Fracture characterization and basement reservoir potential of Phra Wihan Formation in southern part of Uttaradit Province, Northern Thailand

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Abstract

This paper describes the characterization of fractures in the Mesozoic sandstones Phra Wihan Formation exposed at the southern part of Uttaradit province, Northern Thailand. Fracture characterization of outcrop analog is important to determine potential of subsurface reservoir. The methodology used in this study includes field study and petrographical analysis to determine the relationship between fractures and other structures such as bedding plane and fold geometry. In addition, microstructural analysis is performed to evaluate the potential of reservoir. The Phra Wihan Formation composed of thick quartz arenite sandstone laminated with mudstones. Based on outcrop study, the structural architectures consist of two orthogonal open fracture sets dominated in the fold limb. The first fracture set (Set I) is subdivided into Set Ia and Set Ib, developed in WNW-ESE direction perpendicular to the fold axial plane and parallel to the major compression stress. The second fracture set (Set II) is subdivided into Set IIa and Set IIb, developed in NNE-SSW direction parallel to the fold axial plane. These fractures imply to be associated with folding stage related to WNW-ESE compression stress during India-Eurasia collision.

Keywords: Fracture, Basement reservoir, Phra Wihan Formation, Thailand

1. Introduction

Fractured reservoirs represent a large percentage of the world's hydrocarbon reserves and will continue to be an important hydrocarbon exploration target, especially in mature provinces such as North America (Meissner & Thomasson 2001).

Basement reservoir sandstones are one of the main targets in mature onshore oil field in Tertiary basins in Thailand because conventional reservoirs have been more served (Thitipattanakul et al., 2018). But most basement reservoirs of onshore Tertiary basin are pre-Tertiary rocks with low reservoir quality (C&C reservoirs, 2009). Prediction of reservoir quality in low porosity and permeability necessitates understanding of fractures in subsurface. Outcrop analogue is the key one that represents fracture characterization of reservoirs in the subsurface.

Here, this study proposes a conceptual model for the origin and evolution of natural fracture systems in folded Mesozoic sandstones Phra Wihan Formation of Khorat Group (DMR, 2007) (Figure 1). This sandstone is the one of basement discovery in subsurface and encountered oil strain in core samples in the Phitsanulok Basin. In term of lithology and rock samples from subsurface, there are significant similarities between outcrops and core samples. The chosen outcrops in this study illustrated great developed of natural fracture systems. Hence, this outcrops analog could provide a good opportunity to analyze fracture systems for geologic modeling of fracture reservoirs.

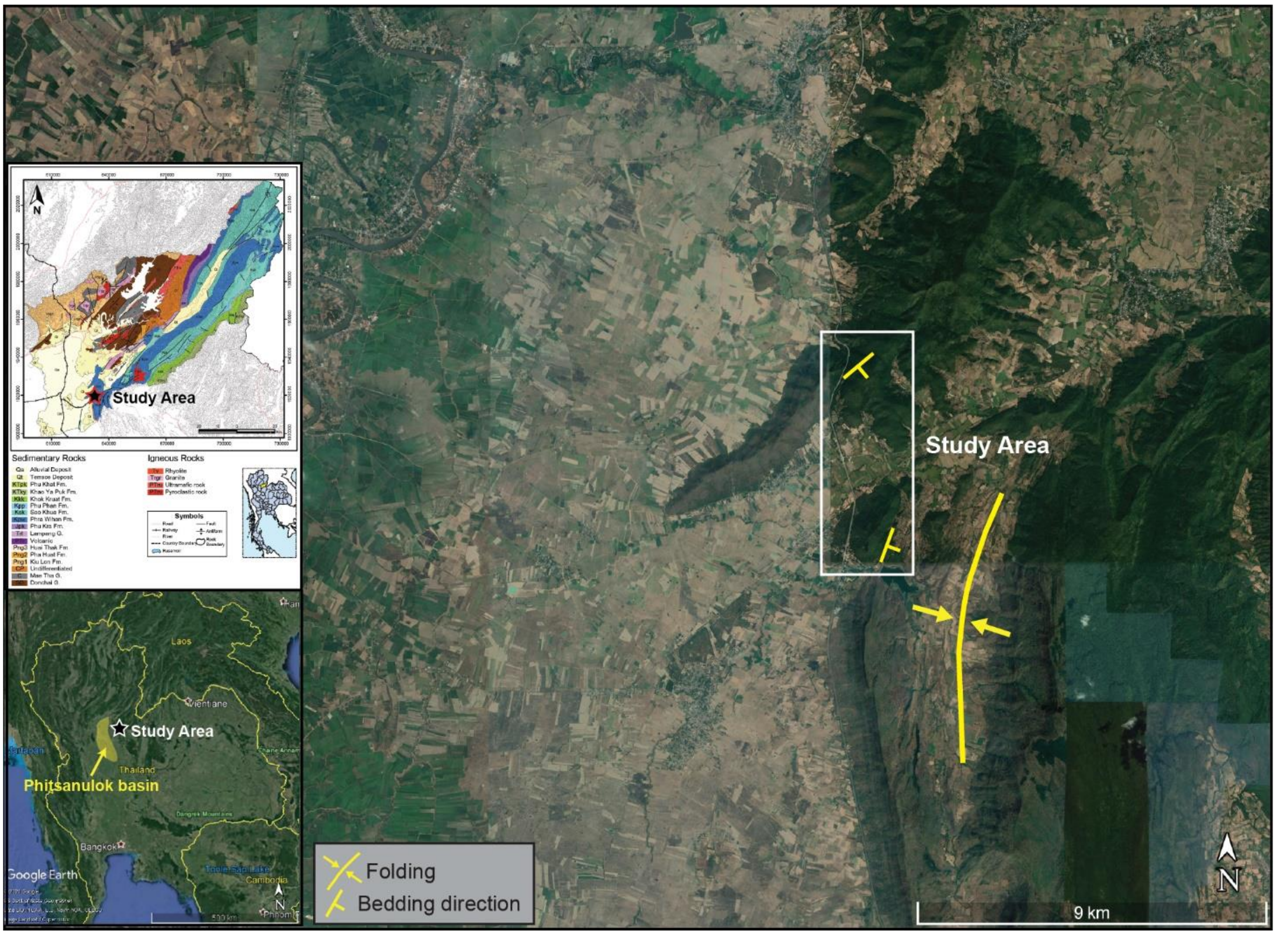

Figure 1 Illustrating google map and geologic map of study area in Uttaradit province, northern Thailand.

2. Geological background and study area

There are two main continental blocks recognized in Thailand: Sibumasu block in the west and Indochina block in the east. The main tectonic events include Triassic-Early Jurassic Indosinian Orogeny and Late Cretaceous-Cenozoic subduction of Indian oceanic plate and consequent collisions of India-Eurasia (Sone & Metcalfe, 2008; Morley, 2004; Morley, 2012).

The study area is located at Highway 11, km 289, Pichai district, Uttaradit province near Sum Bon dam (Fig. 1). This study is a part of Phra Wihan Formation in Khorat Group (DMR, 2007; Sha & Meesook 2013). The Phra Wihan Formation composes of thick bedded to massive white sandstones with rare thin beds of reddish-brown to grey claystone. It is 100~250 m thick and conformable with the underlying Jurassic Phu Kradung and the overlying Sao Khua formations. The sandstones are cross-bedded and fine to coarse grained quartzitic sandstone (Sha & Meesook, 2013).

3. Methodology

Field study and laboratory were integrated for this research. Structural geometries in the exposed outcrop were measured, photographed and sketched. Hand specimen samples were collected for microstructure analysis through thin sections.

Field study focused on fracture sandstone outcrop on pavement area for understanding the relationship between fracture systems and tectonic history.

Main structural analysis techniques included petrographical study (microstructure analysis) and computer-based fracture study using Stereonet 11.

The integration of field study and microstructure analysis can be used to understand relationships of fracture pattern and their evolution.

4. Results

4.1 Field investigation

There are four outcrops in this study area. Bedding orientation and fracture orientation were measured. According to the satellite map and geological map (Figure 1), structural pattern shows NNE-SSW trending ridge in the study area. The study area is a part of the fold limb. In this case, there is no evidence of fold axial plane, however strike of bedding plane can be represented the axial plane direction.

Exposed outcrop of the station 1 (Latitude: 17° 20’ 18” N., Longitude: 100° 14’ 38” E.) is white sandstone (Fig. 2). The pavement outcrop shows bedding orientation in NE-SW (average strike of N034°, average dip of 33°E). Two main open fracture sets were observed in this station: Set I fracture trending WNW-ESE (average strike of N097°, average dip of 88°N) are bed perpendicular and oblique to bedding strike. Their traces are linear and spacing varies from 10-80 cm. Set II fractures trending NNE-SSW (average strike of N009°, average dip of 67°W) are bed perpendicular and oblique to bedding strike. Their traces are linear and spacing varies from 10-30 cm. These two fracture sets are orthogonal. The fracture pattern shows that Set IIa fracture terminates at Set Ia, Set Ib fracture terminates at Set IIa and Set IIb terminate at Set Ib, respectively.

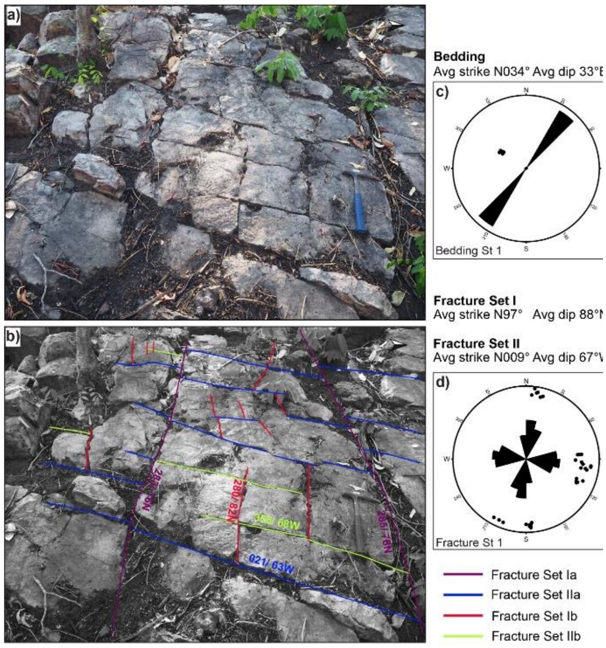

Figure 2 Fracture pattern at the pavement in Phra Wihan sandstone of St 1. a) Field photograph at station 1. b) Line drawing of the outcrop in a) show Set IIa terminates at Set Ia, Set Ib terminates at Set IIa and Set IIb terminate at Set Ia. c) Stereographic plot and rose diagram illustrating bedding orientation in NE-SW direction. d) Stereographic plot and rose diagram illustrating fracture orientation in Set I WNW-ESE direction and Set II NNE-SSW direction.

The station 2 (Latitude: 17° 20’ 22” N., Longitude: 100° 14’ 30” E) exposed outcrop is high weathering white sandstone (Fig. 3). This pavement outcrop shows bedding orientation in NE-SW (average strike of N015°, average dip of 37°E). There are two systematic open fracture sets and some non-systematic fracture set. Set I fracture trending WNW-ESE (average strike of N098°, average dip of 73°N) is bed perpendicular and sub-perpendicular to bedding strike and traces are linear. Set II fractures trending NNE-SSW (average strike of N002°, average dip of 73°W) are not bed perpendicular, but sub-parallel to bedding strike. Their traces are linear. According to high weathering on pavement, the spacing of fracture may be uncertain to measurement. The non-systematic fractures are not considered further due to locally developed. Fracture Set I and II are orthogonal. Fracture patterns show that Set IIa fracture terminates at Set Ia, Set Ib fracture terminates at Set IIa and Set IIb terminates at Set Ib, respectively. The fractures Set I and Set II are orthogonal to each other.

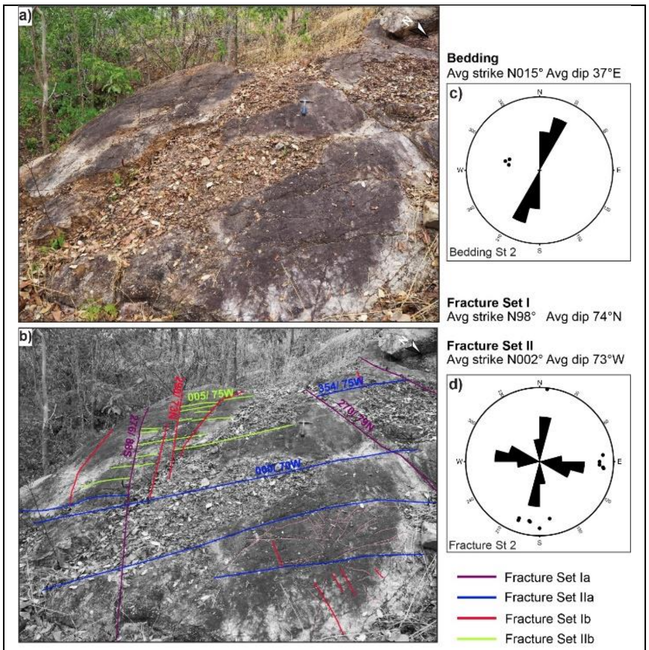

Figure 3 Fracture pattern at the pavement in Phra Wihan sandstone of St 2. a) Field photograph at station 2. b) Line drawing of the outcrop in a) show Set IIa terminates at Set Ia, Set Ib terminates at Set IIa and Set IIb terminate at Set Ia. c) Stereographic plot and rose diagram illustrating bedding orientation in NE-SW direction. d) Stereographic plot and rose diagram illustrating fracture orientation in Set I WNW-ESE direction and Set II NNE-SSW direction.

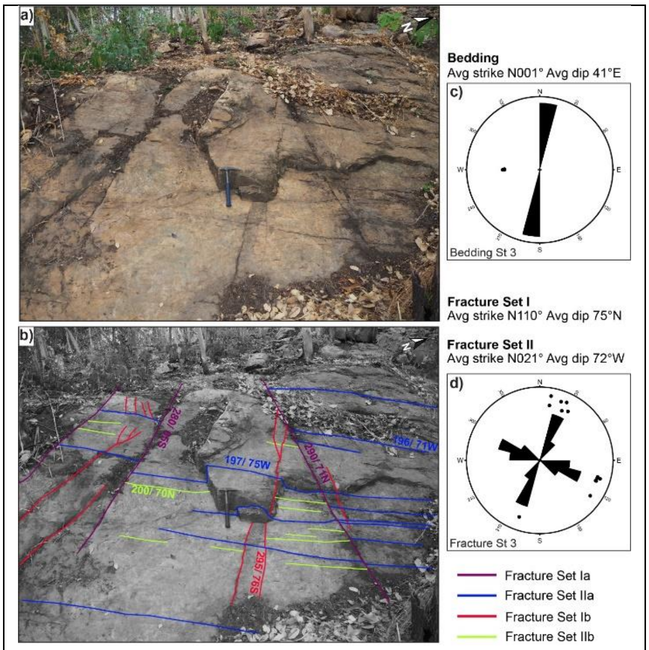

Figure 4 Fracture pattern at the pavement in Phra Wihan sandstone of St 3. a) Field photograph at station 3. b) Line drawing of the outcrop in a) show Set IIa terminates at Set Ia, Set Ib terminates at Set IIa and Set IIb terminate at Set Ia. c) Stereographic plot and rose diagram illustrating bedding orientation in NNE-SSW direction. d) Stereographic plot and rose diagram illustrating fracture orientation in Set I WNW-ESE direction and Set II NNE-SSW direction.

The station 3 (Latitude: 17° 20’ 17” N., Longitude: 100° 14’ 24” E) exposed outcrop white sandstone (Fig. 4). This pavement outcrop shows bedding orientation in N-S (average strike of N001°, average dip of 41°E). There are two open fracture sets in pavement area. Set I fracture trending WNW-ESE (average strike of N110°, average dip of 75°S) is bed perpendicular and oblique to bedding strike. Their traces are linear and spacing varies from 10-120 cm. Set II fracture trending NNE-SSW (average strike of N021°, average dip of 72°W) is not bed perpendicular and oblique to bedding strike. Their traces are linear and spacing varies from 5-70 cm. These two fracture sets are orthogonal. The fracture pattern shows that Set IIa fracture terminates at Set Ia, Set Ib fracture terminates at Set IIa and Set IIb terminate at Set Ib, respectively.

The station 4 (Latitude: 17° 22’ 59” N., Longitude: 100° 13’ 58” E) is road cut outcrop with massive sandstone, km 129 of highway 11 (Fig. 5). The outcrop show side of fracture wall that parallel to bedding strike. Bedding orientation is in NE-SW (strike of N050°, dip of 40°E). There are two fracture sets with open fracture and some quartz filled fracture. Set I fracture trending NE-SW (average strike of N134°, average dip of 76°S) are bed perpendicular and sub parallel to bedding strike. Their traces are linear and some slightly curvature, spacing varies 5-50 cm. Set II fractures trending NW-SE (average strike of N050°, average dip of 35°W) are not bed perpendicular, but parallel to bedding strike. Since the outcrop did not show pavement area on the top of bedding surface, it is invisible spacing of Set II fractures. These fractures are orthogonal to each other.

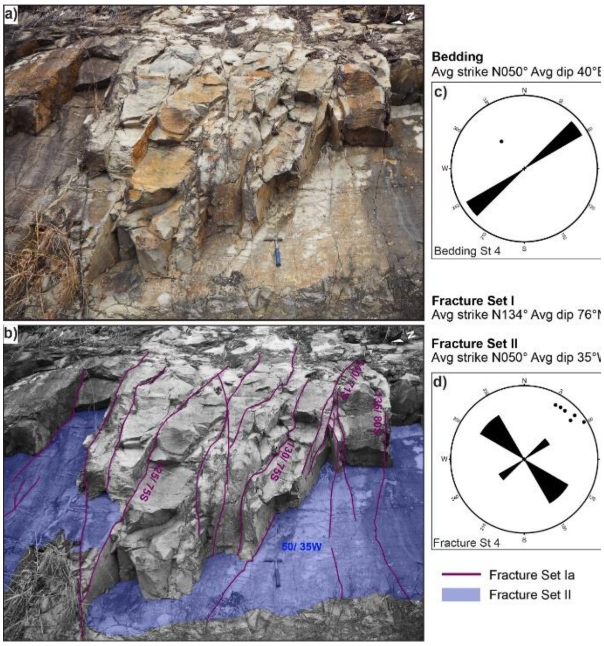

Figure 5 Fracture pattern at the pavement in massive Phra Wihan sandstone. a) Field photograph at station 2. b) Line drawing of the outcrop in a) show Set I fractures and planar of Set II fractures. c) Stereographic plot and rose diagram illustrating bedding orientation in NE-SW direction. d) Stereographic plot and rose diagram illustrating fracture orientation in Set I NW-SE direction and Set II NE-SW direction.

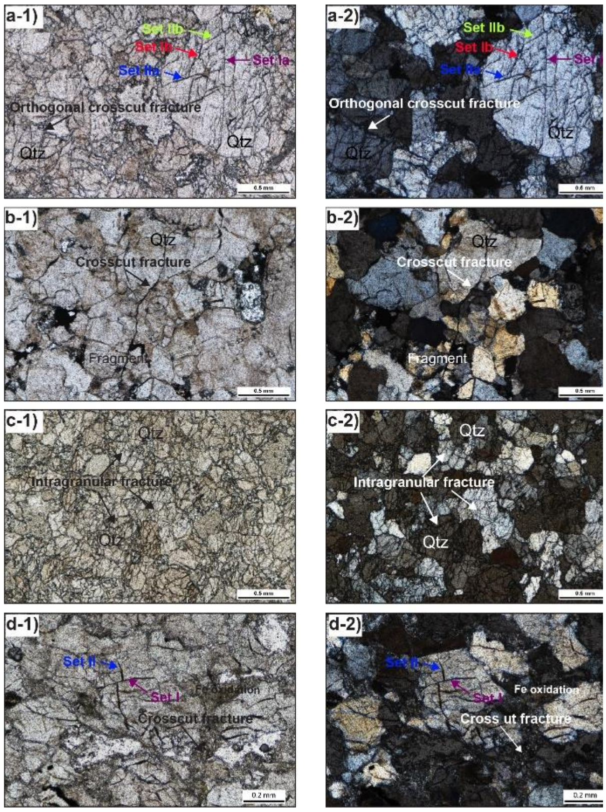

Figure 6 Photomicrograph of outcrop samples showing microfractures. left: plane polarized light and right: cross polarized light. a-1,2, d-1,2) Intragranular fractures of Set I and Set II with orthogonal crosscut fracture between grains. b-1,2) Crosscut fracture between grains with absent intragranular fracture. c-1,2) Abundant of intragranular fracture.

4.2 Petrography and Microstructures

Eight thin sections were examined and descripted under a microscope (Fig. 6). Sandstone lithofacies consist of moderate to well-sorted, fine to coarse-grained, angular to sub-round, mainly quartz content, less abundant of matrix, classified as quartz arenite (Folk, 1980). Sandstone illustrates point and long contact between grains. Photomicrograph shows common microfracture (intragranular fracture and crosscut fracture) which are unmineralized fractures (Fig. 6). Microfractures showing relationship of fracture Set I and Set II which match patterns visible in outcrop observation. Set IIa fracture terminates at Set Ia, Set Ib fracture terminates at Set IIa and Set IIb terminate at Set Ib (Fig. 6 a, d).

5. Interpretation and Discussion

5.1 Fracture characterization and their evolution

Structural analysis in the study area focuses on bedding orientation and fracture orientation which located at the limb of fold. Overall bedding orientation is NNE-SSW (average strike of N022°, average dip of 35°E) and two orthogonal open fracture sets. Set I fracture is trending in WNW-ESE (average strike of N105°, average dip of 89°S). Set II fracture is trending NNE-SSW (average strike of N011°, average dip of 68°W). The northern part of study area in St 4, bedding and fracture orientations were developed differently compared to the southern part (Fig. 7).

As the results, there are two set of orthogonal fractures. Set I fracture is approximately perpendicular to fold axial plane.These sets associated with, and parallel to the WNW-ESE direction of maximum compression and extension perpendicular to tension direction as mode I opening fracture unfilled mineral. Set II fractures are approximately parallel to the fold axial plane. Tension in the fold limb may have contributed to development of this set as mode I opening fracture unfilled mineral due to stress releasing. The relationship of these two fracture sets can interpreted that fracture occurring related with folding.

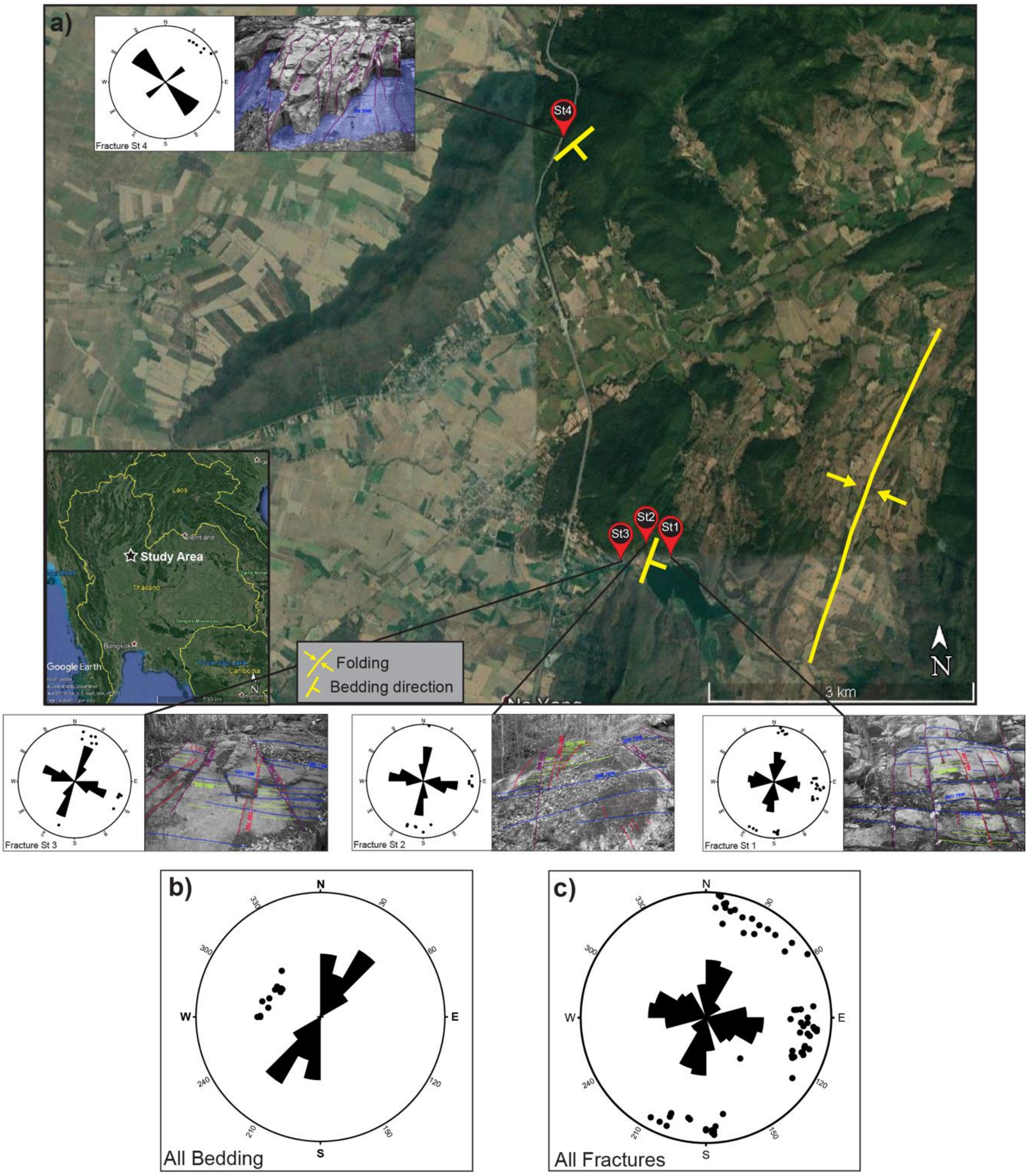

Figure 7 Stereographic plots and rose diagrams of individual locations and all of fracture and bedding orientations in in study area including outcrop pavements.

Conceptual fracture evolution in this study area is shown in Figure 8. In the detail, fractures can be subdivided into four sets: Set Ia, Set IIa, Set Ib and Set IIb. Set Ia occurred first associated with parallel to maximum compression stress in WNW-ESE in early compression stage. Then Set IIa developed in NNE-SSW with perpendicular and terminating at Set Ia in syn-folding stage due to stress releasing and generated local extension in the fold limb parallel to the fold axial plane. After that Set Ib is minor set developed parallel to Set Ia which terminating at Set IIa and Set IIb developed parallel to Set IIa which terminating at Set Ib, respectively. Set Ib and Set IIb developed denser network in during syn-foldingstage following Set IIa which continuously over the period of compression and fold growth.

5.2 Relationship of fractures to other structures and tectonic history

As discuss in section 5.1, Mesozoic sedimentary structural trend and fracture trends indicate a phase of WNW-ESE compression parallel to Set I fracture and the fold axial plane, but perpendicular to Set II fracture which developed in NNE-SSW trending. This investigation interpreted as a result of India-Eurasia collision of Indian oceanic plate subduction beneath West of Burma in late Cretaceous to Paleocene (Morley, 2004) that is early compression and occurring of Set Ia fracture. The continuous of subduction during Paleocene-Eocene (Morley, 2002) related to fold growth generated fracture Set IIa in the limb of fold during syn-folding stage and generated minor Set of Ib and IIb during syn-late folding stage, respectively and associated with folding (Fig. 9).

5.3 Implication to subsurface

Based on fracture evolution and tectonic history, fracture sandstones of the Phra Wihan Formation are possibly potential basement reservoir rock which hydrocarbon migrated from depocenter and charged into them as "buried-hill play" in the subsurface. Fracture reservoirs are significant effect on fluid flow in the form increase porosity and permeability. Example of oil strain in sandstone Phra Wihan Formation in the Phitsanulok Basin was found in drilled well discovered by Shell in 1988. The outcrop analog can be used to predict the fracture reservoirs in the subsurface in the basin.

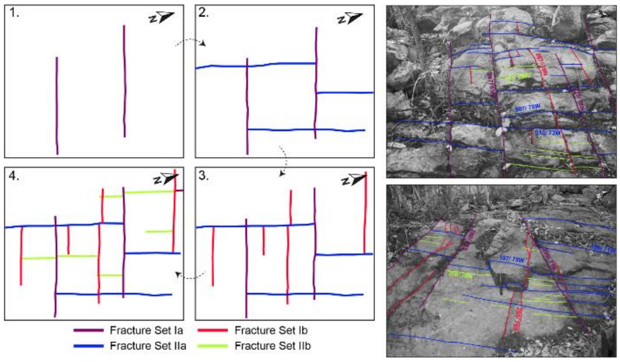

Figure 8 Cartoon illustrating fracture characterization and evolution in top view from outcrops how fracture pattern of terminating and cutting orthogonal fractures might form in four episodes. (Modified after Hancock et al, 1987)

Moreover, fracture reservoirs are potential for storage of carbon dioxide (CO_2) which is interesting because of its potential contribution to mitigate global warming. Carbon dioxide can be injected into depleted hydrocarbon reservoirs or aquifer reservoirs. It is the imperative technology to reducing carbon dioxide to the atmosphere.

The outcrop analog should be integrated in future subsurface data to improve the prediction of fracture systems. This provides more chances for petroleum exploration and new technology of carbon capture storage, which will improve the secondary target in mature filed and new way to reducing global warming.

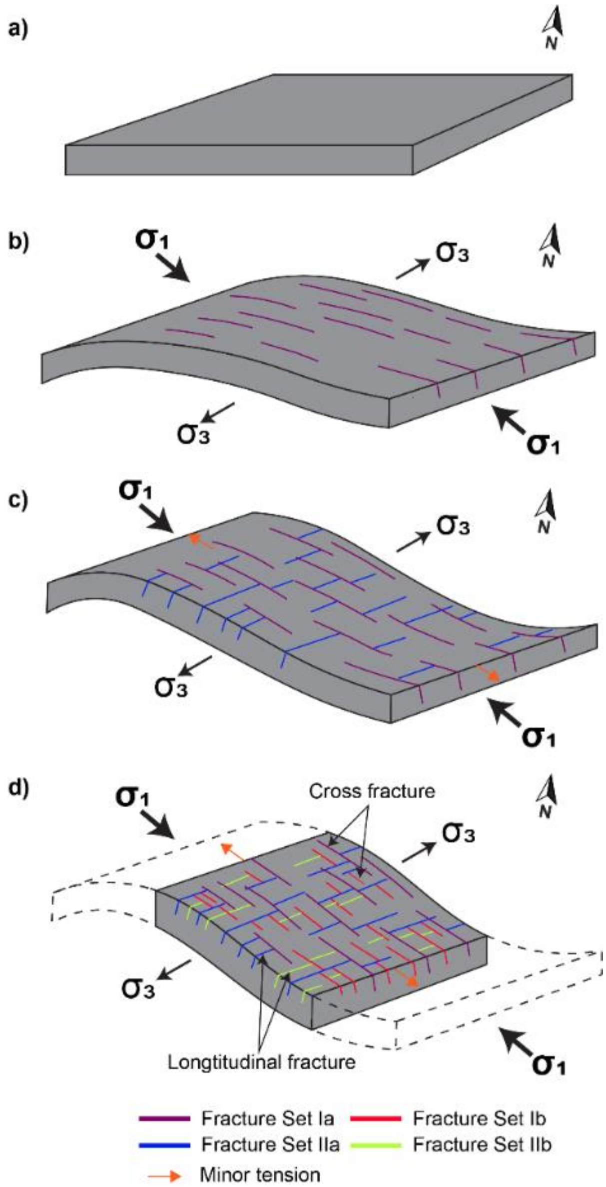

Figure 9 Conceptual model of structural development in study area. a) Pre-folding stage. b) Early compression stage. c) Syn-folding stage. e) Syn-late folding stage continuously over the period of compression and fold growth.

6. Conclusion

This research integrated field work and laboratory study of sandstone Phra Wihan Formation outcrops at Pichai district, Uttaradit province, northern Thailand in order to study reservoir potential. Fracture pattern and other related structures such as bedding orientations and which related to regional tectonic were analyzed in this study.

The study area is situated on the structure of fold limb lining in NNE-SSW direction. Two sets of fracture trends are recognized which were developed in single tectonic event. One is Set I which subdivided into Set Ia and Set Ib, developed in WNW-ESE direction occurring parallel to compression and perpendicular to fold axial plane. Another is Set II which subdivided into Set IIa and Set IIb, developed in NNE-SSW direction occurring parallel to fold axial plane and orthogonal to Set I. These two sets associated with fold which related to India-Eurasia collision during late Cretaceous to Eocene. Fracture characterization in outcrop and petrographic study indicated that open fractures and microfractures can improve reservoir quality in term of porosity and permeability. In addition, fracture reservoirs are potential contribution to mitigate global warming by stored carbon dioxide into subsurface. However, outcrop analog should be integrated with the subsurface data to improve the prediction of fracture systems.

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