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Transition between the Thabsila metamorphic complex and the Lower Paleozoic formations and their sandstone provenance, Kanchanaburi, western Thailand

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Abstract

In Kanchanaburi province of western Thailand, the oldest three rock units include the Thabsila regional metamorphic complex exposed side by side with the Cambrian Chao Nen and the Ordovician Tha Manao formations, possessing field relation, petrography and geochemistry strongly suggesting a transitional relationship. The latter two rock formations are equivalent to the Cambrian Tarutao Group and the Ordovician Thung Song Group from southern Thailand. They are characterized by alternating lithofacies of argillites, siliciclastics and carbonates. The gradational nature among them both in lithology and grade of metamorphism with only a single mode of foliation development indicates one episode of progressive regional metamorphism. Modal compositions of the Upper Thabsila and the Chao Nen meta-siliciclastic sandstones show them as original quartz arenite and subarkose to arkosic sandstones. Their provenances was from a continental block setting. The chemical discrimination diagrams indicate they have been deposited in a passive continental margin environment and have an asymmetrically cyclic sedimentation habit. This evidence implies that there is no unconformity between the Thabsila complex and the Lower Paleozoic formations. Although this terrain was subjected to a series of northwest dextral strike-slip fault movement, their gradational nature in grades of metamorphism is, in part of some sections, still preserved. Their sharing of the same provenance and the tectonic setting show that they were continuously deposited throughout the long history of the Shan-Thai terrane (up to as young as around Carboniferous, the timing of tectonically uplifting by the incoming of volcanism to this terrane). The underlying older Precambrian basement, the source rock of the Thabsila complex have never been observed. Probably have been re-melted to the common foliated Triassic S-type granite in western Thailand.

Keywords: regional metamorphism, sandstone provenance, Cambrian, Ordovician,

Introduction

The lithologic transition between the Thabsila complex and the lower Paleozoic rocks exposed in Kanchanaburi and northern Thailand areas have been questioned for many decades since the German Geological Mission to Thailand (1972) and Bunopas, (1981). The study area is along the road to Sri Sawat district, passing along the Khwae Yai river between Ban Tha Manao and Ban Mong Krathae, Kanchanaburi (Fig. 1). Nevertheless, most of the mentioned records did not study throughout the area but rather concentrated on the known problematic sites. The data under the DMR Hazardous Element Project systematically cover parts of the area in Suphanburi and Uthai Thani, but no sampling in nearby Chainat provinces.

This paper characterizes the apparent similarity between the quartz mica schist, quartz schist and the foliated feldspathic quartzite of the Upper Thabsila complex and the Cambrian Chao Nen feldspathic (-micaceous) quartzites, and shows a commonality in sedimentary, petrographic mode, provenance and geochemistry that constrains their transition.

II. Geological setting

In relation to the field relationship between the high grade Thabsila complex and the nearby Lower Paleozoic (Chao Nen and Tha Manao) formations, the conclusion has been drawn earlier since the time of the German Geological Mission (1972), and subsequently Bunopas (1981) who confirmed the German Mission"s conclusion that in most of the places, there is an obscured and

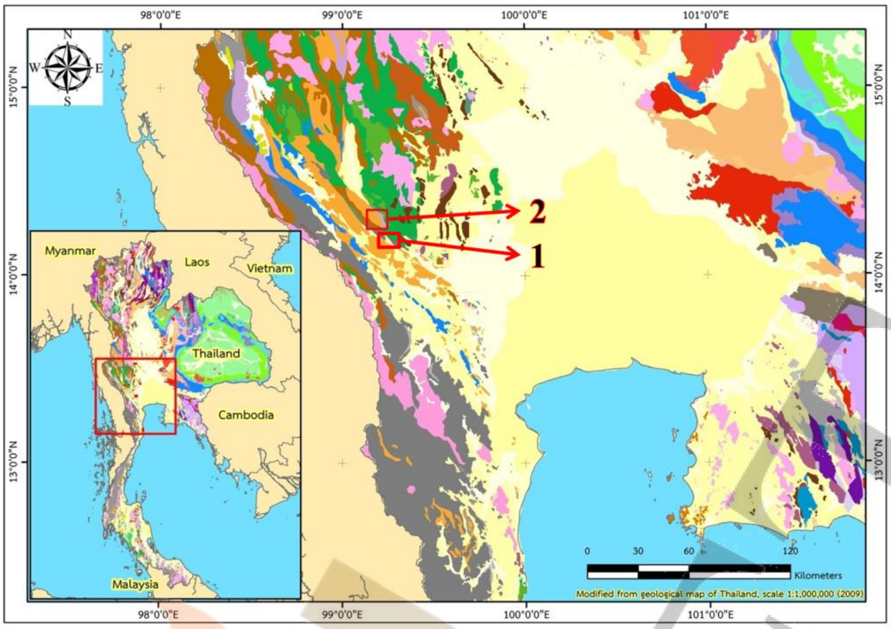
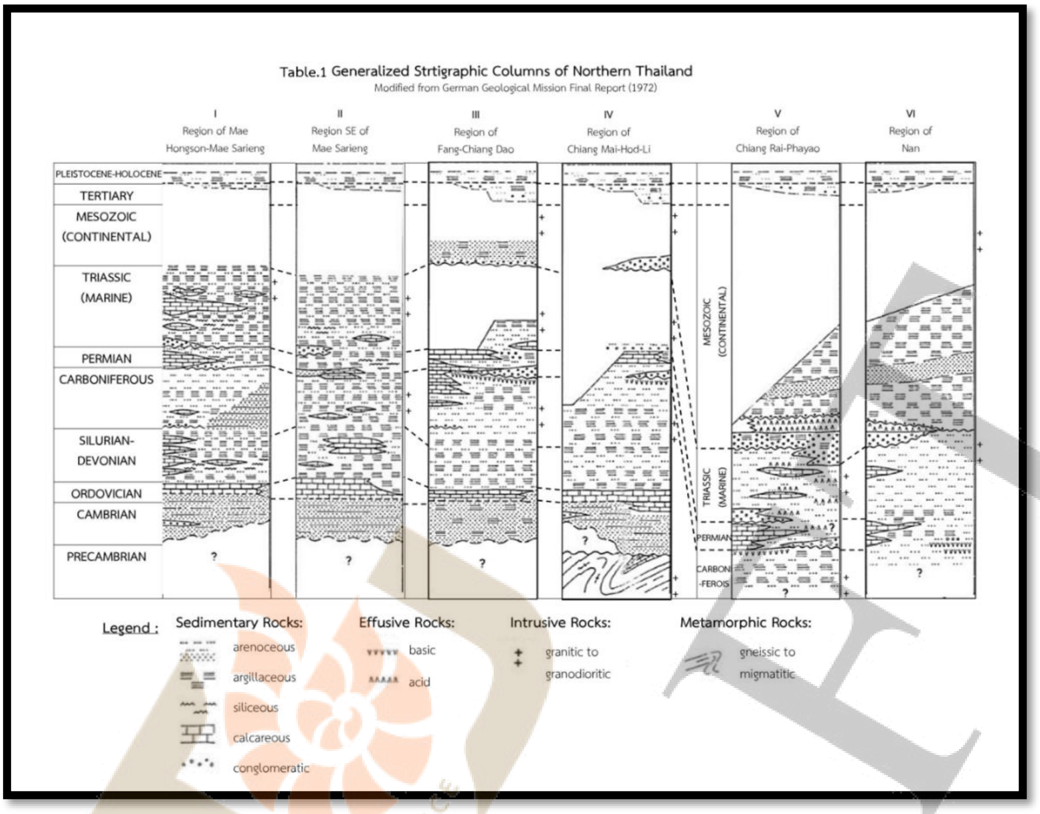


Fig. 1 Index map showing the studied area of the Thabsila complex (1) and the Chao Nen-Tha Manao formations (2) adjacent to the Khwae Yai River, in Kanchanaburi.

questionable unconformity with subsequent slip movement. Bunopas (1981) noted that, there is a drastic change in metamorphic grade in many places between the higher grade Inferred Precambrian and the lower grade Lower Paleozoic rocks in Thailand. This contact relation is generally a fault contact.

In Kanchanaburi (table 2), the metamorphic nature of the lower Paleozoic rocks is quite clearly developed and distinctive cleavage is obvious. For the regional metamorphic rocks that have been subjected to only one episode of metamorphism and range in grades from higher Amphibolite facies progressively lowering to slate or cleaved rock of the lower Greenschist facies and faded away around the Upper Paleozoic rocks. The other kind of metamorphic rocks belonging to the occurrence from contact metamorphism by large body of foliated Triassic S-type, volatile rich granite which is common and widespread in isolated intrusions ranging from batholith to small satellitic and isolated bodies (pluton) but conjoined at depth forming a large batholith. This kind of foliated contact metamorphism is affected only to the lower grade part of the regional metamorphism. By the time of intrusion, the relative thermal control between the intruding and the intruded rocks must be the important control on the occurrence of the foliated contact metamorphic rocks being generated (Salyapongse et al., 2015). Generally, once the originally regional lower grade country rocks have been upgraded to a higher grade and mimically imitated the original foliation and increasing grades up to even calc-silicate rocks and sillimanite mica schist originated from a commonly low-grade Cambrian to Siluro-Devonian rocks.

Nanthasin et. al, (2012) summarized the Thabsila metamorphic complex into four units based on lithology from younger to older units: (1) Unit A is composed of marble, mica schist and quartzite, (2) unit B comprises mylonites, (3) unit C is composed of calcsilicate, and (4) unit D comprises various gneisses. Their approximation has been based on geothermobarometric and pseudo section of the 4 Thabsila unit as indicating PT ranging from Lower T / intermediate P at 500-650 °C / 5-6.5 Kb up to 640-719 °C / 5.5-8 Kb, probably of Barrovian Facies Series conformably from top to bottom as a



progressive sequence. The ages of metamorphic events in western Thailand is controversial. Nanthasin et. al, (2012) gave a metamorphic age of Eocene which contradicts the earlier interpretation on metamorphism age which quoted as Late Triassic (Hansen et al, 2014), and thought to represent a Barrovian Facies Series. Generally, the dislocated metamorphism is restricted to a narrow fault zone which obviously from Nanthasin et. al's description of mylonite unit that seems to be restricted only in the zone B. On the other hand, it is doubtful that the cataclastic metamorphism is high grade enough for the recrystallization of the zircon and produced the Thabsila metamorphic complex which cover an area more than one thousand square kilometer. The commonly tourmaline rich accessory mineral in various kind of rock for example quartzite and quartz schist in Thabsila area is very common as the same as that commonly found in metamorphic pegmatite. A very interesting publication by Hay and Dempster (2009), presented a special kind of low temperature metamorphism which induced a zircon rimming indicating quite young event. Since the Zr age was derived at 55 my which is quite young and seems to relate to the Eocene collision between Asia and Eurasia since the last 55 Ma. However, a detailed survey by Musikarak (2019) reported the event of Eurasia–India collision is related to a dextral movement and only caused brittle deformation contrasting with the common ductile feature in this area which is sinistral and originated earlier.

III. The Upper Thabsila meta-siliciclastic sandstones

This unit, which is about 2400 m thick belonging to the upper part of the Thabsila is exposed just across the Khwae Yai River fault valley to the west around Ban Pong Pat near Tha Thung Na dam (Table 3 and Fig.2). Generally, the transferring of the Upper Thabsila sequence to the Lower Paleozoic rocks frequently has been obscured by faulting and specifically around the Tha Thung Na area (Fig.2). Observation along the

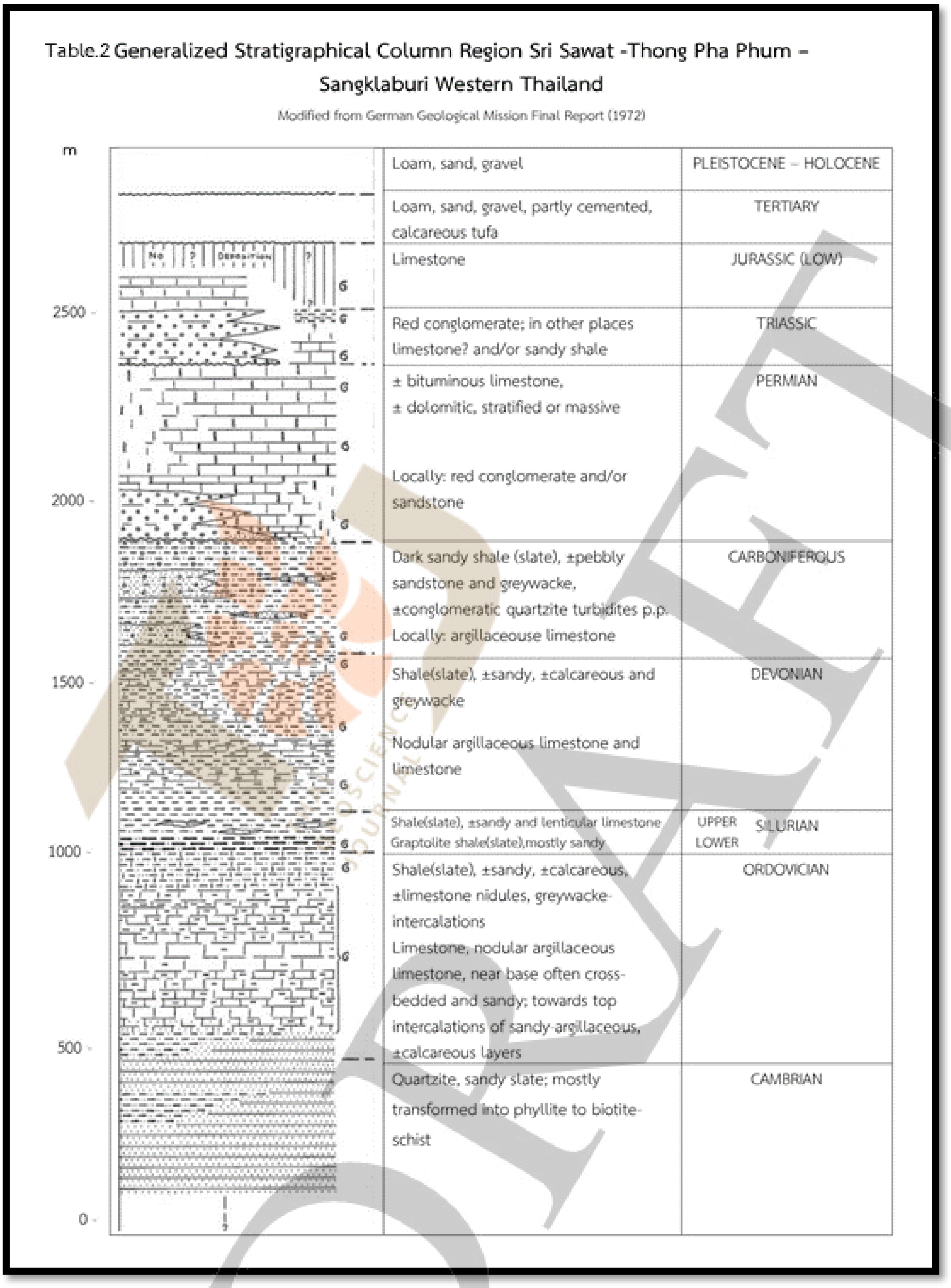


Table.2 Generalized Stratigraphical Column Region Sri Sawat -Thong Pha Phum – Sangklaburi Western Thailand

Modified from German Geological Mission Final Report (1972)

m		
	Loam, sand, gravel	PLEISTOCENE – HOLOCENE
	Loam, sand, gravel, partly cemented, calcareous tufa	TERTIARY
	Limestone	JURASSIC (LOW)
2500	Red conglomerate; in other places limestone? and/or sandy shale	TRIASSIC
2000	± bituminous limestone, ± dolomitic, stratified or massive Locally: red conglomerate and/or sandstone	PERMIAN
	Dark sandy shale (slate), ±pebbly sandstone and greywacke, ±conglomeratic quartzite turbidites p.p. Locally: argillaceouse limestone	CARBONIFEROUS
1500	Shale(slate), ±sandy, ±calcareous and greywacke Nodular argillaceous limestone and limestone	DEVONIAN
1000	Shale(slate), ±sandy and lenticular limestone Graptolite shale(slate),mostly sandy	UPPER / LOWER SILURIAN
	Shale(slate), ±sandy, ±calcareous, ±limestone nidules, greywacke intercalations Limestone, nodular argillaceous limestone, near base often cross-bedded and sandy; towards top intercalations of sandy-argillaceous, ±calcareous layers	ORDOVICIAN
500 – 0	Quartzite, sandy slate; mostly transformed into phyllite to biotite-schist	CAMBRIAN

Khwae Yai fault zone by traversing their geologic cross-section for many kilometers down south revealed an obviously through a unique key bed containing a characteristic metamorphic mineral allowing their equilibration very nicely along both side geology, and can be concluded as an early remark that, the Khwae Yai fault zone was a kind of horizontal strike-slip fault and having dextral offset around 15 km. Even though the lack of unconformity evidence, Bunopas (1981) has assigned the age of the Thabsila as inferred Precambrain basing on their apparent difference in grades of metamorphism as had been impressed at that time.

Table 3. Stratigraphic column of Thabsila metamorphic complex (reconstructed) and Chao Nen-Tha Manao formations in Kanchanaburi.

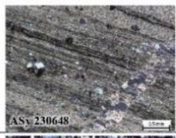
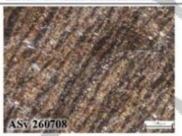
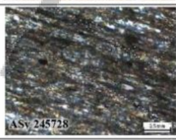
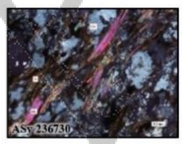
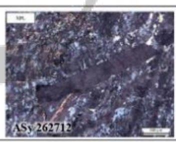
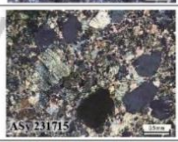
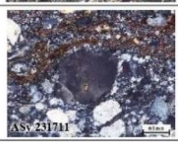
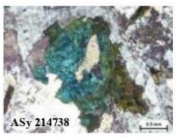
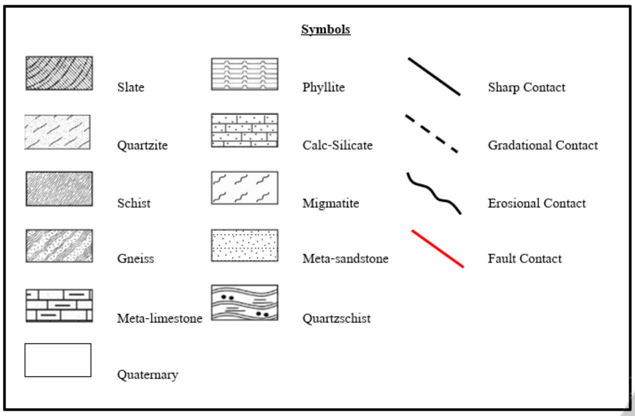
AGE	THICKNESS	STRATIGRAPHY	LITHOLOGY	ZONE	THIN SECTION	DESCRIBE
Quaternary	20 m		Gravel, sand, silt, clay			Alluvium and fluvial sedimentary deposits
Ordovician	900 m		Meta-argillaceous limestone	Tha Manao		Thick beded meta-argillaceous limestone, grey color
Cambrian	600 m		Meta-sandstone	Chao Nen		Thin beded meta-sandstone, medium to fine grained and moderately sorted
Upper Precambrian (Upper Thabsila)	312 m		Slate	Thabsila Zone D		Grey-greenish slate, fine grained, intensively eroded
	249 m		Phyllite and schist interbeded with quartzite	Thabsila Zone C		Grey phyllite, phylliticschist with kyanite and andalusite porphyroblast
	20 m		Meta-limestone			Banded quartzite, medium grained and well sorted, fused quartz grain and foliated
	515 m		Quartzite			
	80 m		Calc-silicate, Marble	Thabsila Zone B		Thick quartzschist, coarse grained, shows schistosity, micaceous rich
	776 m		Quartz-mica schist			
	400 m		Schist and fgr paragneiss			Thin layer schist and shows schistosity with sillimanite and fibrolite.
Lower Precambrian (Lower Thabsila)	500 m		Calc-silicate	Thabsila Zone A		Brownish green, coarse grained, show foliated silica and carbonate minerals
	250 m		Gneiss			Coarse to med grained, alternated light and dark bands
	>300 m		Migmatite			Dark grey-black, coarse grained with partly melted leucocratic vein and restite

Table3.1 Symbols of Stratigraphic column of Thabsila metamorphic complex and Chao Nen-Tha Manao formations in Kanchanaburi.



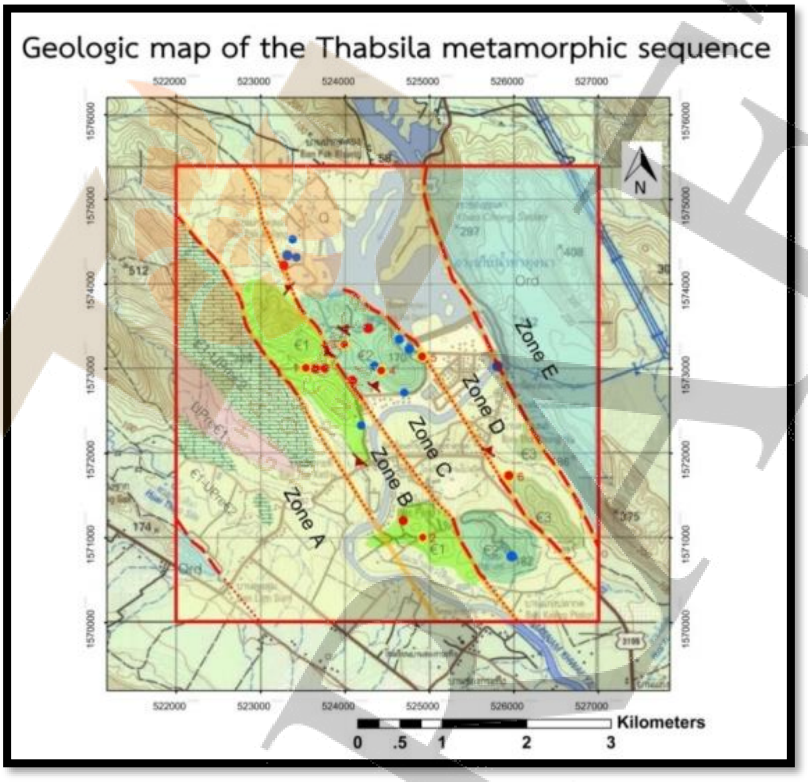


Fig. 2 Geologic map of the Thabsila sequence.

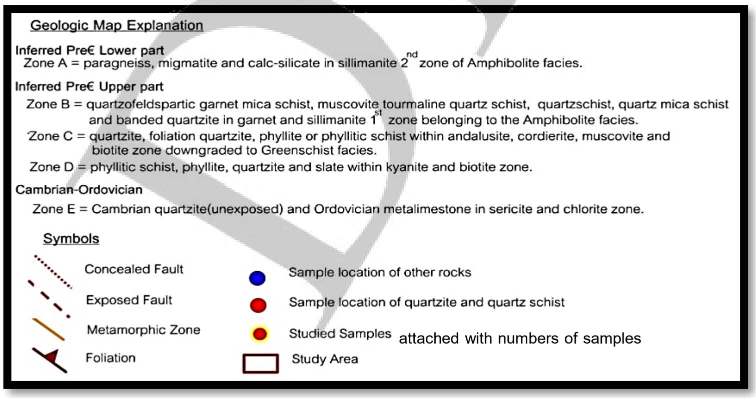


Fig. 2.1 Explanation of Thabsila metamorphic complex.

The geologic map of the Thabsila metamorphic complex (Fig. 2) has been subdivided into the Lower and the Upper parts and in zones from A to E, as a revised version from Muangphongoen and others (2015). Both the Lower and the Upper Thabsila units, have been subdivided into zones lithologically and structurally more or less coincident with the many insignificant fault lines (Fig. 2). The contrast in grades of metamorphism is noticeable also in the meta-siliciclastic sandstones, which alternate with other meta-pelitic rocks only in the Upper Thabsila unit. However, the Upper unit exhibits a transition from a lower grade, finer-grained biotite paragneiss (Fig. 3) grading to a coarser-grained banded or augen biotite-hornblende/quartzofeldspathic paragneiss with calc-silicate and migmatite in the lower part.

Fig. 3 ASy 232731. Fine-grained paragneiss started segregation into many thin leucocratic threads, an indication of a lower grade paragneiss, which has been increased to a higher grade, rendering more thicker bandings and developing feldspathic augen when moving to the west. Ductile shearing is considered localized and not show consistent or extensive distribution.

Generally, all the northwestern strike-slip faults were horizontally dislocated parallel to the metamorphic layering, so that their consecutively transitioning nature are still preserved and can be recognizable along strike across their transitional zone (Fig. 4). This has been observed to establish throughout the stratigraphic column westwardly, although many fault lines have been detected (Fig. 2). The sequential evolution of the mineral assemblages in the Upper Thabsila complex (Salyapongse, et. al., 2019), as well as an eastward decreasing in grades of metamorphism, have been described also from the intercalated pelitic horizons by Muangphongoen et al., (2015). Within the Upper Thabsila unit, however, there are many horizons of quartz-mica schist, quartz schist, and foliated quartzite which are here referred to as meta-siliciclastic sandstones alternating with other meta-pelitic rocks only in the Upper Thabsila complex. Correspondingly, both of the meta-siliciclastic horizons and the meta-pelitic horizons are exhibiting conformably and progressively decreasing in grades eastward in the same fashion and prograding further to the younging direction towards the Lower Paleozoic as well. Another important lithological type was found as alternating calc-silicate, marble and meta-limestone at least two lensoid bodies have been detected.

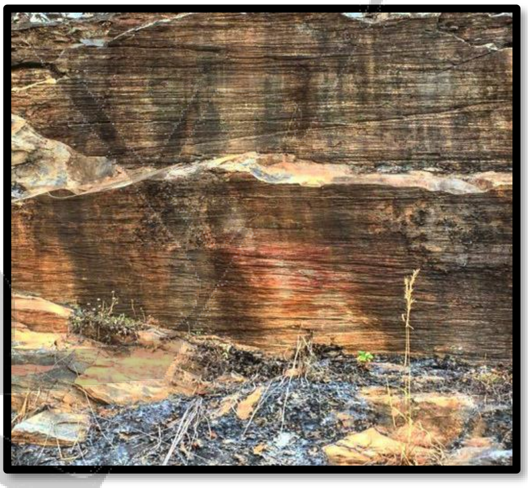


Fig. 4 Horizontal slip fiber (slickenside fibers) in the meta-limestone cliff which developed on the bedding plane of Permian limestone exposed along a road-cut outcrop next to the nearby dextral movement strike-slip fault

III-1. Petrographic analysis of the Upper Thabsila meta-siliciclastic sandstones

The Upper Thabsila sequence from high to low grade starts the alternating sequence with lower grade biotite paragneiss (Fig. 3), quartz-fibrolite-garnet mica schist, quartz schist, andalusite phyllitic schist, banded quartzite, andalusite quartzite, andalusite-kyanite phyllitic schist/phyllite, foliated quartzite and slate (See more detail in Fig. 2). These packages of rocks have strike-slip fault contact with the Lower Paleozoic rocks. In the lowest part overlying the fine-grained biotite paragneiss, a mica schist unit illustrates a foliated texture defined by mica and quartz with hardly recognized minor feldspar, localized red garnet, biotite, fibrolite and muscovite with accessories apatite and zircon (sample no.1 in Table 4). Further in the younging horizons, particularly in the meta-siliciclastic sandstone, they are characterized by dominant muscovite over the biotite and the mineral grain sizes are sharply reduced. (Fig. 5-7). This textural feature shows a decrease in grain size along with a reduction in grade of metamorphism. Considering the whole Upper Thabsila complex, the original sedimentary protoliths show an increasing maturity toward the younger beds (sample no.5 and 6 see Fig. 2 and Fig. 18). To facilitate feldspar identification for point counting, it can be accomplished by etching the uncovered thin section with conc. HF for about 20 seconds (Fig. 12 and 13). By this method, the feldspar relief becomes more distinctive than quartz and turned extinct in XPL.

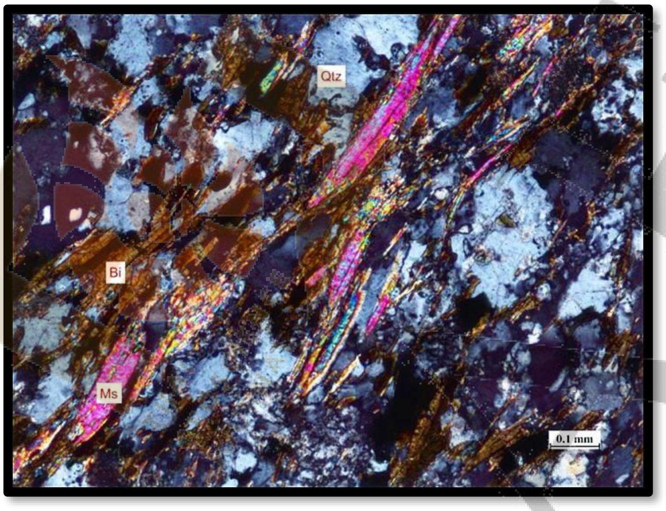


Fig. 5 ASy 236730 (no. 1, Zone B) XPL Quartzofeldspathic garnet mica schist showing foliated texture defined by biotite and a lesser amount of muscovite including with garnet and apatite. The availability of the feldspar is hardly identifiable if it lacks twinning. Comparatively the mica grains are distinctively larger grain sizes than the lower grade units to the east. (Abbrev: ASy = Amphoe Sai Yok 1:50,000 map sheet)

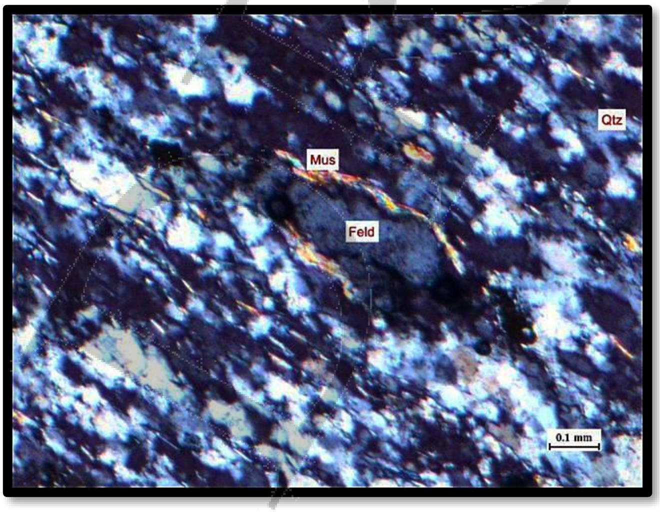


Fig. 6 ASy 243730 (no.4, Zone C) XPL. Foliated quartzite in of lower grade, having foliated texture defined by elongated quartz aggregates with minor muscovite and opaque minerals. Tourmaline is quite common in the Upper Thabsila. Accessory zircon is usually detected. (Abbrev: ASy = Amphoe Sai Yok 1:50,000 map sheet)

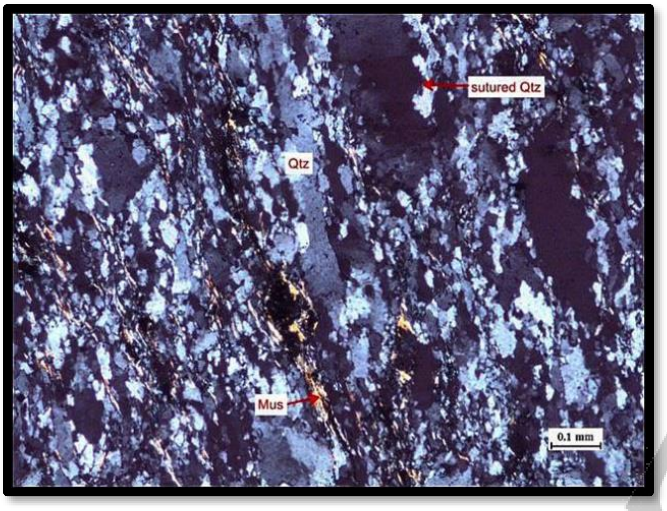


Fig. 7 ASy 257720 (no. 6, Zone D) XPL. Foliated quartzite further eastward, exhibiting foliated texture defined by a very fine-grained flake of muscovite and an elongated quartz aggregate showing sutured grains caused by metamorphism and deformation with accessory zircon. (Abbrev: ASy = Amphoe Sai Yok 1:50,000 map sheet)

IV. The Chao Nen and the Tha Manao meta-siliciclastic sandstones

The Cambrian Chao Nen and the Ordovician Tha Manao rock sequences were formed as elongated bodies sub-parallel to the northwest-trending Si Sawat dextral strike-slip fault zone more or less running along the Khae Yai river valley. Upper Paleozoic and the Mesozoic continental red beds can be respectively observed to the west and far west. Whereas the marine Permian clastic rock units with the fusulinid *Monodiexodina* sp. in a small limestone lens, occurr in a dislocated fault-slab within the fault zone along the Khwae Yai river valley (Fig. 8). The Chao Nen and the Tha Manao formations (Fig. 8) exposing further north along the road, were proposed by Bunopas (1981) to be originally deposited as a continuous sequence from siliciclastic rich graded to calcareous sandstone, sandy limestone, limestone and argillaceous limestone characterizing upward facies change of the two rock units. The total thicknesses of these rock sequences are approximately 3,500 m.

The Cambrian-Ordovician rock sequence has been recognized for quite a long time being extended throughout the western part of the country or along the western Shan-Thai block. They characterize some transitional siliciclastic-carbonate facies of the Lower Paleozoic succession in Thailand. In most localities observed, they are underlain by the inferred Precambrian units and generally demarcated by detachment planes which orientated northwestward. The Chao Nen meta-sandstone and the Tha Manao meta-limestone units are well exposed along road-cut outcrops near to the Srinagarindra dam (Fig. 8) which situated in Khuen Srinagarindra 1:50,000 map sheet.

IV-1. Petrographic analysis of the Chao Nen and the Tha Manao siliciclastic sandstones

Petrographic examination of the Cambrian low-grade meta-feldspathic sandstones suggested that their differences in mineral compositions are basically related to the variation in argillaceous and carbonate or matrix/cement components relative to detrital quartz and feldspar (Fig. 9-13). Since it is a low grade and the generated rock foliation is directly related to the original content of the argillaceous material, the more it contains, the better the foliated texture (see modal comp. no. 1 and 3 in Table 5 and see Fig. 9 and Fig. 10) can be appreciated. In all of the samples, sedimentary relict texture and the original mineral phases are still recognizable although slightly modified by replacements or recrystallization of sericite after clay

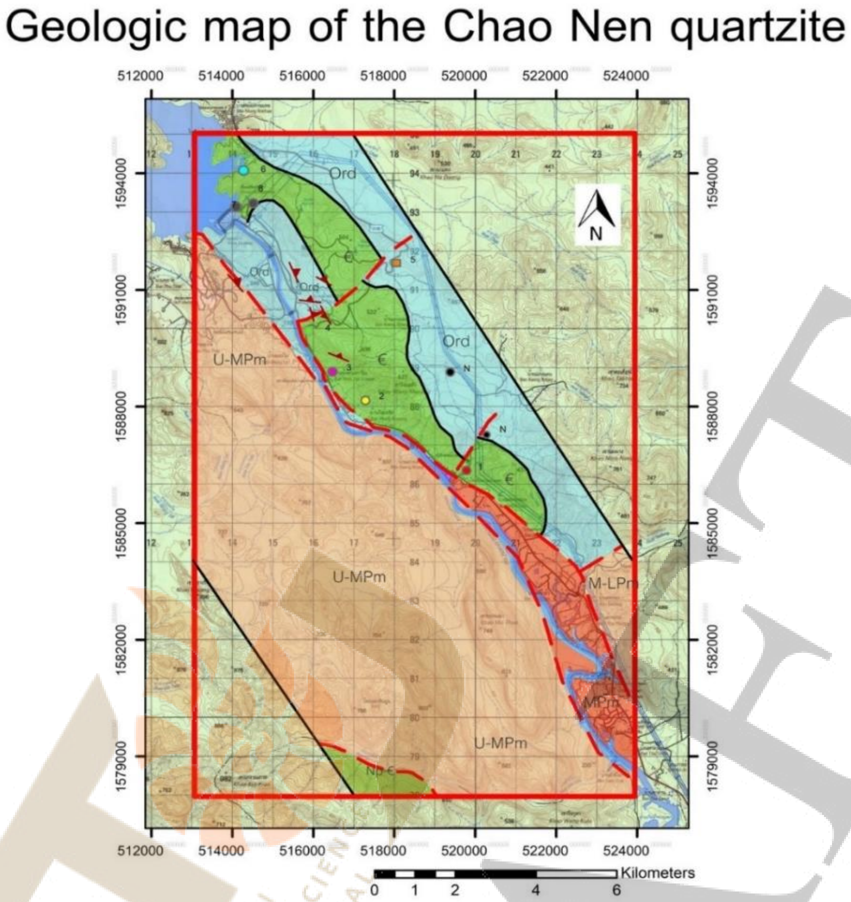


Fig. 8 Geologic map of the Cambrian Chao Nen and the Ordovician Tha Manao

Geologic map Explanations

U-MPm = Meta limestone graded to limestone with fusulinid

MPm = Volcaniclastic sandstone, *Monodiexodina* sp. bearing calcareous sandstone and sandy limestone lense

M-L Pm = Volcaniclastic sandstone and meta banded limestone

Ord = Meta-argillaceous limestone with Nautiloid

Є = Meta-argillaceous arkosic to subarkosic sandstone and calcareous sandstone

Np-Є = Paragneiss, schist and calc-silicate

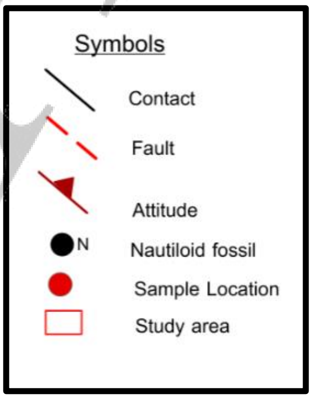


Fig. 8.1 Geologic map explanation and symbols of the Cambrian Chao Nen and the Ordovician Tha Manao formations

mineral/feldspar in noncarbonated sandstone and authigenic replacement of calcite after quartz and feldspars in calcareous sandstone (Fig. 13). The incipient low-grade regional metamorphism is locally indicated by the inconsistent development of the foliation as well. In terms of metamorphic zoning, the occurrence of sericite in the Chao Nen sandstones considered successively lower grade than the biotite-muscovite zone of the Upper Thabsila (Fig. 7 and Fig. 9).

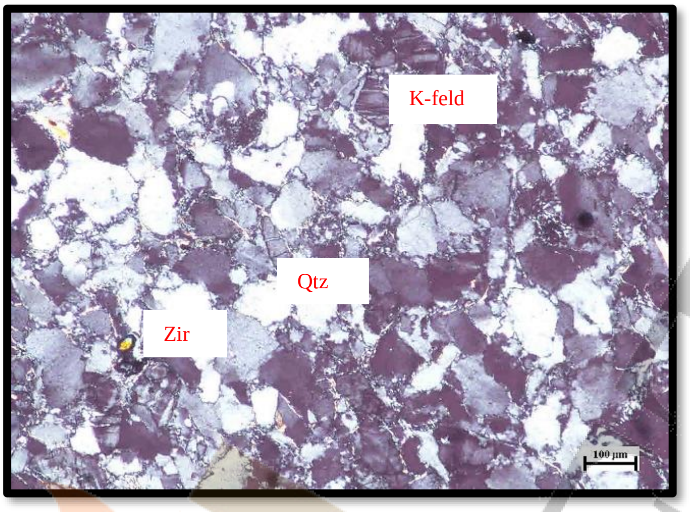


Fig. 9 KSn 171880 (no. 2) XPL. The Cambrian Chao Nen meta-sericitized feldspathic sandstone showing faintly oriented texture defined by a smaller and minor amount of recrystallized sericite crystals which restricted to the grain boundaries. Note the grain supported with subangular shape nature and minor content of the very fine-grained silica cement plus a lesser amount of intergranular sericite crystals. Probably due to this specimen was originally relatively less argillaceous/clayey material and lower grade of metamorphism so that its foliation is not obvious. Accessory detrital zircon is frequently observed. (KSn = Khuean Srinagarindra 1:50,000 sheet).

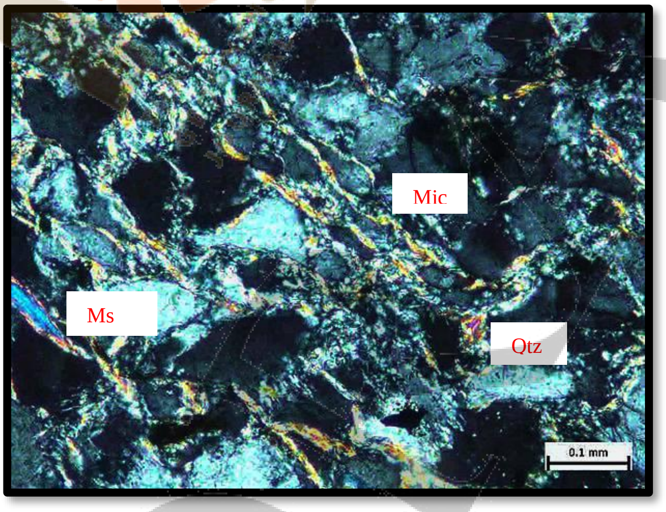


Fig. 10 KSn 141932 (no. 7) XPL. Cambrian meta- sericiticitized feldspathic sandstone. It illustrates angular to irregular grains with very fine-grained matrix support and foliated texture defined by recrystallized white mica which in parts replaced after feldspar grains, possibly formed during the transition from diagenesis to low-grade regional metamorphism. A bigger muscovite grain is possibly detrital muscovite. Note the matrix-supported texture probably originally was argillaceous rich now has been recrystallized mainly to micro quartz and foliated white mica. (KSn = Khuean Srinagarindra 1:50,000 sheet)

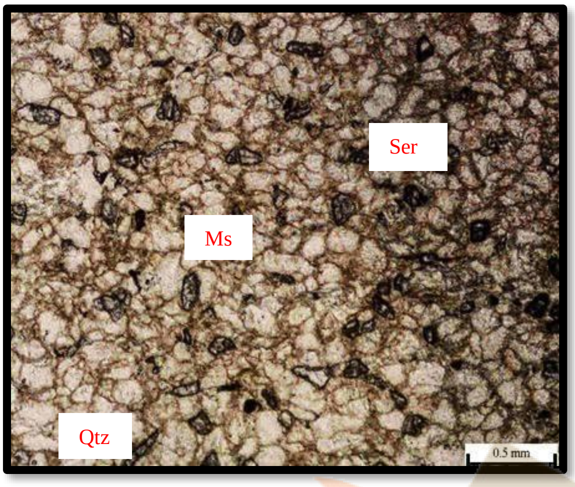


Fig. 12 KSn 141931 (no. 3) PPL. Showing a Cambrian Chao Nen meta-sericitized feldspathic sandstone comprises higher relief feldspar grains after HF etching to facilitate point counting. (KSn = Khuean Srinagarindra 1:50,000 sheet)

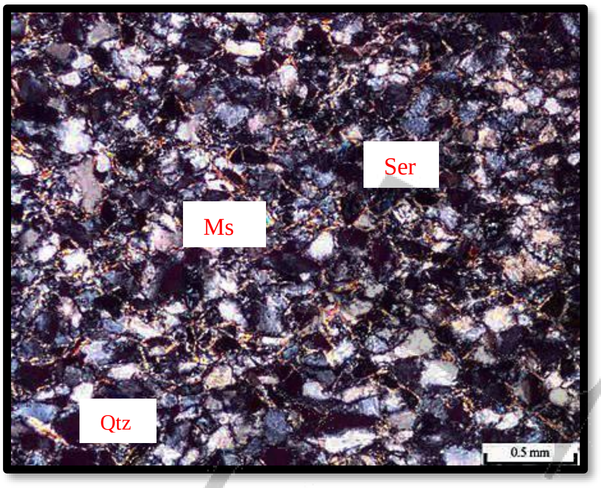


Fig. 13 KSn 141931 (no. 3) XPL. At the same position. Note the development of sericite faintly oriented within the rare matrix part of the meta-sericitized feldspathic subarkose. All the detrital feldspar became extinct. (KSn = Khuen Srinagarindra 1:50,000 sheet)

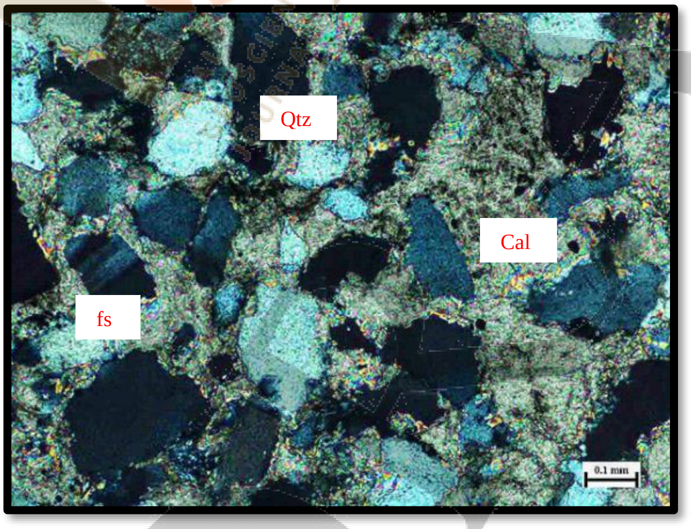


Fig. 13 KSn 180918 (no. 5) XPL. Ordovician calcareous feldspathic sandstone. It shows cement/matrix supported and non-foliated texture probably due to carbonation and the rarity of argillaceous material. Note the replacement boundaries of feldspars and quartz (at extinction) by calcite caused the irregularity in grain shape and the reduction in grain size against the replacing calcite. Although calcite appears extensively replaced after quartz and feldspars, this sample will also be included for point counting for a comparison. (KSn = Khuean Srinagarindra 1:50,000 sheet)

V. Results and discussions

V-1. Modal classification and provenance of the Upper Thabsila, the Chao Nen and the Tha Manao meta-siliciclastic sandstones.

Table 4. Modal compositions of the Thabsila complex.

No.	Grain size	Sorting	Foliated	Quartz	Feldspar	Lithic	Others	Recalculated		
								Quartz	Feldspars	Lithic
1	coarse	mod.	yes	78.33	5	0	16.67 (bi,ms,gar,op)	94	6	0
2	med.	mod.	faintly	89.67	3.67	0	6.67 (bi)	96.07	3.93	0
3	fine	well	yes	84.33	0	0	15.67 (bi,mus,zr)	100	0	0
4	fine	well	yes	91	0.67	0	8.33 (ms,bi,tur,py,zr, op)	99.27	0.73	0
5	med.	mod.	yes	90.67	2.33	0	7 (bi,ms,zr,op)	97.49	2.51	0
6	med.	mod.	yes	87	2	0	11 (ms,bi,py,zr,op)	97.75	2.25	0

Abbrev.: ms = Muscovite, ser = Sericite, tur = Tourmaline, op = Opaque and Zr = Zircon

It can be mentioned shortly from the modal analyses (Table 4) that, the samples contain a significant amount of quartz while the lithics, if originally available, must have all been destroyed during the transportation. Feldspar is not high signifying these feldspars from the mode were the leftover from weathering and erosion of the protolith. The other significant constituent is the micaceous minerals, biotite and muscovite, which most of them represented the regional metamorphic origin (Table 4). Orientation and recrystallization of the metamorphic micaceous minerals are the product of regional metamorphism in the later period subsequence to diagenesis. Types of the micaceous mineral developed in both of the Thabsila and the Lower Paleozoic rocks can be equilibrated with the original content and chemistry of the clay matrix in the former siliciclastic sandstones studied.

Table 5. Modal compositions of the Chao Nen Cambrian meta-sandstones and the Tha Manao Ordovician calcareous sandstone (no.5), Kanchanaburi province.

No	Grain size	Sorting	Foliated	Quartz	Feldspar	Lithic	Others	Recalculated		
								Quartz	Feldspars	Lithic
1	med.	mod.	Yes	84.5	12.5	0	3(ser,ms,op)	87.1	12.9	0
2	med.	well	Faintly	89.0	10.0	0	1(ser,zr)	89.9	10.1	0
3	med.	mod.	Yes	85.7	11.3	0	3(ser,tur,op)	88.4	11.6	0
4	fine	mod.	Yes	87.2	8.8	0	4(ser,ms,op)	90.8	9.2	0
5	med.	well	None	72.0	8.0	0	20(calcite cement)	86.3	13.7	0
6	fine	well	None	77.0	22.0	0	1(ser,ms,tur,zr)	77.8	22.2	0
7	fine	mod.	Yes	71.5	25.5	0	3(ser,ms,op)	73.2	26.8	0
8	med.	well	None	79.0	20.0	0	1(ser,op)	79.8	20.2	0

Abbrev: ms = Muscovite, ser = Sericite, tur = Tourmaline, op = Opaque and Zr = Zircon

Comparatively the same reading about the modal analysis result of the Lower Paleozoic rocks as that of the Upper Thabsila sequence can be apparent here as well. The percentage of quartz is more or less similar to the Upper Thabsila complex. Feldspar is significantly higher. Micaceous minerals are lesser. Tourmaline, considered to represent a metamorphic phase, is available in this Lower Paleozoic meta-siliciclastic sandstone as well as that was already noted from the Upper Thabsila. It may be useful as a support for a continuous depositional environment between the Upper Thabsila and the Lower Paleozoic sequence. Notably, all these meta-siliciclastic sandstones are devoid of any rock fragment.

The nonuniform foliation development and the textural remnants of a diagenetic process (Fig. 9 and 10) in the Chao Nen, may suggest lower grade metamorphism.

V-2. Modal classification and provenance of the Upper Thabsila and the Lower Paleozoic meta-siliciclastic sandstones

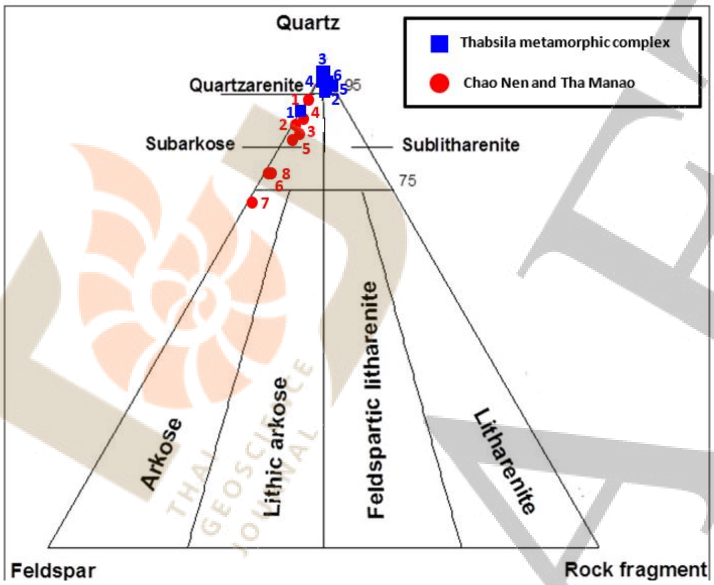


Fig. 14 A Quartz-Feldspar-Lithic ternary diagram modally classified altogether the studied met-siliciclastic sandstones to show an evolution in modal composition relatively to their stratification (Folk,1980).

Modally the mineral volume percentages as counted and recorded as QFL percent suggest the compositional classification spanning from arkose to subarkose and quartz arenite. Considering in detail about the degree of maturity relative to lithology from the older to the younger beds, the Thabsila samples are starting mainly with a lesser mature composition, i.e. subarkose (no. 1, Fig. 14) probably with a higher percentage of feldspar and the least quartz content (the sample numbers are running consecutively from older to younger beds), then evolving further to quartz arenite, i.e., much more mature withlesser amount of the original clayey matrix (Fig. 6 and 7). Continuation to the Lower Paleozoic sequence, the sedimentation seems continuing from the more mature (sample no. 1), i.e. from subarkose toward the less mature, the arkose (sample no.7 in Fig. 14). Other than for the modal classification of all the meta-siliciclastic sandstones, the same modal plot can also be used as a provenance categorization of the source terrane. All of the meta-siliciclastic sandstones studied illustrate a continental block setting. They share the same provenance.

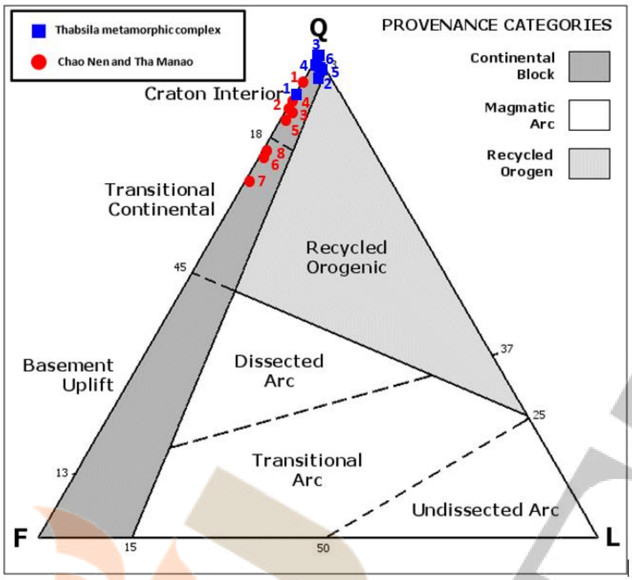


Fig. 15 A Quartz-Feldspar-Lithic ternary diagram showing provenance classification basing on the same plot as that of Fig. 14 with the superimposed provenance categories of all the studied meta- siliciclastic sandstones (Dickinson et. al,1983).

V-2.1 Geochemical analyses by XRF of the Upper Thabsila, the Chao Nen and the Tha Manao meta-siliciclastic sandstones.

Table 6. XRF chemical analyses of major oxides from the Thabsila meta-siliciclastic.

Thabsila Sequence							
Oxide	**Samples**						**Aver.**
	1	2	3	4	5	6	
SiO_2	67.41	90.63	92.31	95.88	96.51	96.04	89.796667
Al_2O_3	14.90	4.822	4.446	2.149	2.266	2.37	5.1588333
TiO_2	0.49	0.2478	0.2088	0.2613	0.149	0.1657	0.2537667
CaO	0.5603	0.1157	0.04631	0.00	0.04371	0.00	0.12767
Fe_2O_3	6.072	1.236	0.9419	0.6015	0.5885	0.5474	1.66455
Na_2O	1.879	0.2304	0.7803	0.00	0.00	0.00	0.4816167
K_2O	7.499	2.283	0.9112	0.8313	0.3313	0.6726	2.0880667
FeO	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MgO	0.779	0.2999	0.2003	0.00	0.00	0.08686	0.2276767
SO_3	0.00	0.01137	0.00	0.02368	0.00	0.00	0.0058417
ZrO_2	0.03182	0.03512	0.04323	0.03914	0.02482	0.02823	0.0337267
P_2O_5	0.1021	0.00	0.02383	0.00	0.00	0.00	0.0209883
Cr_2O_3	0.00	0.04028	0.03337	0.05394	0.04481	0.0429	0.0358833

Table 7. XRF chemical analyses from the Chao Nen and the Tha Manoa meta-siliciclastic.

Chao Nen and Tha Manao									
Oxide	**Samples**								**Aver.**
	1	2	3	4	5	6	7	8	
SiO_2	90.98	91.74	87.23	89.43	72.97	87.04	82.22	84.32	85.7412 5
Al_2O_3	4.04	3.67	6.07	5.18	3.64	5.68	8.49	7.49	5.5325
TiO_2	0.18	0.2	3.67	0.32	0.19	0.18	0.04	0.29	0.63375
CaO	1.1	0.1	0.29	0.03	15.77	0.00	0.19	0.15	2.20375
Fe_2O_3	0.87	0.32	0.62	0.7	1.14	0.78	1.59	1.1	0.89
Na_2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
K_2O	1.97	1.74	2.69	1.91	1.8	3.51	4.15	3.96	2.71625
FeO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
MgO	0	0.09	0.26	0.29	1.41	0.19	0.35	0.33	0.365
SO_3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
ZrO_2	0.02	0.00	0.07	0.06	0.02	0.02	0.03	0.02	0.03
P_2O_5	0	0.05	0.16	0.00	0.08	0.00	0.12	0.07	0.06
Cr_2O_3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0

When considering the inconsistency in a rock name between the different classification methods of the no.1 Thabsila meta-sandstone (fig. 14 and 16), it tells subarkose in mode, while its chemical plot suggests wacke. This disagreement can be realized from the current availability of micas, garnet, fibrolite, and other accessories which have not been plotted in Fig.14. All these minerals considered to be a derivative from the original muddy sandstone (or wacke sandstone) before it has been metamorphosed to sillimanite-garnet-micas schist. From the chemical analysis (Table 6 and 7), the Na_2O content is only available in the Thabsila no. 1 to 3 and never reappear again even in the Lower Paleozoic rocks. These features probably were related to both original source rock compositional control as well as nature of the transporting medium and the weather condition at the time. Another deviated plot has been observed also with the Lower Paleozoic rock sample of no.5. Its deviation (Fig. 19) is considered to be the result of the the presence of calcite replacement after quartz and feldspar and from its availability as the cementing non-silicate Ca bearing mineral (Fig. 13).

V-3. A chemical classification diagram of the Upper Thabsila, the Chao Nen and the Tha Manao meta-siliciclastic sandstones.

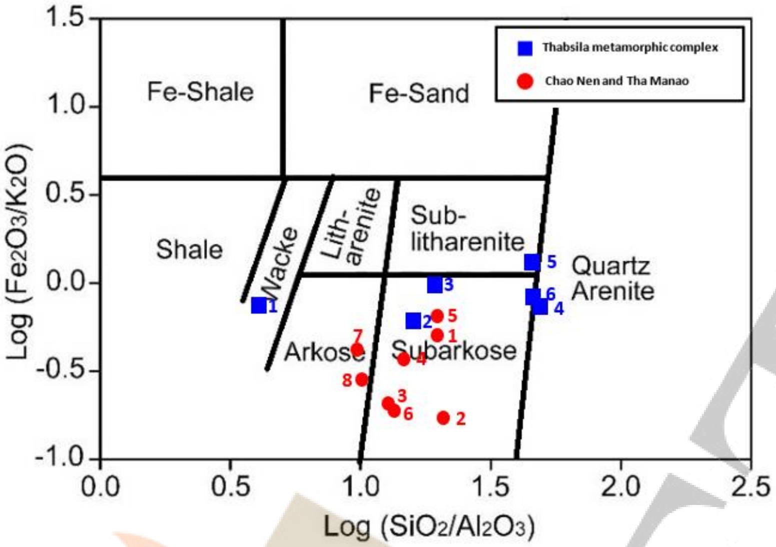


Fig. 16 A geochemical classification diagram for the studied meta-siliciclastic sandstones. (after Herron, 1988)

All the sample populations of both the Thabsila complex and the Lower Paleozoic formations are compositionally separated in 2 superimposing asymmetric cycles both are striding the fields of chemical lithologies ranging from wacke to subarkose to quartz arenite for the Upper Thabsila. The Upper Thabsila rocks are compositionally richer in Fe_2O_3 as indicated by the occurrence of many iron-rich minerals such as biotite, garnet, and opaque iron ore. Compared to the plot of the Lower Paleozoic, they are lower in Fe_2O_3 content. The amount of biotite also reflects the Al_2O_3 and K_2O content in the analyses. Another important supplier of the Al_2O_3 is significantly from the feldspars but only K-feldspar will provide a significant amount of K_2O. All these are the variability between the amount of the mineral phases or mode, correspondingly reflected the amount of the major oxides from the chemical analyses of the same rocks to cross-check if either of them can be reasonably correlated.

V-3.1 A tectonic setting discrimination diagram of the Upper Thabsila, the Chao Nen and the Tha Manao meta-siliciclastic sandstones.

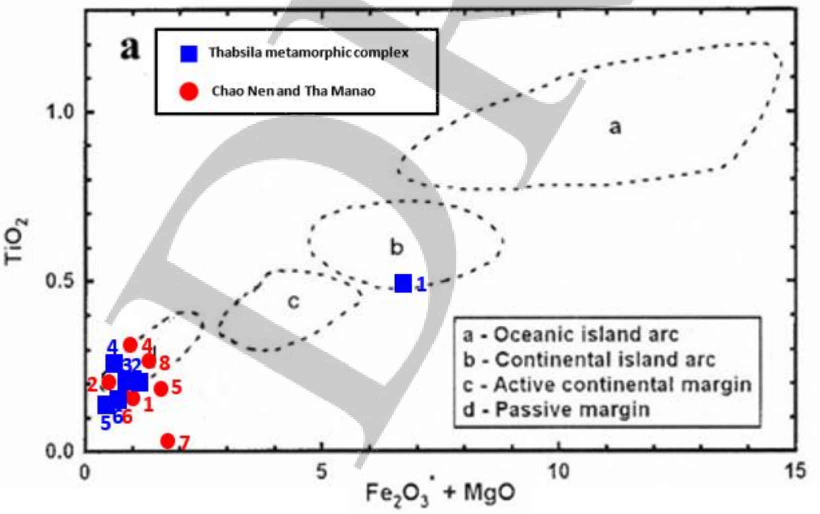


Fig. 17 A tectonic discrimination diagrams (after Bhatia, 1983) for the studied rocks.

Figure 18 shows most of the samples depicting a passive margin tectonic setting. The deviated plot of the Thabsila no1 was due to its composition is more immature, containing more mafic mudrock in the matrix now represented by an increase in the amount of biotite and muscovite among quartz and minor feldspar with additional other minor silicates and iron opaque. More collection of similar samples would fill in the Thabsila sample populations.

V-4. Degree of weathering of the Upper Thabsila, the Chao Nen and the Tha Manao source materials.

This is more or less showing the plot populations are trending in a linear line sloping from the low weathering or more immature toward the intensively weathering or the more mature end. The repeated asymmetric cyclic evolution is also can be apparent to both of the rock units as well as illustrating in the same fashion to all of the other diagrams (comparing Fig. 15 and 19). Most of the Upper Thabsila and the Lower Paleozoic rocks are generally plotted within the moderate weathering regime. The trend of the Upper Thabsila is reached the intensive weathering zone by no.5, an indication that the no.5 was extensively affected by the intense weathering clearing the original fine-grained materials to the best maturity in the younger sequence far more maturer than the older beds. (See Fig. 18 of Thabsila no. 4, 5, and 6) for a comparison. The Thabsila no. 1 is again also far more deviated but approximately in the same trend. While the Lower Paleozoic samples appear less obvious but roughly showing a cyclic returning from the more weathering regime continuation from the Thabsila towards less weathering in the younger beds.

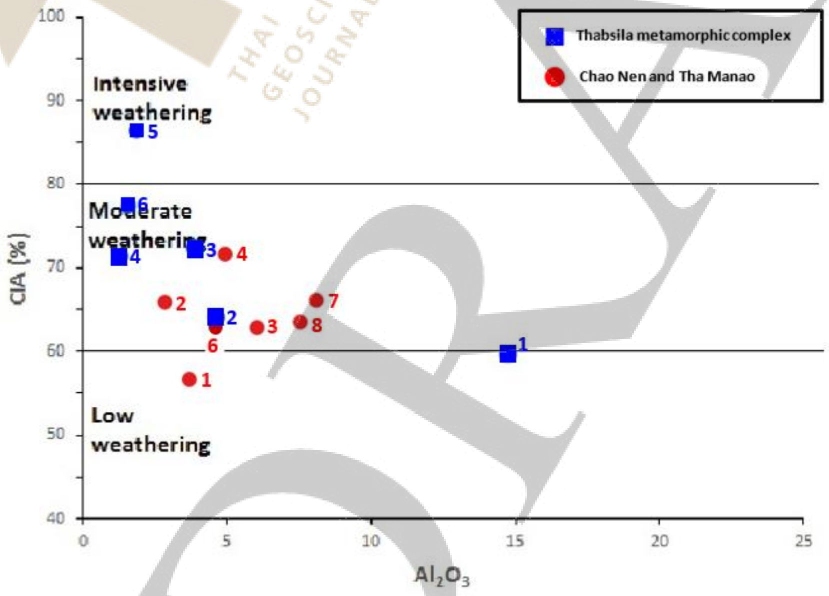


Fig. 18 Chemical index of alteration (CIA) of sandstones and its correlation with Al_2O_3 (after Bonjour and Dabard, 1991)

V-5. Degree of maturity of the Upper Thabsila, the Chao Nen and the Tha Manao source materials.

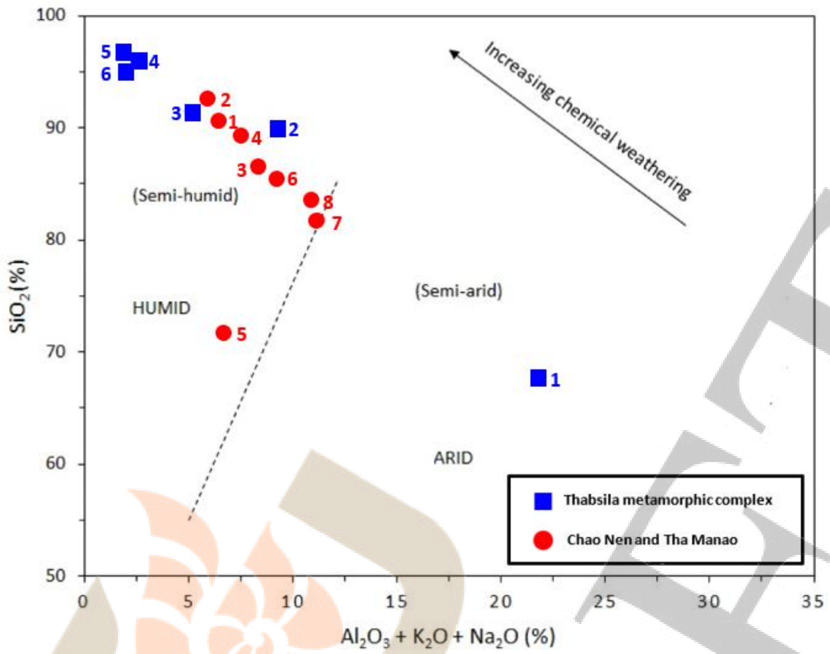


Fig. 19 Chemical maturity of the sandstones expressed by the bivariate plot of SiO_2 versus Al_2O_3+ K_2O+ Na_2O (After Suttner and Dutta, 1986).

Chemical composition spreading of all the studied meta-siliciclastic sandstones can be seen in (Fig. 18 and 19) as they distributed in the way as to indicate the cyclic repetition suggesting rhythmic or cyclic sedimentation. They have been more or less evolving in the same trend which assuming a repeated compositional variation (silica relative to the Al_2O_3+K_2O+Na_2O) both in the Thabsila and the Lower Paleozoic formations. The inclining ratio ranging from SiO_2 66% towards 100% (Fig. 19) suggests all the sample populations of both lithologic groups were of the cyclic evolution starting from sub-mature or wacke composition up to super mature in the Thabsila and then continue a repetition of an asymmetric cyclic from more maturity in the lower horizon of the Lower Paleozoic to gain lesser maturity in the younger beds as can be stratigraphically observed. (See the geologic maps, of Fig. 2 and Fig. 8).

To appreciate the degree of chemical maturity, it can be understood that, the deviated plot of the Tha Manao calcareous siliciclastic sandstone (no.5) which bears a significant amount of the non-silicate carbonate, the Ca bearing phase (Table 5) as well as their authigenetic replacement would cause the discrepancy behavior of the no5 in this diagram. Trending of the meta-siliciclastic plots reflect the cyclicity of each rock unit during their sedimentary evolution from the more immature towards the more mature and turning back reflecting the more humid weather than the arid. (Fig. 19 and Table 4, 5 and Table 6, 7) in an asymmetric (A→ B→ C→ D, A→ B→ C→ D) fashion.

V-6. Type of source rocks of the Upper Thabsila, the Chao Nen and the Tha Manao

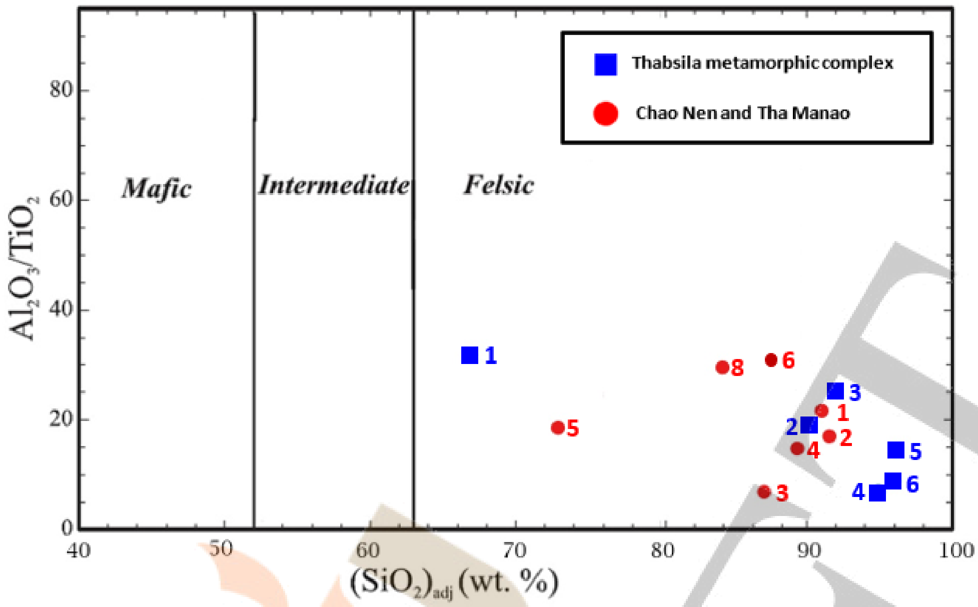


Fig. 20 Geochemical classification of igneous source rocks. (Le Bas et al. 1986)

It can be further discussed in the chemical variation shown in Fig. 20 relative to the modal analyses tabulated in Table 4 and 5 and geochemical analyses in Tables 6 and 7. The variation of SiO_2 which mainly extracted from the silicate mineral i.e. dominantly was from quartz with a minor variation from the content of the feldspar and micaceous minerals (see Table 4 and 5). The trend moves toward 100% SiO_2. While the content of Al_2O_3/TiO_2 also declines from about 30 % to 5% suggesting a more maturity and the elimination of feldspar and finer clay-rich material during their evolution of the Thabsila than the Lower Paleozoic formations.

Considering the felsic types of source rock material as indicated in Fig. 20, it can be interpreted from the modal and the chemical analysis as follows. Since there is no record of any lithic in all of the meta-siliciclastic sandstones studied, source rocks of them were not very likely derived from the fine to very fine-grained volcanic and other rocks, but rather from the less resistance coarser-grained plutonic or gneissic rocks. For the Thabsila meta- siliciclastic sandstones which contain Na_2O only in the immature or sub-mature samples, but not in the mature ones, may reflect the source rock was less felsic and contain plagioclase which has been destroyed leaving only the finer clay material in the younger sequence during more weathering or uplifting of the source terrane.

VI. Conclusions

Both petrographic analysis and geochemical studies suggested the Upper Thabsila and the Chao Nen Cambrian meta-siliciclastic sandstones are compositionally different due to degree of evolution. The Upper Thabsila expresses a longer evolution trend starting from the more immaturity evolving in a straight linear line of evolution towards the super mature end (as shown in the plot of Fig. 16). While the plots of the Lower Paleozoic signify a shorter and hardly defined trend classifying rock composition spanning from meta-argillaceous subarkose to arkose (Fig. 16) returning the cyclic evolution from more maturity in the older beds towards more immaturity in the younger bed complete the cyclic fashion as seen in the comparison between Fig. 14 and Fig. 16. The same conclusion can be read from other related figures (Fig. 18, 19 and 20) also. The lower grade regional metamorphic characteristics of the Chao Nen are signified by the preservation of diagenesis and inconsistency of their foliation development due to the variation in the amount of the original argillaceous contents, a significant variable constituent in rocks. The Chao Nen has been mildly metamorphosed developing a lessening amount of the foliated sericite (or fine-grained muscovite)..

Both of the rock units shared the same depositional regime on a passive margin setting and performing the repeated asymmetric cyclic evolution, a common feature of the rhythmic sedimentation of the rocks studied. The sediments might have been derived from either granite or granite gneisses (ranging in composition starting from the less felsic to the more felsic) of the unknown Precambrian basement, which presumably characterized a change in source rock composition during the Precambrian basement peeling off process or cycle of tectonic activity. The lithologic resemblance between them as well as their progressively decreasing in grades of metamorphism suggested their transitional relation and were subjected to a single episode of metamorphism. The Precambrian cratonic source terrane of this Thabsila-Cambrian-Ordovician continuous sequence is so far unknown in Thailand (Hansen et al, 2014) and possibly might have been all transformed to the common Triassic foliated S-type granite in the western Shan-Thai.

VII. Acknowledgments

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