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Strain Analysis of Rocks in Lansang Waterfall, Tak Province, Northwestern Thailand

Peekamon Ponmanee and Pitsanupong Kanjanapayont *

Department of Geology, Faculty of Science, Chulalongkorn University, Bangkok 10330, Thailand
* Corresponding author e-mail: pitsanupong.k@hotmail.com

ABSTRACT

Lansang Waterfall is located inside the Lansang National Park, Tak, northwestern Thailand, and claimed to be a part of the affected zone of past India penetration. Such area exposed the mylonitic core, which made of reworked metamorphic rocks in the greenschist facies with the steep foliation and nearly horizontal stretching lineation. These characteristic imply nearly plane strain and also present clear left- lateral shear criteria on various markers for instance boudin trails or deformed minerals, thus it suggested a proper area for strain quantitative analysis in other previous studies. For the strain analysis in sense of quantitative, the Fry method was applied for quantify the finite strain of rock from recrystallized quartz grain in the mylonitic gneisses of Lansang waterfall. The strain magnitude, including with the strain ratio, R_s obtained from the strain ellipsoid of Fry's diagram are ranged from 1.40 to 1.91. The longest axes of recrystallized quartz grains intense the characteristic of left- lateral shear sense on this area. Based on these useful data led it be concluded that a significant component of simple shear was involved and related within an area of Lansang waterfall.

Keywords: Strain analysis, Fry method, Lansang Waterfall, Thailand

1. Introduction

Despite the fact that the widely spread studied used various dating techniques, geo-morphological offsets or Global Positioning System (GPS) measurement in Plate- scale kinematic reconstruction of past India- Asia collision on the areas, which claimed to be the result of the collision; Ailao Shan - Red River shear zone and Mae Ping shear zone, but the better understand and clearly conclusion about the structural evolution on this complex area after collision occurred is still difficult.

The large strain area in Tibet and adjacent regions has induced by the indentation of India into Asia. The N- S crustal shortening was imprinted by geological and geophysical evidence that occurred in the region that facing with the Indian's indenter. On the sides of the collision zone, this past penetration has produced a large area of deformation and later successively pushing Indochina and Tibet/ South China toward the ESE along the sinistral strike- slip faults, which removed the volume of Asia lithosphere after the collision. Besides, because of this strike- slip motion such shortening was mentioned that transformed into crustal extension, seafloor spreading and also subduction nearby the strike- slip faults.

One of the models of the Tertiary extrusion of Indochina and concurrent opening of the South China Sea used evidence on rocks of the Ailao Shan- Red River shear zone and the field investigation modeled and proposed that the sinistral motion occurred between 35Ma to 17Ma by ductile shear (Harrison *et al.*, 1992; Lacassin *et al*., 1997; Schärer *et al*., 1990; Schärer *et al*., 1994). Moreover, the southern part of the Indochina claimed to be the major deformation phases, which reported to be Paleozoic or Lower Mesozoic age (Ahrendt *et al*., 1993; Bunopas, 1981; Lacassin *et al*., 1997). However, to proposed the truly model about the timing of major deformation phases and an extrusion of the Indochina block, including with the movement of this strike- slip faults and shear zones are still be questioned. As a step of those questions to answer, to better understand in the deformation history of this past continental deformation required not only the recognition and dating of large shear zone, but also in senses of quantitative analysis for determined the direction and sense of movement in the crustal shear zones (Lacassin *et al*., 1993).

The strain quantitative analysis refers and relates to useful mathematical equation which uses to calculate a quantity of finite strain on high strain zones from the geometry of shear criteria; strain makers of rocks which reveal how much rock obtained strain inside after the collision occurred. Such zones are affected by strong recrystallization due to metamorphism process during the plate tectonic collision occurred which gives the different trails in the geometry of markers for instance; elliptical (conglomerate) or spherical (ooids or radiolaria) deformed objects or microfossil (Ramsay, 1967; Dunnet, 1969; Wallis, 1992; Sarkarinejad, 2007), deformed mineral (recrystallized quartz grain) (Bailey and Eyster, 2003) and the boudinage structure (Lacassin *et al*., 1993) can be used as strain markers for quantify the finite strain (Ramsay and Huber, 1983). The Fry (1979) is one of the useful and simply quantitative techniques for quantify the finite strain from deformed minerals inside of rocks for instance recrystallized quartz grains and the products present in forms of strain ellipsoid of the finite strain (Fry, 1979; Hanna and Fry, 1979).

Although the theoretical model of the finite strain for the transpressional system zone has been developed in a series as mentioned earlier but the field investigation of finite strain analysis in sense of quantitative assessment are needed to improve our understanding in the deformation history on this system. Therefore, it led this research has an objective and motivation to describe the movement and deformation history of this past collision shear zone by using technique of Fry (1979) quantify the finite strain from deformed rocks on a part of Mae Ping shear zone at Lansang waterfall, Tak, northwestern Thailand.

2. Geological setting

Northwestern part of Thailand located in the triangle- shaped northern corner of Indochina that the geological setting is a mountains region with moderate elevation and rock of various types and ages. The most imprint structural feature of the NW Thailand is the Chiang Mai- Lincang belt (CM- L belt) that is a north- south metamorphic and magmatic rock widely about 70 km. This belt is offset by the plenty of strike- slip faults, which the most dominant ones is the left- lateral Mae Ping, and Three Pagodas fault zones. Within this are the metamorphic rocks that mostly high- grade orthogneisses, paragneisses and micaschists. By the overlain of less metamorphic Paleozoic, rocks lead this metamorphic rock: gneisses and micaschist defined to Precambrian age (figure 1). Later they pass and deformed into migmatites and are intruded by mainly Permo- Triassic age of granitic plutons. The syntectonic migmatization and granite intrusion involved with two important stages: during a Permo- Triassic age instead of Precambrian for the high- grade metamorphism and during Cretaceous or Tertiary granite for an event of younger magmatic and metamorphic in the CM- L belt (Cobbing *et al*., 1992; Dunning *et al*., 1995). Besides, the characteristic of left- laterally which occurred by the Three

Pagodas fault zone presence in Cretaceous to Paleogene granite plutons located on the west of the belt along the Tenasserim mountain of southern Burma and Shan scarp region.

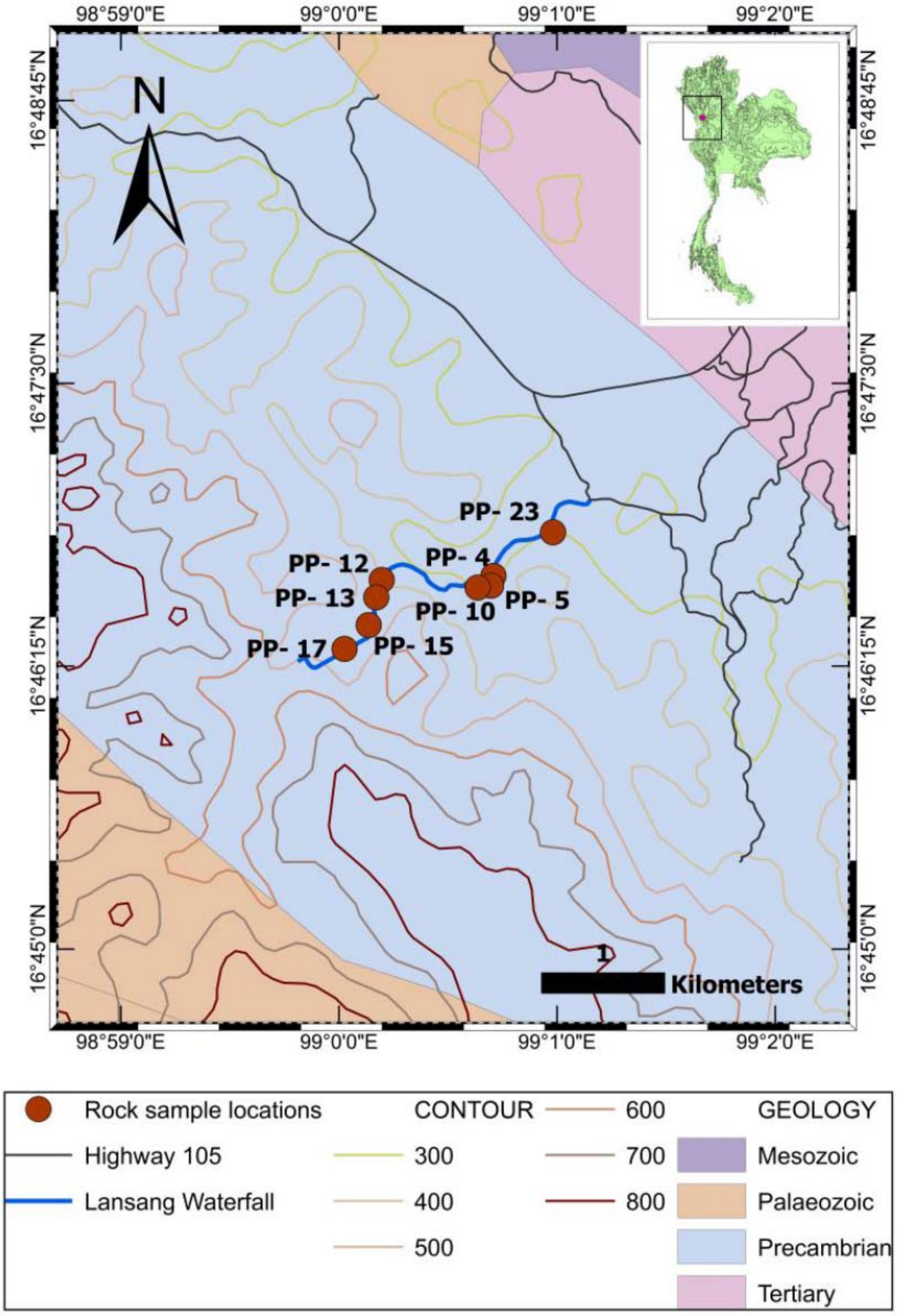

Figure 1. Geological map of the Lansang Waterfall and adjacent area, northwestern Thailand and the rock sample locations of this study (modified from Department of Mineral Resources, 1999).

On Eastern part of CM- L belt, the low- grade Paleozoic rocks of the Sukhothai fold belt have intruded by the other large Triassic granite plutons (Department of Mineral Resources, 1982; Hahn *et al*., 1986; Lacassin *et al*., 1997). Apart from the Siluro- Devonian rocks on east of Chiang Mai, the Sukhothai belt is made of a series of upper Paleozoic to Mesozoic of sedimentary, volcanic and volcaniclastic rocks. Most of the Sukhothai belt located along the Simao basin where it is clears to the ENE- WSW compression during the Tertiary (Bunopas, 1981; Department of Mineral Resources, 1982; Hahn *et al*., 1986; Lacassin *et al*., 1997; Tapponnier *et al*., 1990a).

Across the NW Thailand, the N- S trending fold axes are curved into an S shape toward the strike- slip faults, north of Chiang Rai and later upright through eastward- southeastward presence along the border of the Sukhothai belt. During the Late Cenozoic, the grabens are located along synclines of this fold belt that has bound by the nearly N- S normal faults and claims it to be activated (Tapponnier and Molnar, 1977; Lacassin *et al*., 1997; Polachan *et al*., 1991). Besides, the N- S grabens also located beneath Quaternary sediments and including with the Gulf of Thailand.

The yield of metamorphic rocks on the NW Thailand has been studied since late 1970s by various dating techniques depends on limitation of data set. For the study that using Rb- Sr dating technique, the yield were recorded in a series. For instance Tak granodioritic to syenogranitic batholiths gave ages between 208 ± 4 and 219 ± 12 Ma, as same as for the Lampang granite and the granitoids in both CM- L and Sukhothai belts fall in the same range 212 ± 12 Ma and 240 Ma to 200 Ma, respectively (Beckinsale *et al*., 1979; Braun *et al*., 1976; Cobbing *et al*., 1992; Hahn *et al*., 1986; Lacassin *et al*., 1997; Mahawat *et al*., 1990). Unless, the Lincang batholiths and the Thabsila gneisses gave age older 270 ± 59 Ma and 391 to 560 Ma, respectively (Bunopas, 1981; Liu Changshi *et al*., 1989).

K- Ar dating on biotites and illites from Lansang gneisses yielded in range between 31.9 Ma to 29.6 Ma, which is claimed to have resulted from Tertiary cooling as similar as from those of biotites and muscovites from the eastern border of the CM- L belt, Bhumibol dam and nearby Hot and Chiang Mai with ages ranging between 18 Ma to 22 Ma (Ahrendt *et al*., 1993; Braun *et al*., 1976; Lacassin *et al*., 1997). Besides, on the south of the Gulf of Thailand, U- Pb zircon dating on the main batholith gave the ages ranging between 220Ma to 198 Ma, which imply the age of the N- S magmatic belt in Triassic (Liew and Page, 1985; Hutchinson, 1989; Lacassin *et al*., 1997). On the west of Chiang Mai, orthogneisses from the Doi Inthanon was yielded by U- Pb zircon dating gave ages between 211 and 203 Ma that interpreted to the age of the granitic intrusion (Dunning *et al*., 1995; Lacassin *et al*., 1997). For monazites gave U- Pb zircon dating nearly concordant of 84 ± 2 and 72 ± 1 Ma and claimed as the age of the high- grade metamorphism (Dunning *et al*., 1995; Lacassin *et al*., 1997). Moreover, the K- Ar dating of biotites from the Thabsila gneisses gave the Tertiary ages of 36 ± 1 and 33 ± 2 Ma (Bunopas, 1981). All of these results concluded that the CM- L belt has on period of Upper Cretaceous, Tertiary deformation and metamorphic events (Lacassin *et al*., 1997).

An area of Mae Ping and Three Pagodas fault zones and adjacent are offset about 450 and 250 km respectively with orientated in NW- SE trending area and also made up of striking NW- SE, which parallel to the Red River fault zone (Lacassin *et al*., 1997). Both of them cut and presented left- lateral shear sense to the CM- L belt, which found the post Jurassic N- S trending fold axes. Lead it inferred that this zones was a result of the Tertiary indentation of India within Asia on the area about 300 km (Tapponnier *et al*., 1986). The geological maps of western mountain of Thailand and western part of Kanchanaburi, were mapped the exposure of metamorphic rocks as Precambrian or Lower Paleozoic (Bunopas, 1976; Dheeradilok and Lumjuan, 1983; Lacassin *et al*., 1997).

The metamorphic facie series was proposed in two main facies; the low pressure of Amphibolite facie series (high T/ low P) of the Precambrian to Carboniferous rocks which orientated along the axial part of the metamorphic belt and the low pressure Greenschist (high T/ low P) facie series of Lower Paleozoic age which occurred along both sides of the N- S trending metamorphic belt (Dheeradilok and Lumjuan, 1983). These metamorphic rocks generally steep foliation and horizontal stretching lineation with oriented NW- SE trending parallel to the Three Pagodas Fault zone. Within the Lansang National Park which an area apart of the Mae Ping Fault zone, deformed rocks are exposed in forms of 5- 8 km wide belt of mylonitic gneisses or Lansang gneisses. On northwestward of Lansang National Park present an offset of triangular facets and suggest that recent uplift of the gneisses core occurred by NE dipping fault which push the gneisses to NE (Lacassin *et al*., 1997).

3. Strain analysis

Since structural geologists have been motivated and focused for over 10 years finding the truly understanding on the deformation conditions and tectonic mechanism that occurred significantly on high- strain zones; the Mae Ping shear zone, the number of techniques for quantify finite strain in deformed rocks are increased (Bailey and Eyster, 2003; Erslev, 1988). The Fry method (Fry, 1979) is one of all useful modern structural techniques for quantified finite strain in deformed rocks as mentioned by Ramsay and Huber (1983) which was applied from the nearest- neighbor centre- to-centre technique (Sarkarinejad, 2007) and proposed by Norman Fry in 1979 (figure 2). This powerful and useful method was applied for quantified finite strain of rocks from rigid particles for instance quartz grains, tillites or pebbles in conglomerates (Genier and Epard, 2007). This method works on a plot of the position of each particle center with respect to a particle put at the origin, then the origin repeated placed on others particle center and plot the relative position of every other particle center. This produce called a Fry diagram, which presents an elliptical vacancy field around the origin, and for homogeneous deformation these vacancy field is representative of finite strain ellipse (Genier and Epard, 2007; Erslev, 1988).

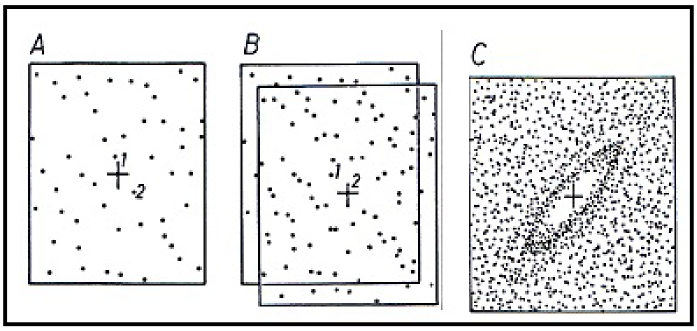

Figure 2. The finite strain ellipsoid followed by Fry method. (A) and (B) are presenting the methodology of Fry (1979) for quantifies the finite strain, (C) describes the vacancy field of Fry diagram (modified from Ramsay and Huber, 1983).

The successful and clearly result of an elliptical vacancy field of Fry diagram mentioned earlier that depends on size, number and pattern of natural particles center distribution. For homogeneous deformation, the distribution type and number of particles center mentioned as anticlustered and isotropic which refer that the deposition of particle occurred on random pattern (Fry, 1979; Erslev, 1988; Genier and Epard, 2007) and about hundreds of particles would give a strongly anticlustered distribution and clearly vacancy field of Fry diagram respectively (Lacassin and Van Den Driessche, 1983). Moreover, for the size distribution, in generally the large grains distribution tends to be more anticlustered (Crespi, 1986). However, in cases of sorting, packed or well sorted particles do not mention that always produce a successful result of Fry diagram (Genier and Epard, 2007).

The cross section line of Mae Ping shear zone, the profile of Lansang Waterfall was selected to be the proper area for quantify the finite strain of rocks. The application of Fry (1979) was applied for quantify finite strain in two types of rocks: orthogneisses and paragneisses from 8 sample locations of Lansang Waterfall followed by traverse line method (figure 3), then the rocks were measured.

Table 1. Strain data of rocks in Lansang Waterfall, Tak province.

Rock sample number	Strain ratio (Rs)
PP - 4	1.80
PP - 5	1.45
PP- 10	1.60
PP- 12	1.40
PP- 13	1.60
PP- 15	1.64
PP- 17	1.91
PP- 23	1.45

4. Strain magnitude

The X/ Y strain ratio for all 8 samples of orthogneisses and paragneisses are determined by Fry method and present in table 1. For PP- 5 and PP- 23 are fall in same value, Rs = 1.45. The others are ranged between 1.60 to 1.91 while PP- 12 gives the lowest value with Rs = 1.40. Thus, it can be concluded that the strain quantitative analysis by using Fry's method for all rock samples in area of Lansang waterfall, Tak, northwestern Thailand is range between 1.40 to 1.91 (table 1) which the strain ratio of all samples related together as show by graph between strain ratio (Rs) and rock sample location.

Figure 3. (A) and (B) present the outcrop of rock sample location number PP-4 and PP- 5. (C) present the orthogneiss rock sample of location number PP- 10 while (D) the rock sample location number PP- 12 where the orthogneiss located within this area. (E) An outcrop number PP- 13 where the dominantly present characteristic of paragneiss within, (F) present the outcrop number PP- 17 of paragneiss.

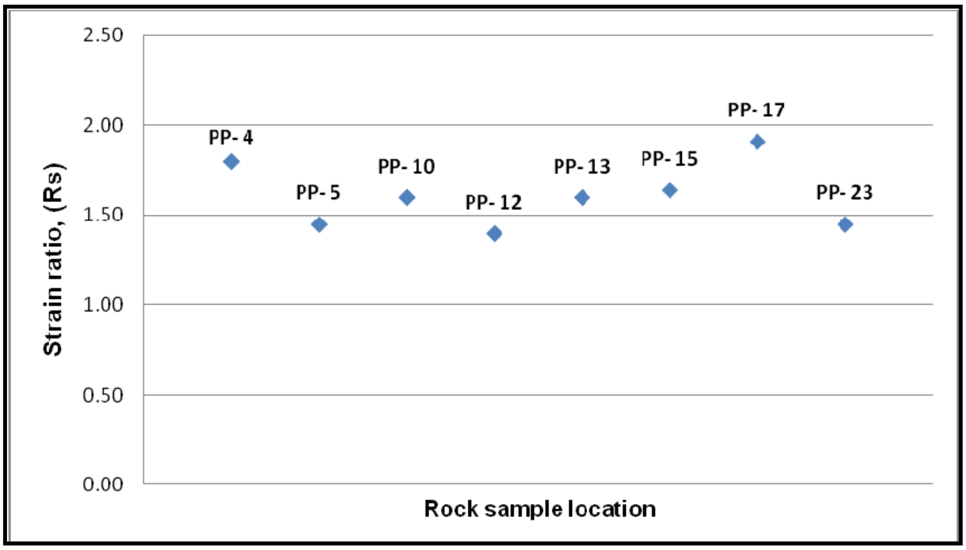

Figure 4. Graph presents the relative between the average finite strain ratio of each rock sample locations and their locations along the profile of Lansang Waterfall inside of Lansang National Park, Tak province, northwestern Thailand.

5. Discussion and conclusion

Fry (1979) is a useful and simply method for using in strain quantitative analysis of rock with rigid particles such as recrystallized quartz grains in gneisses. The Fry's plot present the distance between the different objects in rock which their relationship represented by strain ellipsoid. The ratio between the longest and shortest axes of strain ellipsoid are source for quantify the finite strain of rocks and sense of the movement that had occurred on an area of Lansang waterfall, Tak, northwestern Thailand where is a part of Mae Ping shear zone.

Such zone exposed various types of rock for both granite intrusion and metamorphic rocks which present clear left- lateral shear criteria on various markers for instance boudin trails or deformed minerals (*e.g.* recrystallizd quartz grain) as same as in the longest axes of recrystallized quartz grains that used as strain marker for Fry's method also intense the characteristic of left- lateral shear sense on this area.

Besides, from the strain of rocks data by using Fry method, the strain ratio (R_s) are ranged between 1.40to 1.91 which these finite strain data can be implied that a significant component of simple shear- dominated was involved and related in a part of deformation history of Mae Ping shear zone as shown in the strain data along the profile of Lansang waterfall (figure 4). Moreover, the strain ratio of all samples related together as show by graph between the strain ratio (Rs) and rock sample locations which confirm that the technique of Fry's method is the powerful and accurate material for quantify the finite strain of rocks in Lansang waterfall; a part of Mae Ping shear zone, northwestern Thailand (Fig. 4).

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