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Paleoearthquakes along Xaignabouli Fault Zone in Western Lao PDR

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Abstract

A paleoseismic investigation has been carried out to identify the faults at the Xaignabouli (XYB) area in western Lao PDR to determine if they are seismologically and geologically active. There have been earthquakes of intermediate magnitudes reported recently (5.4 and 3.9 M_L in February and March 2011, respectively) suggesting that the area is seismologically active. Our remote-sensing data show that these two earthquakes may have been related to the northeast-southwest trending fault. Regionally, the fault commenced in the north from Dien Bien Phu (DBP) in Vietnam. Lineaments analysis using SRTM DEM image data together with epicentral distribution suggest that there are not only northeast-southwest trending lineaments but also those of the northwest-southeast and north-south strikes. Our interpretation and synthesis using geological, present-day seismicity, seismotectonic, and paleoseismological data reveal that there are at least two active strike-slip fault zones with sinistral movement and these faults are branches of the DBP fault. The first fault zone passes the western part of the XYB and is oriented in the NE-SW direction and comprised of about 20 segments ranging from 10 km up to 110 km with a total length of about 450 km. The second is almost subparallel to first and has a total length of 350 km also consisting of shorter segments. Results of morphotectonic features and Quaternary age dating imply horizontal slip rate at ca. 0.8 mm/yr. The main northeast-southwest trending fault is estimated at about 16.8 km east of the XYB area. Our study reveals that the area has been subject to multiple tectonic phases of deformation, with the most essential episode occurring during late Cenozoic time. OSL dating result indicates that three earthquake faulting events ca. 3,000, 2,000, and 1,000 years ago support a recurrence interval of approximately 1,000 years. Surface rupture length indicates maximum credible earthquake magnitudes between 5.6 and 7.3 Richter.

Keywords: Active fault, Lao, OSL dating, Paleoearthquake, Paleoseismicity, Xaignabouli

1. Introduction

There exists a major fault zone, named as the Xayabouri fault zone (XYB) which trends in the northeast-southwest trending active faults which commences in the north from Dien Bien Phu in northern Vietnam through the study Xaignabouli area and to the eastern part of northern Thailand, particularly in Nan and Uttaradit areas. The locations and orientation of faults are mainly from Pailoplee (2010). In general the study area is located in the so called Loei–Paklay fold belt (Stokes et al., 1997). There is no detailed investigation that has been done so far for the geology and neotectonic studies within and around the Xaignabouli area.

It is also believed, based on the earthquake records, that the Xaignabouli fault zone is located in the area which seismotectonically active (Tapponnier et al., 1982; Hutchison, 1989; Polachan et al., 1991), There are a few earthquakes with the intermediate magnitudes (5.4 and 3.9 M_L in February and March 2011, respectively) in the study area as reported very recently by TMD (Thailand Meteorological Department, 2011). However, as reported very recently by Wanitchai (2011), the Xaignabouli area may have been subject to earthquakes related to the Xayabouri fault zone. Additionally, in the year 2000, at least six earthquakes with magnitudes between Mw 6.5

and Mw 7.1 were also recorded in the vicinity of the XYB zone. It can be stated that the XYB is active. These evidences strongly assure that the location of Xaignabouli area may be effected by the upcoming earthquake hazard in the future.

This study is an attempt to evaluate a number of earthquake events along the XYB activity in the past and to interpret the mean recurrence interval and probability of the large earthquake of the XYB in the future.

2. Geological Setting

Geologically, the study Xaignabouli area is located in the so-called Loei-Paklay fold belt (Stoke et al., 1997), which extends from the eastern part of northern Thailand to western Lao and is the same as the Loei fold belt of Bunopas (1981). However, Charusiri et al. (2002) introduced the term "Nakhonthai plate" which is dominated by the oceanic plate to replace the Fold Belt which is less meaningful. It is therefore regarded in this study that the Xaignabouli area is situated within the so-called Nakhonthai plate. This plate collided with the Indochina plate during Late Triassic age in response to Indosinian Orogeny. The result of this compression tectonics was able to trigger the essential faulting event. In this circumstance we infer that many of the strike-slip faults in the Xaignabouli barge and nearby areas have been formed in response to this collision tectonics. Generally, there are several fracture and fault sets in mainland SE Asia. However, based on Charusiri et al. (2002), only 2 major conjugate sets of faults are of importance, including one in the NE-SW direction and the other in the NW-SE direction, both of which took place during that Triassic time. Charusiri et al. (2002) also show evidence of slip movement in Thailand that the NE-SW trending fault set has the dextral sense of movement and the NW-SE trending fault set has the sinistral sense of movement.

Subsequently, these two major sets of faults may have been reactivated in Tertiary time in response to Himalayan Orogeny, producing the other sets of faults whose major trends are almost the same as those of the pre-existing fault sets. However, the only contrasting feature is that these new fault sets display the opposite sense of movement. That is the set with the NW-SE trend is dextral and the other set with the NE-SW trend has the sinistral slip. Moreover, it is regarded that these faults may have been active till present because the northward push of the Indian plate toward Asia is still going on (Fig. 1.). However, the stress distribution has reached the study area or not is the subject of interest at present.

Seismotectonically, it is recognized that the Xaignabouli area is located in the Luang Phrabang – Nan zone where the structure is mainly in the NW-SE direction. It is also believed that the stress distribution and fault reactivation have continued towards the study area. However, not all faults in the study area are considered to be active. In fact there are only some faults which are still active. Therefore, it is an aim of this geological study that which faults in the study may have been active, when and how strong the latest movement occurred, and what is supposed to be for the recurrence interval (or return period) for those active faults.

3. Paleoseismic Investigation

The study area covers the XYB zone in western Lao PDR as shown in Fig. 2. This study commenced from data collection from previous and related studies. Data concerning XYB fault, seismicity and seismotectonics of Lao PDR were compiled from published and unpublished literatures.

Interpretation of both Shuttle Radar Topography Mission Digital Elevation Model (SRTM DEM) and stereographic aerial photographs were used to locate and map the XYB. The SRTM DEM is most useful to initially delineate traces of the potential active fault. Subsequently, interpretation of black and white aerial photographs was performed to investigate geomorphic features indicative of active faults, including fault scarps, triangular facets, offset streams, sag ponds, etc, at specific places identified from the SRTM DEM. Several remote sensing data have been applied for the current investigation. The joint interpretation of Digital Elevation Model (DEM) and satellite images (LANDSAT) are analyzed for identifying the candidate morphotectonic index implying the possible active fault segments in the DBFF zone (Fig. 3.). DEM with the resolution of 30 x 30 m was applied for re-tracing lineaments and fault segments in the regional scale (Fig. 3.) whereas satellite images of different types can support the morpho-tectonic evidence associated with surface faulting in more detail. Moreover, aerial photographic interpretation was used to identify proper locations of paleoseismic trenching investigation.

Field investigation was carried out to check the interpretation of fault identification and location as well as geomorphic features from aerial photographic analysis. Outcrop checking and mapping including bedrocks and Quaternary deposits along the length of the fault can reveal both long-term offset across the fault and the recent movement along the fault. Fault scarp heights and slope angles were estimated in order to approximate the nature and the movement of the fault. Slope angles can be used to determine the time since the last surface faulting.

Paleoseismic trenching was carried out at the selected sites by using backhoes. The purpose of the trenching is to check the geologic unit and fault traces as well as to collect soil samples and organic matters for age dating (if any). Interpretation and logging of stratigraphic and structural relationships exposed on walls of the trench were performed. Logging was carried out at a scale of 1:50 or greater in order to identify in details of fault zone structures. Soil samples cut and not cut through by each fault event were collected by using 15 cm length PVC pipe. Collected soil samples were dated by the Optically Stimulated Luminescence Dating (OSL dating) techniques.

Depositional age of soils overlying faulted and folded laterites were applied to be the age of earthquake events. Each earthquake event in individual exploratory trenches was adopted to depict a space-time diagram. A number of faulting events with the age of movement can be obtained. A mean recurrence interval with a standard deviation was computed.

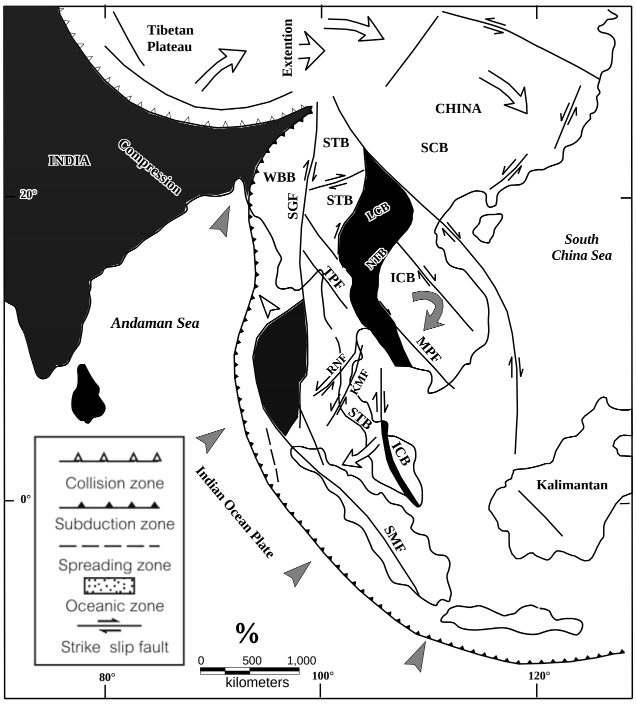

Figure 1. Major tectonic elements in Southeast Asia and Southern China. Arrows show relative directions of motion of crustal blocks and fault zone during the Late Cenozoic (Polachan et al., 1991).

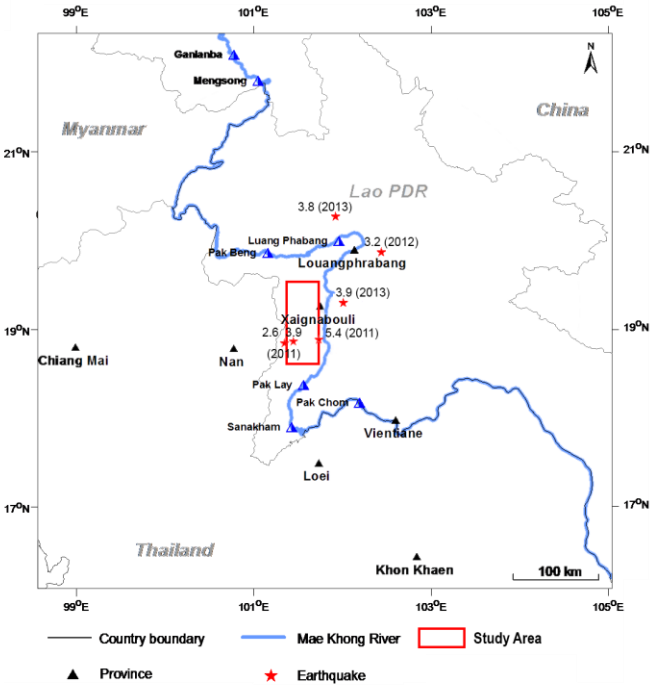

Figure 2. Map of northern and central Lao PDR and adjacent areas showing the location of the past earthquake events with magnitude >6 Richter in the study area.

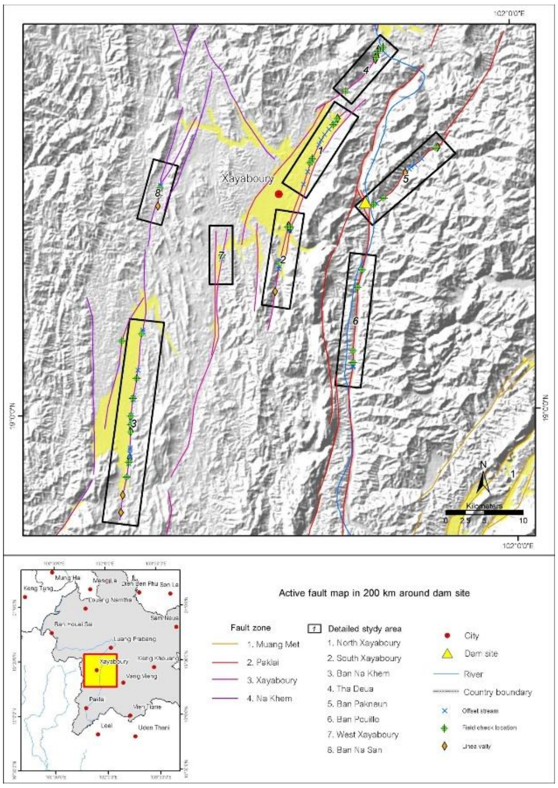

Figure 3. Detailed interpreted map from SRTM DEM and Google images showing areas of interestwith well –defined morphotectonic features related to active faults, Xaignabouli area, Lao PDR.

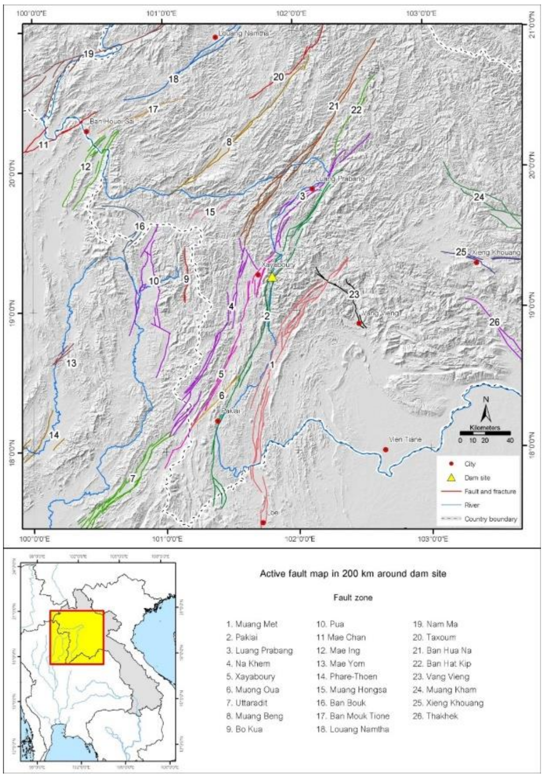

Figure 4. Location map of the study area along the XYB fault zone. The figure on the top is the result of DEM interpretation showing lineaments along the Xaignabouri Fault Zone

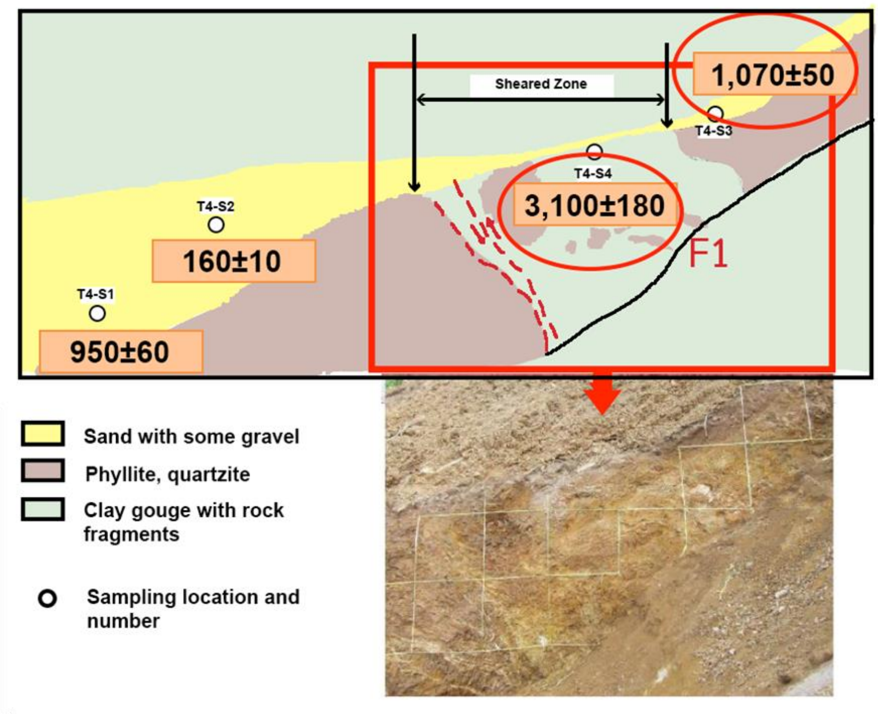

Figure 5. Stratigraphic log of trench no.T4, Xayaburi district, Lao PDR

4. Results

4.1. STRM DEM and Aerial Photographic Interpretation

Both Shuttle Radar Topography Mission Digital Elevation Model (SRTM DEM) and stereographic aerial photographs were used to delineate geomorphologic features of any active faults. Results of STRM DEM analysis shows that prominent lineaments indicate active faults in western Lao PDR and adjacent areas (Fig.4.). Fault escarpments, offset streams, and triangular facets were observed in photographs.

4.2. Field Investigation

To check and to confirm the interpretation of both STRM DEM and aerial photographs, field investigation was performed. In the field investigation, we attempted to follow the XYB zone from Xaignabouli and Phiang Basins, western Lao PDR. Shutter ridges can be observed along the XYB zone. Several outcrops exposed along the road sides and in borrow pits were observed.

The field investigation also included the selection of potential fault trench sites to determine the history of movement of the XYB.

4.3. Paleoearthquake Trenching and Age Dating

We excavated and cleaned eleven trenches and exposures for the study on recurrence interval of faults. Additionally, soil samples were collected for the Optically Stimulated Luminescence (OSL) dating with application of quartz inclusion technique, regeneration technique and total bleach technique.

The trenches at the Xaignabouli and Phiang basins were completed. Faults were observed only in the bedrocks. Most of sediments overlying the bedrocks are gravel beds. Sands with some gravels were found at the trench no. T4 (Figure 5). Six sand samples and one fault gouge samples in the bedrocks were collected from the trench no.T4 for the age-dating.

5. Discussion

As shown in the satellite image interpretation maps (Figures 3 and 4) together with supports of our field evidence, it is likely that the Xaignabouli basin is a fault – controlled Cenozoic basin which may have formed by the development of two major sets of faults at the western and eastern rims of the basin. The faults which are mainly oblique strike slip fault and run in the NE –SW in the northern part and deviate to NNE-SSW in the southern portion. Several lines of morphotectonic evidence including many sets of offset streams and linear valleys reveal that the faults are still active till present. However, the faults in the west are less developed than those of the east as seen from the morphotectonic features. These basin-bound faults are thought herein to be the subsidiary branch of the NE-SW – trending Dien Bien Fu Fault.

5.1. Faults in the Phiang Basin

Faults in this basin are similar to those of the Xaignabouli Basin in that they are the oblique strike-slip fault and become the boundary faults. The faults are characterized by offset streams, offset spur, triangular facet, linear valleys, sag pond and scarplets. The faults are in the NE-SW direction and some sets are located in the basin. The basin is about 20 km long and its rims are controlled by two faults which merge into one fault to the northern end. It seems likely that the fault line in the east is more prominent than that in the west. We consider that the faults in the eastern side are more subsided or less uplifted than those in the west, suggesting that the vertical movement component become more prominent than that of the horizontal component.

5.2. Fault age determination

Data on luminescence age determination were taken from two alluvial samples (T4-S1 and T4-S2) and two fault gouge samples collected from the southern wall of trench no T-4 at the Xaignabouli basin. The result reveals that the dates of young sediments vary approximately from 160 to 950 yrs whereas those of the fault gouge samples show two age data - one (no T4-S3) of about 1070 yrs and the other (no T4-S4) of about 3,100 yrs. It is considered that two faulting events may have been encountered at the barge site. The older faulting event occurred at ca. 3000 yrs ago and the younger event took place at ca. 1,000 yrs ago.

6. Conclusion

Based upon our results on remote sensing, geological ground truth, and geochronological investigations, the Xaignabouli fault zone and nearby areas has been subject to multiple tectonic phases of deformation. The most important episode is the event occurring during late Cenozoic time. Field survey, trench log data, and remote sensing interpretation demonstrate that the strike –slip faults in the Xaignabouli area show the sinistral movement and are the branch of the NE-SW trending Dien Bien Fu Fault. They are proved to be active till present.

Our information on luminescence dating results reveals that at least there are three prominent paleoseismological events with the current interval of 1,000 years. These events are episodes of 1,000, 2,000, and 3,000 years. Surface rupture length along the studied faults due to past earth shaking has been estimated to be equivalent to the earthquakes with the magnitudes of ca. 5.6 to 7.3 on the Richter scale. Difficulty on estimation of the average vertical slip rate has been encountered due to the fact that no well – defined vertical offset of fault movement has been observed in the trench. However, offsets of the stream courses allow us to roughly estimate the average horizontal movement to be about 0.8 mm/yr.

It is likely that our estimation is based largely upon limited data on the Quaternary dating result. More detailed geochronological and trench log investigations are required to determine the more precise and accurate slip rates as well as the return period.

The following conclusion provide newly encountered evidences on the Xaignabouri fault zone that are important for further studies especially the seismic hazard analysis in the western LAO PDR.

- The Xaignabouri fault zone is an active fault.
- The total length of the Xaignabouri fault zone is about 140 km and capable of generating an earthquake with a maximum moment magnitude of M 7.3
- The mean recurrence interval is 1,000 years.

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