Basin classification and tectonic framework of the Nam Pat Group, Uttaradit Province, Thailand: Implications for the Nan Suture Zone

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Abstract

The Nam Pat Group of the Nam Pat Basin, Uttaradit Province, Thailand is situated in the Nan Suture Zone. Two contrasting tectonic framework models of the Nan Suture have previously been proposed: as a main Paleo-Tethyan suture and as a remnant of a closed back-arc basin. The goal of this study is to analyze the tectonic framework of the Nan Suture and reevaluate the existing tectonic models. This research infers the tectonic setting of the basin based on basin-filled lithofacies distributions, provenance, and paleocurrents. Three facies groups are identified. Facies A, B, and C are polymictic conglomerate, interbedded sandstone and mudstone, and mudstone with thin-bedded sandstone, respectively. Generally, the strata strike NE-SW, steeply dip NW, and fine toward the SE. Petrographic results of sandstone samples show that the majority of lithic fragments are volcanic rocks with lesser amount of metamorphic rocks and sedimentary rocks. The modal compositions of sandstones are analyzed on QFL, QmFLt, QmPK, LmLvLs, and QpLvmLsm ternary diagrams. The plots indicate that the sandstones of the Nam Pat Group have high proportions of volcanic-arc detritus. Paleocurrents, determined from the orientation of clast imbrications and cross-stratification, are toward the SE. The results suggest that large quantities of sediment traveled...
southeastward from a nearby volcanic arc into the basin. The Nam Pat Group stratigraphically overlies the Pak Pat Volcanics. The chemical features of the Pak Pat Volcanics, located to the west of the basin, show that they are andesitic volcanic rocks formed as a magmatic arc. Thus, the nearby Pak Pat Volcanics are the main sediment source of the Nam Pat Group, and the basin is best interpreted as back-arc basin rather than as a forearc basin.

Keywords: Earth sciences, Geology

1. Introduction

Mainland Southeast Asia consists of at least two major geotectonic terranes, the Indochina Terrane and the Sibumasu Terrane [e.g., 1]. Thailand was created by the collision between two continental masses during Palaeozoic-early Mesozoic [2]. Several different models of geotectonic and tectono-sedimentary subdivisions of Thailand have been proposed [3]. This research focusses on the tectonic history of the Nan Suture (Nan-Uttaradit Suture) which is located between the Sukhothai Zone (Sukhothai Fold Belt or Sukhothai Arc) and Indochina Terrane (Fig. 1). Two contrasting tectonic framework models of the Nan Suture have previously been proposed: a main Paleo-Tethyan suture [e.g., 4, 5, 6] and a remnant of a closed back-arc basin [e.g., 1, 7, 8]. The two existing models have been proposed on the basis of the distribution of Paleo-Tethyan oceanic materials, stratigraphic characters and fossil ages.

Here, the Nam Pat Group of the Nam Pat Basin, Uttaradit Province, northern Thailand which is situated in the Nan Suture Zone is analyzed in order to identify the basin type and sediment transport pathways. The goal is to assist the

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Fig. 1. Geotectonic subdivisions of Thailand (modified from Ueno and Hisada [7]). The study area is located in between Sukhothai Zone and Indochina Block.
interpretation of the tectonic framework of the Nan Suture and reevaluate existing tectonic models. This research is based on basin-filled lithofacies distributions, provenance and paleocurrents.

2. Background

2.1. Proposed tectonic models of the Nan Suture: a main Paleo-Tethyan suture

In this model, the paleogeographical evolution of Thailand is represented by the collision between the Shan-Thai (recently referred to as Sibumasu) Terrane on the west and the Indochina Terrane on the east along a suture zone located in central Thailand [e.g., 4, 9, 10] (Fig. 2a). Both the geometry and timing of the collision have been controversial. The geometry of the collision between the terranes has been proposed as westward subduction of the Indochina Terrane underneath the Sibumasu Terrane [5, 11, 12] or eastward subduction of the Sibumasu Terrane under the Indochina Terrane [e.g., 13, 14]. In this tectonic model, regardless of the subduction geometry or timing, the Nam Pat Basin is considered to be a forearc basin located in the suture zone between the Sibumasu and Indochina Terranes. This suture zone was later referred to as the Nan River Suture Zone, Nan Suture, or Nan-Uttaradit Suture [e.g., 5] and was thought to represent a closed remnant of the main Paleo-Tethys Ocean [e.g., 2].

Fig. 2. (a) The tectonic subdivision of Thailand by Bunopas [4] in which the Paleo-Tethyan suture is located along the Nan-Uttaradit Suture Zone in ophiolite belt. (b) The tectonic subdivision of Thailand by Barr and Macdonald [45] in which the Paleo-Tethyan suture is located along between the Inthanon Zone and the Sukhothai Zone.
2.2. Proposed tectonic models of the Nan Suture: a closed back-arc basin

In this model, Thailand consists of four geotectonic subdivisions from west to east. They are Sibumasu Terrane (Western Thai Zone), Inthanon Zone, Sukhothai Zone, and Indochina Terrane (Phetchabun Zone) [e.g., 1, 7, 15] (Fig. 2b). This tectonic model is based on the distribution of Paleo-Tethys oceanic materials, stratigraphic characteristics, and paleobiogeographic constraints. For example, radiolarian cherts found in the Nan Suture are from the Early Permian to Middle Triassic [10] while the Paleo-Tethys Ocean was opened in the Devonian and completely closed in the Late Triassic or Early Jurassic [16]. Late Paleozoic tilloid-bearing units only exist in the westernmost peninsular Thailand that is represented by the Sibumasu Terrane, not in the Inthanon and Sukhothai Zones. The Late Paleozoic foraminiferal faunal association of the Sibumasu Terrane is different from those found in the Inthanon Zone, Sukhothai Zone, and Indochina Terrane [16]. A recent study on U-Pb ages of detrital zircons from Permian-Triassic sediments in the Sukhothai Zone and ophiolite association in the Nan-Uttaradit Suture showed that the Nan-Uttaradit Ocean existed in the Late Carboniferous [17]. Hara et al. [18] concluded that the Nan Basin was a consequence of the Sukhothai continental island arc development and already in a deep-sea environment by the Late-Middle Permian because of the presence of radiolarian cherts [10] in the Nan-Uttaradit Suture Zone.

The mentioned evidences suggest that the Nan Suture is not a boundary between the Sibumasu and Indochina Terranes nor a closed remnant of the main Paleo-Tethys Ocean. It, instead, represents a closed back-arc basin which is located between the Sukhothai Zone and Indochina Terrane [e.g., 2, 7, 19].

2.3. Stratigraphic framework of the Nam Pat Group

Lithostratigraphic correlations of Triassic sedimentary unit in Thailand are illustrated in Fig. 3. The Nam Pat Group is made of marine turbidites deposited in a deep, narrow, elongate basin [4]. It is further subdivided into two formations—Huai Lat and Huai Bo Khong (Fig. 4). The former formation is the lower unit deposited as proximal turbidites; the latter formation is the upper unit deposited as distal turbidites. The Huai Lat Formation comprises of grey and red conglomerates—with clasts of andesite, quartz, metamorphic rocks and limestones. The Huai Bo Khong formation is made of interbedded turbiditic sandstones and mudstones. Microfossils found in limestone clasts of the Huai Lat Formation have been identified as Middle Triassic in age [20]. This formation is older than the limestone clasts and is regarded as Late Triassic. Based on petrographic and geochemical characteristics, the provenances of the Huai Bo Khong Formation are the nearby intermediate igneous rocks, the Permian-Triassic Pak Pat Volcanics [21].
**Fig. 3.** Lithostratigraphic correlation of Triassic sedimentary units in Thailand (modified from Chonglakmani [46]).

| Age      | Location                     |
|----------|------------------------------|
|          | Uttardit         | Phetchabun       |
|          | Nam Phong Fm     | Nam Phong Fm     |
| Triassic | Huai Bo Khong Fm | Huai Hin Lat Fm |
|          | Huai Lat Fm      |                 |
|          | Pak Pat Volcanics |                 |
| Middle   |                 |                 |
| Early    |                 |                 |

**Fig. 4.** Stratigraphic column of the Nam Pat Group (modified from Bunopas [4]).
3. Methods

This research includes two parts: fieldwork investigation (June and July 2015, July 2016 and January 2017) of sedimentary rocks distributed in the southeastern side of Sirikit Dam of Uttaradit Province and petrographic study of sedimentary rock in thin-sections. We chose this study area because the Nam Pat Group is well-exposed and slightly weathered. The Nam Pat Group in the study area strikes in NNE-SSW direction. We chose five transects perpendicular to the strike: Huai Ta Long, the 1146th Road, Huai Bo Khong, Huai Khrai, and the 1339th Road (Fig. 5). The field study includes lithologic description, facies identification, paleocurrent direction measurement, and facies distribution mapping. Paleocurrent direction was measured from preferred orientations of clasts and cross-bedding and was identified by the methods proposed by DeCelles et al. [22] and further corrected for tectonic tilt using stereographic projections [23]. Ninety-four measurements of paleocurrent were collected in the field. Forty-five sedimentary rock samples along the survey lines were collected and prepared in thin-sections for petrographic studies (CFI 50 Infinity Eclipse Ci Polarizing microscope) including mineral

![Fig. 5. Geologic map of the study area displays the locations of five transect surveys (1) Huai Ta Long, (2) the 1146th Road, (3) Huai Bo Khong, (4) Huai Khrai, and (5) the 1339th Road (modified after Singharajwarapan [39]).](image-url)
identification, grain size, grain shape, and sorting analysis. Modal analysis was carried out on the prepared thin-sections using the Gazzi-Dickinson point-counting method, and the data were plotted in the tectonic provenance discrimination diagrams of Dickinson and Suczek [24] and Dickinson et al. [25] in order to identify the tectonic setting of the Nam Pat Group.

4. Results

4.1. Sedimentary facies

Based on our field surveys, the study area is composed of conglomerate, sandstone, mudstone, siltstone, and shale. The strata strike NE-SW and steeply dip NW, at least 58°. Three facies groups are recognized. Facies A, B, and C are polymictic conglomerate, interbedded sandstone and mudstone, and mudstone with thin-bedded sandstone, respectively. Facies descriptions are reported below.

4.1.1. Facies A: polymictic conglomerate

Facies A is adjacent to the Pak Pat Volcanics [21]. The contact between the underlying volcanic rocks and the overlying conglomerates is sharp. This facies is further subdivided into facies A1 and A2 that are, respectively, massive polymictic conglomerate and interbedded polymictic conglomerate and coarse-grained sandstone (Fig. 6). Facies A1 is matrix-supported and up to 4 m thick. The clasts are 5–10 cm in diameter, well-rounded, and elongated. They comprise mostly of volcanic rocks with minor amounts of granite, serpentinite, phyllite, sandstone, chert, and limestone. These clasts are floating in a dirty matrix of fine-grained sandstone.

The clasts of facies A2 are well-rounded, elongated, pebble-cobble size made up mainly of volcanic rocks. Clasts are andesite, basalt, granodiorite, chert, sandstone, quartz, and limestone. The thickness of polymictic conglomerate bed ranges from 10 cm to 3 m. The polymictic conglomerate is interbedded with coarse-grained sandstone 20–30-cm thick. Locally, the polymictic conglomerates contain pebbly of sandstone lenses that are 5–15 cm thick. Some polymictic conglomerate beds are

![Image of Facies A1 and A2]

Fig. 6. (a) Polymictic conglomerate of facies A1 at grid reference 0670257 E, 1953716 N. (b) Polymictic conglomerate of facies A2 at grid reference 0673821 E, 1961924 N.
inversely-graded and some are disorganized. Internal sedimentary structures are not observed in facies A2.

4.1.2. Facies B: interbedded sandstone and mudstone

Facies B is sandstone dominated and displays multiple fining upward packages. It is further divided into facies B1, B2, and B3 that are pebbly sandstone and massive sandstone, medium- to thick-bedded sandstone with mudstone, and thin-bedded sandstone with mudstone, respectively (Fig. 7). The sandstone of facies B1 is light grey, medium- to coarse-grained, moderate- to poorly-sorted, and up to 1-m thick. Mudstone clasts are observed along the base of the sandstone. These clasts are often inversely graded; the rest of the sandstones are normally graded. The majority of these sandstone beds are structureless and few faint horizontal lamination and cross-lamination are present.

The sandstone of facies B2 is light grey, very fine- to medium-grained, and fining upward. Each sandstone bed is about 30-cm thick and capped with thin mudstone, siltstone, and/or shale. The sandstone beds are either structureless or show sedimentary structures such as large-scale cross-lamination, climbing ripple, cross-lamination, undulating lamination, and planar lamination. Mud rip-up clasts, flute marks, groove marks, and sole marks are observed at the base of the sandstone. Facies B2 is made up of repetitive cycles of the Ta-e divisions of the Bouma sequence (dominated by the T_b and T_c divisions).

Fig. 7. (a) Pebbly sandstone and massive sandstone of facies B1 at grid reference 0673821 E, 1961924 N. (b) Medium- to thick-bedded sandstone with mudstone of facies B2 at grid reference 0671139 E, 19518949 N. The total width of view is 9 m. (c) Thin-bedded sandstone with mudstone of facies B3 at grid reference 0671459 E, 1957165 N. (d) Ball-and-pillow structures observed in facies B3.
Facies B3 is composed of light grey, fine- to medium-grained, thin-bedded sandstone and thin-bedded mudstone, siltstone and/or shale. Planar lamination, climbing ripple, and ripple lamination are observed toward the top of sandstone bed. Each sandstone bed is separated by thin-bedded mudstone, siltstone, and/or shale. Flame and ball-and-pillow structures are found along the base of sandstone beds that are interbedded with mudstone (Fig. 7d).

4.1.3. Facies C: mudstone with thin-bedded sandstone

Facies C is mudstone dominated and subdivided into facies C1 and C2 that are massive mudstone with sandstone and thin- to medium-bedded mudstone with sandstone, respectively (Fig. 8). Both facies display multiple fining upward packages (repetitive rhythms of the $T_c$–$e$ divisions of the Bouma sequence), and the thickness of each package is about 10–40 m. The mudstone of facies C1 is massive. The sandstone of facies C1 is fine- to medium-grained and very thin- to thin-bedded. Ripple cross-lamination and climbing ripples are observed in this sandstone.

The mudstone and siltstone of facies C2 is black and thin- to medium-bedded. The sandstone of facies C2 is greenish grey and fine- to medium grained. Sandstone laminae are intercalated with mudstone or siltstone laminae.

4.2. Sandstone petrology

4.2.1. Texture

Samples are poorly to moderately sorted, fine to very coarse grained sandstones. Most samples contains less than 7% matrix. Grains are angular to subrounded. Grain elongation indices range from very elongate to equant. The index varies from 0.55 to 0.75 with the average of 0.67 ± 0.01. The majority grain falls in the intermediate elongation class. Grain elongation indices are plotted against the average grain size (phi) of each thin-section (Fig. 9) showing that they are

![Fig. 8.](a) Massive mudstone with sandstone of facies C1 at grid reference 0671551 E, 1957246 N. (b) Thin- to medium-bedded mudstone with sandstone of facies C2 at grid reference 0671462 E, 1957179 N.)
statistically correlated, \( r = 0.49, p < 0.05 \). In other words, larger grains tend to be more elongate than smaller grains.

### 4.2.2. Detritus

Lithic fragments are composed of igneous, sedimentary, and metamorphic rocks. Igneous clasts constitute 86.3\% (s.d. 3.8\%) of the total rock volume. The majority are fragments of volcanic rocks plus very few acidic plutonic rocks. The mafic volcanic rock fragments have porphyritic texture; phenocrysts are plagioclase and epidote (Fig. 10). The rhyolitic fragments also have porphyritic texture; phenocrysts are orthoclase, albite, and plagioclase. Plutonic clasts include sub-rounded granitic and granodioritic rocks. Granitic fragments are fine-medium crystalline and equigranular and composed of quartz, orthoclase, plagioclase, microcline, and perthite (Fig. 11). Metamorphic rock fragment content is low (avg. 9.1\%, s.d. 2.7\%).

**Fig. 9.** Elongation index with respect to average grain size (phi) of the Nam Pat sandstone thin-sections.

**Fig. 10.** (a) Photomicrograph of facies A2 sandstone under plane polarized light displays basalt (Bas), quartz grains (Qtz), and partial replacement of mafic minerals to epidote (Ep). (b) Fig. 10a under crossed polarized light. Each image is 2.42 cm wide and 1.58 cm tall.
They are sub-angular to sub-rounded and composed of quartzite, phyllite, muscovite schist, muscovite-biotite schist, slate, and calc-silicate rocks. Sedimentary rock fragments are fine- to medium-grained and rounded. Their content averages 4.6% of the total rock volume (s.d. 1.9%). Sedimentary rock fragments include sandstone, siltstone, shale, claystone, limestone, dolomite, and chert (Fig. 12). Criteria for their identification as terrigenous grains are from Argnani et al. [26] and Lugli et al. [27]. Limestone clasts contain bioclastic fragments such as foraminifera, echinoderm, and algae. Ooid fragments are rounded and replaced by silica.

Quartz contributes 27.8% of the total rock volume (s.d. 5.5%). The majority of quartz is monocrystalline (avg. 60% of the total quartz) and polycrystalline is subordinate (Fig. 13). Polycrystalline quartz is fine- to coarse-grained; each crystal tends to be elongate and their boundaries are smooth, crenulated, or sutured. Boehm lamellae and needle-like inclusions of biotite and muscovite are observed in quartz grains.

Feldspar of various grain sizes and types constitutes 15.7% of the total rock volume (s.d. 4.6%). The majority of feldspar is plagioclase while alkali feldspars (orthoclase and microcline) are subordinate. Plagioclase is rectangular in shape and shows multiple twinning (Fig. 14).
Common accessory minerals of the Nam Pat sandstones are biotite, muscovite, epidote, zircon, tourmaline, apatite, and opaque minerals (Fig. 15). Alteration minerals such as sericite, kaolinite, and chlorite are observed.

4.2.3. Modal composition

Framework grains are reported in Tables 1 and 2. Based on the classification of Pettijohn et al. [28], all sandstones are lithic arenite. Lithic fragments in the sandstone are of igneous, metamorphic and sedimentary. All samples contain less than 7% matrix and/or carbonate cement. On the QFL diagram, the framework composition of the majority of sandstones suggest a transitional and dissected arc provenance of the sediments, only two samples fall into the subcategory recycled orogenic (Fig. 16a). On the QmFLt diagram, the compositional data plot in transitional arc and lithic recycled provenance regions (Fig. 16b). On the QmPK ternary, sandstone composition falls along the Qm-P join (Fig. 16c). On the LmLvLs and QpLvmLsm ternaries, the samples have high proportion of volcanic detritus (avg. Lv and Lvm of 86% and 71%, respectively) and fall into the subcategory magmatic arc (Fig. 16d and e).
4.3. Paleocurrent direction

Paleocurrents were determined from the orientation of clast imbrications and cross-stratification. A total of 94 measurements have been collected from the Huai Ta Long, the 1146th Road, Huai Bo Khong, and Huai Khrai transects (Table 3). Since

Table 1. Grain parameter from Ingersoll and Suczek [47].

| Symbol | Expression | Description |
|--------|------------|-------------|
| Q      | Qm + Qp    | total quartzose grains |
|        | Qm         | monocrystalline quartz grains |
|        | Qp         | polycrystalline aphanitic quartz grains |
| F      | P + K      | total feldspar grains |
|        | P          | plagioclase feldspar grains |
|        | K          | potassium feldspar grains |
| Lt     | L + Qp     | total aphanitic lithic grains |
|        | L          | unstable aphanitic lithic grains |
| L      | Lm + Lv + Ls | metamorphic aphanitic lithic grains |
|        | Lm         | volcanic hypabyssal aphanitic lithic grains |
|        | Lv         | sedimentary aphanitic lithic grains |
|        | Ls         | sedimentary and metasedimentary aphanitic lithic grains |
| L      | Lvm + Lsm  | volcanic hypabyssal and metavolcanic aphanitic lithic grains |
|        | Lvm        | sedimentary and metasedimentary aphanitic lithic grains |
|        | Lsm        | sedimentary and metasedimentary aphanitic lithic grains |
the strata are tectonically deformed, the determination of foreset dip direction is needed [29]. At each sampling location, dip and strike of paleocurrent indicator and bedding were recorded for further correction of paleocurrent direction on a stereographic net. We applied the method of Decelles et al. [22] for two- and three-dimensional exposures of cross-stratification. The paleoflow data are unimodal with locally bimodal distribution (Fig. 17). The majority of paleocurrents are oriented in the southeast direction (104° ± 5.73°).

### Table 2. Modal analyses and recalculated data (component abbreviations explained in Table 1).

| Location       | QFL (%) | QmF (%) | QpL (%) | QmF (%) | LmF (%) | LmF (%) | LmF (%) | P/F  | Qp/Q | Lv/L |
|----------------|---------|---------|---------|---------|---------|---------|---------|------|------|-------|
|                 | Q      | F       | L       | Qm     | F       | L       | Qm     | Lm   | Lm   | Lm   |
| 1146th Road     | 21.1   | 9.8     | 69.1    | 10.1   | 9.8     | 80.1    | 13.2   | 81.4 | 5.4  | 50.7  |
| Huai Ta Long (HTL) |       |         |         |        |         |         |        |      |      |       |
| HTL1            | 34.3   | 18.1    | 47.6    | 19.8   | 18.1    | 62.1    | 21.1   | 65.9 | 13.0 | 52.2  |
| HTL2            | 36.9   | 18.9    | 44.2    | 28.6   | 18.9    | 52.5    | 14.7   | 72.8 | 12.6 | 60.2  |
| HTL3            | 36.5   | 13.8    | 49.7    | 21.4   | 13.8    | 64.8    | 21.1   | 66.2 | 12.7 | 60.7  |
| HTL4            | 20.1   | 17.3    | 62.7    | 12.0   | 17.3    | 70.8    | 10.8   | 81.8 | 7.4  | 41.0  |
| HTL5            | 20.8   | 11.4    | 67.9    | 9.1    | 11.4    | 79.5    | 13.3   | 70.5 | 16.2 | 44.6  |
| HTL6            | 19.2   | 14.1    | 66.8    | 10.1   | 14.1    | 75.8    | 11.1   | 80.6 | 8.3  | 41.9  |
| Huai Bo Khong (HBK) |       |         |         |        |         |         |        |      |      |       |
| HBK1-1          | 32.9   | 21.3    | 45.8    | 24.1   | 21.3    | 54.5    | 14.9   | 73.4 | 11.7 | 53.1  |
| HBK1-2          | 35.6   | 20.4    | 44.0    | 22.7   | 20.4    | 56.9    | 20.8   | 68.1 | 11.1 | 52.7  |
| HBK3-1          | 28.4   | 19.9    | 51.6    | 19.9   | 19.9    | 60.1    | 12.5   | 71.1 | 16.4 | 50.0  |
| HBK3-3          | 28.4   | 24.2    | 47.5    | 16.7   | 24.2    | 59.1    | 18.2   | 70.1 | 11.7 | 40.9  |
| HBK7-2          | 21.5   | 18.2    | 60.3    | 15.8   | 18.2    | 66.0    | 7.9    | 80.2 | 12.0 | 46.5  |
| HBK11-2         | 21.6   | 20.7    | 57.7    | 14.5   | 20.7    | 64.8    | 10.0   | 76.9 | 13.1 | 41.1  |
| HBK12           | 24.0   | 14.7    | 61.3    | 17.1   | 14.7    | 68.2    | 9.6    | 78.7 | 11.6 | 53.6  |
| HBK13-1         | 22.6   | 12.6    | 64.8    | 12.0   | 12.6    | 75.4    | 13.1   | 75.5 | 11.3 | 48.8  |
| Huai Khrai (HK) |         |         |         |        |         |         |        |      |      |       |
| HK2             | 35.9   | 16.2    | 47.8    | 18.8   | 16.2    | 64.9    | 24.9   | 67.5 | 7.6  | 53.7  |
| HK4-1           | 28.0   | 8.5     | 63.6    | 18.9   | 8.5     | 72.6    | 11.6   | 77.5 | 10.9 | 69.1  |
| HK6-1           | 28.3   | 7.9     | 63.7    | 14.4   | 7.9     | 77.6    | 17.0   | 75.0 | 8.0  | 64.6  |
| HK6-2           | 28.5   | 11.1    | 60.3    | 13.3   | 11.1    | 75.5    | 19.0   | 70.4 | 10.5 | 54.4  |
| HK8             | 31.5   | 14.6    | 53.9    | 16.3   | 14.6    | 69.1    | 20.9   | 72.0 | 7.1  | 52.8  |
| HK9             | 28.8   | 21.2    | 50.0    | 20.9   | 21.2    | 57.9    | 13.0   | 80.7 | 6.3  | 49.7  |
| 1339th Road (1339Rd) |       |         |         |        |         |         |        |      |      |       |
| 1339Rd 1        | 29.6   | 22.9    | 47.5    | 20.2   | 22.9    | 56.9    | 15.2   | 74.9 | 10.0 | 46.9  |
| 1339Rd 2        | 23.9   | 9.0     | 67.0    | 12.4   | 9.0     | 78.6    | 13.7   | 75.7 | 10.7 | 57.9  |
| 1339Rd 3-1      | 31.6   | 13.3    | 55.1    | 17.5   | 13.3    | 69.2    | 18.7   | 70.0 | 11.2 | 56.9  |
| 1339Rd 3-2      | 26.1   | 12.7    | 61.2    | 16.7   | 12.7    | 70.6    | 12.6   | 79.7 | 7.7  | 56.7  |

http://dx.doi.org/10.1016/j.heliyon.2018.e00517

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5. Discussion

5.1. Facies distribution

The Huai Lat Formation consists of facies A1, A2, and B1. This formation represents the main upper channel or major channel fill complexes, probably in the most proximal depositional areas [30, 31, 32, 33]. Facies A1 is matrix-supported (sand sized), pebble-cobble massive conglomerate, and its basal contact is erosive. Facies A1 occurs in the lower part of the Huai Lat Formation. Clast orientation and imbrication indicate fairly rapid deposition from a high-velocity suspension [34]. The assemblage of conglomerate with minor sandstone corresponds to a product of high-density turbidity current in proximal [30, 35, 36, 37]. Facies B1 is marked by tractional structures, relatively weak-poor grading, and little to no interbedded pelagic clay and terrigenous mud. Facies B1 represents a deposit from high-density
Table 3. Summary of the paleocurrent data of the Nam Pat Group in the study area.

| Section           | Facies | Frequency | Azimuth | Sedimentary structures     |
|-------------------|--------|-----------|---------|-----------------------------|
| 1146th Road       | A2     | 7         | 107     | Gravel imbrication         |
| Huai Ta Long      | A2     | 2         | 114     | Gravel imbrication         |
|                   | B2     | 11        | 117     | Cross bedding              |
|                   | B3     | 9         | 119     | Cross bedding              |
|                   | C2     | 3         | 066     | Cross bedding              |
| Huai Bo Khong     | A2     | 5         | 114     | Gravel imbrication         |
|                   | B1     | 2         | 138     | Cross bedding              |
|                   | B2     | 13        | 130     | Cross bedding              |
|                   | B3     | 22        | 112     | Cross bedding              |
|                   | C1     | 6         | 075     | Cross bedding              |
|                   | C2     | 2         | 086     | Cross bedding              |
| Huai Khrai        | A2     | 3         | 109     | Cross bedding              |
|                   | B2     | 9         | 084     | Cross bedding              |

Fig. 17. Rose diagram of paleocurrent data of the study area. The majority paleocurrents are oriented in the southeast direction (104° ± 5.73°, n = 94).
turbidity currents. The presence of mud clasts, local scours, and amalgamation surfaces are indicators of energetic and locally erosive currents [38].

Facies B2, B3, C1, and C2 represent the Huai Bo Khong Formation. The lower part of the Huai Bo Khong Formation consists of thick sequences of sand-rich turbidites. It is characterized by the predominance of medium-grained, thin- to thick-bedded, sandstone bodies of thick amalgamated sandstone beds of facies B2. The upper part of the Huai Bo Khong Formation contains thin- to medium-bedded, fine-grained sandstones of facies B3 interbedded with mudstones and thin-bedded, very fine- to fine-grained sandstones of facies C1, with subordinate amounts of (locally) massive mudstone deposits of facies C2.

The Nam Pat Group is a fining-upward stratigraphic sequence. The lower formation is dominated by conglomerate and coarse-grained sandstone that developed as proximal deposits in the main upper channel or major channel fill complexes. The upper formation is dominated by rhythms of sandstone and mudstone, and sand to shale ratio decreases eastward. In this study the effective thickness of the Huai Lat Formation and the Huai Bo Khong Formation could not be determined because most of the strata are tightly folded and those along the hinge zone are extremely weathered. The distribution of the two formations is illustrated in Fig. 5. The Huai Lat Formation and Huai Bo Khong Formation are distributed along the western and eastern parts, respectively, of the Nam Pat Basin.

5.2. Provenance

The QFL and QmFLt plots indicate that the sandstones contain a significant proportion of lithics and have magmatic arc ( undissected, transitional, and dissected arc) and recycled-orogen provenance compositions. Fewer samples fall into the recycled-orogen region. The QpLvmLsm and LmLvLs ternary plots are useful for distinguishing magmatic arc suites from recycled-orogen suites [24]. The plots indicate that sandstones of the Nam Pat Group have a high proportion of volcanic detritus and their provenance are volcanic arcs. All of the Nam Pat sandstone samples plot along the Qm-P join and have high plagioclase to total feldspar ratios (P/F) which indicate that the sediments are arc-derived. Therefore, volcanic rocks were the major sediment contributors whereas plutonic and metamorphic rocks provided a minor proportion of sediment. These volcanic lithic fragments, found in both sandstone and clast of conglomerate, were derived from the nearby magmatic arc located to the northwest of the Nam Pat Basin. This is proved by (1) the detrital framework grains are texturally immature, (2) the Nam Pat Group is fining toward the southeast, (3) proximal deposits are along the northwestern part of the basin, and (4) the majority paleocurrents are oriented in the southeast direction (104° ± 5.73°). Thus, large quantities of sediment shed southeastward from nearby volcanic arc into the basin.
5.3. Tectonic settings

By integrating the petrologic data, which allows recognition of provenance, with the facies distribution map and paleocurrent directions (Fig. 18), the conceptual model for evolution of the Nam Pat Basin can be identified (Fig. 19). Our data agreed with the studies of Lüddecke et al. [20], Singharajwarapan [39], and Singharajwarapan and Berry [6] that the Nam Pat Group, both the conglomerates and sandstones, received large quantities of sediments from nearby andesitic Pak Pat volcanic rocks.

However, we disagree with the interpretation of the Nam Pat Basin as a forearc basin [e.g., 4, 39] because, in that model, the Pak Pat volcanic arc, would have been located to the east of the Nam Pat Basin and the basin would have been fed from the east. In fact, the Pak Pat Volcanics are located to the west of the basin, along its northwestern rim. Thus, the basin is best interpreted as back-arc basin. Our interpretation is similar to those of Sone and Metcalfe [1], Metcalfe [8], Ueno and Hisada [19], Ricou [40], Wang et al. [41], and Hara et al. [18].

Fig. 18. Simplified geologic map of the study area displays the paleocurrent directions (arrow). The Huai Lat and Huai Bo Khong Formations are distributed on the western and eastern parts of the basin, respectively.
interpreting the Nam Pat Basin as a short-lived back-arc basin. The reconstruction for evolution of the Nam Pat Basin is illustrated in Fig. 19 and explained below.

5.4. The evolution of the Nam Pat Basin

The basin opened and the Nan-Uttaradit Ocean existed in the Late Carboniferous [17] as a consequence of the Sukhothai Zone development [18]. During the back-arc extensional phase, volcanic lithic fragments were shed into the Nam Pat Basin and accumulated as proximal Huai Lat Formation and distal Huai Bo Khong Formation (Fig. 19a and b). The Huai Lat conglomerate has clast imbrication and sandy matrix which indicates deposition from turbulent flows [31]. The Huai Lat Formation shows inverse-to-normally graded patterns. This inverse-to-normal grading pattern is interpreted as turbiditic facies deposited from flow on a relatively steep slope, downstream from the disorganized bed of the feeder channels or canyons [34]. The Huai Bo Khong Formation has the repetitive fining upward cycles of interbedded sandstones and mudstones of classic turbidites. This formation formed where the paleoslopes flatten out [34] and the turbidity currents have relatively lower flow velocities [42]. As turbidity currents travel across the basin floor, from northwest to southeast, they wane progressively and yield depositing sequences that are fining along their travel path. Thus, during the basin extensional phase the western margin of the basin floor was steeper than the eastern part, and sediment provenance located to the west of the basin (Fig. 17). Additionally, the bases of sandstones that are interbedded with mudstones show ball-and-pillow structures (facies B3) which could be induced by seismic events [43]. Thus, this facies could be syn-rift deposits occurring while the basin was opening.

The basin started to close around Late Triassic [7]. Compression began after the Huai Lat and Huai Bo Khong Formations were consolidated because (1) high angle faults were observed in the Huai Lat conglomerate and (2) upright folds, axial
plane cleavage, and spaced cleavage were observed in the Huai Bo Khong Formation [3]. The high angle faults in the Huai Lat Formation were developed in a high-strain zone due to rheological contrast between the underlying Pak Pat Volcanics and the overlying conglomerates [39]. The mentioned evidences suggest that the compression started after consolidation. Our field observation of the orientation of the strata is similar to that of Singharajwarapan and Berry [44]. The deformation structures are caused by the continental subduction of the Nam Pat Basin underneath the eastern margin of the Sukhothai Zone. The final stage of the Nam Pat Basin is illustrated in Fig. 19c. The evolution of the basin during this period is represented by the allochthon model where the strata along the eastern part of the Sukhothai Zone were thrusting over the western part of the Nam Pat Basin due to tectonic compression.

 Declarations

 Author contribution statement

 Kritsada Moonpa: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

 Kannipa Motanated: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

 Competing interest statement

 The authors declare no conflict of interest.

 Funding statement

 This work was supported by Development and Promotion of Science Technology Talents (DPST) Research Grant 040/2558 and Science Achievement Scholarship of Thailand (SAST).

 Additional information

 No additional information is available for this paper.

 Acknowledgements

 We would like to thank Dr. Michael M. Tice from Texas A&M University, Texas, USA for suggestions and valuable comments on the manuscript.
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