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Bukit Tinggi earthquakes: November 2007 – January 2008

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Abstract— The quiet and idle lives enjoyed by the people around Bukit Tinggi, Pahang were disrupted by the occurence of not one but three earthquakes on November 30, 2007. Their towns were further jolted by more than ten earthquakes in the last two months. Records of these quakes, obtained from the Malaysian Meterological Services, were analysed to make some sense of the tremors and speculate on the probable causes. This is the first occurence of earthquakes with epicentres in Peninsular Malaysia since the reservoir-induced quakes of Kenyir in the 1980s. The quakes do fit the characteristics of cluster earthquakes or earthquake swarms which are associated with motions along a fault line or within a fault zone. There are some speculations that can be made about the cause of these tremors. More research is due to get a better picture of the seismotectonics of this area.

Keywords: earthquake, seismicity, earthquake clusters, Bukit Tinggi Malaysia

INTRODUCTION

The notion of the Penisular of Malaysia situated in the stable Sunda Platform was abruptly shattered when Bukit Tinggi, Pahang area was hit by several tremors. The earthquakes that were recorded by the Malaysian Meteological Department seismic network range in local magnitude from 2.5 to 3.5. Officially, a total of 13 earthquakes were recorded from 30 November 2007 to 14 January 2008. The area where the tremors were felt is confined to Genting Sempah, Bukit Tinggi, Kampung Janda Baik and Kampung Chemperoh.

Two site visits to this area revealed no surface traces of rupture or any other type of surface movement related to fault activity. There are several responses given by the resident as to how they felt the quake. Residents at Bukit Tinggi reported is as "sounded like a truck going to hit the house". Few others did not hear the sound but felt the ground shaking and rolling. Some residents complained that their houses developed cracks after the quakes. Those who felt the tremors were quite rattled by the prospect of having more tremors. This area is also home to several hotels and resorts such as the Selesa Hillhomes, Berjaya Resort and Genting Highlands Resort. There are concerns on the impact on the tourism industry. The Selesa Hillhomes' manager complained of cancelled bookings and possible financial loss.

As more information is gathered, more questions arise than answers. However, it is prudent to put forth some of the results obtained so far and some theories regarding the recent seismic activity in Bukit Tinggi. This study could also serves as an attempt to calm the nerves of the population caught by suprise by the recent activities. This paper, however, should be taken more as a preliminary study and as a platform for further research into this unchartered territory of Malaysian earthquakes.

THE EARTHQUAKES

Thirteen earthquakes were recorded between 30 November 2007 till 14 January 2008 for the first time on the Malaysian Peninsular since the occurence of the Kenyir earthquakes between 1984 to 1986. The epicentres were all located in the vicinity of the Bukit Tinggi area in Pahang (Figure 1). The nearest towns are Bandar Baru Bukit Tinggi, Genting Highlands, Kampung Janda Baik, and Kampung Chemperoh. The earthquakes were located by the seismological stations maintained by the Seismology and Tsunami Division of the Malaysian Metereology Department (MMD). All six stations on the Malaysian Peninsula are a part of world-wide seismological stations network (WWSSN).

Table 1 list the earthquakes chronologically with information on their magnitudes, depths and locations. The biggest magnitude, a 3.5, occurred twice, one on 30 November and the other on 9 December 2007. An earthquake of this magnitude is classified as "small" by the United States Geological Survey earthquake information website and thus were not reported in the USGS online site that monitors global seismicity. Small as it is, a magnitude 3.5 releases energy equivalent to 15,000 tons of TnT so there is no wonder that it was felt in a wide area here in Bukit Tinggi and caused some minor damages. The vibrations felt would be equivalent to standing next to a road as a truck pass by at the modified Mercalli Intensity scale of IV (USGS, 2008).

Other than the 13 earthquakes located by the MMD network, there were other smaller tremors that were reported or felt by the residents. These smaller quakes were not recorded by the local stations because they are too small to be detected. For any earthquake to be detected and located by the local network, it has to trigger at least three stations. A magnitude 3 earthquake usually spawns

about 10 or less magnitude 2 earthquakes as aftershocks and about a hundred magnitude 1 earthquakes. The lowest magnitude reported by MMD is a 2.5. Earthquakes with magnitudes greater than 2 could still be felt. Earthquakes with magnitudes of less than 1.5 are typically not only go unrecorded but also unnoticed.

EFFECTS FROM THE EARTHQUAKE

The Bukit Tinggi earthquakes were felt in the Bukit Tinggi area, Kampung Janda Baik area and Kampung Chemperoh. A few residents reported hearing loud noises like a truck coming towards them before they felt the tremors. Some described as being shaken while others said they felt and saw the ground rolling. These are common responses to earthquakes of these range of magnitudes.

The difference in how the earthquake was felt depends on several things such as the subsurface material the seismic wave is travelling through and the type of seismic wave the resident was subjected to. Residents standing on solid ground would experience less shaking compared to one standing on loose materials. Sharp, shaking motion is usually caused by the primary body waves (P) while the rolling motion is commonly associated with secondary body waves (S) and the surface waves. Sound associated with oncoming tremor was also commonly reported. One theory is that as the waves travel through the subsurface, there are vibrations through the soil and rocks caused by interparticle collisions. The compounded effect of the vibrations could cause the ground to rumble.

A few houses in Kg. Janda Baik and Kg. Chemperoh had hairline cracks believed to be caused by the tremors (Figure 2). Two apartments on 2nd and 4th floors of Bukit Tinggi police barracks also sufferred the same fate. Sekolah Menengah Bukit Tinggi, which is located to the east of the epicenters also have several cracks. Upon closer observations, these could be due to slope movement; a condition that existed since 2005 that may be aggravated by the tremors. Two chunks of cements fell off in the science laboratory on the ground floor (Figure 3). The Public Works Department (JKR) attributed this incident to poor construction practice and might be unrelated to the tremors.

EARTHQUAKE ANALYSIS

The earthquakes in Bukit Tinggi fit into a category called cluster earthquakes (CEQs). CEQs are earthquakes that last for a short time, usually a few weeks to a few months. The locations are confined to a small area. The activity normally consists of small to moderate size earthquakes.

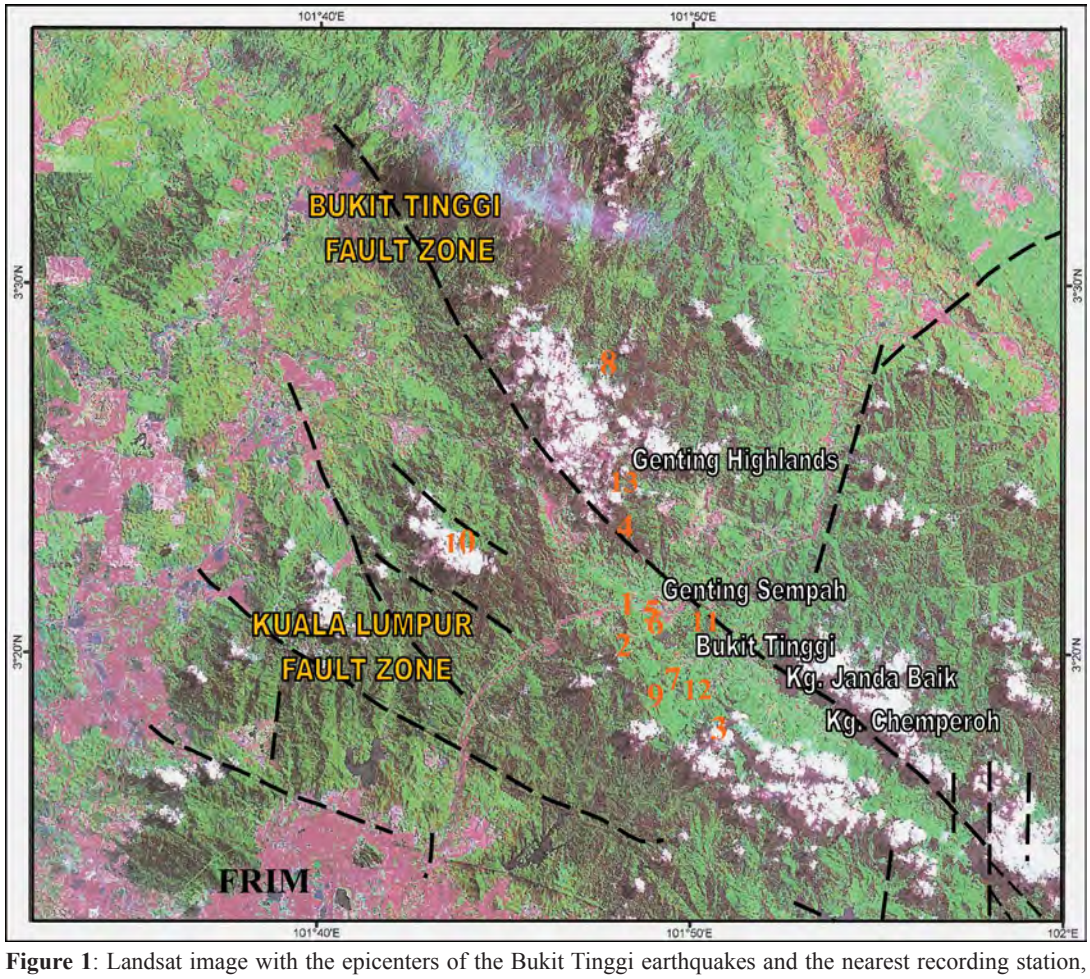

Figure 1: Landsat image with the epicenters of the Bukit Tinggi earthquakes and the nearest recording station, FRIM. Also shown are the fault traces in the area obtained from GSD (1985).

Table 1. Bukit Tinggi Earthquakes: November 2007 – January 2008 (Source: MMD, 2008).

Event	Date (yrmmdd)	Time (UTC)	Latitude	Longitude	Richter Magnitude	Depth (km)
01.	071130	02:13:36.37	3.365	101.800	3.5	2.38
02.	071130	02:42:36.18	3.345	101.799	2.8	#
03.	071130	12:42:33.18	3.308	101.838	3.2	6.66
*04.	071204	10:12:00	3.40	101.80	3.0	#
05.	071204	19:57:47.04	3.36	101.81	3.3	#
06.	071206	15:23:08.00	3.357	101.812	2.7	#
07.	071209	12:55:42.89	3.331	101.819	3.5	4.9
08.	071212	10:01:47.7	3.475	101.792	3.2	#
09.	071231	09:18:46.35	3.323	101.812	2.5	#
10.	080110	15:38:16.76	3.394	101.731	3.0	3.0
11.	080113	2:24:18.96	3.358	101.832	2.5	#
12.	080113	10:18:03.41	3.326	101.829	2.9	#
13.	080114	15:45:04.75	3.421	101.799	3.4	2.15

* Location by manual analysis/calculation; # Undetermined depth but classified as shallow (< 10 km)

The earthquakes often originate from shallow depths of less than 30 km.

The largest earthquake in Bukit Tinggi were two 3.5s with the range of magnitude between 2.5 to 3.5 (Table 1). There may be more earthquakes with lower magnitudes that were not recorded by the seismic array. Here, the earthquakes were confined to a relatively small area of 18 km x 12 km, roughly 200 km^2 (Figure 1). Geographically, this area is bounded by the towns of Genting to the north, Kg. Chemperoh to the south, Genting Sempah to the west and Kg. Baru Bukit Tinggi to the east.

In addition to spatial limitations, these earthquakes only occur for a short span of time. As clearly shown in Figure 4, there were two distinct clusters; the first cluster (Cluster 1) lasted approximately 15 days, from 30 November 2007 (M 3.5) to the last earthquake on 12 December 2007 (M 2.5) while the second cluster (Cluster 2) started on 31 December 2007 (M 2.5) and lasted for 16 days, ended on 13 January 2008 (M 2.5). The number of earthquakes vary with each cluster; Cluster 1 consisted of 8 tremors while Cluster 2 had only 4. Again, this data does not include the earthquakes that goes unrecorded or even unreported in each of the clusters.

As to the depth limitation, most of Bukit Tinggi earthquakes are from depths of less than 10 km. Even though some locations were not recorded precise enough to give an exact depth, the earthquakes are still located as being of shallow depths, ranging from 2.3 km to undetermined depths of less than 10 km (Table 1).

TECTONIC SETTINGS

The Peninsular of Malaysia is located on the stable Sunda Platform or Sunda Plate which is the southern extension of the Eurasian Plate. The Sunda plate, bounded on the west by the Sunda trench and to the south by the Java trench, formed as the Indian-Australian plate subducts under the Sunda Plate. To the east, we are bounded by the Philippines trench, formed as the Philiphine plate subducts under the Eurasian plate. The Indian-Australian plate is moving in the north-easterly direction while the Philippine plate subducts to the west (Hutchinson, 1996).

Almost all of the Bukit Tinggi earthquakes are located within the area between the Bukit Tinggi fault zone and Kuala Lumpur fault zone (Figure 1). Both fault zones had been classified as inactive. These fault zones are said to cover an area of 40 kilometres wide (east – west) and 80 km long (north – south). This area is also in rather close proximity to the north-east trending Sg. Benus fault to the east of this study area. The N-S and NW-SE trends that formed here may be associated with a larger, rather discontinuous fault zone that occur from Thailand all the way to south of Singapore (Hutchinson, 1996); similar trends can also be seen in the strike-slip faults that cut across Sumatra.

The clustering pattern of the tremors in this area corresponds very well to earthquakes that happen in or near a fault zone (Lat, 1989). These earthquakes tend to cluster in time and space. They correspond to slow releases of energy in small spurts. The first one is often the largest as it is associated with the largest amount of energy needed to overcome the inertia. It is then followed by smaller quakes as the fault regain its stability. The mainshock-aftershock trend may continue for several months.

RESULTS AND DISCUSSIONS

The question at hand is what caused the Bukit Tinggi earthquakes. The characteristics of these earthquakes matched with earthquakes that are associated with fault motions (Lat, 1999). Shuib (2008) discussed several possible mechanism for the Bukit Tinggi earthquakes; these possible causes are included along with other theories. Bear in mind that this is a preliminary evaluation of the earthquakes. It is unfortunate that we have not found any surface traces of the faults validate fault movement in this area. The two site visits only revealed effects to surface structures but no ground motion was seen.

There are several preliminary theories in the working. One is extensional movement (John Kuna Raj, personal communication). Even though the mechanism that caused

the 2004 Sumatra earthquake was a thrust fault, the Sunda Plate is said to be moving westward on top of the Indian-Australian plate. This westward motion probably cause the weak zone within the vicinity of the Bukit Tinggi fault to rupture or open due to extensional movement in the East-West direction.

Figure 2: Hairline cracks on the wall at a house; the crack on the wall goes all the way through the house. Location: Kampong Chemperoh.

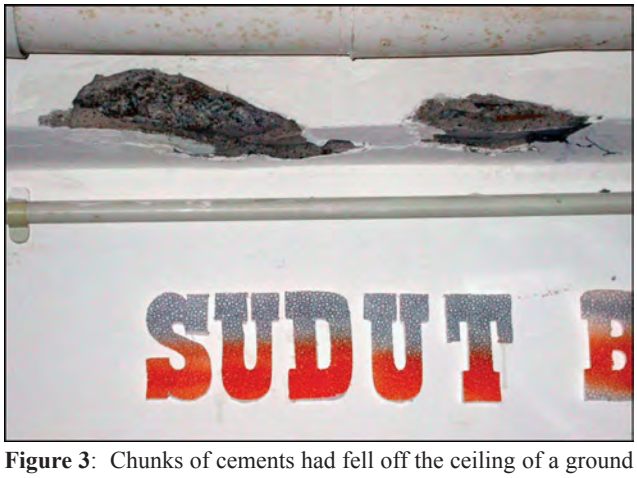

Figure 3: Chunks of cements had fell off the ceiling of a ground floor laboratory. Location: Sek. Men. Bukit Tinggi.

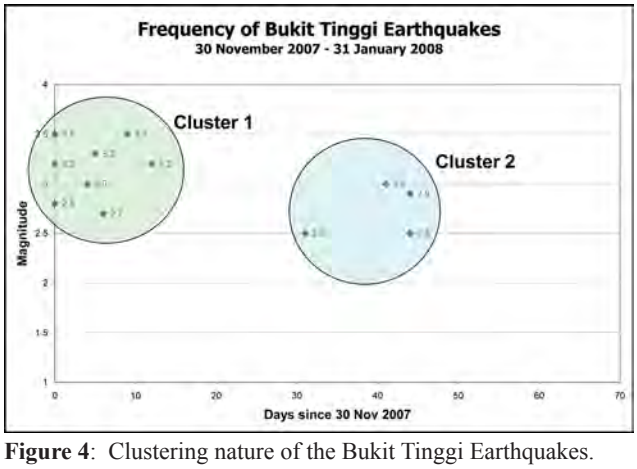

Figure 4: Clustering nature of the Bukit Tinggi Earthquakes.

Instead of extensional mechanism, the earthquakes could also be caused by compressional force as the Indian – Australian plate and the Philippine plate both moving towards the Sunda plate and squashing whatever lies in between. Stress build-up was one mechanism discussed in Shuib (2008); subduction from at the Indian-Australian plate boundary together with the covergence of the Australian and Philippine plate gave rise the increase in stress in this area.

This notion seemed to be supported by the increase of major earthquakes (magnitude 6 or higher) in this area over the last two decades (Figure 5).

On a similar line of thought, another plausible explanation to the Bukit Tinggi earthquake is that they are after-effects of the 2004 Great Sumatra earthquake. As shown in Figure 5, there is an increasing trend in seismicity in the Southeast Asia region. The change in activity is expected as the region is basically restabilising itself. Even though there are peaks and throughs in the curves, generally, the trend is an ascending one. Trendline exibited positive slopes of 1.12 and 0.07 for magnitude 6 and 7 data respectively showing that there is an increase of seismicity. There was no magnitude 8 earthquake in this region prior to 1997. After the 1997 occurence, a magnitude 8 occurred once every 2 years, with an exception of 2003. The absence of a magnitude 8 in 2003 may cause a stress buil-up that lead to the occurrence of magnitude 9 in 2004. The magnitude 9 earthquake of December 24, 2004 was not plotted in Figure 5 for its obvious rarity. A more detailed discussion about the increase in seismicity can be found in Lat (2007).

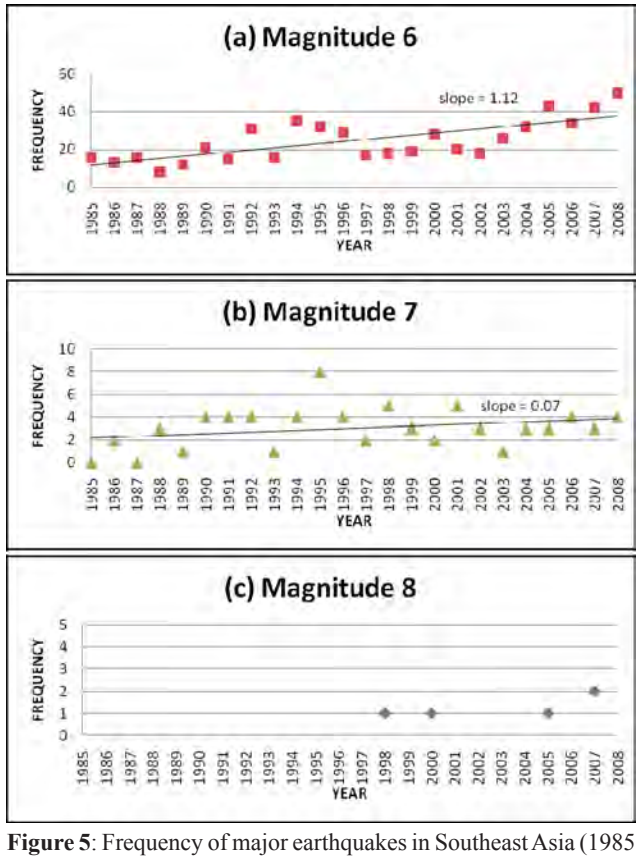

Figure 5: Frequency of major earthquakes in Southeast Asia (1985 – 2008) (Data source: USGS website)

The Bukit Tinggi area, weakened by existing faults criss-crossing the area would be prime for rupture and in turn caused the earthquakes. Simmons *et al*. (2007), incorporating data supplied by the Malaysian Survey and Mapping Department (JUPEM), analysed GPS data observed in Southeast Asia within a ten-year span. It was shown that the movement on the west is faster than that on the east. This backlog can cause some pushing that could release enough energy to trigger movement on any weak plane, such as in the Bukit Tinggi fault zone. The stress regime for this area indicates that the force in play is compressional (Simmons *et al*., 2007). Focal mechanisms constructed from the Bukit Tinggi earthquakes could show the possible fault mechanisms, unfortunately there are only six stations recording the quakes, a far too small number required to solve for the mechanism.

There is also another theory that the quakes were reservoir-induced as proposed by Prof. Hutchinson in the Star (7 January 2008). This possible cause was also mentioned in Shuib (2008), stating that while the small and shallow quakes do fit the criteria, the location of the quakes were too far away from major dams. The closest dams are the Batu Dam and the Sungai Selangor dam. Could the fault movement be triggered by the increase in volume in these dams due to the recent heavy downpour? This theory, however, is very unlikely. The dams did not fit all the criterias of dams that induce earthquakes as discussed in Lat (2002). The larger of the two dams, the Sungai Selangor Dam is 110 m high (Splash website, 2009), barely surpassing the 100 m height criteria. In the other hand, the total volume of water of dams with RIS are usually in excess of 1000 million cubic metres whislt Sungai Selangor Dam's volume is only 235 million cubic metres at maximum capacity.

The only documented RIS case in Malaysia is at the Kenyir Dam in the 1980s. Three of the quakes were recorded by the USGS database with magnitudes ranging from 4 to 5. The Kenyir Dam did fit the criteria for dams likely to have reservoir-induced seismicity; its height is 150 metres with storage capacity of 13,600 million cubic metres of water (Kenyir Dam Wikipedia website, 2009). Another argument against this notion that the Bukit Tinggi earthquakes were caused by a dam is that reservoir-induced seismicity usually happen around the first time the dam was filled to capacity (Lat, 2002). According to Splash website, Sungai Selangor Dam was filled in 2005, therefore the probability of the reservoir-induced tremors to occur now is quite small.

There were also talks of recent constructions and mining activities in the vicinity of the area may have caused the earthquakes. This is not very plausible; intensive and heavy constructions have been carried out in this area, in building the resorts and the highways, but no induced earthquakes had been recorded before. The energy released by a magnitude 3.5 quake is equivalent to 15,000 tons of TNT (USGS, 2008); an amount of energy far beyond the scope of mining and construction works. Furthermore, tremors caused by blasting in mines usually recorded at fixed times and with depths of less one kilometre (Lat, 1989). This does not correspond to the times and depth of earthquakes recorded in this area. The times of the earthquakes were quite random and the depths, even though some are not confirmed, were more than 1 km (Table 1).

CONCLUSION

It is too early at this stage to reach a definite conclusion. Further studies need to be done to ascertain the focal mechanisms of the quakes. The good news is that the stations locating the quakes are situated in all four quadrants of the grid. The bad news is that there are only six stations to work with. The results obtained may not be conclusive but maybe we can establish a pattern with several earthquakes' mechanism. Preliminary look at the traces showed promise since the first motions were relatively easy to recognise.

Another area to explore is to analyse the satelite imagery of the area. Comparison between before and after the tremors may show some displacement. There were similar studies done with Global Positioning System (GPS) after the 2004 earthquake, for example by JUPEM and Simmons *et al*. (2007). On the other hand, there may be a problem in this case since a magnitude 3.5 may not have caused large displacements and may not be significant enough to be detected by satellite or GPS.

The individual seismic traces recorded at each stations could also be analysed to determine the travel path of each seismic wave. This would give us information of the possible subsurface lithology and their corresponding elastic moduli. Local earthquakes usually have unique characteristics reflecting the path the waves take from the source (focus) to the seismometers. A portable seismograph was placed in Kg. Janda Baik in January 2008. Even though this instrument would only provide an analog record of activity in the area, it would be able to record smaller events that may not be detected by the national seismic network monitored by the Malaysian Meterological Department. The records could be analysed to determine the local microseismic activity of the area. Previous studies (e.g. Lat, 1989) showed that signals caused natural earthquakes can be differentiated from man-made causes such as traffic and mining by their frequency contents and appearances. The data gained would help in determining the seismicity pattern and fault behaviour here. The portable data were not yet available as of the time this paper was written.

LAST THOUGHTS

Many people wonder if the activity is going to continue. Some even ponder if these events are precursors to a larger event. It is very difficult to ascertain one way or the other at this point in time. Peninsular Malaysia has not experienced any earthquake in recent memory. Kenyir's seismicity was reservoir related, but the Bukit Tinggi ones are probably caused by tectonic motions as mentioned in Shuib (2008) and discussed in this paper. Since there are no data to compare with, we are threading in unknown waters. Any

speculations are just that, speculations. It's anyone guess at this point. If the seismicity is truly that of CEQs, then the activity will die down eventually. One would just have to wait and see.

Theories aside, one has to remember that the accuracy of each earthquake location is essential in obtaining data with sufficient quality to analyse. Any inaccuracies in the time, coordinates and depth of the quake would affect the interpretation of the results. Since we are dealing with local earthquakes, misreading the P arrival by a second on the record could mean a shift of more than 5 km in the location on the ground. Regional earthquakes could be reported to the nearest 1 place after decimal degree; this would be sufficient, but local earthquakes need to be reported to at least three places after the decimal degree, giving an accuracy of about 100 meters needed for a more accurate analysis and interpretation.

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