowd-sourced paleontology volume. In 2012 she launched the real-time social media platform—Expedition Live! connecting the public with paleontologists in the field. Zanno's published impact ranges from top science journals such as Nature to everyday Tweets, including over 140 technical works.

Committee

Host Committee

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Dr. Lindsay Zanno, Terry Gates, & Ethan Hyland, *North Carolina State University, USA*
Ms. Lisa Herzog, *North Carolina Museum of Natural Sciences, USA*
Dr. Ryan King, *Western Colorado University, USA*
Dr. Ryan Tucker, *Stellenbosch University, South Africa*
Dr. R. Hanta, *Suranaree University of Technology, Thailand*
Dr. W. Aswasereelert, *Kasertsart University, Thailand*

Host committee from the Department of Mineral Resources, Thailand

Dr. Sommai Techwan, *Director-General of Department of Mineral Resources*
Mr. Niwat Maneekut, *Deputy Director-General*
Mr. Naramase Teerarungsigul, *Senior Expert (Mineral Resources Management)*
Dr. Apsorn Sardsud, *Director of Division of Mineral Resources Analysis and Identification*
Mr. Suvapak Imsamut, *Director of Division of Mineral Resources Conservation and Management*
Miss Sasa-On Khansubha, *Researcher, Paleontology*
Dr. Pradit Nulay, *Researcher, Sedimentology*
Miss Cherdchan Pothichaiya, *Coordinator,geology*
Miss Janram Putthasem, *Coordinator, Policy and Plan Analyst*

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