GEOLOGICAL SOCIETY OF HONG KONG NEWSLETTER

Volume 22, No. 2, October 2016

Exploration of Southern and Eastern Taiwan – Geological and Geotechnical Perspective

The readers who are interested in discussing the content of the article please email to the Geological Society of Hong Kong at
geolsoc.hongkong@gmail.com

Editor: Ir. Raymond S M Chan

Exploration of Southern and Eastern Taiwan - Geological and Geotechnical Perspective

By
Jane P.S. LEE

Jacob Consultants Ltd

Abstract

Introduction

Between 26th and 30th Mar 2016, the Professional Branch of Geological Society of Hong Kong organized a site visit to southern and eastern Taiwan for the purpose of understanding the geology, geomorphology and significance of the active fault systems in Taiwan.

Geology

Taiwan, an island formed by collision between the Eurasian Plate and the Philippine Sea Plate, was divided longitudinally into the Western Foothills, the Central Range and the Coastal Range, which were uplifted as a result of plate collision since the Pliocene time. (Refer to the Geological Map in Figure 10). It is well illustrated by Zang et al. (2016) who proposed a model (Refer to Fig 1) for the formation of the Kenting Melange (墾丁混同層) and Lichi Melange (利吉混同層) since 11 Ma to Recent time. As a result of this specific geological setting of Taiwan, unique geology can be found at various localities on the island.

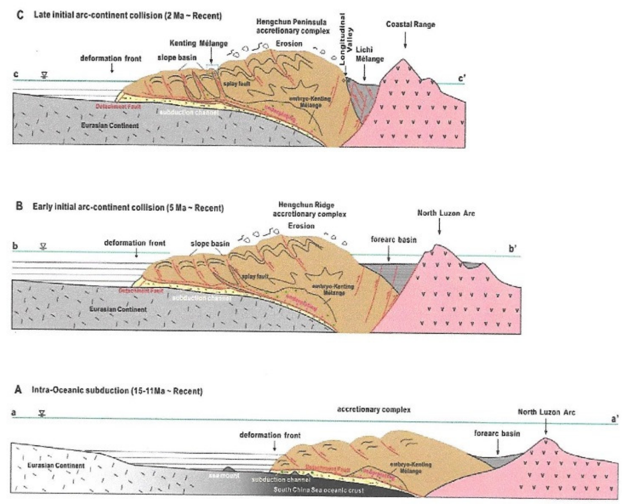

Figure 1. Formation of Kenting Melange and Lichi Melange (From Zhang et al 2016)

On the first day of the trip, we arrived in Hengchun Peninsula (恆春半島), which, situated at the southern tip of Taiwan, has been interpreted as a limb of a giant folding system in Taiwan. The western part of Hengchun Peninsula, capped with recent limestone reef, has a moderate uplift rate at slightly less than 1cm/yr. The surficial geology is dominated by coarse clastic sediments resulting from uplift of the continental slope which began rising in the upper Pleistocene. Moving along the coast and towards the west, more resistant exotic blocks were found near a site known as Tachienshan (大尖山) and Xiaochienshan (小尖山). These blocks are mainly composed of conglomerate, sandstone, shale and amphibolite. The amphibolite is believed to be part of the Kenting Melange or the submarine canyon formed as a result of the plate collision and the associated subduction.

We also visited the 'Eternal Flame' (出火) in Kenting as shown in Figure 2. Covering by the Kenting Shale, the surficial geology of the Eternal Flame is characterized by the fault fissures where methane (CH_4) is leaked and ignited from the underlying strata. According to the explanation of our geological leader, Professor Chu, a rise in groundwater table forces the methane (CH_4) to escape through the ground surface, and therefore, the gas can be ignited by fire on ground.

Figure 2. The Natural Fire in Kenting

On the second day, we travelled towards northeast and arrived in Jielesui (佳樂水) where an outcrop of deep marine turbidite deposit are exposed (Figure 3). The turbidite (濁流岩) outcrop is characterized by intercalated sandstone and shale beds of centimetre thickness. According to Chang et. al. (2003), the turbidites belongs to the Middle-Late Miocene Mutan Formation (牡丹層) which, typical deep sea fans deposits extending from the continental slope to the base of the slope, has now over thrust the Kenting Melange. Our site observations indicate that folding structures (close folds with interlimb angles of around 40 degrees and open folds with interlimb angles of about 100 degrees respectively) were prominent. However, measurements of dip and strike could not be taken for the sake of safety.

Figure 3. Turbidites in Jielesui

Also commonplace in Jielesui, honeycomb weathering (Figure 4) is present on many sandstone surfaces and along the rock joints. These honeycomb features are thought to have been formed by differential erosion in the presence of NaCl-salt bearing moisture and Fe-oversaturated groundwater.

Figure 4. Honeycomb weathering in Jielesui

The another spot of the day was a famous tourist spot known as 'Fongchueisha' (風吹沙) as shown in Figure 5. Based on sand dunes classification, it is classified as secondary dunes which are located rather inland and disconnected from wave process through coastal transgression. The name "Fongchueisha" is literally translated as wind-blown sands, denoting aeolian transportation. When onshore wind encounters obstacles along its path, the surface shear velocity are accelerated at the upwind side and decelerated at the leeward side; it is these differential sediment transport rate and pattern that created various kinds of sand dunes. The types of dunes are determined by such factors as density of shoreline vegetation, geomorphology, etc.

Figure 5. Fongchueisha sand dune

After a glimpse of the sand dune, our next stop was in Xiaoyeliu (小野柳) where the beautiful sedimentary structures are characterized and printed on the Fugang Sandstone. The geological structures such as marks, flutes casts, groves, graded beddings, cross laminations, loads and convolute laminations (Figure 6A) are well preserved in the area. These sedimentary structures suggest that the Fugang Sandstone (Turbidite) has been overturned. Huang et al (2014) estimated that there were over 200 cycles exposed in turbidite sequences as shown in Figure 6B. The Fugang Sandstone (富岡沙岩), located at the southern tip of the Coastal Range, was deposited on the continental shelf and formed a huge exotic block within the Lichi Formation. The uplift rate of this area is approximately 1 cm per year.

Figure 6A. Ripple marks and graded bedding in Xiaoyeliu (小野柳)

Figure 6B Fugang Sandstone (Turbidite), an exotic block, overturned within Lichi Formation in Xiaoyeliu (小野柳)

On the third day, we visited the boundary of collision (Suture) zone of the Eurasian and Philippine Plates, located at a river called the Peinansi River in Xiaohuangshan (小黃山) in the Eastern Taiwan. The western side of the river is dominated by the yellowish white conglomerate of Central Mountain Range which extends over 2 kilometres in length, with steeply tilted conjugate joints, and represents the continental crust of the Eurasian Plate (Figure 7A). In the eastern side, it is a badland topography comprising dark grey mudstone of the Lichi melange with exotic blocks (such as ophiolite, serpentinite, spilite, diabase and pillow lava which imply oceanic origin) as shown in Figure 7B1 and 7B2 respectively. Regarding the Lichi melange, some believed that it was the sediment of the Northern Luzon Arc forearc basin which was being crushed and moved towards northwest by plate tectonic movement.

Figure 7A Peinansi River in Xiaohuangshan, eastern Taiwan, (Eurasian Plate)

Figure 7B1. Philippine Plate melange at the eastern side of Peinansi River

Figure 7B2 Lichi Melange (Philippine Plate, East side of Peinansi River), Mudstone with blocks and gravels of exotic rocks

Before the seafood lunch, we stopped at Sanxiantai (三仙台) where coral reefs and volcanic agglomerates of Du-Luan-mountain layer of the Coastal Range of the Luzon Arc (呂宋火山弧) are found. It includes andesitic gravels and tuff (Figure 8). There are beautiful landscapes like sea eroded trenches, potholes, stacks, caves and wave-cut notches.

Figure 8 Volcanic Agglomerates at Sanxiantai

After lunch, we visited the Shihtiping (石梯坪) coastal park where outcrops of pyroclastic rocks with many volcanic bombs (Figure 9A & B) are exposed.

Figure 9A Layers of Pyroclastic rocks with volcanic bombs

Figure 9B Lava flow rounded the volcanic bomb

On the 3rd day, we stopped at Baxian Cave (八仙洞) as shown in Figure 10. It is located in Changbin Township where the volcanic breccia was pushed upwards by the Philippine Sea Plate at the rate about 0.7 cm per year (Geology Magazine, 2015). Caves were formed by sea wave action in long period of time as the rising rate of sea level due to finish of the glacial epoch was about the same as the rate of uplift created by tectonic movement. Besides, there are more than thirty caves found in the area nowadays, and the highest cave is also the oldest one which is about 200m above present sea level.

Figure 10 Baxian Cave, eroded by sea wave action

Figure 11. Unstable block at Baxian Cave

Slope Treatment in Eastern and Southern Taiwan

Similar to Hong Kong, various types of slope treatment works can be seen at Baxian Cave, Dabochi and Jielesui such as gabion wall, soil nails, shotcreted slope surfaces etc. At Baxian Cave, a large block of boulder with height of 10 m was observed at the crest of a sea cave. As the sea cave becomes a temple now, the overhanging boulder can be classified as Consequence to-life Category 2 based on Hong Kong's GEO Technical Guidance Note No. 15 which may fail in the form of wedge failure due to the presence of fallen debris found at the toe with water seepage, and vegetation grown along the intersecting joints (Figure 11). Albeit the risk, no preventive measure has been carried out to stabilize the boulder.

Another interesting stop was along part of the Southern Cross Taiwan Highway (Route 20). We walked from Tianlong Hotel, Wulu to Six Hole hot spring. It is located at the east flank of the Central Mountain Range as this region was pushed upwards by the Philippine Sea Plate. There are phyllite, slate, schist and metamorphic sandstone with distinct schistosity, cleavage and joints. The rock types are changed from muscovite schist (Figure 12) at Wulu to metamorphic sandstone, the Lido Formation (麗都層), where hot springs flow out from the steep rock face (Figure 13),

Figure 12 Highly stressed muscovite Schist at Wulu

Figure 13 Metamorphic sandstone with various hot spring holes

Indications, monitoring and mitigations of Fault movement

Subject to the effects of plate collision, earthquakes and fault movements are active in Taiwan. The Chishang Fault (池上斷層) in Figure 14 measures 60-70 km in length, and defines part of the boundary between the Philippine Sea Plate (which moves to NW at approximately 7cm per year) and the Eurasian Plate. Although the local agricultural industry and wetland ecosystem have been benefited from, perhaps active groundwater circulation and elevated geothermal gradient, the impact of the fault on structural safety for buildings raise much concern to the local government. On the 4th and 5th day of our trip, we spent time at Dapo Primary School of Dapochi (大坡池) where we observed signs of movement of the Chishang Fault, as indicated by the cracking and displacement of retaining walls, bridges and cottages, particularly at the corners of the building. Structural supports have been provided to reduce the rate of displacement at certain spots. (Figure 15).

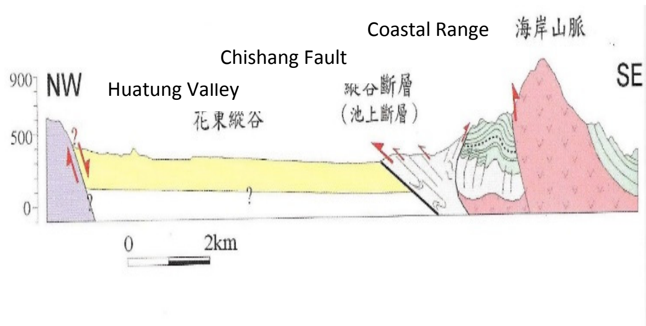

Figure 14 Chishang Fault (Huang et.al, 2014)

Figure 15. Structural supports of retaining wall against horizontal movements at Dapo Elementary School

Although Taiwan has the densest coverage of seismographs and GPS stations in the world, the three major difficulties of earthquake prediction that include exact time, the exact area and the magnitude still cannot be surmounted. In Dapochi, the probabilistic approach is being adopted to predict the ground movement by earthquake. By means of measuring the degree of tilting and displacement of the affected structures, surface slip history can be traced and hence the recurrence time of large scale earthquake could be predicted at a higher accuracy. In Figure 16, two average rates of the fault movement, in 1986-1991 and 1992-1997, were drawn respectively. From the creepmeter measurements, it can be observed that the Chengkung Earthquake (成功地震) occurred on 10 December 2003 when the green line deviated from the line of average values by approximately 50mm. the event happened that likely indicates that can be the threshold of that particular quake. It showed that the displacement was small before the major Chengkung Earthquake which might imply a significant stress were built up in the area.

Nevertheless, recurrence time of quake varies at different parts of the faults. When stress in a fault is released, the stress distribution in the front and behind of the fault is changed, and hence location of recurrence, to a certain extent, is uncertain. Another problem is that the upslope angle for most of the retaining walls in the Dapochi area may not be zero. Hence, it is unknown that the horizontal movements and cracking of walls are in result of downslope movement or thrusting of fault, and it remains to be determined later.

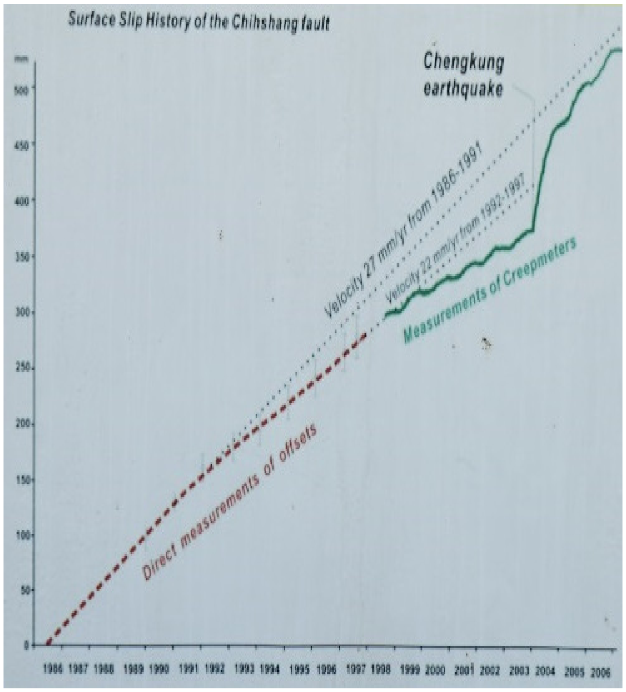

Figure 16. Surface Slip History of the Chishang Fault

Acknowledgement

The author would like to express her gratitude towards Professor H. C. Chu (朱傚祖教授) from the National Taiwan University for his guidance and detailed explanations on geological features of each locality. Special thanks should also be given to organizers, the Professional Branch of Geological Society of Hong Kong, for organizing this interesting and informative excursion.

References

Geology Magazine (臺灣的山川土石), Volume 34, No. 2(第 34 卷第 2 期). Central Geological Survey, MOEA (經濟部中央地質調查所) 2015 年 6 月。

Taiwan Geology Tours (台灣地質旅遊) (2014). 黃鑑水、余炳盛、曹恕中編著。

Zhang, X. C., Cawod, P. A., Huang, C. Y., Wang, Y. J., Santosh, Y. M., Chen, W. H. & Yu, M. M., 2016. From convergent plate margin to arc-continent collision: Formation of the Kenting Melange, Southern Taiwan.

Chang, C. -P., Angelier, J., Lee, T. -Q. & Huang, C. -Y., 2003. From continental margin extension to collision orogen: Structural development and tectonic rotation of the Hengchun peninsula, southern Taiwan. Tectonophysics, Volume 361, pp. 61-82.

Water Resources Agency, 2005, Geology of Taiwan [Online] Available at:
http://eng.wra.gov.tw/public/Data/gh012_p3.htm
[Accessed 14 05 2016].

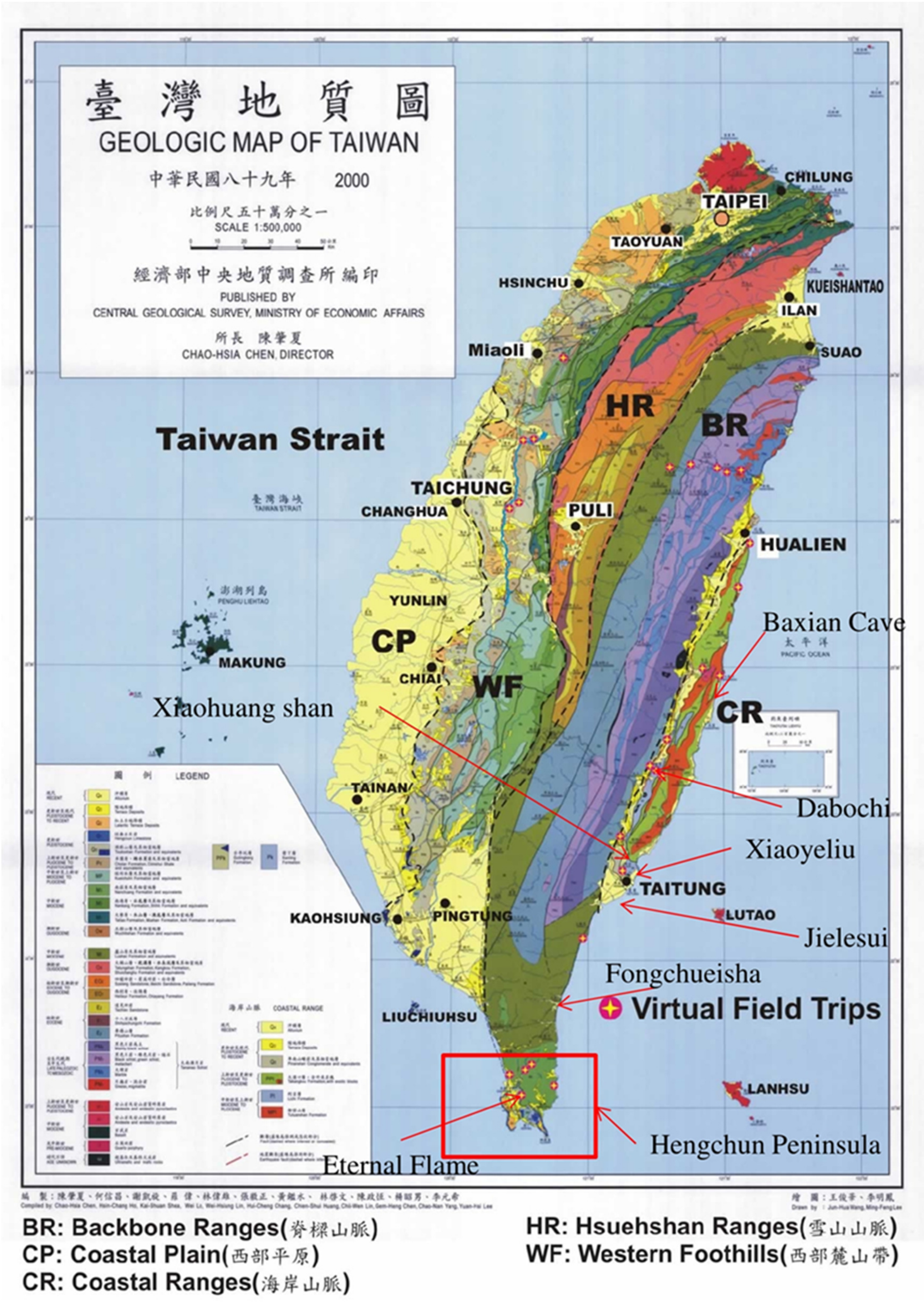

Figure 10. Geological Map of Taiwan (WRA, 2000)