

Geodynamic Evolution of Loei and Phetchabun Regions - Does the Discovery of Detrital Chromian Spinel from the Nam Duk Formation (Permian, North-Central Thailand) Provide New Constraint ?

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Abstract

The discovery of the chromian spinel detritus in sandstones from the Permian Nam Duk Formation (Phetchabun region) confirms that the siliciclastic part of this formation is related to the erosion of a mountain belt caused by compressional deformation. The question discussed is whether this detritus is derived from an older orogen exposed today in the region of Loei east of the Nam Duk Basin, or it is from a mountain belt which evolved during Permian times in the west (Nan-Uttaradit region).

In the first case the Nam Duk Formation would represent the passive continental margin sequence of the "Indochina craton", and in the second case it would be part of the sedimentary wedge associated with the compressional deformation and subsequent uplift to the erosional level during Middle to Upper Permian of a rising mountain belt further in the west. In this contribution, arguments in favour of the second scenario are discussed. The region close to the Nan-Uttaradit suture zone shows evidence of compressional deformation and subsequent uplift to an erosional level in the Permian when the chromian spinel detritus was deposited in the Nam Duk Formation.

Key Words: Geodynamic evolution, chromian spinels, Nam Duk Formation, Nan-Uttaradit suture, Loei, Phetchabun.

Introduction

Based on the discovery of chromian spinel in sandstones of the Permian Nam Duk Formation, Chutakositkanon et al. (1997, 1999a) suggest a new suture and terrane boundary in north-central Thailand, which they named "Loei Suture" and which they trace from north of Loei through Phetchabun to the region of Saraburi (Fig.5 in Chutakositkanon et al., 1999a).

We fully recognize the importance of discovery of chromian spinel detritus in sandstones of the Nam Duk Formation since it confirms the interpretation that the siliciclastic part of the Nam Duk Formation is related to the erosion of a mountain belt caused by compressional deformation (Helmcke and Kraikhong, 1982). But we disagree with the interpretation that the influx of the chromian spinel is due to the closure of a previously

unknown suture which runs from the P.R. of Laos via Loei in northeastern Thailand to the south. We still favour the view that the evolution recorded in the sediments of Nam Duk Formation reflects the closure of the Nan-Uttaradit Suture (Chonglakmani, 1998 ; Helmcke and Lindenberg, 1983). To substantiate our point of view we here reiterate and re-evaluate some previously published information by various authors.

Orogenic Activity in Loei Area

From Chiang Khan on the Mekong River to Wang Saphung south of Loei an apparently important tectonic line can be drawn which marks the western boundary of the region tentatively described by Workman (1975) as a Hercynian Massif. Based on the fossil findings by Fontaine et al. (1981) and our own data, Altermann et al. (1983)

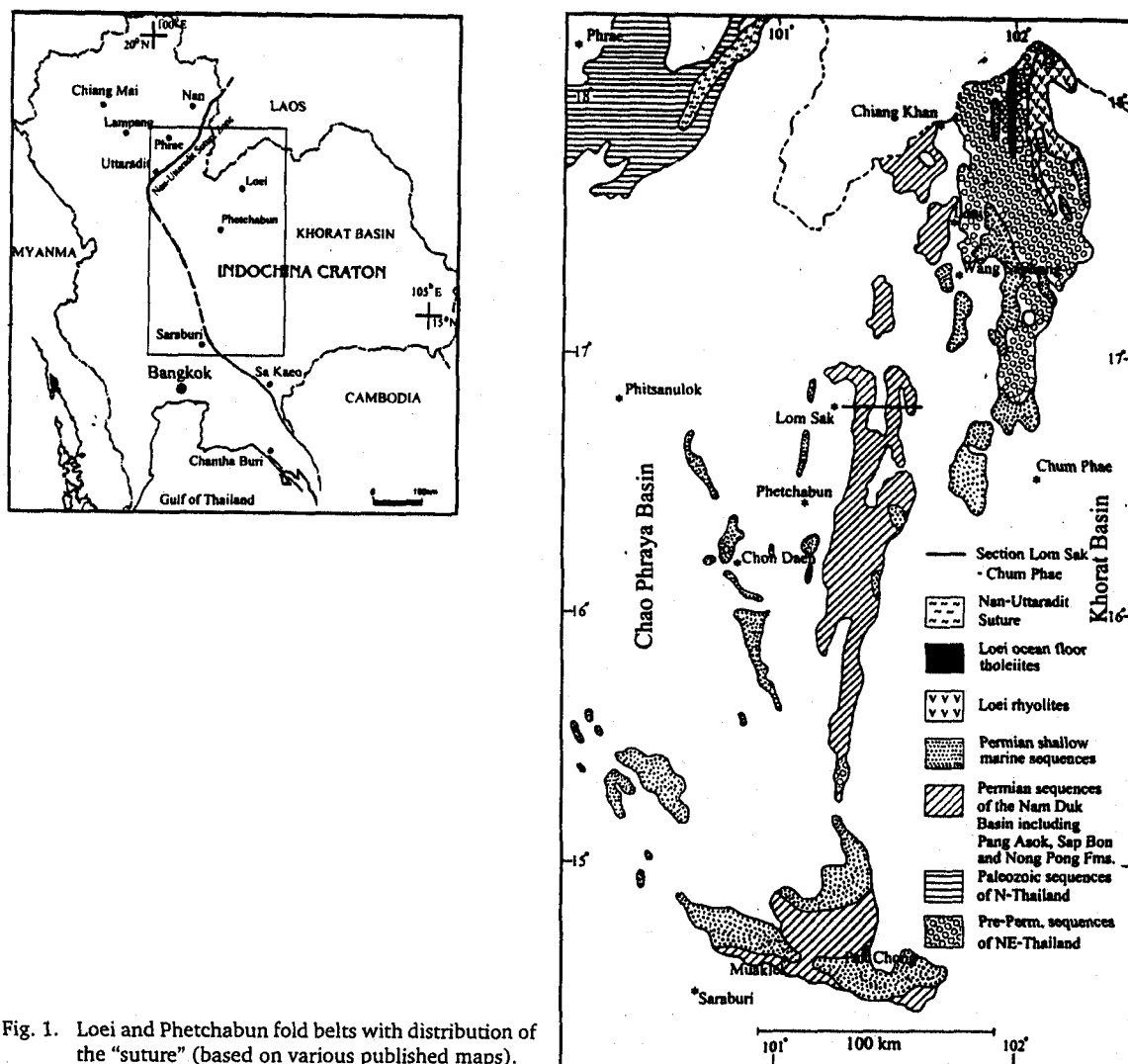


Fig. 1. Loei and Phetchabun fold belts with distribution of the "suture" (based on various published maps).

suggested that the main deformation in this region can be dated approximately at the Devonian/Carboniferous boundary. The Carboniferous and Permian strata are clearly much less deformed. The description of the Loei area by Chairangsee et al. (1990) does not highlight the stratigraphic age of the main orogenic event. They described an orogenic event which is older than late Silurian and mentioned that the next orogenic cycle started during the middle Devonian, reached its climax in the late Carboniferous and faded away before the commencement of late Permian-Triassic igneous activity.

However, data on the basement of the Khorat Basin (Kozar et al., 1992) prove that the basin developed in a region affected by an early Carboniferous event, which is manifested in an angular unconformity. This unconformity divides the Loei Group from the upper Carboniferous and Permian Saraburi Group (Mouret, 1994). It is still controversial that whether this compressional

deformation was followed by a phase of late Carboniferous rifting (Kozar et al., 1992) or the Saraburi Group was deposited due to newly started subsidence (Mouret, 1994). Strata of the Saraburi Group are distributed in most parts of the Khorat Basin indicating that the likely southern continuations of the Loei rhyolites (374 ± 33 Ma) and the Loei ocean floor tholeiites (361 ± 11 Ma), dated by Intasopa and Dunn (1994) by Rb-Sr whole-rock method, could not have been eroded during Permian times.

Orogenic activity of this age (mainly early Carboniferous) is well known from regions in Vietnam (Fontaine and Workman, 1978) and according to Mouret (1994) a collision occurred in the Truong Son Zone, where deep water strata of Devonian to lower Carboniferous are located. The ages reported by Intasopa and Dunn (1994) for the Loei ocean floor tholeiites and the Loei rhyolites (Fig. 1) are not in conflict with the given interpretation (a more detailed discussion will follow). The ages recorded

	Ma		Thailand	Yunnan (Simao)	Phetchabun
Triassic	250	Lower	Griesbachian	Folding-uplift	
		Lopingian	Changxingian	Dorashamian	limestone-siliceous clastic rock assemblage
Wuchiapingian	Dzhulfian				
Permian	260	Guadalupian	Capitanian	Midian	molasse
			Wordian	Murgabian	flysch
	270	Roadian	Kubergandian	Folding-uplift	Pre-orogenic sediments
		280			
	290		Artinskian	Yakhtashian	
		Sakmarian	Sakmarian		
Asselian		Asselian			
Carboniferous	300	Upper	Gzhelian		

Fig. 2. Correlation of the discussed data with the international stratigraphic scheme.

in detrital muscovites of the Khorat red beds mentioned by Heggemann (1994) support Devonian to Carboniferous orogenic activity.

Orogenic Event in Phetchabun Area

In contrast to the above mentioned region, the Permian strata of the Nam Duk Formation along the Lom Sak-Chum Phae highway, which contains the detrital chromian spinels reported recently by Chutakositkanon et al. (1997, 1999a), are severely affected by compressional deformation. This deformation was first dated by Chonglakmani and Sattayarak (1978). They discovered a pronounced angular unconformity between the deformed Permian Nam Duk Formation and the upper Triassic Huai Hin Lat Formation approximately at 34 km of the above mentioned highway (Fig. 15 in Chonglakmani and Sattayarak, 1978). In the following years the stratigraphy and facies of the Nam Duk Formation were being studied. The youngest deformed fossiliferous strata found were dated by H.G. Lindenberg (Figs. 16, 17 in Helmcke and Kraikhong, 1982) and by R. Ingavat (Fig. 4 in Altermann et al., 1983) as Murgabian and very likely also part of Midian (a correlation with stage equivalents is given in Fig. 2). These data are now independently confirmed by Chutakositkanon et al. (1997, 1999a). Based on these data, the main orogenic event which affected this region has been dated as approximately late middle Permian - early late Permian. Only some K-Ar age determinations on the fine mineral fractions (Ahrendt et al., 1993) support this interpretation. The younger ages

found are probably caused by younger thermal overprint respectively by younger intracontinental deformations. The pronounced angular unconformity (Chonglakmani and Sattayarak, 1978) between the folded Permian strata and the upper Triassic sediments cannot be overlooked.

Recent investigation in the Saraburi and Pak Chong areas (about 200 km south of Lom Sak) suggest that the so-called Pang Asok, Sap Bon and part of Nong Pong Formations (Hinthon et al., in Sudasna and Pitakpaivan, 1976) are equivalent to the Nam Duk Formation. They are distributed approximately in east-west trend and extend eastwards underneath the southern part of the Khorat Basin.

Paleocurrent indicators recorded in the siliciclastics deposited by turbidites point to a sediment transport parallel to the axis of the basin and gave therefore no conclusive result where to expect the source area. If we discuss the possibility that the source area of the siliciclastics deposited by turbidity currents of the Nam Duk Formation was to the east as some authors suggested, we have to correlate the stratigraphic column of the Nam Duk strata very carefully and in more detail. Mouret (1994) may serve an example. He suggested that the sudden sand influx in the Nam Duk Formation is caused by a major relative sea level fall which occurred according to the data by Dawson and Racey (1993) during the Bolorian. This possible explanation cannot be substantiated by stratigraphic results obtained in the Nam Duk Formation because they indicate that the sudden influx of siliciclastics started not earlier than the late Kubergandian-Murgabian (R. Ingavat in Winkel et al., 1983; Fig. 2).

However, the geographic distribution of the Nan-Uttaradit ophiolites and the geometry of the folds exposed in the Nam Duk strata suggest that the subduction zone was located to the west. Therefore we expect the source area of the newly discovered chromian spinel detritus in the more internal zones of the rising mountain belt farther to the west. We regard the areas to the east of the section along the highway Lom Sak-Chum Phae as foreland areas and the possibility of major influx of detrital material during the late middle Permian from the foreland area seems to be unlikely.

Age and Uplift of the Nan-Uttaradit Suture Zone

In the above discussion on the possible source area of the newly described chromian spinel detritus, we expressed our conviction that the ophiolites of the Nan-Uttaradit zone are most likely the source region. The discussion in the latest paper by Chutakositkanon et al. (1999b) shows that they also now favour this interpretation.

However, the timing of compressional deformation and subsequent uplift into the erosional level of the Nan-Uttaradit region is still subjected to controversial scientific discussions. In fact, published data are scarce and still quite open for varying interpretations. In our context the most interesting data are those which give age control on the generation of the basalts, rhyolites etc., data on the stratigraphic age of accompanying sediments, data on the metamorphic overprint and the uplift history as well as the data on the cover sequences.

Crawford and Panjasawatwong (1996) published a $^{40}\text{Ar}/^{39}\text{Ar}$ whole-rock age of 256 Ma (late Permian) for a subgroup A-2 ocean-island dolerite; this age is considered to be the primary crystallization age. Helmcke (1985) published a K/Ar age of 344 ± 22 Ma (courtesy of D. Muller-Sonius and P. Horn, Min. Petr. Inst. Univ. Muenchen) obtained from amphiboles in a metamorphosed "ophiolite" sample from the Sirikit reservoir area (Uttaradit), which was interpreted as the age of the metamorphic event respectively as the post-metamorphic uplift.

Barr et al. (1985) published a K/Ar age of 269 ± 12 Ma (middle Permian) obtained on actinolite from a greenschist (Phasom Group) from the Uttaradit area and concluded that this represents the minimum age of metamorphism (presumably collision related).

Radiolaria found in accompanying cherts were dated as late Middle to late Permian by Hada (Sukhawatananan and Asawapatchara, 1987) thus proving that the Nan-Uttaradit zone was still part of a relatively deep basin in the Permian and thus proving that the Carboniferous age

of the "ophiolite" reported by Helmcke (1985) is not the age of metamorphic event, but it could be the age of crystallization.

The most convincing evidence for an orogenic event in the Nan-Uttaradit region would be an outcrop clearly showing an angular unconformity. Though work seems to be in progress (for example compare new Geological Map 1:50,000 sheet Lampang, Charoenprawat et al., 1994) there is, to our knowledge, still no outcrop known in this part of Thailand which gives this approval of compressional deformation and subsequent uplift into the erosional level.

In the Simao region of southern Yunnan (P.R. of China), however, such an outcrop is now discovered (Feng and Helmcke, submitted). Based on a re-evaluation of existing data and our own field-work it could be demonstrated that in the Yunxian anticline, (approximately 40 km NW of Simao) strongly deformed Carboniferous to lower Permian sediments, which were deposited in a deep basin, are separated by an angular unconformity from the overlying shallow marine strata of upper middle Permian age. There is good evidence that the Simao region has to be regarded as the northern continuation of the Lampang region of Thailand. There is growing evidence to support that the Lampang region and the Nan-Uttaradit region were affected by a compressional orogenic event during the upper part of the middle Permian (approximately 265 Ma). The compressional phase in both areas were followed by the onset of extensional deformation, which caused the creation of new depo-centers in half grabens. This new phase of sedimentation started earlier (early Triassic) in the western part (region of Lampang) and later (late Triassic) in the eastern part (regions of Phrae and Nan-Uttaradit). Therefore, although the existence of younger strike-slip faults and reverse faults is evident in the whole region, we do not hesitate to accept a former close connection between these two regions.

According to our data, there is sufficient evidence that the region of the Nan-Uttaradit suture zone went through an event of compressional deformation and subsequent uplift before the Triassic, from areas closer to the Nan-Uttaradit suture zone than the section of the Nam Duk Formation along the highway Lom Sak-Chum Phae mentioned in the last chapter. West of Phrae along the highway Phrae - Long, Mickein (1992) could date phyllites as approximately 265 ± 7.9 Ma and Senowbari-Daryan and Ingavat-Helmcke (1993) described clastics and limestones of the latest Permian age, which were not subjected to metamorphic overprint from nearly the same region, thus indicating that onset of a new transgression followed soon afterwards. Luddecke et al. (1991) analyzed the pebble content of a Carnian - Norian conglomerate

sequence along the highway Rong Kwang - Nan and reported that 36% of the pebbles are metamorphic rocks (mainly phyllites and quartzites). Skythian - Ladinian sediments are not known in this region.

Discussion

Chutakositkanon et al. (1997, 1999a) suggested a new "Loei suture" in northeastern Thailand and also suggested that the chromian spinel detritus discovered in the Nam Duk Formation of the Phetchabun region is derived from this suture. However, Intasopa and Dunn (1994) interpreted the Loei rhyolites and the Loei ocean floor tholeiites as belonging to two different magmatic episodes. The rhyolites (374 ± 33 Ma) are interpreted to belong to an older suturing process and the ocean floor tholeiites (361 ± 11 Ma) are interpreted to indicate a younger sea-floor spreading, i.e., a quite mature stage of rifting. These are two different processes, which cannot be combined into a single "Loei suture".

In southern Yunnan southeast of the Ailao Shan (region between Mojiang and Yiancheng in the eastern Simao Basin) lower Carboniferous basalts are known, which also indicate rifting (Oral communication, Prof. Feng Qinglai, 2000). The occurrence of the *Paripteris* flora (Laveine et al., 1993) in the Loei area is of special paleogeographic importance since *paripteris* is an excellent northern Tethyan index fossil, i.e., the mentioned rifting developed within marginal regions of the continental crust. If the Carboniferous age of the "ophiolite" from the Nan-Uttaradit suture reported by Helmcke (1985) could be interpreted as the age of the crystallization, then both regions would show indications of extension and formation of new oceanic crust during the Carboniferous.

There seems to be still an important difference between the region of the Loei ocean floor tholeiites and the Nan-Uttaradit zone. While the stratigraphic column of the Loei area does not show any indication of a compressional deformation event in the upper middle to lower upper Permian, we think that the Nan-Uttaradit zone does show indications that this event can be proved here. The interpretations by Crawford and Panjasawatwong (1996) and by Hada (in Sukhawatananan and Asawapatchara, 1987), however, do not fit readily into this scenario. At least it can be discussed that there remains the possibility that there are still some discrepancies in age dating during middle to upper Permian when fusulinid-stratigraphy radiolarian-stratigraphy is applied respectively. The whole-rock age published by Crawford and Panjasawatwong (1996) would fit much better, if it would be considered to represent the minimum age of metamorphic overprint.

Conclusion

According to the data discussed, we interpret the chromian spinel detritus recorded in the siliciclastic part of the Nam Duk Formation of the Phetchabun region as closely related to the closure of the Nan-Uttaradit Suture. The Nam Duk Formation is represented not as part of a passive margin sequence of the "Indochina craton" but as part of the sedimentary wedge associated with the compressional deformation and subsequent uplift of the Nan-Uttaradit region to the erosional level. The Loei area to the east represents the foreland region which was, after an initial rifting, subsequently covered by thick column of Carboniferous and Permian strata, which were not subjected to compressional deformation and subsequent uplift during Permian times.

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References

- Ahrendt, H., Chonglakmani, C., Hansen, B.T. and Helmcke, D. (1993) Geochronological cross section through northern Thailand. *J. SE Asian Earth Sci.*, v. 8, pp. 207 - 217.
- Altermann, W., Grammel, S., Ingavat, R., Nakornsri, N. and Helmcke, D. (1983) On the evolution of the Paleozoic terrains bordering the northwestern Khorat Plateau. *Conf. on Geol. and mineral resources of Thailand*, Bangkok, 5p.
- Barr, S.M., MacDonald, A.S., Yaowanoyothin, W., and Panjasawatwong, Y. (1985) Occurrence of blueschists in the Nan River mafic-ultramafic belt, northern Thailand. *Warta Geologi*, v. 11, pp. 47-50.
- Chairangsee, C., Hinze, C., Machareonsap, S., Nakornsri, N., Silpalit, M. and Sinpool-Anunt, S. (1990) Geological map of Thailand 1 : 50,000 - Explanation for the sheets Amphoe Pak Chom 5345 II, Ban Na Kho 5344 I, Ban Huai Khop 5445 III, King Amphoe Nam Som 5444 IV. *Geol. Jahrbuch*, B, v. 73, 55p.
- Charoenprawat, A., Chuaviroj, S., Hinthong, C. and Chonglakmani, C. (1994) Geological map of Changwat Lampang Quadrangle, scale 1 : 250,000. *Geol. Surv. Div., DMR*, Bangkok, Thailand.

- Chonglakmani, C. (1998) The Triassic system of Thailand : implication on geotectonic evolution of southeast Asia. Ninth Regional Congress on Geology, Mineral and Energy Resources of Southeast Asia, Abstracts, Kuala Lumpur, p.48.
- Chonglakmani, C. and Sattayarak, N. (1978) Stratigraphy of the Huai Hin Lat Formation (upper Triassic) in northeastern Thailand. Proceedings of the Third Regional Conf. on Geol. and Mineral Resources of SE Asia, Bangkok, pp. 739 - 762.
- Chutakositkanon, V., Hisada, K., Ueno, K. and Charusiri, P. (1997) New suture and terrane deduced from detrital chromian spinel in sandstone of the Nam Duk Formation, north-central Thailand. Preliminary report. Intern. Conf. on Stratigraphy and Tectonic Evolution of Southeast Asia and the South Pacific, Bangkok, p. 368.
- Chutakositkanon, V., Hisada, K., Charusiri, P. and Arai, S. (1999a) Detrital chromian spinels from the Nam Duk Formation : a key to elucidate the tectonic evolution of central mainland Southeast Asia and the Loei suture zone in Thailand. Intern. Symposium Shallow Tethys 5, Chiang Mai, pp. 450-456.
- Chutakositkanon, V., Hisada, K., Charusiri, P., Arai, S. and Charoentitirat, T. (1999b) Characteristics of detrital chromian spinels from the Nam Duk Formation : implications for the occurrence of mysterious ultramafic and volcanic rocks in central Thailand. Symp. Min., Energy and Water Resources of Thailand : Towards the year 2000, Bangkok, pp. 604-606.
- Crawford, A.J. and Panjasawatwong, Y. (1996) Ophiolites, ocean crust, and the Nan Suture in NE Thailand. Intern. Symp. On lithosphere dynamics of East Asia, Extended Abstract, Taipei, pp. 84-89.
- Dawson, O. and Racey, A. (1993) Fusuline-calcareous algal biofacies of the Permian Ratburi limestone, Saraburi, Central Thailand. J. SE Asian Earth Sci., v. 8, pp. 49-65.
- Feng, Q. and Helmcke, D. (submitted) Late Paleozoic contractional deformation in the Simao region, southern Yunnan, P.R. of China, Newsletter on Stratigraphy.
- Fontaine, H., Poumot, C. and Songsirikul, B. (1981) New upper Paleozoic formations of northeast Thailand in Devonian and lower Carboniferous. - CCOP Newsletter, v. 8, pp. 1-7.
- Fontaine, H. and Workman, D.R. (1978) Review of the geology and mineral resources of Kampuchea, Laos and Vietnam. Proceedings Third Regional Conf. on Geol. and Mineral Resources of Southeast Asia, Bangkok, pp. 739-762.
- Heggemann, H. (1994) Sedimentäre Entwicklung der Khorat-Gruppe (Ober-Trias bis Paläogen) in NE- und N-Thailand. Gottinger Arbeiten zur Geol. u. Paläont., v. 63, 146 p.
- Helmcke, D. (1985) The Permo-Triassic "Paleotethys" in mainland southeast-Asia and adjacent parts of China. Geol. Rundschau, v. 74, pp. 215-228.
- Helmcke, D. and Kraikhong, C. (1982) On the geosynclinal and orogenic evolution of central and northeastern Thailand. J. Geol. Soc. Thailand, v. 5, pp. 52-74.
- Helmcke, D. and Lindenberg, H.-G. (1983) New data on the "Indosinian" orogeny from central Thailand. Geol. Rundschau, v. 72, pp. 317 - 328.
- Intasopa, S. and Dunn, T. (1994) Petrology and Sr-Nd isotopic systems of the basalts and rhyolites, Loei, Thailand. J. SE Asian Earth Sci., v. 9, pp. 167-180.
- Kozar, M.G., Crandall, G.F. and Hall, S.E. (1992) Integrated structural and stratigraphic study of the Khorat Basin, Rat Buri limestone (Permian), Thailand. National Conf. on Geol. Resources of Thailand : Potential for Future Development, Bangkok, pp. 692-736.
- Laveine, J.P., Ratanasthien, B. and Sithirach, S. (1993) The Carboniferous flora of northeastern Thailand : its paleogeographic importance. C.R. Acad. Sci. Paris, t. 317, v. 2, pp. 279 - 285.
- Luddecke, S., Chonglakmani, C. and Helmcke, D. (1991) Analysis of pebble associations from the marine Triassic of northern Thailand. J. Thai Geosci., v. 2, pp. 91-101.
- Mickein, A. (1992) Alter und Intensität der schwachmetamorphen Überprägung des Nam Pat-Fachens E Sirikit Dam (N-Thailand) (K/Ar-Datierung-Illitkristallinität). Unpubl. M. Sc. Thesis, Univ. Goettingen, 80 p.
- Mouret, C. (1994) Geological history of northeastern Thailand since the Carboniferous. Relations with Indochina and Carboniferous to early Cenozoic evolution model. Proc. Intern. Symposium on Stratigraphic Correlation of Southeast Asia, Bangkok, pp. 132-158.
- Senowbari-Daryan, B. and Ingavat-Helmcke, R. (1993) Upper Permian sponges from Phrae province (northern Thailand). Proceeding Intern. Symp. on Biostratigraphy of Mainland Southeast Asia. Facies and Paleontology, Chiang Mai, v. II, pp. 439-451.
- Sudasna, P. and Pitakpaivan, K. (1976) Geological Map of Changwat Phra Nakhon Si Ayuthaya, Scale 1:250,000. Geol. Surv. Div., DMR, Bangkok, Thailand.
- Sukhawatananan, P. and Asawapatchara, S. (1987) Geology of Amphoe Sa (5146 II) and Ban Nam Muab (5145 I) Sheets, Scale 1:50,000. Paper presented at DMR Geol. Meeting, 25-26 August, 1987, Geol. Surv. Div., DMR, Bangkok, Thailand, 40p. (in Thai).
- Winkel, R., Ingavat, R. and Helmcke, D. (1983) Facies and stratigraphy of the lower - lower middle Permian strata of the Phetchabun fold-belt in central Thailand. Proceedings, Workshop Stratigraphic Correlation Thailand and Malaysia, Haad Yai, v. 1, pp. 293-306.
- Workmann, D.R. (1975) Tectonic evolution of Indochina. J. Geol. Soc. Thailand, v. 1, pp. 3-19.