Active Faults In Peninsular Malaysia With Emphasis On Active Geomorphic Features Of Bukit Tinggi Region

Mustaffa Kamal Shuib, Mohammad Abdul Manap, Felix Tongkul, Ismail Bin Abd Rahim, Tajul Anuar Jamaludin, Noraini Surip5, Rabieahtul Abu Bakar, Mohd Rozaidi Che Abas, Roziah Che Musa, Zahid Ahmad

1 Department Of Geology, University of Malaya, 50603 Kuala Lumpur; Minerals and Geoscience Department Malaysia, Headquarters Bangunan Tabung Haji, Jalan Tun Razak, 50658 Kuala Lumpur; 3School of science and technology, Universiti Malaysia Sabah, 88999 Kota Kinabalu, Sabah; 4School of Environmental and Natural Resource Sciences, UniversitiKebangsaan Malaysia, Bangi, Selangor; 5Faculty of Engineering, Technology & Built Environment, UCSI University, 56800 Kuala Lumpur; 6Malaysian remote Sensing Agency, Jalan7 Tun Ismail, 50480 Kuala Lumpur; 7Malaysian Meteorology Department. Jalan Sultan, 46667 Petaling Jaya, Selangor.

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ABSTRACT

In this paper, we summarize the results of recent geomorphic investigations of active faults in Peninsular Malaysia with emphasize on Bukit Tinggi region using IFSAR and field verification. The evidences for active faulting, and their characteristics are discussed. Several fault segments within in the Bukit Tinggi fault zone are deemed active. The Bukit Tinggi fault zone is considered to be active and is a potential source of future earthquakes. Outside Bukit Tinggi area, the Benus and Karak faults are also deemed active. These fault zones show the following active neotectonic geomorphic features: 1) displays geomorphic features indicative of recent fault activity; 2) show evidence for displacement in young (Late Quaternary) deposits or surfaces; and/or 3) is associated with a pattern of microearthquakes suggestive of an active faults. They were ancient faults that were reactivated in the Quaternary period and continued into the present. The magnitude of paleoearthquake estimated from the activity and stream offsets suggest a minimum of 6 magnitude on the Richter scale have affected the region due to movements along these faults. Over the past decades, Peninsular Malaysia has experienced mild earthquakes. Virtually all earthquakes recorded in Peninsular Malaysia are under magnitude 5.0. However, the reactivation of active faults exhibiting active tectonic landforms suggests that these faults have produced damaging earthquakes before and have potential to trigger similar tremors in the future.

Introduction

Due to a lack of large, damaging earthquakes during historical time, Peninsular Malaysia has not been considered to be a seismically active country. However, it is subjected to seismic hazards and not free from earthquake damage. However, there is no reliable, long-term earthquake record and an absence of historical fault surface ruptures. Therefore, it is necessary to examine the geologic and geomorphic record, in order to quantify the activity on suspected active faults, and thereby determine their contribution to the seismic hazards of the country. In this paper, we summarize the results of recent geomorphic investigations of active faults in Peninsular Malaysia with emphasize on Bukit Tinggi region using IFSAR with field verification.

The evidences for active faulting, and the characteristics of these faults are discussed. Several fault segments within the Bukit Tinggi fault zone are deemed active. The Bukit Tinggi fault zone is considered to be active and is a potential source of future earthquakes. The fault zone show the following active neotectonic geomorphic features: 1) displays geomorphic features indicative of recent fault activity; 2) show evidence for displacement in young (Late Quaternary) deposits or surfaces; and/or 3) is associated with a pattern of microearthquakes suggestive of an active fault.

Tectonic setting

Peninsular Malaysia (Figure 1) is situated on SUNDALAND, the southern prolongation of the Eurasian Plate. Sundaland is a region that comprised of the Malay Peninsula and Maritime Southeast Asia islands of Sumatra, Java, Borneo and surrounding smaller islands. It is situated at the core of Sundaland that has been considered a tectonically stable region since the Cenozoic. Generally, it is considered as tectonically stable with low seismicity profile. It experienced dam induced seismicity of low magnitude (less than 4.5 on the Richter scale) at Kenyir Dam in 1985

Seismic hazard

-Tremors from field- observations:
The peninsula is bounded by two of the most seismically active plate boundaries. To the west the inter-plate boundary between the Indo-Australian and Eurasian Plates defined by the Sunda Subduction Trench and the inter-plate boundary between Eurasian and Philippines Plates to the east Philippines Subduction Trench. It is situated close to the most seismically active plate boundaries between the Indian-Australian Plate and Eurasian Plate in the west and between Philippine Plate and Eurasian Plate in the east. It occasionally experienced tremors due to earthquakes from these far-field sources.

-Tsunami:

In also did not escape the 2004 megathrust tsunami. The tsunami raised the alarm that the peninsula is not free from seismic hazard.

Local earthquakes:

Since 2007 the peninsula is experiencing occasional earthquakes of local origin for example the 2007-09 Bukit Tinggi earthquakes. These events stirred awareness among the public and authorities on the potential seismic hazard and risk faced by the peninsula.

Thus, empirical evidence suggests that Malaysia is not totally free from seismic risks. Recent seismicity in Peninsular Malaysia has been confined to low levels with no clear association with existing mapped faults. The identification of active faults is the subject of this study.

Young active neotectonic deformation

The identification of neotectonic deformation and active faults in Peninsular Malaysia has been hampered by:

1) the comparative lack of fault studies;
2) extensive weathering of bedrock and extremely active erosion acting together to prevent the preservation of faults. The most resistant geomorphic features;
3) large areas of thick forest vegetation, and
4) the probable slow slip rates of the intraplate faults in Peninsular Malaysia.

These factors result in a lack of recognizable, long-lived surface faulting geomorphic features. Despite these shortcomings, Quaternary deformation investigations in Peninsular Malaysia have been successful and indicate that it is ongoing and that these activity may pose a seismic hazard (e.g., JMG, 2008 and 2012). Lacking a well-defined Quaternary framework for Peninsular Malaysia, recent studies (e.g., JMG, 2008 and 2012) concentrated on the relationship of earthquake epicentres to geomorphic lineament expression of faulting, and the comparison with features observed along other active faults in similar tectonic settings worldwide.

In Peninsular Malaysia Raj (1979) reported the presence of a Quaternary fault near Bentong Pahang. Tija (2010) and Mustaffa Kamal Shuib (2011 & 2012) summarized some evidences for Quaternary deformational activities onshore and offshore of Peninsular Malaysia. The evidences of active tectonic deformations include an Early Quaternary pillow-basalt flow near Kuantan on the eastern shore of the Peninsula is traversed by long fractures oriented parallel to faults in the pre-Tertiary basement.
The fractures in the basalt are essentially vertical and are evident manifestations of reactivation of the older faults. In Southeast Johor at the edge of the Penyu basin, crustal uplift of 0.5 - 0.8 m during the past 5000 years is suggested by an abrasion platform that is much higher compared to the eustatic Holocene sea-level curve of the Peninsula which was established from almost a hundred radiometrically determined bio- shoreline indicators. In the northwest on the shores of Langkawi, a 2500- year old abrasion platform is cut by a long fault zone whose associated secondary structures suggest sinistral displacement.

Active major faults

Generally, major fault in the Malay Peninsula (Figure 1) appeared to be inactive. However, a series of large earthquakes in recent years had changed the tectonic scenario in the Southeast Asian region, including the Peninsular Malaysia. In spite of its crustal stability, the 2004 Sumatra earthquake had caused horizontal shifts of GPS monuments in the Peninsula in the order of up to 7 mm. There are also indications of co-seismic uplifts. In Langkawi, stacked doublets of recently live specimens barnacle-oyster bands suggest uplift in the order of half a meter by the same event. The Malay Basin region offshore the Peninsula is on a stable crust, and yet seismic shows major, deep-reaching faults to approach the seabed to within 150 m, indicating activity on these structures to have persisted into the Pleistocene.

A series of seismic activities with local epicentres (Figure 1) occurred in the peninsular since 1978. From 1978 to 2006 Peninsular experienced local earthquakes up to 4.6 Mw (IRIS Earthquake Database). From 2007 to 2010 it experience earthquakes up to 4.2 Mw (MMD). The series of seismic activities is believed as preliminary indications of the reactivation of major faults in Peninsular Malaysia. Therefore, many believed that the reactivation of the faults system in Peninsular Malaysia was associated with the great Sumatra-Andaman Earthquake (26 December 2004), Nias Earthquake (28 March 2005) and Bengkulu Earthquake (12 September 2007). Subsequently, local earthquakes that had occurred in Bukit Tinggi (between 30 November 2007 to 25 May 2008), Jerantut (17 March 2009), Manjung (29 April 2009) and Kuala Pilah (29-30 November 2009) were associated with these events. Recently, the Southern Sumatra Earthquake that occurred on 30 September 2009 had reactivated the Bukit Tinggi Fault system, and caused a series of 7 weak local earthquakes around the Bukit Tinggi area (8 October and 4 December 2009). Another weak tremor of 2.6 magnitude was recorded on 10 March 2011 at 11.19pm local time, at Tanjung Malim (latitude 5.1°N and longitude 102.8°E). 43km southwest of K.Terengganu, 22km west of Kuala Berang.

A plot of the earthquake epicentres on the regional fault maps of Peninsular Malaysia is shown in figure 1. The epicentres apparently seem to be diffusely distributed throughout the Peninsular, typical of intraplate seismicity. However in a closer look they seem to be close to and aligned along major faults. The epicentres are aligned along the NWW lineament at latitude 5.1°N, N-S Senus and Karak faults (Bukit Tinggi epicentres), the NWW Lepar fault (Jerantut epicentre), Bokbak fault zone (Baling epicentre), Mersing fault zone (mersing epicentre), Terengganan fault (Kenyir epicentre). These faults show prominent lineaments but does not show any surface rupture related to the present earthquakes. They are believed to have been reactivated to give rise to the local earthquakes

Identification of active faults in Bukit Tinggi area

1) Earthquake epicentres and fault relationship

In the Bukit Tinggi region (Figure 2 and 3), the epicentres are diffusely distributed around Bukit Tinggi. Their distribution in relation to geology is shown in figure 4. They seem to align along NW-SE, NNE-SSW and N-S trends. They coincide with the major faults which are clearly seen as shoreline indicators. In figure 5, it is interpreted as fault scarps features. Within the basin the surface is cut by sub-parallel lineaments that define a terraced topography (figure 10). This suggest that the alluvial basin is fault-controlled and have undergone internal displacements suggesting the basin infillings were subjected to internal deformation. Figure 11 shows a panoramic view of the alluvial plain bounded by steep scarps. These implied that the alluvial plain have undergone neotectonic deformations.

2) Geomorphic features of active faulting

To determine the active segments of the faults it is necessary to analyze the geomorphology of the area. In this study, we applied digital enhanced IFSAR images study and interpretation is to assist in delineating small-scale neotectonic features and to define the orientation and direction of the investigated active fault segments. Practically, automatic and visual interpretation was used. This is regarded as the prime and most effective approach for identification of neotectonic or active fault geomorphic features. The following geomorphological features were picked up in the IFSAR analysis and verified in the field:

a) Primary neotectonic features/ landforms

Several morphotectonic pieces of evidence can be recognized from the IFSAR data. Among them, the most outstanding features are step-sides basins, triangular facets and steep scarps.

i) Step-sided Quaternary alluvial basins.

IFSAR analysis reveals several pieces of morphotectonic features such as step-sided Quaternary alluvial basins with steep and facetted scarps. Figure 8, 9 and 10 shows the steep-sided Quaternary alluvial basins as mapped based on IFSAR. In Bukit Tinggi the basin trend NW along the Bukit Tinggi fault zone. At Janda Baik area there are several narrow linear sub-parallel NE trending alluvial basins along the NE lineaments (Figure 8). When superimposed on lineament and fault maps (Figure 8-10), it is noted that the step-sided basins are bounded by steep lineaments. Thus it is interpreted as fault scars features. Within the basin the surface is cut by sub-parallel Quaternary alluvial basins with steep and facetted scarps. Figure 11 shows a panoramic view of the alluvial plain bounded by steep scarps. Outcrops along the scarps reveal the presence of fine to coarse grain alluvial deposits (figure 12). These deposits contain large boulders at their base and exhibit warped bedding (figure 12A). These implied that the alluvium have undergone neotectonic deformations.

b) Secondary neotectonic features

The drainage network derived from IFSAR DEM is shown in figure 13. It shows that the main drainage pattern is flowing from NW to SE. The distributaries flowed from N-S and from W to E. From the drainage pattern it is noted that there are several places where the streams form dog-leg pattern. From the pattern it was noted that the dog-legs are due to stream offset, beheadings and shifting streams (figure 13 & 14).

a) Stream off-sets (figure 13 & 14) can be located at several places along the river at several localities. At these localities the streams have been shifted for about 500m to form the dog-leg pattern. The offset line is generally extended on both sides against negative lineaments of about 5 km long bounded triangular facets with hour glass geometry typical of active faulting. One or two earthquake epicentres may aligned along the lineaments. These suggest young fault controlled on the stream offsets.

b) Shifting streams (figure 13 & 14). At one locality the major stream form dog-legged pattern due to stream offsets of about 600m. Along the offset region a small Quaternary basin developed bonded by steep scarps. In addition to that it was found several parallel curvilinear abandoned
CONCLUSIONS

In this research, it is concluded that there are several likely active faults in Peninsular Malaysia based on earthquake epicentres distribution. Present geomorphic study from satellite images and earthquake evidences clearly depicts that within the NW trending Bukit Tinggi fault zone, there are several strands of both oblique and parallel active fault segments suggesting that the main Bukit Tinggi fault is an active fault. Offsets streams also suggest active faulting along the Benus and Karak faults.

They were ancient faults that were reactivated in the Quaternary period and continued into the present. The magnitude of paleoearthquake estimated from the activity and stream offsets suggest a minimum of 6 magnitude on the Richter scale have affected the region due to movements along these faults.

Over the past decades, Peninsular Malaysia has experienced mild earthquakes. Virtually all earthquakes recorded in Peninsular Malaysia are under magnitude 5.0. However, the recognition of active faults exhibiting active tectonic landforms suggests that these faults have produced damaging earthquakes before and have potential to trigger similar tremors in the future.

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5. Gobbett, D.J. and Hutchison, C.S., 1973. Sea-level changes in the tectonically stable Cenozoic times. Others interesting lineament features, which are regarded as old faults, are also observed in the east-west and northeast-southwest directions.

Within the Bukit Tinggi fault zone, IFSAR revealed the presence of Quaternary basins, and young geomorphic or active tectonic landforms such as stream offsets, beheaded streams, steep scarps and faceted spurs. They formed short lineaments that coincided with earthquake epicentres. The are believed to be the surface manifestation of active faults that occurred as short segments within the Bukit Tinggi fault zone. Most of these active fault segments trend NW-SE parallel to the main fault zone. Others trend WNW-ESE and NNE-SSW. From the sense of offsets they exhibit both dip – slip and strike–slip movements with sinistral motions likely due to the secondary effect of the active movements along the Bukit Tinggi fault zone.

At Bentong and Karak area, the Benus and Karak faults also shows evidences of active faulting in the form of stream offsets. It is of particular interest that these recently reactivated faults produced active geomorphic features which were likely related to paleoearthquakes suggesting that they are active faults. Based on the presence of active geomorphic features, the magnitude of the paleoearthquake that occurred must be not less than 6 on the Richter Scale.

Further study is in progress to determine the ages of these paleoearthquake occurrence to determine their magnitude, slip rates and recurrence intervals for seismic hazard and risk analysis.
1. Geologic map map of Malay Peninsula (JMG 2006) showing the distribution of local earthquake epicentres. 1. Bok B Fault, 3. Terengganu Fault, 4. Bukit Tinggi Fault, 5. Kuala Lumpur Fault, 6. Lepar Fault and 7. Mersing Fault.  

(geologic 1G)
Figure 2 The relationship between earthquake epicentres with mapped fault as plotted on SRTM.
Figure 3: The relationship between earthquake epicentres with mapped faults in Bukit Tinggi area as plotted on SRTM.
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Figure 5. IFSAR imagery of Bukit Tinggi area with epicentres localities.
Figure 6: The relationship between epicentres and lineaments in the vicinity of Bukit Tinggi New Village interpreted from IFSAR.

Figure 7: The distance relationship between epicentres and lineaments in the vicinity of Bukit Tinggi New Village on IFSAR.
Figure 8. The distribution of alluvial basins (Qa) in the Bukit Tinggi region, bounded by lineaments interpreted as faults.

Figure 9: 3D view of the Bukit Tinggi region showing the flat lying Qa alluvial basins.
Figure 10 3D view showing the Qa alluvial basin with terraced surface bounded by steep scarps. Note the prominent lineaments bounding the basin.

Figure 11 A photograph showing the Quaternary alluvial plain bounded by steep scarps.

Figure 12 Alluvial deposits A) with boulders at the base and B) warped bedding. (location Taman Bukit Tinggi)
Figure 13: The distribution of various active geomorphic features and suggested sense of slip along the interpreted active fault segments along Bukit Tinggi fault zone.

Figure 14: 3D DTM of Bukit Tinggi area showing young active tectonic landforms such as stream offsets, beheaded streams and migrating streams where these offsets occur along lineaments that pass through earthquake epicentres.
Figure 15 SRTM of Bentong and Karak areas.

Figure 16 View of Karak area showing the Karak fault.
Figure 17 shows a 3D view of the active Benus fault recognized by stream offsets.