

The Geological Society of Hong Kong - 30th Anniversary Conference

*The Geological Society of
Hong Kong
Since 1982*



**RECENT DEVELOPMENT ON
GEOLOGY AND ENGINEERING GEOLOGY
29 JUNE 2012
HONG KONG**

Organised by The Geological Society of Hong Kong



PROGRAMME AT A GLANCE

8:45-9:15	Registration
9:15-9:25	Opening Ceremony Welcome Speech <i>Mr. Paul CHEUNG, Chairman of the Conference Organizing Committee</i>
9:25-10:50	Session 1 - Chairman - Prof. Lung Sang CHAN (Department of Earth Sciences, HKU) <u>The Advances of Submarine Geosciences in China</u> <i>Prof. Xinag Long JIN, State Oceanic Administration</i> <u>Geo-engineering lessons learned from the 2008 Wenchuan Earthquake in Sichuan and Their Significance to Reconstruction</u> <i>Prof. Run Qiu HUANG, Chengdu University of Technology</i> <u>Updating of Hong Kong Geological Survey 1:200,000-scale Geological Maps</u> <i>Dr. Roderick J SEWELL, Geotechnical Engineering Office, HKSAR</i>
10:50-11:10	COFFEE BREAK
11:10-12:00	Session 2 - Chairman - Prof. Lung Sang CHAN (Department of Earth Sciences, HKU) <u>Long-term Strategy for Rock Cavern Development in Hong Kong</u> <i>Dr. Samuel K C NG, Geotechnical Engineering Office, HKSAR</i> <u>Interactions of Surface Processes with Tectonics of Taiwan: Insights from Sandbox Experiments</u> <i>Prof. Chia Yu LU, Department of Geosciences, National Taiwan University</i>
12:00-12:30	-Q&A
12:30-14:00	LUNCH (INCLUDED)
14:00-15:25	Session 3 - Dr. Samuel K C NG (Geotechnical Engineering Office, HKSAR) <u>Cavern Design and Construction in Challenging Ground Conditions</u> <i>Mr. Felix AMBERG, Amberg Engineering Limited</i> <u>Example of Determining Sensitive Zones of Active Reverse Fault Based on Field Observation : Case Study of the Hukou Fault and the Chihshang Fault in Taiwan</u> <i>Dr. Hao Tsu CHU, Taiwan Central Geoloical Survery</i> <u>New Evidences of Paleovolcanic Plug in Tuen Mun Area, Hong Kong</u> <i>Mr. Kuen Wai LAI, Fugro (Hong Kong) Limited</i>
15:25-15:45	COFFEE BREAK
15:45-16:35	Session 4 - Dr. Samuel K C NG (Geotechnical Engineering Office, HKSAR) <u>Sustainable Use of Reservoirs in Taiwan - Underwater Tunnel Piercing Method</u> <i>Mr. Chia Han LEE, United Geotech. Inc.</i> <u>Thirty Years of Hong Kong Geology</u> <i>Prof. Lung Sang CHAN, Department of Earth Sciences, HKU</i>
16:35-17:00	-Q&A

*Proceedings of the 30th Anniversary Conference
The Geological Society of Hong Kong
Since 1982*



**Recent Development on
Geology and Engineering Geology**

29 June 2012
Hong Kong

Organised by
The Geological Society of Hong Kong



Foreword

This is a special conference to mark the 30th Anniversary of the Geological Society of Hong Kong. The Society had organised several influencing seminars in the past, such as Superficial Deposits, Karst Geology and Marine Sand and Gravel Resources. The Society had also organised conferences/seminars for delegates coming from mainland, Taiwan and Hong Kong.

To follow the tradition, the Organising Committee has invited speakers from mainland, Taiwan and Hong Kong to cover a broad geological theme which includes submarine geology, earthquake, mapping, petrology, structural geology and engineering geology. I trust this conference could give you an update development of various fields of geology.

I would like to thank the President of the Geological Society of China (Minister of the Minerals and Resources), Deputy Minister, The Liaison Office of the Central People's Government in the Hong Kong Special Administrative Region and Presidents of the Taipei and Taiwan Association of Professional Applied Geologists on their greetings. I also like to thank all authors on their valuable contribution to this conference.

I, on behalf of the Society, wish to express our warmest gratitude to all sponsors for their generosity and support to this special 30th Anniversary conference. Lastly, I must thank the Organising Committee for their wonderful work in making this conference and 30th Anniversary activities possible.

Dr. Margie Chen

President of the Geological Society of Hong Kong

敬賀香港地質學會30週年誌慶

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服務香港

中國地質學會理事長
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中國地質學會理事長
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徐紹史題

*Congratulation Message from
The President of the Geological Society of China
The Minister of the Ministry of Land and Resources
Of the People's Republic of China*



香港地质学会三十周年会庆

繁荣地质科学 造福锦绣香江

中央政府驻港联络办副主任 殷晓静



*Congratulation Message from
Deputy Minister, Liaison Office of
The Central People's Government in
The Hong Kong S.A.R.*

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慶祝香港地質學會成立 30 周年 賀函

致 香港地質學會暨會員

欣聞 貴會成立 30 周年並舉辦慶祝大會，深感喜悅，也替香港 30 年來地質專業人員為社會民眾提供之專業地質服務與資訊等，同感光榮。

地質領域是一門基礎科學，它並不只是冷冷冰冰一些的岩石礦物組成的數據或公式而已，而是深切的與民眾生活息息相關的一門科學。舉凡重大工程施工，交通、水利、發電等基礎建設，甚至民眾住家周遭環境的邊坡安全，都與地質科學息息相關。以近年來之經驗，在異常極端氣候之影響下，山崩土石流等環境地質議題益發重要，同時在異常降雨影響下，水資源分配管理亦顯未來之重要性，包括地下水資源的調查與管理，以及地下水被大量不當抽取後地層下陷問題等。上列領域只是地質與民眾生活連結的一小部分，未窺全貌，但已凸顯地質專業人員身負之責任，也代表著未來地質人員尚有許多共同交流與合作的方向。

值此 貴會成立 30 周年時刻，喜見 30 年來 貴會暨眾多前輩之努力成果，並期待未來更多個 30 年，更多的地質人員能為民眾與發展盡更多的力量。

恭賀 大會成功！

臺北市應用地質技師公會 理事長

王豐仁

臺灣省應用地質技師公會 理事長

陳本康

*Congratulation Message from
Taipei & Taiwan Associations of
Professional Applied Geologists*

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GEO-ENGINEERING LESSONS LEARNED FROM THE 2008 WENCHUAN EARTHQUAKE IN SICHUAN AND THEIR SIGNIFICANCE TO RECONSTRUCTION

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ABSTRACT: The Wenchuan earthquake of 2008 is only a memory of the very recent past, but has already left lasting consequences to geo-environments. Differing from the general point-quake-triggering source, the Wenchuan earthquake's quake-triggering source extended along an active hundred-kilometer-long fault. Widespread mountain rock fragments were shaken loose during the earthquake. Consequently landslide and debris flow geohazards are dominating factors in planning for post-disaster recovery and rebuild. This paper presents lessons to be learnt from coping with various geohazards and disasters. We also describe geological factors in relocating disaster area's residents. We discuss the necessity of establishing a national emergency management system for huge scale catastrophe, earthquake precursor identifications, town construction to keep away from active faults, town safety with high risk of seismic and geological hazards, importance of geohazard investigation and remediation for quake-loosened mountain rock fragments. We also describe geological factors in risk reduction in the quake disaster area, site selection for re-settlement, infrastructure reconstruction, and earthquake relic-site selection and protection.

1 INTRODUCTIONS

The Wenchuan earthquake, of magnitude 8.0 on the Richter scale, which hit China in the relatively densely populated mountainous areas of Sichuan on May 12, 2008, was the largest in the past 100 years. Recent surveys showed that the quake had induced about 35,000 counts of rockfalls and landslides, in addition to a great number of cracked and loosened mountain mass, and hidden troubles for subsequent debris flows in rainy seasons. Therefore, it can be said that in the post-quake disaster areas the originally fragile geo-environments have deteriorated. The geological stability has become more fragile. Differing from general point-triggering quake, the Wenchuan earthquake had an area-triggering epicenter along Longmen Mt fault (Figure 1). The earthquake triggering fault traverses several populated cities and towns, resulting in the collapse of city and town buildings, even destruction of whole cities and towns. Two typical examples are Yingxiu and Beichuan, which happened to be located on this strong quake's triggering fault—Yingxiu-Beichuan fault zone (Figure 1).

The Wenchuan earthquake's post-disaster recovery and rebuild are also unprecedentedly difficult, involving very huge and complicated systematic engineering feats. The rebuilding not only receives broad attention from the whole country but also from international communities. At the same time, it is related to the direct interest of the residents in the disaster area and its subsequent economic development.

One year after the Wenchuan earthquake, we look back into the super effort in the quake rescue and relief, and the on-going reconstruction and relocations. Both the lessons learned from the disasters and the considerations of geological factors will not only help disaster area's residents to re-settle safely, but also prepare us to cope with possible future disasters.



Figure 1. Illustration of the Longmen Mt. quake-triggering fault zone and the epicentral area of the Wenchuan earthquake of May 12, 2008.

This paper discusses lessons learned from the Wenchuan earthquake's disaster and other mountainous area's geohazards (Section 2). Specifically, we learnt the need to establish national response management system for super catastrophe (Section 2.1), earthquake precursor identification study (Section 2.2), town construction to keep away from active faults (Section 2.3), geohazard reduction and remediation for town safety with high risk of seismic hazard

and geohazards (Section 2.4), as well as the importance of geohazard investigation and remediation of quake-loosened mountain rock fragments (Section 2.5). We also describe geological factors in settlement spot selections in relocating disaster area's residents (Section 3). We discuss geohazard risk management and reduction in the disaster area (Section 3.1), site selection for settlement spots (Section 3.2), infrastructure reconstruction (Section 3.3), and the earthquake site protections (Section 3.4).

2 MAIN LESSONS FROM THE WENCHUAN EARTHQUAKE AND OTHER DISASTERS

2.1 *Necessity of Establishing National Emergency Response Management System for Huge Catastrophe*

After catastrophic events such as earthquake, the critical issue is how to timely acquire disaster loss information and organize after-disaster rescue, to maximize the efforts to rescue life and relief work, and to minimize societal property loss. Some situations after the Wenchuan Earthquake expose limitations of our capability, for example:

- (1) Communication disruption lasted long after the earthquake. Disaster areas were cut off communication totally right at the moment of the earthquake was taking place. In metropolitan area like Chengdu, which is close to the quake areas, major mobile communication corporations were also disrupted instantaneously when the quake occurred. Even though calls can be put through several hours later, extreme congestion and hardship in communications lasted 24 hours after the quake.
- (2) Lack of necessary satellite images and air photos hindered correct determination of the disaster areas, especially the severely affected ones, which directly disrupted the timely response of the commanding systems. Differing from generic earthquakes, the Wenchuan earthquake is not a point-source earthquake, but an areal one that extended along the Longmen Mt. fault zones. The strongly affected areas stretch for nearly 300 km, about 50 km wide along the Longmen Mt. fractures (Figure 1). Even ten-odd hours after the earthquake, all the rescue work and disaster relief work were still organized around the general epicenter "Wenchuan County town seat". This is due to communication disruption in the disaster areas and lack of necessary satellite and remote sensing images to identify the epicenter and range of epicentral areas. Air-photographing work for the disaster areas did not start until the afternoon of May 15, 2008.
- (3) Lack of mechanism for effective catastrophe emergency management and coordination among departments.

A catastrophe such as the Wenchuan earthquake, which is extremely rare in the modern history of China (at the time of the Tangshan Grand Earthquake of 1976, China was still in the era of planned economy and the cultural revolution), is worsened by the mountainous terrain, with attendant paralyzed road traffic and city-and-town systems. Accordingly, the experience gained in the past in handling quake rescue and relief as well as organized management of settling hardly affected residents, even though all levels of governments have compiled emergency response plan for major and super scale disasters, and even though our governments are unusually strong in organizing the national strength to launch into fights against quake and into relief work. Facing such an enormous catastrophe as the Wenchuan earthquake, our emergency management remained somewhat unprepared and many problems emerged. Examples include how to effectively find and rescue survivors inside the ruins; how to effectively organize victims to evacuate safely and temporarily relocate and transitionally relocate; how to effectively cope with the potential risks similar to quake barrier lakes, to prevent the occurrence of secondary hazards; and how to effectively supervise and organize volunteers, etc. Still there remains relatively big flaws in coordination and cooperation among departments.

There is an old saying in China, called "Nip the trouble in the bud". Despite the magnitude and hence rarity of the quake which hit Wenchuan, the peculiar geographic, climatic, and geological environments in China, still pose very high risks for strong quake events and other large scale catastrophic events. Therefore, it is imperative that the government should set up and perfect a fast response and emergency management system for gigantic catastrophe.

In modern times, this system should possess the following major features:

- a timely image-acquiring system based on high resolution satellite-to-earth observation and fast air photos
- self-improvement on image quality of satellite monitoring system, and strengthening capability of data acquiring and processing
- effective emergency communication system
- effective rescue system
- effective governmental organizing and management system
- effective societal management and aid system
- strengthening international corporation in this field

2.2 Earthquake precursor identification and prediction study, and establishing system of quake hazard monitoring and early warning, and system of observation and prevention

Generally speaking, there are two approaches to earthquake hazard prevention: one is earthquake prediction, and the other is anti-quake fortification for buildings and structures. In terms of present day science and technology and the understanding of earthquake mechanism theory, earthquake prediction remains a thorny problem. Therefore, developed countries have gradually adopted instead the approach of strengthening the anti-quake performance of construction, and put earthquake prediction in a relatively minor role or only limited to scientific research.

After the Xingtai earthquake of the 1960s and the Tangshan earthquake of the 1970s, China strengthens her scientific research for earthquake prediction, and has done a large amount of work on popularizing earthquake knowledge and “pooling the wisdom from the practices of everyone”. These activities peaked in the 1970s. Since 1980s, along with the gradual decrease in Chinese mainland’s destructive earthquake activities and loss to earthquake hazards, people’s interest in earthquake prediction has waned. Dissemination and popularization of earthquake prevention and disaster reduction have also gradually declined, so that it seems to most of the general public that earthquake is far away from us. The Wenchuan earthquake resulted in large numbers of casualties, many of whom are related to weakness in earthquake prevention and disaster reduction.

China is a country with abundant earthquake activities, with about half of its population living in areas with relative high earthquake risks. China is also a developing country. Most people live in under-developed villages and medium and small cities and towns. The buildings in these areas are poor in earthquake resistant ability. Most country houses essentially do not consider the problems of withstanding earthquake hazards. As a result, the Wenchuan earthquake led to large numbers of country houses collapse. The after-quake rebuilding program has made country houses and town-and-city buildings greatly resistant to seismic activity. Important buildings like School houses also have improved their resistance, but construction works with even low seismic resistance will proceed for a long time in under-developed areas, especially in mountainous areas. Therefore, in the prevention of seismic hazards, it is obviously insufficient to only rely on improvement

of the seismic stability of buildings. It is a must to take the approach that unites the efforts in strengthening seismic resistance of constructions and in raising seismic prediction capability. Earthquake prediction is a world-wide difficult problem. Correct prediction of earthquake still has a long way to go. However, the following two aspects of efforts at least would work in the near future.

One approach is to establish the technical means to strengthen earthquake prediction and precursor identification, and establish monitoring and early warning system for seismic hazards. This system includes:

- Monitoring of earth crust’s deformation in active seismic areas. Applying satellite remote sensing techniques and GPS techniques to monitor crustal deformation in China’s seismic active areas is fundamental work, and very essential. China’s national seismic bureau and others have started relevant work.
- Deep hole monitoring of fault activities: Carry out 3000-5000 m depth deep-borehole drillings at China mainland’s typical active faults, especially those threatening safety of metropolitan areas, in order to monitor the behavior of their deep underground activity and to capture earthquake’s precursors. The data to be monitored should include deep underground deformation, stress field, fluid pressure, minor quakes, temperature, aqueous compositions etc.
- Identifications of earthquake precursors.

The other approach is to establish a preventive system and incorporate the findings from “Observation and Preventive practice of Everyone” for seismic hazards. Currently this work is also pressing.

- Disseminate earthquake knowledge, popularize the education.
- General public’s participation in identification of earthquake precursors.
- Possibility of using animal abnormal behavior as earthquake precursors.
- Organizations for “pooling the wisdom and preventive practices of everyone”.
- Disseminate and perpetuate knowledge of earthquake prevention and disaster reduction
- Regular rehearsal and training of seismic preventions participated by the general public

2.3 City-and-town construction sites to avoid active faults of potentially strong quakes

The Wenchuan earthquake led to severe seismic disasters. In the complete destruction of these two towns of Yingxiu and Beichuan, about 30,000

persons died which accounted for 35% of the total death toll in the earthquake. According to statistics, about 60% of the death toll was concentrated in towns on the earthquake fault zone or those next to the earthquake fault zone. Obviously, it is necessary that town and village construction should stay away from active faults, especially those active faults of potentially strong earthquake. This should be considered as an important or even controlling principle for potentially strong earthquake areas or after-quake rebuilding for the Wenchuan earthquake disaster areas.

It needs to be pointed out that, the construction standard for anti-seismic design prescribes the distance to keep away from earthquake fault for various constructions and different scales of towns (Table 1). Obviously, in many regions the standard has not been strictly followed.

Someone would still say, a gigantic earthquake like the Wenchuan earthquake has a very long repetition cycle, perhaps a thousand years, and as land used for construction in mountainous areas is in great demand, recovery and reconstruction can for the time being do without considering earthquake hazards. This opinion is wrong. "Long repetition cycle for gigantic earthquake" cannot be used as an excuse for neglecting the potential threat of seismic hazards. This attitude not only falls short of historical responsibility, but it also neglects the impact of the characteristics of seismic activities in western Sichuan. Once the Longmen Mt. fault was activated, chances for 8-magnitude gigantic earthquakes in the near future have surely become low. However, earthquakes with magnitudes at 6 or 7 or above could greatly shorten the repetition cycles. They are also destructive earthquakes. Taking the Xianshui River fault as an example, since 1725, there have been 28 earthquake events at magnitude 6 or above, 8 events at 7 or above. Since 1900, magnitude 6 and 7 earthquakes have been recorded 14 and 3 times respectively. That is to say, the repetition cycle for magnitude 7 or above earthquakes is 30-40 years, and that for magnitude 6 or above earthquakes is only 8-10 years. Therefore, the outbreak of strong earthquakes in the future along the Longmen Mt. fault must not be taken lightly.

Table 1. Safety Distances from earthquake fault for different class-level constructions (GB50011-2001)

Intensity	Class 1 Construction	Class 2 Construction	Class 3 Construction	Class 4 Construction
8	Special study	300	200	/
9	Special study	500	300	/

Table 2 Suggested safety distances from earthquake fault for different class-level constructions

Intensity	Class 1 Construction (incl. county town etc.)		Class 2 Construction (incl. town)		Class 3 Construction (incl. village and resident concentrated settling spots)		Class 4 Construction	
	UP wall	BT wall	UP wall	BT wall	UP wall	BT wall	UP wall	BT wall
8	800	500	500	300	300	200	50	/
9	1000	600	800	500	500	300	100	50

Specifically what is the reasonable distance for construction to keep away from fault lines? This is a very complicated problem. The suggestions in Table 1 neglect two problems: one is "hanging wall effect" of seismic hazards, i.e., the hanging wall of a fault is much more destructive than the footwall. Therefore, the safety distance on the hanging wall should be greater than that on the footwall. The other consideration is the impact of induced geohazards. West Sichuan is a medium-high and high mountainous region. High mountain and canyon geomorphic features stand out; with fully developed geological structures, weak lithology (e.g., thin layered slate, carbonaceous slate, schist, phyllite, etc.), strong weathered and fragmented rock mass, and fragile geoenvironments. Disastrous geohazards can easily be induced by strong earthquakes. Hence the keep-away distance should be lengthened.

Based on the above discussion, we provide the adjusted safety distance from earthquake fault for different important constructions (Table 2).

2.4 Geohazards reduction for Southwest region's town safety with high risk of seismic and geohazards

In the southwestern region, towns with high risks of seismic and geological hazards should highly regard safety problem, and take measures to lower risk of hazards. This earthquake taught us a series of painful lessons, which warrants serious thinking. Gigantic earthquakes can trigger large scale rockfalls, promote landslide hazards and destructed towns, which when sighted are shocking and serve to keep people vigilant. For example, the Wangjiayan landslide and rockfall at the new Beichuan high school (discussed later) in Beichuan county town seat, the Eastern River Mouth landslide at Qingchuan Hongguan village and others, all have disastrous consequences. Death tolls are staggering. After the earthquake, there were still large numbers of towns and villages seriously threatened by mountain landslides, and several tens of

thousands people had to be temporarily relocated. Western Sichuan is located in the eastern side of Qinghai-Tibet plateau. Unique terrains and geoenvironments have resulted in developed active fault structures, prominent high-mountain-and-canyon geomorphology, strongly weathered and fragmented mountain bodies, bad geoenvironmental condition, and high risk geohazards. These contributes to environmentally hostile living conditions for humans.

Looking into active fault structures, besides this quake's triggering large-scale active fault zone of the Longmen Mt. faults, there are still other fault zones on the same scale including, for examples, the Xian-shui River fault zone, the Anning River fault zone, etc. Historical they were more active than the Longmen Mt. fault zone.

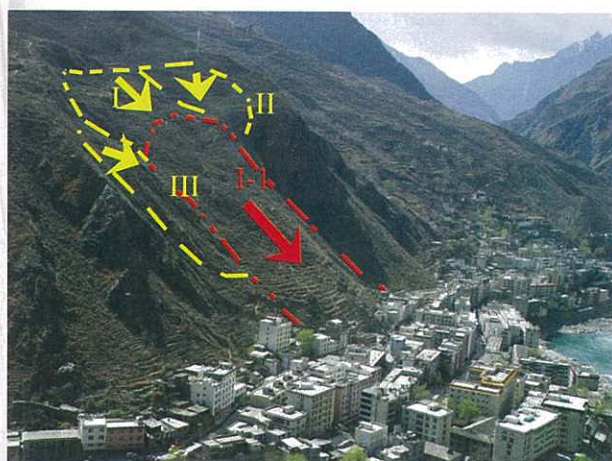
Because of high-mountain-and-canyon features, in the western part of Sichuan considerable numbers of county town seats and towns are built on one side of narrow platforms, e.g., Baoxing, Luding, Danba, Kangding, Shimian, etc. They face big rivers, with their backs against cliff and high slope. Once a nearby active fault zone triggers strong quakes, they are threatened by surrounding mountain landslides. None of them could be considered safer than the Beichuan county town seat. Since these town sites are narrow and limited in spaces, there would not be any spaces at all for escaping and refuge when big disasters strike. In 2005, at Danba county town seat by the Dadu River, a landslide on the back mountain of the county town seat was activated, showing significant down-sliding trend. Fortunately that moving was detected in time, and the problem emergently remedied (Huang, 2009), thus protecting the city from disappearance from the surface of the earth (Figure 2). Therefore, in this national earthquake disaster recovery and rebuild, strategically it is meaningful that the overall planning considers all factors contributing to high risk seismic geohazards, and takes essential measures to lower the risks. We have the following suggestions:

Figure 2. Sichuan's Danba county town seat (looking southwest): dangerous condition of sliding landslide was developing on the back mountain in February 2005. The county town seat survived the destruction from the impending disaster by taking timely remedial measures.

- (1) In these high risk towns urgently build a set of refuge sites, or escape routes.
- (2) For the unstable mountain boulders around these towns, take necessary reinforcing remedial measures.
- (3) Establish long term safety monitoring system keyed to surrounding mountain bodies, which would be integrated and managed by relevant departments.
- (4) Relocate some of the towns, and steer residents away from danger zones by moving them to other places.
- (5) Conduct relevant survey and scientific research centers to provide scientific basis for the above measures.
- (6) Disseminate and popularize knowledge of disaster prevention and disaster avoidance.

2.5 Importance of geohazard investigation and remediation of quake-loosened mountain bodies

We should be vigilant of the protracted and hidden nature of geohazards in the earthquake disaster areas, especially geohazards of quake-loosened mountain bodies. Hazards of this kind should be properly investigated, prevented and rectified. The Wenchuan earthquake did not simply trigger large numbers of explicit rockfalls and landslides. It rendered instability to many rock bodies. We call this portion of mountain bodies "Quake-cracked mountain bodies". Quake-cracked mountain bodies have their interior structures damaged and slackened, and are susceptible to, upon changes in external environmental conditions, generating new landslide and rockfalls, especially debris flow in rainy seasons. This kind of mountain bodies not only exists in disaster areas, but also has long-term and extensive existence especially in mountainous areas having undergone magnitude-8 earthquakes. They usually have strong concealment, and hard to find out. Therefore, they have hidden risk of hazards, and play a major role in defining the long term nature of geohazards in earthquake disaster areas. On September 24, 2008 and July 17-18, 2009, in the Wenchuan earthquake disaster areas at a number of places large scale debris flow hazards were generated, which precisely are closely related to quake-cracked mountain bodies of this kind.



On September 24, 2008 a once in every 20-year huge storm hit the region around the most severely afflicted Beichuan county town seat, triggering outbreaks of region wide debris flows. A large scale debris flow developed at Talcum board gully (Xishanpo gully) charged into the nearby former Beichuan county town seat, forming a 900 m by 150-200 m deposition fan with an area of 0.17 km². The thickness of deposition eventually reached about 10-12 m at its upper section, and 7-8 m at its middle section near the main stream line. Within an hour, the place disappeared from sight, with all the facilities of the county seat buried under the rubble of a three-storey building.

Field survey results showed that the September 24 storm triggered a total of 72 debris flows of various sizes around the former Beichuan county town seat strip, flushed and destroyed post-quake aid-and-build board houses, plus flood hazards, resulting in 42 deaths and many gone missing. Because the roads leading to villages were almost all destroyed by debris flows, some 4,000 people were trapped in the mountains for several tens of hours. This Beichuan super debris flow hazard sent a warning to the ongoing geohazard-prevention work. Post-event investigation and analyses indicate that, the Beichuan 9.24 super debris flow hazards have the following characteristics and points that demand attention:

- (1) That regions near the fault zone were quake-loosened is the fundamental reason for the region wide debris flow outbreak: The Wenchuan earthquake is a typical quake-triggering fault of thrusting dextrorsal strike-slip type (Figure 1). As the hanging wall around the Beichuan region is made up of weak rocks like schist and slate, large quantities of rocks were loosened by strong quakes. The rock body structures suffered severe damage and destruction. Rock body strengths were greatly lowered and weakened. Buffeted by heavy rain, rock bodies are extremely easy to collapse, thereby providing basic material condition for the outbreak of region wide successive debris flows.
- (2) After the earthquake, critical rainfall for triggering debris flows has been significantly lowered: Relevant data and survey show that, before the earthquake in Beichuan county region, for triggering debris flow, the early cumulative rainfall was 320-350 mm, and the critical rainfall intensity is 55-60 mm per hour. And in the regional debris flow occurrence on September 23-24, 2008, the early accumulated rainfall was reduced to 272.7 mm, and the critical per-hour rainfall is 41.0 mm. For the same region, critical

rainfall conditions for debris flow before the quake and after the quake have significantly changed. After the Wenchuan earthquake, the early accumulated rainfall for debris flows in this region has been lowered about 14.8-22.1%, and per hour rainfall intensity lowered about 25.4-31.6%. This trend is similar to that of the 1999 Taiwan Chi-Chi earthquake area, where the accumulated rainfall and critical per-hour rainfall intensity were 1/3 lower than that before the earthquake (Shieh et al., 2009).

- (3) After the earthquake the ways of triggering and moving debris flows changed significantly: Investigations show the post-quake debris flows can be triggered in two ways: first, surface-layer rubbish formed during rainstorm, downwardly transports loose materials that hang over slope surface and at the foot of slopes, and turns into debris flow. Second, "fire hose effect" enables gully channel's water flows to quickly converge, and fiercely erode and loosen solid materials in the gully bed, resulting in initiating the moving of the materials in the gully bed and forming debris flow. Investigation and analyses also found, significant barrier effect on debris flow movement coming from accumulated rockfall-and-landslide materials inside the gully channel. Once these clogging bodies burst, they could lead to sharp increase of instant flood peak flux. Out-washing and eroding capability are greatly strengthened along the way, triggering large scale paroxysmal debris flow.
- (4) After a quake the debris flow accumulated at river channels increases the risk of flooding hazards: Investigation showed that, after the Sept 24 rainstorm, on the banks of Jianjiang river near the Beichuan county town seat and at other places newly-burst debris flow can be seen everywhere. Multiple accumulation fans locally raise riverbed of the main river channel, congest and even partially block the river. In addition, river sand content is high, and water level rises fast. The chances of flooding hazards in disaster areas increase significantly. The relocated resident areas on the banks face increased threats of flood and road destruction.

The Sept 24 Beichuan super region-wide debris flow hazard presents a serious warning to after-quake disaster prevention in the Wenchuan earthquake disaster area. We need to learn the experiences and lessons from among the events and pay keen attention to prevention and remedial work on hidden geohazards in protracted, quake-loosened mountainous areas. Therefore, the following

recommendations are in order:

- (1) Strengthening detailed investigation and assessment of quake-loosened mountain rocks in the Wenchuan earthquake disaster areas with special attention to those susceptible to regional debris flow (especially the Wenchuan earthquake epicentral area of quake intensity IX) (Figure 2). Find out from the quake-loosened mountain rocks the specific distribution locations, development characteristic, formation mechanism, potential endangered objects, potential of barrier forming in river and partial blocking of river. And conduct stability assessment and mapping work for quake-loosened mountain rocks to delineate potentially dangerous districts. The aforementioned can then be integrated with disaster area's after-disaster rebuild planning, in order to conduct risk assessment and sectional division work for quake-loosened mountain rocks.
- (2) Detailed investigation and assessment of gullies and slope surfaces rich in newly transported material. The purpose is to pinpoint the development and distribution of gullies and regions under the threat of debris flow, analyze and assess potential and danger of congesting or blocking river after debris flow event. Conduct assessment and sectional planning for the danger and risk of after-quake debris flow. And delineate potentially dangerous regions, to provide basis for decision making and carrying out of after-quake recovery and rebuild planning.
- (3) Study of debris flow startup condition. The work is to investigate the startup conditions for debris flow in different regions, under various lithological and structural conditions. And especially the work should focus on research and analytical statistics of critical rainfall. Rainfall early-warning criteria for debris flow outbreak in the disaster areas of the Wenchuan earthquake would form the basis of weather early-warning work for disaster area's small regions.
- (4) Geohazard emergency response mechanism and regular rehearsals in those key disaster areas with potential of regional, continuous debris flow and rockfall hazards. It would take homeland resource department and meteorological department to work together, to establish and perfect monitoring and early-warning of geohazards, and small region weather early-warning system of geohazards.

3 SOME GEOLOGICAL CONSIDERATION TO RELOCATION OF THE WENCHUAN EARTHQUAKE'S DISASTER AREA

3.1 Geohazard risk assessment and reduction in the disaster areas

The Wenchuan earthquake's epicenter is located in a region where intermediate-high and high mountains prevail. For a long time into the future, the areas will be endangered by rockfalls, landslides, and debris flows, which are great risks for post-quake recovery and rebuilding. For example, on September 24, 2009 at Weijiagou of the old Beichuan county town seat, rainstorms induced a large scale debris flow, which resulted in old town district of the previous site of the county town seat partially buried by 7-10 m debris flow. We believe, in areas with 8.0 or above intensity (Figure 3) the geo-environments could take 5-10 years to stabilize. This is to say, the quake disaster areas face and will face high risks of geohazards, especially debris flows for a rather long time into the future.

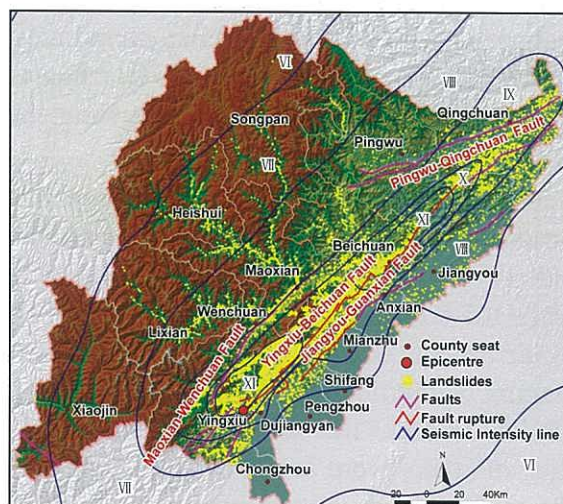


Figure 3. Earthquake intensity distribution map

Surveys found that the geohazards generated by the Wenchuan earthquake are similar to others. But they also have their own particularity, e.g., wide-spread quake cracks in mountain boulders, steep accumulation of mud and debris inside gullies, lowering of the threshold for triggering landslides and debris flows. The debris flows have small catchment area and small flow section, but have big bursting flow rate and large volume of one-time outflow. These characteristics are not possessed by the past regular geohazards. Therefore, it is necessary to detail surveys and identifications of disaster area's geohazards, especially quake-cracked mountain boulders of this kind with unique, potential geohazards. Correspondingly,

this necessitates modification and improvement in the pertinence of current survey methodology and relevant technical guideline. On the other hand, it is imperative to compile geohazard district division plan by county territory using detailed survey data, to provide a basis for regulatory departments to conduct risk managements and risk control.

An effective way to lower geohazard risk is to further improve on the existing system of “pooling the wisdom and prevention measures adopted by everyone”, and the system of geohazard monitoring and early-warning. With post-quake geohazard characteristics in mind, it is imperative to establish pertinent indexing system and monitoring scheme; and to substantiate and improve organization and station setups for monitoring the individual’s hazard preventive tactics.. On the organizational aspect, homeland resources department needs to further cooperate with earthquake, meteorological, irrigation, and construction departments, to improve and elevate the effectiveness and pertinence of monitoring and early-warning system. Meanwhile, civilians need to acquire knowledge of disaster prevention and reduction and are to be informed of the geohazard risk of their living environments and mobilized to take part in “monitoring and taking preventive measures”.

Currently, in the recovery and rebuilding practices of every disaster area, some farmer victims, particularly those in relatively good, road-accessible areas, are re-settled in village compounds under governmental unified planning. About 40-50 percent of the victims are, however, scattered elsewhere randomly in the relocation exercise. Such farmer households with not more than five members are not looked after by the government regarding geohazard and geoenvironment assessment. In considering factors as occurrence commonality, hidden long term risk of geohazards, we recommend that government organizations also take appropriate action to conduct geohazard assessment or examining work for them as well. If possible, they should be grouped together in the move. It is to the advantage of effective management and administration when moderate-size victim populations are relocated to a given site.

In addition, in farmer housing construction, local homeland resources department should also provide timely guidance, to avoid erecting buildings at or near hazardous locations such as steep-cut slopes.

3.2 Site selections for settling spots for rebuilding

The Wenchuan earthquake resulted in a large number of towns severely damaged. If not rebuilt, some of

these towns need to be relocated. The list includes 2 county town seats, 10 villages and towns, and a large number of other resident-concentrated settlement areas. The Wenchuan earthquake disaster areas are typically areas with extremely complicated geomorphic settings in medium-high and high mountains. To begin with, on the one hand, the available sites for town construction have always been very limited. On the other hand, the earthquake has worsened the geoenvironments and increased geohazards, making it more difficult for selecting sites with proper safety. Under these circumstances, the planning of town and resident re-settlement necessitates that the following geological factors be considered:

- (1) First and foremost, in selecting new locations for settlement, especially county town seats, and thousand-odd population towns, the places that must be avoided are the three major fault zones (Qianshan fault, Yingxiu-Beichuan fault, and Maowen fault). In terms of the earthquake disaster, all the constructions in the fault zone were directly destroyed by quake-triggered fault displacement, with the Beichuan county town seat’s destruction the most severe (Figure 4). Therefore, the sites for rebuilding needs to take into consideration places where the three fault zones do not pass through them. The keep-away distances are as suggested in Table 1. In future, no more county town seat or important towns are to be built in earthquake fault zones again.



Figure 4. Beichuan county town seat (looking northeast). The Yingxiu-Beichuan fault runs right through the old county town. Post-earthquake Wangjiayan landslide (front) and new Beichuan high school rockfall (back) are shown.

- (2) Settlement areas and those within certain ranges need to be chosen to be away from geohazardous spots. To ensure that the most dangerous geohazard-hidden spots, especially potentially unstable slopes containing "quake-loosened mountain rocks", are kept out, it warrants that row-investigations of suspected locations be conducted. Whenever a geohazard in a populated area is identified, technically feasible and economically viable measures should be taken to remedy the situation. Especially it needs to be pointed out, a strong earthquake generates large amounts of loosened landslide rockfall. As debris source, either on steep slope or hanging over the middle and upper parts of gullies, they can trigger debris flow in rainy seasons, a hidden danger for selection of site for re-settlement. This should be highly regarded in the planning.
- (3) In addition to considering selecting settlement areas from level surfaces and river terraces between mountains, special attentions should be paid to the utility of gentle slopes at the foothills and overlapping hilly areas. This is decided by restricted favorable geomorphic conditions. These areas could be construction-appropriate sites, since they are usually geoenvironmentally friendly, and rarely have secondary geohazards. Even though there probably exist locally unstable slopes, but they can be fixed.
- (4) Avoid construction on secondary hazards, using reference of a lesson from residents relocated to the Three Gorges Reservoir area. This scenario easily arises in mountainous areas. It seems simple. But actual implementation is hard for a variety of reasons, and there could be mistakes.
- (5) Refrain from construction in highly elevated (above 1,500 m), steep and precipitous or sharply incised, topographically heaved or isolated zones. Investigations revealed that the earthquake induced landslides and rockfalls are mostly concentrated in these places.
- (6) Settlement sites near rivers must be assessed for the risk of barrier lake geohazard, as landslide could possibly block the river in the upstream by potential rockfall, landslide, and debris flow.
- (7) Selected settlement sites should be assessed for the risk of geohazards.
- (8) In areas with high earthquake intensity, it is surely necessary to reinforce slopes at construction sites. Around an important facility, it is better to fix the natural slopes found with potential risk. Based on the operation performances of slope protection mechanism during the Wenchuan earthquake,

continuously operated measures are evaluated for their safety performance from high to low in turn as: (1) anti-slippery peg, rope-bolt + frame; (2) cell structure + bolt; (3) general cell structure, hanging net + gunite. A passive protection network only is not a viable option.

Lastly, in selecting new sites for town rebuilding and concentrated-residential settlement, corresponding hazard risk and societal risk should also be evaluated, in addition to the above existing geoenvironmental conditions. For some sites pose relatively high societal and natural hazard risk, under the premise of respecting the nature, certain measures should be taken to comprehensively resolve the societal risk. Examples include reducing town size, adjusting overall functional arrangement, changing development orientation, etc. Population migration across regions should be reduced by all means.

3.3 Infrastructure reconstruction

3.3.1 The natural and scientific factoring in fundamental facility rebuilding

In the planning by Sichuan province, there will be 3,000 billion RMB investments for after-quake rebuild, among which 1,200 billion RMB would be allotted for 2009. The funding would be largely arranged for construction of transportation infrastructures with priority for railroads and highways. And there will be heavy constructions in years ahead. According to the announced projects, quite a number of them would start construction in 2009 and 2010. To our knowledge, currently these projects badly need early stage survey and design, and cannot meet the requirements for starting constructions. Some projects will cut cross the Longmen Mt. heavy disaster area, where geomorphic and geological conditions have been altered considerably, and require heavy pre-implementation exploration work. We believe that we must abide by scientific development view in expediting the rebuild well and fast. For the disaster area rebuild, we should strictly follow procedures and standards, to ensure the successful completion of the necessary survey-and-design period, and construction period. In the case that engineering overall planning has been approved, for area or project with simple geological condition, survey and design can be performed first, followed by construction. As for areas with complex conditions, enough time must be allocated.

At the same time, relevant departments need to consider the practical needs in the Wenchuan earthquake disaster areas, to amend and put into effect standards or guidelines for exploration and

design of geohazard prevention and remediation appropriate to strong quake destruction area. Specifically, the work includes emending standards of exploration, design, and construction regarding landslides, rockfalls, and debris flow hazards; and compiling guidelines of exploration, design and construction for prevention and remediation of quake-loosened mountain boulders, and induced barrier lakes.

3.3.2 Optimization of road network and raising routes standards to ensure the "life line" unblocked

One significant characteristic for the May 12 Wenchuan earthquake is that the quake happened in mountainous areas of Longmen Mt. with fragile geoenvironments. The quake caused collapse and landslide, resulting in road interruptions, which there is no way to bypass and are difficult to repair in time. Rescue operations were hindered. In this earthquake, various degrees of damage had done to structures within Sichuan territory including 9 railroads, 21 express highways, 16 national and provincial main line highways, road bed and road surface of 24,000 kilometer country road, bridges and tunnels. The roads to the disaster area were severely damaged, which made the rescue operations extremely hard. Especially the roads to Wenchuan's Yingxiu were all severely damaged and blocked. Even though the northern road route and western road route were connected and open by racing to repair by all out effort relatively quickly. However, Wenchuan is only 80-odd km away from Chengdu, but could only be accessible through a 700-km detour route by way of Maerkang and Lixian. This was difficult situation for rescue operations. It also reflects the road network's unreasonable arrangement, and low standard, especially fragility of the "life line" engineering, and the incompetence of disaster resistance. Therefore, we can make the following recommendations:

(1) In mountainous areas with complex geomorphic, geological conditions, existence of a reasonable road network is a must. Especially in the geoenvironmentally fragile "Tri-state areas", priority should be given to constructions of "life lines" to densely populated areas such as county town seat, towns and villages. Key areas need backup roads.

(2) Raising roadway standards and boosting the disaster resistance of roadways are desirable, including that for tunnels, open tunnels, shed tunnels and slopes. Under extreme condition, at least one working "life line" should be provided for.

3.3.3 Geohazard control over roadways

In the construction of transport infrastructures such as highways and railroads, high attention should be paid to geohazard control in roadway planning. Tactics include detour and avoidance as main scheme, in conjunction with remediation.

In the Wenchuan earthquake, transportation infrastructures such as highways and railroads were severely damaged. Rescue operations were greatly hindered. The earthquake touched off geohazards such as rockfalls, landslides, and destroyed bridges, roadbeds and slopes. These are the main causes for impaired transportation infrastructures such as highways, and railways. For example along the 79 km road section of national route 213 from Yingxiu to Wenchuan, there occurred 300-odd landslides and rockfalls. In most seriously affected Yingxiu to Caopo section, landslides reach 6-7 counts/km, and 70% of the road was destroyed. Three railroads (Bao-Cheng, Guang-Yue, and De-Tian) were once rendered useless. The steel rails were struck and twisted or even broken by collapsed falling rocks. Bridge structures were displaced, with support seat twisted broken, and piers of bridge cracked open. Tunnel linings were cracked and so on. Along Baoji-Chengdu railroad between Huixian and Yuguan the 109 tunnel collapsed and caused gas tank cars on fire, resulting in great loss as traffic was interrupted for 11 days and 19 hours. It is obvious that geohazard threats must be removed when complex mountainous area transportation infrastructure construction is carried out.

Underground tunnels have been believed to be quake-resistant. This was demonstrated again by the good anti-quake characteristics in several tunnels along national route 213 traversing the epicenter of the Wenchuan earthquake (Figure 1). In addition, the Wenchuan earthquake also indicates that even if an earthquake of magnitude 9 should come, engineered slopes also can protect themselves from disastrous consequences on the condition that they have certain or better support system in place (even if not that strong). Therefore, we recommend:

(1) In the after-quake rebuilding, in selecting routes for transportation infrastructures such as railroads and high-order highways, that traverse the quake faulting zones of Longmen Mt., we need to abide by the following fundamentals: 1). The blue print of the route lines should first detour and avoid section of frequent geohazards as well as strong quake-faulted section. 2). For the section such that construction through a geohazard cannot be avoided, it should be monitored all the way by

engineered tunnels. The tunnels should be designed following the principle of “early entering hole, and late exiting hole”, to ensure that the slopes at the entrance and exit have good geological conditions and sufficient support measures (these sections mainly means area threatened by quake intensity 9 or above). 3) In areas with intensity below 9 and sections with less geohazards, the designs are to be optimized to lower slopes and include reasonable support measures for slope safety.

- (2) Construction of roadwork for routes through active faults should be away from complex engineering work as far as possible, by avoiding crossing by high road embankment, deep trench, steep slope or high fly bridge, and enormously cut slope for road bed.
- (3) For existing highways and railroads, it is necessary to conduct overall quake-geohazard risk assessments. The assessment results would provide a basis for quake disaster prevention measures, including maintenance and improvement of engineering measures, vehicle operation safety measures, and people safety measures.

3.3.4 Recovery and rebuild: irrigation and hydropower projects

In the recovery and rebuilding processes, attention should be paid to the fundamentals of environment priority, and coordination of functional recovery and eco-environmental protection. In this earthquake, no hydropower dams collapsed, and the majority of large-and-medium hydropower dams, powerhouses and machine units remained largely intact. No induced secondary disasters occurred. No great loads of work are needed for the recovery and rebuilding.

- (1) Most hydropower plants in the disaster areas were constructed differently. They were built decades ago, without incorporating in the design basic discharge mechanism to withstand base flow for downstream eco-environment, without corresponding discharge structure and appropriate flow control scheme. This leads to zero flow or reduced flow sections in downstream of the dam, leaving river channel exposed and riverbed dried up. The aqueous ecosystems of mountainous rivers have been destroyed. Therefore, during this recovery and rebuild, we should follow the existing regulations to check eco-environment water usage, and take measures to satisfy the requirement for eco-flow discharge, improving the conditions of

before-quake's zero flow and reduced flow. Small hydropower plants in the recovery and rebuild should solve previous left-over environmental problems such as non-standard discarded dirt and debris, and no-implemented vegetation recovery.

- (2) In the disaster areas, large numbers of small hydropower plants are widely scattered. Most of them were built in remote mountainous areas. In addition, some of the hydropower plants were built decades ago. The constructions were done with little protection against earthquake and are in poor maintenance. The earthquake directly damaged some power houses, water taking hub, water diversion channel, tunnels, pressured pipelines, electric power generating and transmitting facilities, and work rooms. Some hydropower plant facilities also suffered destructive damage by quake-induced disasters such as mountain rock-falls, landslides, induced barrier lakes, etc. During this recovery and rebuilding, we should not rebuild small hydropower plants that do not fit in with the drainage area's hydropower planning. They include those that are costly and difficult to rebuild, with adverse environmental impact.
- (3) For river areas with large scale geohazards and significant alteration of geo-environmental conditions, it is necessary to overhaul the planning. for river irrigation and hydropower plants, and adjust irrigation and hydropower step planning, considering requirements of the overall planning of homeland and resources, river way's hydrological conditions, and circumstance of induced barriers.

3.4 Earthquake site protection

3.4.1 Planning for site protection during an earthquake

In planning for site protection against earthquake, scientific consideration and feasibility should take precedence. After the Wenchuan earthquake, all levels of governments came up with as many as 20-odd plans for monumentalizing victims and tourism development. The current planning is mostly concerned with reviving and protecting objects labeled as “relic protection”, which are mainly quake-destroyed buildings. The number of such related sites is somewhat too many and the scales are somewhat too large, so certainly there would be situations that take up too much ground surface, and hard to sustain for their high cost in operation and maintenance in the future. All these make them unable to function properly as protecting earthquake relic and sufficient usage of resources. Therefore, we suggest the following criteria for selections:

be pointed out that, current Weijiagou and sources of other several debris flow channels nearby the county town seat are still having large amounts of accumulated materials and in unstable state. Once the rainy season comes, or a strong storm arrives, there is still the possibility for eruption of large scale of debris flow, leading to burial of a portion of the previous old county town seat site again. The peculiar mechanism of after-quake debris flow allows unusually big eruption, which is very hard to avert and difficult to fix. Therefore, in a rather long time of the future the county town seat's relic sites still face very high risk of debris flow hazards, which also are great threats to relic site protections.

- (2) Beichuan county town seat also faces very high risk of flood hazard. The "June 10" Tangjiashan barrier lake's discharge brought down large amounts of material of barrier dam to deposit downstream, which greatly raised riverbed elevation for the section from Tangjiashan barrier dam downstream to Tongkou River downstream of the previous site of Beichuan county townseat. The riverbed along the section from previous county town seat to Tongkou River was generally raised 6-8 m. The raised riverbed greatly reduced the flow and flooding section. Therefore, when rainy season comes and once the upstream causes flooding, the previous Beichuan county town seat, especially the old county town seat portion would have little chance to escape from the doom of being flooded again. If no counter measures were taken, the invasion of floods year after year would accelerate the process of relic site collapse and destruction. Unfortunately, in July 2009, a rainstorm had already deposited sand and sills and half buried the relic site's name sign of tremendous size. Current Beichuan county town seat's quake relic site in fact is facing double threats of geohazard and flooding. The difficulties confronting protection are extremely harsh. Practical ways to deal with this situation could be: (1) Find out as soon as possible the geohazards that are threatening the previous Beichuan county town seat, especially the ranges, volumes, and triggering mechanisms and conditions of quake-cracked -and-loosened mountain rocks and loose materials along the channels and gullies. Based on the findings, effective hazard reduction plans could be made. (2) Reduce the risk of flooding hazards to the previous county town seat. A practical way is to alter previous Bei-Mao road's Longwei tunnel near the county town seat to a flood diversion tunnel;

Besides, at the "root part" of bar shape mountain ridge formed at return water bay of Tongkou River, an arrangement could be made to build a new flood diversion tunnel, which is estimated to be about 400 m long and not too difficult to construct.

4. CONCLUSIONS

We have summarized lessons learned from the Wenchuan earthquake and other disasters. We have analyzed geo-environmental factors that must be considered in planning for post-earthquake recovery and rebuilding.

The Wenchuan earthquake disaster validates the need of a national level emergency response and management system for gigantic catastrophe. Similarly in mountainous areas regional level geohazard monitoring and early-warning systems are also warranted for geohazard risk reduction and management. Pre-earthquake signs identification is an area subject to further study.

Because the Wenchuan earthquake's epicentral area extended along Longmen Mt. fault, widespread mountain rocks were loosened. Consequently this lowers the critical cumulative rainfall for debris flows by about 14.8-22.1%, and per hour rainfall intensity by about 25.4-31.6%.

Active faults pose extremely high risks to town constructions and infrastructures. In this paper we suggest modified distances to keep away from active fault, considering the effect of upper/foot walls. Geohazard threats are also dominant factors in selecting sites for re-settlement of victims, and relic protection. Our work provides guideline of geological consideration in planning construction and relocation site selection for the earthquake disaster area's residents. Our work also provides a basis for further development and studies of national emergency response and management of huge catastrophe, and geohazard monitoring and pre-warning systems.

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References

- Huang, R.Q. High slope stability simulation and process control (manuscript), 2009.
- Shieh, C.L., Y.S. Chen, Y.J. Tsai, J.H. Wu. Variability in rainfall threshold for debris flow after the Chi-Chi earthquake in central Taiwan, China. *International Journal of Sediment Research*. 24(2), 177-188, 2009.

- (1) The earthquake relic sites should provide protection for objects with prominent scientific values and educational significance. Constructions of commemoration venues should be integrated with scientific values and educational significance, and take full considerations of resource utilization and construction feasibility.
- (2) The choice of earthquake relic sites should depend on whether they need to be protected against natural phenomena such as fault displacement caused by earthquake activities, and ground surface uplifts, and whether there is a need for erecting typical, commemorative constructions to replace those damaged by earthquakes. Examples include earthquake faults and ground surface ruptures, typical geohazards, representative earthquake damaged construction, etc. Specifically, the objects to be protected include the following three types: The first type is earthquake faults or geohazard relic sites of scientific values, e.g., two to three sites containing fault displacement profiles (needed protections by artificial means), and several relic sites of typical geohazards. This type of relic protection can be integrated with geological park construction, mainly to help keep their natural conditions. The second type is representative quake-damaged constructions, e.g., the clock tower frozen right at the moment of the earthquake occurrence, as well as one to two typical factory buildings (constructions that are typically damaged do not fall within the protected objects category). This type of relic sites needs protection by artificially reinforced measures. The third type is comprehensive protection area both with construction relics and geological relics. For example, previous Beichuan county town seat and its periphery not only have construction relics but also earthquake faults, large scale landslides, debris flows, Tangjiashan barrier lake . etc., which can be protected as a comprehensive research and popular scientific education base. However, the protection format still mainly aims at preserving natural states, supplemented by some artificial maintenance measures.
- (3) Reasonable planning and scientific overall arrangement of earthquake relics.

In the protection setup, it is recommended to down size construction scale of single unit of relic protection site or commemoration venue. Relevant governmental departments can select their own representative relic or site to make planning to protect or construct commemoration venues, along the 300 km

earthquake zone according to relic types such as earthquake geological relic, geohazard relic, quake-damaged construction relic, etc. The number of protection sites and the scale are reasonably and scientifically determined, based on the types of relic sites and regional distribution. Meanwhile, it is recommended that the scale of common earthquake damaged construction relic sites should be strictly controlled. Large numbers of typical damaged construction should not be listed as protection objects. All earthquake commemoration venues can use the unified name: "May-12 Wenchuan Grand Earthquake so-and-so relic site".

3.4.2 Harsh circumstance for the protection of Beichuan county town seat earthquake relic sites

The protection of quake relics in Beichuan faces harsh reality. The previous site of Beichuan county town seat as the most representative quake destruction relic site has been included and relevant parties are arranging planning and design for quake relic protection. But findings of our surveys indicate that the protection of relic sites are also greatly challenged and must be seriously dealt with. These challenges mainly come from the following two aspects:

- (1) Previous county town seat faces extremely high risk of geohazards, which are hard to be relieved in the short term. The former seat is located at a narrow platform sandwiched on both sides by high and precipitous mountains. The mountain rocks on the left side are of relatively low strength slate and schist, and those on the right side limestone cut into blocks by multiple sets of fractures. Moreover, the Wenchuan Grand Earthquake's quake-generating fault—Yingxiu-Beichuan fault—passes right through the former Beichuan county town seat. Consequently, strong earthquake not only led to large scale landslides (Wang Jiayan landslide and rock collapse in Beichuan High School's newly developed area) on both sides of the former county town seat, but also led to the cracking, loosening and disintegration of large areal mountain rocks, especially for the high and precipitous mountain slopes, on the left side, made of weak strata such as slate and schist, etc. This provides sufficient material source for that "Sept 24" large scale debris flow of 2008, which generated many relic sites. It needs to

UPDATING OF HONG KONG GEOLOGICAL SURVEY 1:20,000-SCALE GEOLOGICAL MAPS

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Abstract: *The first edition 1:20,000-scale geological maps and accompanying memoirs covering the whole territory of Hong Kong were produced by the Hong Kong Geological Survey (HKGS) between 1986 and 1996. They were based on detailed field surveys, borehole interpretation, offshore seismic interpretation, petrographic and stratigraphic analysis. In 2003, the HKGS embarked on a programme to update the 1:20,000-scale geological maps and to release them in digital form. The updating programme is not a re-survey and relies heavily on desk studies of available information. It incorporates a vast amount of new information, and knowledge gained since the previously published maps were first surveyed. The updated geological maps are being implemented on a Geographical Information System (GIS) platform using a standard GIS template. The objective is to produce up-to-date, on-demand geological maps for specified use, and to enable site searches to be carried out more effectively, enabling geological enquiries to be handled more efficiently.*

INTRODUCTION

Geological information is of primary importance to engineers and planners involved with infrastructure development, geohazard risk management, utilisation of natural resources, and geoconservation. Geological information is most efficiently promulgated through the publication of geological maps and accompanying explanatory memoirs. Preparation and publication of geological maps is normally undertaken by dedicated governmental survey organisations that are tasked with updating and maintaining an archive of geological information. Managing this data efficiently has become a major challenge, and has necessitated the introduction of computerised databases and Geographic Information Management Systems. This paper describes how the Hong Kong Geological Survey (HKGS) has migrated from a conventional cartographical map production system, to a fully digitised map production system and archive using the latest GIS techniques.

FIRST EDITION 1:20,000-SCALE GEOLOGICAL MAP PRODUCTION

On the 5 May, 1982, the HKGS was established as a unit within the Hong Kong Government to carry out detailed geological surveys to facilitate physical planning and land use management in Hong Kong. In addition to publishing geological maps, a major objective of the HKGS was to establish itself as the hub of the territory's geological knowledge, providing expert geological advice to the Government, public and private sectors.

Up until 1982, the Hong Kong Government had relied upon two 1:50,000-scale geological maps and accompanying memoir that were produced by a territory-wide survey carried out in the late 1960's (Allen & Stephens, 1971). However, owing to the rapid infrastructure development and high demand for reliable geological information, a key mandate of the newly established Hong Kong Geological Survey was to carry out a re-survey of the whole territory with a view to publishing a series of 1:20,000-scale geological maps. Thus, the HKGS's core 1:20,000-scale mapping programme was given high priority, and the maps that were produced over the subsequent 14 years show considerably more detail than on the regional geological maps of most other national surveys owing to the large amount of borehole data, tunnel logs, cut slope exposures, and seismic records that were available. By the end of 1996, fifteen 1:20,000-scale geological maps with six accompanying geological memoirs covering the onshore and offshore areas of Hong Kong and the New Territories were available to professionals and the public (Figure 1).

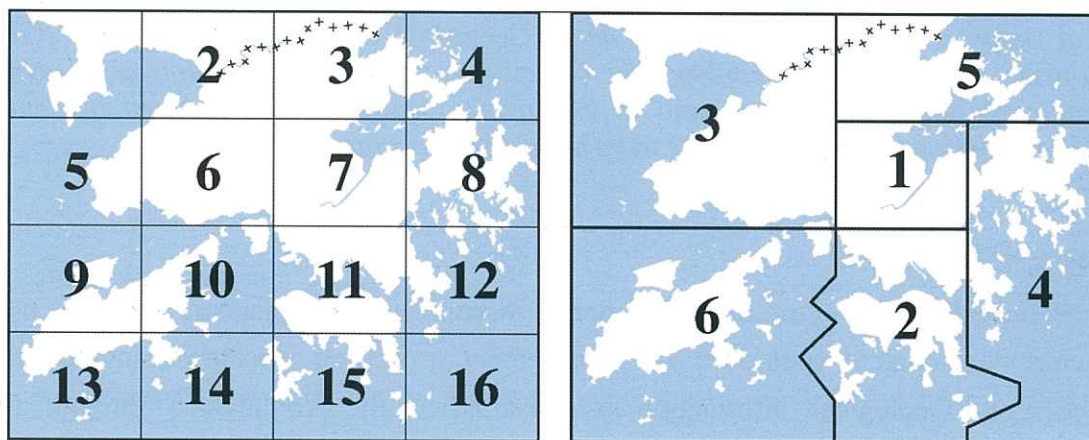


Figure 1. Published First Edition Hong Kong Geological Survey 1:20,000-scale Geological Maps (15 no.) and memoirs (6 no.).

During the 1990s, the HKGS also produced a number of 1:5,000-scale geological maps to cope with a growing demand for detailed, high quality geological information for strategic development areas. Many of these development areas are underlain by marble or marble-related rocks that can present difficulties for foundation design. Supported by a number of specialist projects such as a geochronology study and gravity survey, the mapping programme culminated in the production of 23 no. 1:5,000-scale solid and superficial geological maps, and six accompanying Sheet Reports.

Between 1996 and 2000, the solid and superficial geological data were updated and synthesised into two volumes, with an accompanying set of 1:100,000-scale geological and thematic maps

(Sewell et al. 2000; Fyfe et al. 2000). The thematic maps include magnetic anomalies, shaded relief, seabed sediments, onshore topography and offshore bathymetry.

UPDATING OF 1:20,000 GEOLOGICAL MAPS

Since the publication of the first edition 1:20,000 scale maps (Figure 2), new geological information has become available and advances in knowledge and map publishing techniques have occurred. In addition, the HKGS has developed a comprehensive series of geological datasets that have been progressively transferred onto a GIS platform. The components of the datasets include scanned records of field notes and sketches, sample descriptions, structural measurements, field and thin section photographs, and analyses compiled during the original field surveys and contained in the original HKGS paper archive. The datasets also include borehole records, tunnel data, whole-rock geochemical analyses (Sewell and Campbell 2001), stream sediment geochemical analyses (Sewell 1999; 2007), heavy mineral analyses, seismic track plots and scanned seismic records (Cheung and Shaw 1993).

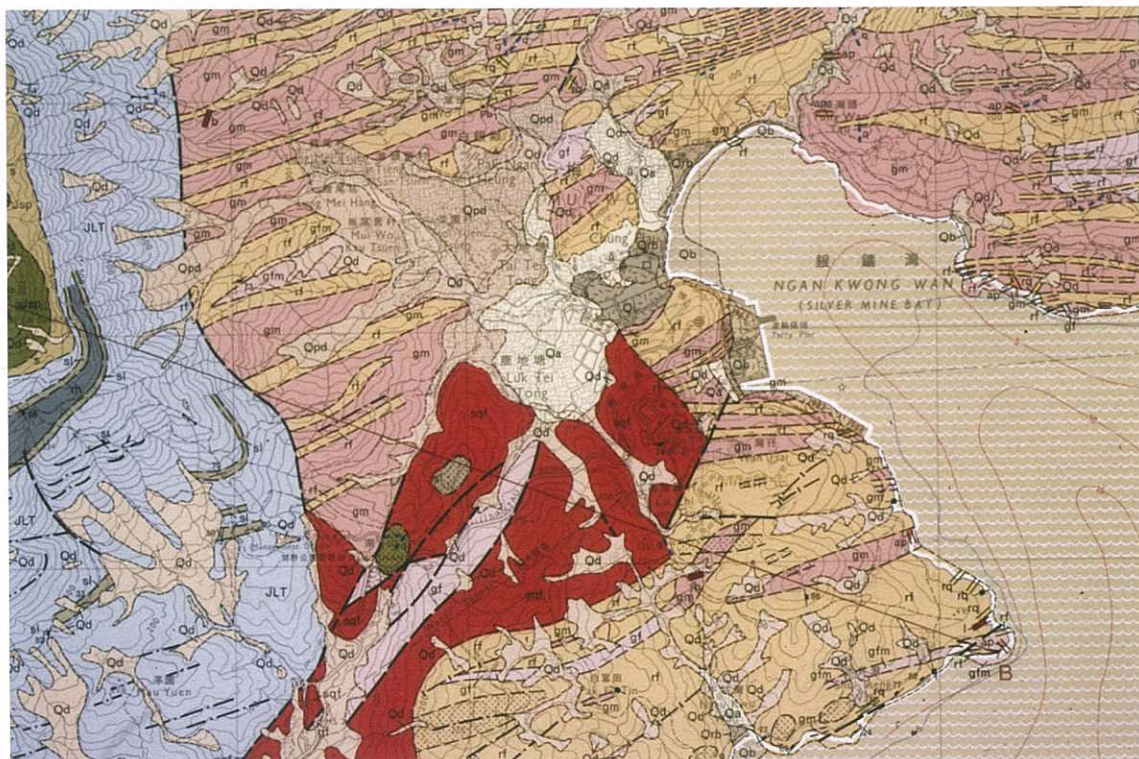


Figure 2. Part of 1:20,000-scale Geological Map Sheet 10 (GEO, 1991).

Accordingly, it soon became apparent that updating of the 1:20,000-scale geological maps was necessary in order:

- (a) To improve the reliability of the geological maps using the vast amount of information, and knowledge gained since the published maps were surveyed, from ground investigation (both onshore and offshore and including results from recent geophysical surveys), site formation, and tunnelling, and the current limits of reclamation, since the published maps were actually surveyed. Updating of the topographic base is also required.
- (b) To resolve inconsistencies between individual map sheets, as some have been on more recent maps at 1:100,000 scale. The inconsistencies resulted from evolution in terminology and interpretation that occurred during the preparation of the 1:20,000-scale maps.
- (c) To address specific issues not previously addressed, such as the geology of the c.10 km² of offshore areas not previously surveyed (including part of Deep Bay, and areas northwest, west and southwest of Lantau), which since 1997 have been included within the HKSAR, the locations of faults concealed by superficial deposits in both onshore and offshore areas, and the geology of key areas, such as Tuen Mun, where there exist divergent views within the local engineering geological community as to the interpretation.

The main benefits of the updating are the improved reliability of the geological maps that incorporate the vast amount of new information gathered since the original survey. Importantly, the digital maps and associated digital archives enable site searches to be carried out more effectively, enabling geological enquiries to be handled more efficiently. As a result of a project implementation review of the Harbour Area Treatment Scheme Stage I Project, a Government technical policy circular was issued in 2005 to require the project departments to submit all factual geological data obtained from government projects to the Geotechnical Information Unit (GIU) of CEDD. The HKGS will refer to such data when preparing new or revised geological maps.

The map updating project commenced in 2003 and is being conducted on a map-by-map basis. Two updated geological maps have been published so far (GEO 2008; GEO 2010). The geology of the approximately 10 km² of offshore areas not previously surveyed (including part of Deep Bay, and areas northwest, west and southwest of Lantau Island), which have been included within the HKSAR since July 1997, is being incorporated within the update. Priority is also being given to establishing the locations of faults concealed by superficial deposits in both onshore and offshore areas, and to revising areas of complex geology, such as Yuen Long and Ma On Shan. Several inconsistencies between individual map sheets, which resulted from developments in terminology and interpretation that occurred during the preparation of the

1:20,000 scale maps between 1986 and 1996, are also being reviewed.

Although the scope of the map updating project is comprehensive, it is not a re-survey and relies heavily on desk studies of available information with only limited field confirmation. The desk studies involve integration of new data together with a re-evaluation of the data collected during the original field survey (e.g. original field records, sketches, field photographs, sample descriptions, etc). Other published maps and related publications are being reviewed where necessary, including the 1:100,000 scale maps covering the whole of the HKSAR, and other results of recent rock age-dating and geochemical analysis investigations. The objective is to produce up-to-date, on-demand geological maps, including geological reports, cross-sections, and legends for specific areas.

In addition to making general purpose 1:20,000-scale geological maps available on demand, the updating programme will facilitate development of a GIS which will provide an important foundation for a comprehensive geological map data model. The geological map data model provides a structure for the organization, storage and use of geological map data, and defines the grammar, vocabulary and content to be used to represent information in the database system. Thus, considerably more information than will appear on the published map is required by GIS components for input and identification. The procedures and specifications for the compilation, capture and storage of HKGM20-GIS map data are described in this report. The purpose is to document the content and geographic extent of datasets, the data collection methods, integration and validation techniques applied to various components of the data, the accuracy of data sets and appropriate scales of use, and the data dictionaries used. Subsequent map sheets to be updated and digitized will follow the general procedures and specifications set out here so as to attain a consistent standard for compilation of the map sheets to be updated. As more data will invariably be generated in the preparation of future map sheets, they will be incorporated into the master datasets and therefore revision and updating of this report will be carried out after the completion of each new map sheet. As updated geological data will be added and stored in the HKGM20-GIS, a seamless geological map covering the whole of Hong Kong will be available on demand upon the completion of the map updating project.

MAP COMPILATION

The primary data sources for the geological map update are the published 1:20,000-scale geological maps, records of field notes, sketches, rock samples, mapping traverses, structural measurements, photographs, and analyses compiled during the original field survey and contained in the HKGS archive. These records are accessible within the HKGS GIS

Geodatabase¹. In addition, GIU borehole records, whole-rock geochemical analyses (Sewell & Campbell, 2001), stream sediment geochemical analyses (Sewell, 1999; 2007), landslide data (Enhanced Natural Terrain Landslide Inventory, GEO 2011), seismic lines and selected scanned traces (Cheung & Shaw, 1993; HKGS archive), and reclamation histories, have also been added to the Geodatabase. Magnetic data used in the map update have principally come from existing onshore and offshore surveys and interpretations (EGS, 1997; 1999a; 1999b; IGGE, 2000; Cosine Limited, 2000), and a summary in Sewell et al. (2000). The onshore superficial deposits are being revised mainly using the 1964 high-level (12,500 feet) aerial photographs which are of very high resolution.

The new information compiled from various data sources is initially transferred in full detail to stable media film with metric grid and compared with the published geological maps. The maps are compiled at 1:2,500 scale for reduction to be read at 1:20,000 scale. Geological data are drawn as accurately as possible. Adjustments are made to linework where necessary, and justification (e.g. borehole data, additional field spot checking, etc) for such amendments annotated on the map accordingly. All structural data and geological contacts are plotted using standard geological symbols as used on previous 1:20,000-scale Hong Kong Geological Survey maps. The stratigraphic nomenclature follows, as far as possible, that outlined in the published 1:100,000-scale geological map of Hong Kong, with the addition of member units, geological lines, etc, as shown on the 1:20,000-scale geological maps. All map features on each 1:2,500-scale data source sheet are accompanied by lists of attributes which describe them according to the standardized data definitions. For example, boreholes should have a list of GIU Report Number, types and depth of each superficial deposit layer, rock types and depth of rock head etc. As far as possible, the stratigraphical nomenclature is aligned with that on adjoining map sheets.

General point and line spacing and polygon size criteria are observed according to a strict set of rules appropriate for reproduction at 1:20,000 scale. Similarly, minimum line spacing and polygon widths, and minimum sizes of symbols used for structural measurements, adhere to a strict set of guidelines based on the published 1:20,000-scale geological maps. Generalisation of some linework is sometimes necessary but where possible, changes are kept to a minimum.

GIS DIGITISATION

Once the draft updated map has been compiled and approved for digitisation, the compilation sheet is processed for GIS data capture. The compilation sheet is generally digitised to a level of detail appropriate for 1:20,000-scale output, bearing in mind that there will be a 8x reduction of

¹ The GIS Geodatabase comprises geological datasets that are defined as GIS layers established for the preparation of HKGM20 GIS maps.

clarity from the 1:2,500-scale compilation. Data for additional attributes which describe the digitised features are normally entered at this time. Where the required updating work is minimal, the existing 1:20,000-scale digital linework may be amended to save time.

After digitisation, the digital map is checked against the compilation sheet for errors in digitising. Data verification includes mainly checking the accuracy of plotting, the consistency of attributes, and the reliability of data from various sources.

MAP PRODUCTION

After the digital data have been verified for each 1:2,500-scale sheet, a preliminary draft map at 1:20,000 scale is printed in-house from the GIS. All map elements, including cover panel, geological symbols, legends, cross sections, scale, map index, acknowledgments, geological explanatory notes are assembled to prepare a draft layout.

The draft 1:20,000-scale geological map is then circulated to the Senior Mapping Geologist for review and discussion. For map sheets which have involved significant change in stratigraphic or structural re-interpretation, peer review from external authoritative geological survey organizations will also be sought. After review, all feedback will be considered and the map will be edited, checked, and passed through the Senior Mapping Geologist to Chief Geotechnical Engineer/Planning, for final review and approval.

The digital file of the map is then sent to a selected printer for offset printing. Exceptional care is taken to ensure that high quality and accurate reproduction of the hard copy of the map is achieved during the printing process. The printed copy of the map is then made available for purchase from the Hong Kong Government Bookstore. Upon request, a CD will be prepared by the Hong Kong Geological Survey to disseminate in ArcReader format the digital version of the map sheet.

GENERAL REVISIONS AFFECTING ALL MAPS

Some general revisions have been made to all updated 1:20,000-scale geological maps in order to make them consistent with the territory-wide 1:100,000-scale geological map.

Volcanic-Plutonic Rock Nomenclature

The first editions of the HKGS 1:20,000-scale geological maps (GCO, 1986a, b; GCO, 1987; GCO, 1988a, b; GCO, 1989a, b, c & d; GCO, 1991; GEO, 1991; GEO, 1992, GEO, 1994; GEO, 1995; GEO, 1996) assigned the volcanic, sedimentary and metamorphic rocks to lithostratigraphic formations, whereas the intrusive, granitic rocks were classified primarily on the basis of grain size. Subsequent detailed petrological, geochemical and geochronological analyses of the mapped units, enabled a volcanic formation and pluton-based nomenclature to

be adopted for the major extrusive and intrusive units depicted on the 1:100,000-scale geological map (Sewell et al., 2000). Similarly, formation or pluton names and rock type descriptors have been assigned to all the geological units depicted on the updated maps. Thus, on the new map, rock type descriptors indicate the dominant lithology of the geological units, so it is possible to depict lithologies alone, or to depict the formation and pluton nomenclature. As a result, several inconsistencies between the original 1:20,000-scale maps have now been rectified, and the nomenclature has been brought into line with the 1:100,000-scale geological map.

Dyke Annotation and Nomenclature

Some changes in rock nomenclature have also been necessary in order to bring terminology into line with international practice. For example, dark-coloured dykes mapped as “basalt” on 1:20,000-scale maps are in fact either “basaltic andesite” or “lamprophyre” according to the recommendations of the International Union of Geological Sciences Subcommittee on the systematics of igneous rocks (LeMaitre 1989). Therefore, they have been broadly termed “mafic dykes” on the updated maps. Also, many dykes less than 5m wide were depicted as over-thickened bodies on the first edition maps. In order to better reflect their dimensions, these dykes have been depicted as line thickness on the updated maps.

Superficial Geology

In common with the onshore pre-Quaternary stratigraphy, understanding of the Quaternary stratigraphy of Hong Kong steadily evolved over the original ten-year mapping period (1983 to 1993). As the mapping progressed, differences emerged in the nomenclature adopted, and the classifications employed, for the superficial deposits. Consequently, the terminology has been re-examined and rationalised as part of the map-updating programme. For example, various terms for “raised beaches” have recently been addressed by Wong and Shaw (2007). Important advances have been made in the offshore area, particularly as a result of the SEAMAT Study (Cheung & Shaw, 1993), a territory-wide offshore reconnaissance seismic and borehole survey that ran concurrently with the original geological mapping programme. Following finalisation of the 1:20,000 scale maps and memoirs, a comprehensive Quaternary onshore and offshore lithostratigraphy was compiled and presented by Fyfe et al. (2000).

On the updated maps, both the onshore and offshore superficial deposits are, wherever possible, being assigned to the formations defined in Fyfe et al. (2000). Onshore, the superficial deposits are being reassessed on the basis of detailed aerial photograph interpretation (API) and/or borehole interpretation, supplemented by existing data on absolute ages (Sewell et al., 2000, and references therein). However, it has not been possible to reclassify all the onshore superficial deposits, and there remain large areas of undifferentiated mass movement deposits that are grouped as “Pleistocene and Holocene” without a unit

designation. Offshore, the superficial deposits are being assigned to their respective formations.

Solid Only Geological Maps

Combining the available gravity, magnetic and borehole data for offshore areas, with borehole data for onshore areas, solid only geological interpretations are being produced as part of the map updating programme. This is the first time such an interpretation has been undertaken for the 1:20,000-scale maps, and it will form a separate GIS layer.

DEVELOPMENT OF 3-D GEOLOGICAL MODELS

Because a large volume of new geological data becomes available annually from borehole, seismic reflection profile, tunnel, and geotechnical investigations, the geological models for Hong Kong are continually being refined. Growing demand for accurate, site-specific geological information has necessitated the introduction of three-dimensional (3-D) software technologies to improve geological interpretations and development of geological models.

Geological Survey organization's worldwide are moving to adopt GIS technology for geoscience data management and delivery. Along with improvements in digital technology, geological maps have become more sophisticated and are now entering a 3-D phase of development. There is now enormous scope to manage large volumes of geological data and to model and visualize these data in three dimensions.

The HKGS is currently keeping pace with these developments by improving its capability in GIS and related technologies. The software, known as GSI3D, is available in the form of a subscription to a British Geological Survey (BGS)-led research and member-users consortium. The HKGS has now become a member of the consortium which is dedicated to developing GIS-based software for visualising 3-D geological models.

Membership licences grant subscribers access rights to the software, with regular updates, supported by user documentation. In addition, membership allows access to the user consortium's community, which will function as a knowledge pool for experience-sharing and to facilitate further improvements to the GSI3D software system.

The GSI3D software is ideally suited to the HKGS's borehole database currently being developed on an Arc-GIS platform as part of the 1:20,000-scale map updating programme (Figure 3).

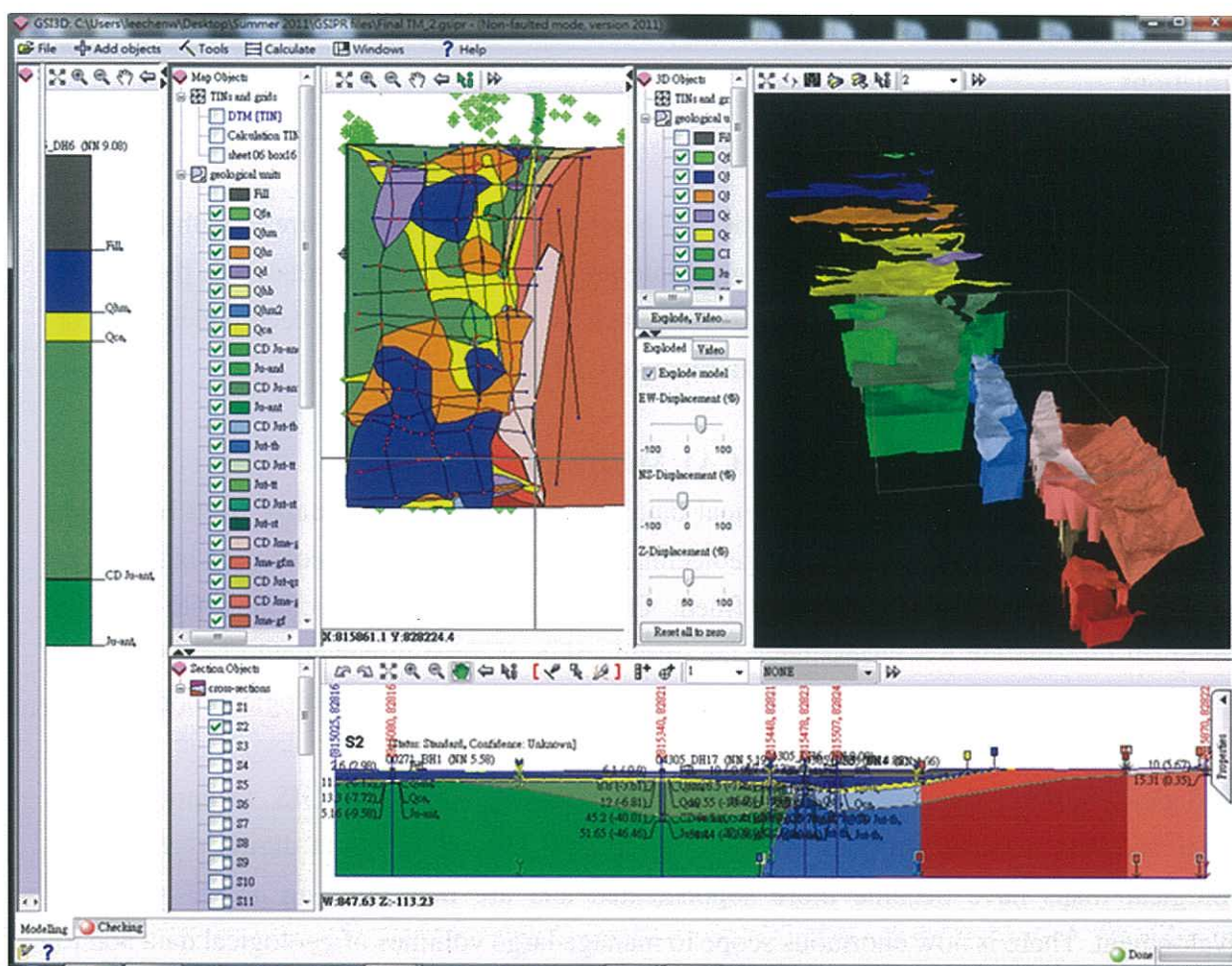


Figure 3. Screen Snapshot of GSI3D Software Used for Modelling Complex Geology in the Tuen Mun Area.

REFERENCES

- Allen, P.M., and Stephens, E.A. (1971). Report on the Geological Survey of Hong Kong. Hong Kong Government Printer, 107 p. plus 2 maps.
- Cheung, P.C.T. & Shaw, R. (1993). SEAMAT Study : Final Report. Geotechnical Engineering Office, Hong Kong, 163 p.
- Cosine Limited (2000). Merging of Datasets and Generation of Offshore Magnetic and Geological Maps – Hong Kong SAR Marine Area. Cosine Limited, 13p.
- Electronic & Geophysical Services Ltd. (EGS) (1997). Strategic Sewage Disposal Scheme Stage II Preliminary Project Feasibility Study Geophysical Survey. Final Report Job No. HK144799, Electronic and Geophysical Services Ltd., Hong Kong, 46 p. plus 6 appendices and 49 drawings.

Electronic & Geophysical Services Ltd. (EGS) (1999a). Cheung Chau, Lamma Island and the Po Toi Islands Marine Magnetic Survey. Final Report Job No. HK136898, Electronic and Geophysical Services Ltd., Hong Kong, 42 p.

Electronic & Geophysical Services Ltd. (EGS) (1999b). Additional Data Interpretation Geophysical Survey. Final Report Job No. HK145599, Electronic and Geophysical Services Ltd., Hong Kong, 15 p.

Fyfe, J.A., Shaw, R., Campbell, S.D.G., Lai, K.W., & Kirk, P.A., (2000). The Quaternary Geology of Hong Kong. Geotechnical Engineering Office, Civil Engineering Department, The Government of the Hong Kong Special Administrative Region, 209 p. plus 6 maps.

Geotechnical Control Office (GCO) (1986a). Sha Tin. Hong Kong Geological Survey Sheet 7, Solid and Superficial Geology, 1:20,000 Series HGM20, Hong Kong Government, 1 map.

Geotechnical Control Office (GCO) (1986b). Hong Kong and Kowloon. Hong Kong Geological Survey Sheet 11, Solid and Superficial Geology, 1:20,000 Series HGM20, Hong Kong Government, 1 map.

Geotechnical Control Office (GCO) (1987). Hong Kong South and Lamma Island. Hong Kong Geological Survey Sheet 15, Solid and Superficial Geology, 1:20,000 Series HGM20, Hong Kong Government, 1 map.

Geotechnical Control Office (GCO) (1988a). Yuen Long. Hong Kong Geological Survey Sheet 6, Solid and Superficial Geology, 1:20,000 Series HGM20, Hong Kong Government, 1 map.

Geotechnical Control Office (GCO) (1988b). Tsing Shan. (Castle Peak). Hong Kong Geological Survey Sheet 5, Solid and Superficial Geology, 1:20,000 Series HGM20, Hong Kong Government, 1 map.

Geotechnical Control Office (GCO) (1989a). San Tin. Hong Kong Geological Survey Sheet 2, Solid and Superficial Geology, 1:20,000 Series HGM20, Hong Kong Government, 1 map.

Geotechnical Control Office (GCO) (1989b). Sai Kung. Hong Kong Geological Survey Sheet 8, Solid and Superficial Geology, 1:20,000 Series HGM20, Hong Kong Government, 1 map.

Geotechnical Control Office (GCO) (1989c). Clear Water Bay. Hong Kong Geological Survey

Sheet 12, Solid and Superficial Geology, 1:20,000 Series HGM20, Hong Kong Government, 1 map.

Geotechnical Control Office (GCO) (1989d). Waglan Island. Hong Kong Geological Survey Sheet 16, Solid and Superficial Geology, 1:20,000 Series HGM20, Hong Kong Government, 1 map.

Geotechnical Control Office (GCO) (1991). Sheung Shui. Hong Kong Geological Survey Sheet 3, Solid and Superficial Geology, 1:20,000 Series HGM20, Hong Kong Government, 1 map.

Geotechnical Engineering Office (GEO) (1991). Silver Mine Bay. Hong Kong Geological Survey Sheet 10, Solid and Superficial Geology, 1:20,000 Series HGM20, Hong Kong Government, 1 map.

Geotechnical Engineering Office (GEO) (1992). Kat O Chau. Hong Kong Geological Survey Sheet 4, Solid and Superficial Geology, 1:20,000 Series HGM20, Hong Kong Government, 1 map.

Geotechnical Engineering Office (GEO) (1994). Tung Chung. Hong Kong Geological Survey Sheet 9, Solid and Superficial Geology, 1:20,000 Series HGM20, Hong Kong Government, 1 map.

Geotechnical Engineering Office (GEO) (1995). Shek Pik. Hong Kong Geological Survey Sheet 13, Solid and Superficial Geology, 1:20,000 Series HGM20, Hong Kong Government, 1 map.

Geotechnical Engineering Office (GEO) (1996). Cheung Chau. Hong Kong Geological Survey Sheet 14, Solid and Superficial Geology, 1:20,000 Series HGM20, Hong Kong Government, 1 map.

Geotechnical Engineering Office (GEO) (2008). Sha Tin. Hong Kong Geological Survey Sheet 7, Solid and Superficial Geology, 1:20,000 Series HGM20, 2nd Edition, Hong Kong Government, 1 map.

Geotechnical Engineering Office (GEO) (2010). Hong Kong South and Lamma Island. Hong Kong Geological Survey Sheet 15, Solid and Superficial Geology, 1:20,000 Series HGM20, 2nd Edition, Hong Kong Government, 1 map.

Geotechnical Engineering Office (GEO) (2011). Enhanced Natural Terrain Landslide Inventory (updated to Year 2009). Geotechnical Engineering Office, Civil Engineering and Development Department, Hong Kong SAR Government.
<http://hkss.cedd.gov.hk/hkss/eng/slopeinfo/siswelcome.asp>

Institute of Geophysical and Geochemical Exploration (IGGE) (2000). Eastern Hong Kong Waters marine Magnetic Survey. Final Report. Institute of Geophysical and Geochemical Exploration MLR, PRC, Hong Kong Office, 52p.

Le Maitre, R.W. (ed.) (1989). A classification of the igneous rocks and glossary of terms. Recommendations of the International Union of Geological Sciences on the Systematics of Igneous Rocks. Blackwell Scientific Publications, Oxford, 193 p.

Sewell, R.J. (1999). Geochemical Atlas of Hong Kong. HKSAR Government Printer. 120 p.

Sewell, R.J. (2007). Geochemical Data for Hong Kong Stream Sediments. Geological Report GR 1/2007, Geotechnical Engineering Office, Hong Kong, 274 p.

Sewell, R.J., Campbell, S.D.G., Fletcher, C.J.N., Lai, K.W. & Kirk, P.A. (2000). The Pre-Quaternary Geology of Hong Kong. Geotechnical Engineering Office, Civil Engineering Department, The Government of the Hong Kong Special Administrative Region, 181 p. plus 4 maps.

Sewell, R.J. & Campbell, S.D.G. (2001). Geochemical data for Hong Kong rocks. Geotechnical Engineering Office Report GR 4/2001, 120 p.

Wong, J.C.F. & Shaw, R. (2007). High Level Coastal Deposits in Hong Kong. Geological Report GR 2/2007. Geotechnical Engineering Office, Hong Kong, 51 p.

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LONG-TERM STRATEGY FOR ROCK CAVERN DEVELOPMENT IN HONG KONG

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ABSTRACT: *Land is a scarce resource in Hong Kong and there is a pressing need to optimize the supply of land to support social and economic development. In March 2011, the Civil Engineering and Development Department (CEDD) of the Hong Kong SAR Government completed a strategic study on “Enhanced Use of Underground Space in Hong Kong”, which concluded that the geology and topographical setting of Hong Kong are very suitable for cavern development.*

The 2011-12 Budget Speech under “Increasing Land Supply” highlighted the need to formulate a long-term strategy for cavern development, and to explore the feasibility of relocating suitable existing government facilities to rock caverns in order to release land for housing and other uses. In 2011, a study was commissioned by CEDD on “Increasing Land Supply by Reclamation and Rock Cavern Development cum Public Engagement”. Technical studies are to be carried out to establish the selection criteria for identifying suitable government facilities for relocation to caverns and the public’s views and support on the option of increasing land supply through rock cavern development have been sought.

The Hong Kong Chief Executive’s 2011-2012 Policy Address under “Policy on Land Development and Accumulation”, also stressed the need to actively explore the use of rock caverns to re-provision existing government facilities and releasing such sites for housing and other uses as one of the innovative measures to expand Hong Kong’s land resources. This paper describes the key planning and technical issues that need to be considered in order to provide a systematic and sustainable approach to develop rock caverns as a credible means to increase land supply in Hong Kong, particularly in the urban area.

Keywords: Planning, rock cavern, underground space

LAND SUPPLY IN HONG KONG

Hong Kong’s topographical setting with steep natural hillsides pose significant constraints to development (Figure 1). Land, particularly in the urban area, is a scarce resource. To support social and economic development, there is a pressing need to optimise land and improve the supply of land for various uses by sustainable and innovative approaches. One possible way is through rock cavern development for suitable types of land use.



Figure 1. Aerial view of Hong Kong Island

Over the past few years, Hong Kong has faced several challenges in land development that have hindered realization of the strategy and affected housing land supply. They include rising public concerns about building heights and high development density as well as nature and heritage conservation and problems of land resumption, compensation and clearance for developments in the New Territories.

The Hong Kong Special Administrative Region (HKSAR) Government has identified Six Industries in the Hong Kong economy where Hong Kong enjoys clear advantages for further development. These are the cultural and creative industries, medical services, education services, innovation and technology, testing and certification services, and environmental industries. The Administration's initiatives to develop the Six Industries may also require more land. We need to ensure that land will be available in time to capture "windfall" opportunities for economic development projects to suit the fast changing market conditions.

STUDY ON ENHANCED USE OF UNDERGROUND SPACE IN HONG KONG

In October 2009, Hong Kong's Chief Executive presented the 2009-10 Policy Address on 'Breaking New Ground Together'. The Development Bureau put forward a new initiative under the Policy Agenda of 'Developing the Infrastructure for Economic Growth', to launch strategic planning and technical studies to facilitate planned development of underground space aiming at promoting the enhanced use of rock caverns as part of Hong Kong's pursuit of sustainable development.

A strategic planning and technical study on 'Enhanced Use of Underground Space in Hong Kong', hereafter referred to as the "Underground Space Study" was commissioned by the Geotechnical Engineering Office of the Civil Engineering and Development Department (CEDD) of the HKSAR Government to help take the policy initiative forward. The study, which was completed in March 2011, explored the opportunities to enhance the effective use of land resources in Hong Kong from a new perspective through the planned development of underground space. The key findings were:

- Hong Kong is particularly suitable for developing rock caverns from the geological perspective. The hilly areas in the urban fringes of Hong Kong with strong rocks and convenient access are particularly suitable for rock cavern development.
- By reprovisioning suitable government facilities inside caverns and releasing the original land as well as the adjacent sterilized land for housing and other uses, cavern development is a viable option to increase land supply.
- Cavern development could also be a good source of land supply for accommodating new infrastructure facilities which will otherwise occupy land and territorial space. Reserving underground space could accommodate future projects and expansion of facilities underground.
- For those “Not-in-My-Backyard” (NIMBY) facilities like sewage treatment works and refuse transfer station, the cavern option may help reduce adverse impacts on the local environment, remove incompatible land uses and alleviate the NIMBY sentiment.

The key findings of the study as summarised by Chan (2011) and the Executive Summary has been made publicly available (Arup, 2011). During the course of the Underground Space Study, various local professional bodies were consulted and they were generally supportive of the initiative. Upon completion of the study, the feedback of Government consultative bodies and the public response to the initiative of enhancing the use of rock caverns as part of Hong Kong’s pursuit of sustainable development was generally positive.

STUDY ON INCREASING LAND SUPPLY BY RECLAMATION AND ROCK CAVERN DEVELOPMENT CUM PUBLIC ENGAGEMENT

The 2011-12 Budget Speech under “Increasing Land Supply” highlighted the need to formulate a long-term strategy for cavern development, and to explore the feasibility of relocating suitable existing government facilities to rock caverns in order to release land for housing and other uses. In 2011, a further study was commissioned by CEDD on “Increasing Land Supply by Reclamation and Rock Cavern Development cum Public Engagement”. The main purpose of the study is to develop a set of selection criteria, based on the guiding principles of social harmony and benefits, enhanced environmental performance and economic efficiency and practicality, and identify suitable government facilities for relocation to caverns. Under the study a public engagement exercise has been launched to engage the public in considering rock cavern development as an innovative means to increase land supply in Hong Kong. Members of the public are generally supportive of the initiative of enhancing the use of rock caverns as part of Hong Kong’s pursuit of sustainable development.

BACKGROUND TO CAVERN DEVELOPMENT

Hong Kong has a rich legacy of underground tunnelling and during its development some 430 km of tunnels have been constructed and some 180 km are planned up to 2020 (Pang & Woodrow, 2009). These underground structures cater for water supply, mass

transportation (such as railways and roads), drainage, conveyance of sewage and electrical cables. Hong Kong also has a diversity of deep basement-type excavations formed by cut and cover methods for MTR station concourses, car parks, retail and commercial space and more recently flood control.

Cavern construction is an established technology that has seen continual improvement in its application. Since the 1980s, the HKSAR Government has already carried out the necessary technical and preparation work for cavern development in Hong Kong. Technical standards on cavern engineering and fire safety design, as well as planning guidelines to establish the ground work for rock cavern development in Hong Kong have been published. The details have previously been outlined by Chan and Ng (2006). A few purpose-built rock caverns were constructed in the mid-1990s to accommodate public facilities to meet the needs of the community (Figure 2), namely the Island West Refuse Transfer Station (1997), Stanley Sewage Treatment Works (1995) and Kau Shat Wan Explosives Depot (1997). Also in 2009, the University of Hong Kong reprovisioned the Western Salt Water Service Reservoirs in rock caverns to release the site for the Centennial Campus development.

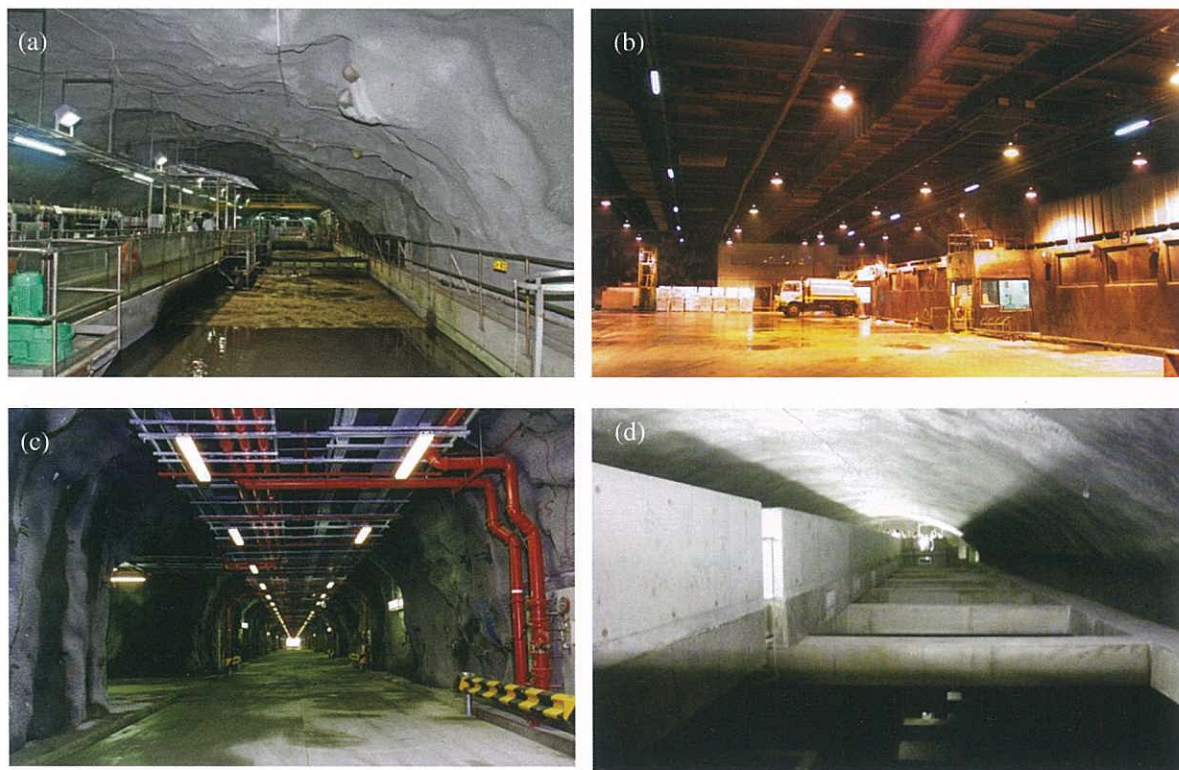


Figure 2. Examples of purpose-built caverns in Hong Kong: (a) Stanley Sewage Treatment Works, (b) Island West Refuse Transfer Station, (c) Kau Shat Wan Explosives Depot and (d) Western Salt Water Service Reservoirs

Despite having demonstrated that rock caverns can be cost-effective, through release of valuable surface land for other beneficial uses, and in some cases, yielding additional environmental, safety and security benefits, the development of cavern schemes to house suitable facilities in Hong Kong has generally been limited. To date, rock cavern development is either out of necessity or in circumstances where suitable surface land is not available.

CONSTRAINTS TO ROCK CAVERN DEVELOPMENT

The Underground Space Study has benchmarked Hong Kong's practice against worldwide practice, and has raised the issue of whether we can do more and how the HKSAR Government can facilitate this. In Hong Kong, the owner of the surface also owns to the sky and to the depths and has the right to develop its underground space. Underground development for public purposes can be developed underneath private lots pursuant to the relevant ordinances (e.g. Lands Acquisition Ordinance, Land Resumption Ordinance); however, this is subject to compensation to the land owner. Conversely, privately orchestrated underground development cannot be developed beneath private lots under the ownership of others.

The development model for many of Hong Kong's projects is a mixed-use development and the ownership of the land is often amongst multiple parties. From an administrative viewpoint, it would be difficult to organize all of the owners to consent to the underground development beneath these land plots. To avoid complicated and potentially contentious land ownership issues it is preferred to develop caverns to house government facilities beneath areas where there is no private ownership. In this respect the hillsides in the urban fringes are particularly suited for cavern development.

To facilitate optimal underground development, a revised regulatory framework would be required. Components of these amendments would include the ability to create joint ownership between surface and underground developments. However, this would only be an option in case of newly disposed land and legislative amendments may be required for the interfacing between joint landowners.

Despite the promulgation of planning and technical guidelines on rock cavern development in Hong Kong in the early 1990s, there has been no systematic assessment of the potential and the benefits of rock cavern development in the land use planning process and the development of public works projects, as demonstrated by the few public facilities that have been housed in rock caverns.

The Hong Kong Planning Standards and Guidelines (PlanD, 2008) with regard to rock cavern development were revised in 2008 to highlight the need to identify the opportunities in the early stage of the land use planning process and to assess the cavern option at the initial project planning stage for new project proposals, as well as to set out some of the implementation issues affecting rock caverns. Despite the guidelines, there is still slow progress on the development of underground space.

It is recognised that each individual public works project by its very nature must have a public demand and public support. Whether a particular facility should be located within caverns is largely left to the individual facility providers to decide (Ling, 2011). One of the key issues amongst potential end users, is the general perception that caverns are more expensive in terms of both capital and operating/maintenance costs. It is likely that in some cases operating/maintenance costs can be expected to be higher, which is mainly a result of the additional energy costs associated with lighting and ventilation for an underground facility.

Notwithstanding this, the ground mass surrounding the underground space provides

insulation and all-weather protection from the surface climate, and rock caverns can offer a relatively uniform environment for year-round operation or use, even during inclement weather conditions. Furthermore, for some land uses there may be opportunities to apply innovative and sustainable approaches to harness energy developed during the process for use in the daily operation of the facility, thereby reducing costs. Examples that could be further explored include capture of biogas in the sludge digestion of sewage treatment processes for generation of electricity or installation of turbines within pipe networks that rely on gravity and differential heads to drive the water system.

The present economic analysis for considering the cost of a specific government facility has assumed that the land is provided at no extra cost to the facility provider. This has resulted in any cost comparisons between the surface and cavern option being skewed in favour of the surface option. An example would be for a new government facility proposed for an area of reclaimed land adjacent to steep hillsides where the cavern option may also be considered. In comparing the cost options, as the site formation for caverns is an integral part of the works it is normally included in the overall cost. However, the previous cost of formation of the reclaimed area prior to the project implementation is not required to be considered a cost in the surface option resulting in an inequitable comparison.

The analysis has also not taken into account the opportunity cost of any alternative use of that specific site or the cost of any adverse impact or sterilisation on the potential use of the neighbour sites (Ling, 2011), i.e. in building the facility at that location, Hong Kong has forgone the opportunity to build other facilities to meet the community's needs, or to improve the local environment by freeing up land for other community uses. In addition, many of these benefits of underground space to the community are intangible, e.g. additional open space and reduced congestion or likely reduction in complaints. For NIMBY facilities which are needed to support the needs of the community, they can be located away from the public eye if they are placed underground. Examples of this are the Stanley Sewage Treatment Works and Island West Refuse Transfer Station, where the daily operations have been effectively shielded from the public view to the extent that many of the local population are unaware of their existence (Figure 3). There is currently no framework to take intangible benefits into account to offset the additional costs associated with underground space development.



Figure 3. Cavern portals of (a) Stanley Sewage Treatment Works and (b) Island West Refuse Transfer Station

UNDERGROUND PLANNING

Some countries have now recognised that the unplanned development of underground space based on the 'first-come-first-served' approach will have adverse impact on the growth of cities. To address this, Helsinki in Finland has developed an underground master plan with legal status to reserve underground space for long-term development of public and private facilities. Singapore is also taking measures to catalyse the development of underground space and strategic initiatives have been introduced, which include developing an underground master plan and creating an underground land bank.

Previously, there was a lack of public awareness of the use of rock caverns in Hong Kong, which was testament to the success of the existing cavern schemes in effectively hiding the facilities from the public's view. The acceptance of NIMBY facilities within the urban areas is a contentious issue. The planned use of underground space could offer advantages in locating new facilities away from the public eye, reducing visual and other impacts on the residents. Furthermore, if needed, existing NIMBY facilities that have the flexibility to be reprovisioned on the urban fringes without compromising the services to the community could be moved, freeing up valuable land for other, more attractive and beneficial community uses.

Given the demand for surface land, a more holistic and innovative approach to increase land supply is required. Planned use of underground space, e.g. housing suitable new/existing government facilities in rock caverns, thereby releasing the land for other beneficial uses, could contribute towards this aim. Furthermore, introducing innovative cavern usage could help to accommodate those facilities that have difficulty in finding suitable surface sites (e.g. columbaria and rock processing plants) and those that could benefit from the stable environment underground (e.g. archives, data centres and laboratories).

FUTURE CAVERN DEVELOPMENT IN HONG KONG

Hong Kong's planning and engineering professions have continually risen to the challenge of the changing future development needs of Hong Kong. We have the appropriate ground conditions and certainly the required skill sets, as demonstrated by the wealth of underground development in Hong Kong. However, systematic consideration of the cavern option will require a change in mindset for not only the government but all stakeholders. It will require the willingness to evaluate and embrace the latest technologies so as to reduce the facility footprint whilst maintaining and ideally upgrading and improving the existing service.

We need to create an environment in which the cavern development option is not overlooked or treated as unconventional. The planning and execution of cavern development needs to become part of the mainstream development process to help create the optimal living environment. This will require the formulation of policy guidelines to facilitate cavern development for both public and private sectors.

The Cavern Suitability Map developed in the Underground Space Study has identified that

64% of Hong Kong's land area is of medium to high suitability for cavern development (Figure 4). However, it is recognised that those areas closest to the urban fringes have higher potential due to relatively easier access from existing transport networks and lower excavation and support costs for the relatively shorter access tunnels to the proposed strategic cavern areas. These urban fringe areas are also not generally compromised by private land ownership issues.

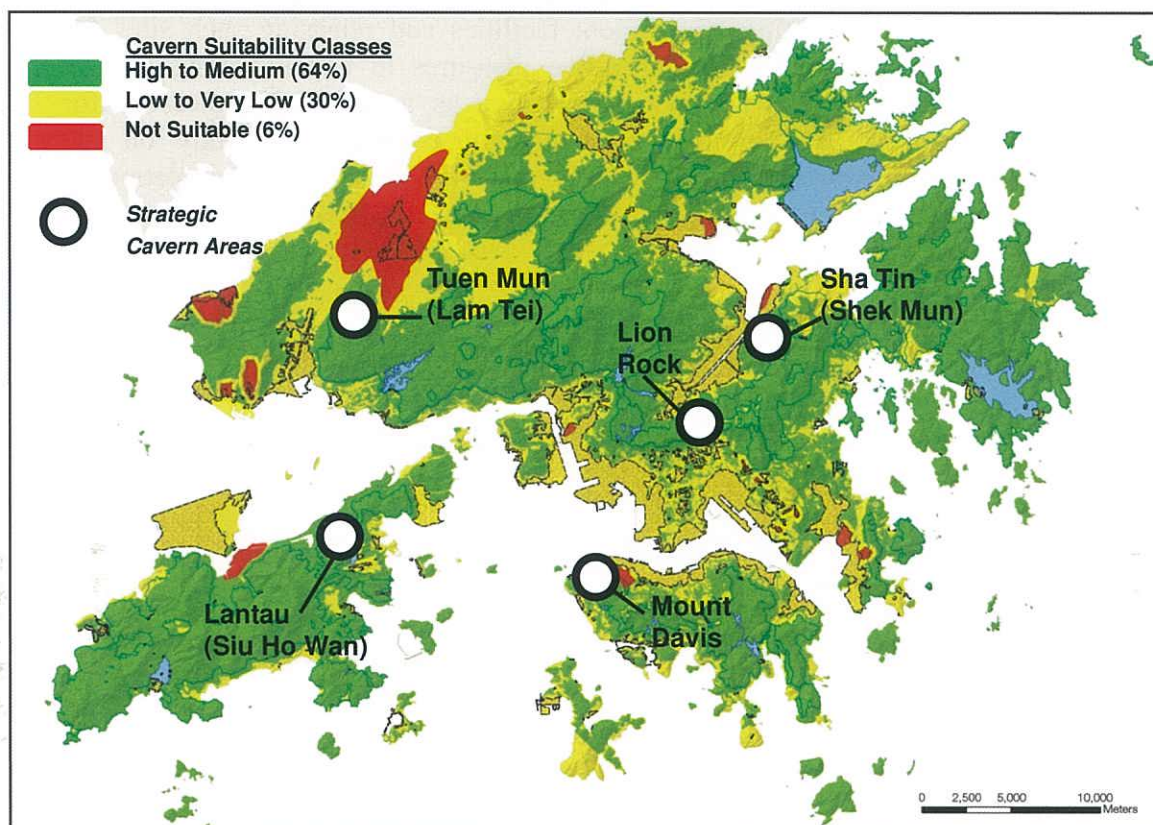


Figure 4. Plan of simplified cavern suitability map showing strategic cavern areas

The Underground Space Study identified five strategic cavern areas that were of plan area greater than 20 hectares and with potential to house multiple cavern facilities (Figure 4). The study requirement was to identify at least one strategic cavern area in Hong Kong Island, Kowloon and the New Territories to demonstrate the broad suitability for cavern development throughout Hong Kong.

The next logical step would be to fine tune the previous rationale used, delineate other strategic cavern areas throughout Hong Kong and match these with nearby government facilities with potential for relocating to caverns. Ling (2011) suggests that the plans could show the location of the identified cavern development areas, their planned uses, the facilities that would be relocated into caverns, the location of the surface sites that would be released and the planned use of the released sites. These cavern master plans would become effective platforms for the government to communicate with the stakeholders on the underground development strategy for the selected districts. It is expected that this will lead to a systematic programme for relocation of selected government facilities to caverns, thereby releasing the surface land for other uses of benefit to the community.

Recognising that the private sector could have a significant role to play in cavern development in Hong Kong, the recommendation for encouraging private sector involvement that was outlined in the Underground Space Study will need to be further examined and developed.

The Hong Kong Chief Executive, in his 2011-2012 Policy Address under “Policy on Land Development and Accumulation”, stressed the need to actively explore the use of rock caverns to reprovise existing government facilities and releasing such sites for housing and other uses as one of the innovative measures to expand Hong Kong’s land resources. To take forward the cavern initiative as a sustainable measure for increasing land supply, the HKSAR Government will commence a study on the “Long-term Strategy for Cavern Development in Hong Kong” in 2012, for completion by late 2015. This study will aim to address the key issues identified above and the scope includes the following key items:

- (a) formulation of policy guidelines to facilitate cavern development for both public and private sectors;
- (b) preparation of cavern master plans to reserve strategic areas for cavern development;
- (c) formulation of a long-term strategy to systematically relocate existing government facilities to rock caverns;
- (d) review of technical issues related to cavern development; and
- (e) public engagement and consultation exercises with relevant stakeholders.

CONCLUSIONS

In 2011, the CEDD completed the study on “Enhanced Use of Underground Space in Hong Kong”, which concluded that the geology and topographical setting of Hong Kong are very suitable for cavern development. Members of the public are generally supportive of the initiative of enhancing the use of rock caverns as part of Hong Kong’s pursuit of sustainable development.

By reprovise existing government facilities inside caverns and releasing the original land as well as the adjacent sterilized land for housing and other uses, cavern development is a viable option to increase land supply. Cavern development could also be a good source of land supply for accommodating new infrastructure facilities which will otherwise occupy land and territorial space. Reserving underground space could accommodate future projects and expansion of facilities underground. For those NIMBY facilities like sewage treatment works and refuse transfer station, the cavern option may help reduce adverse impacts on the local environment, remove incompatible land uses and alleviate the NIMBY sentiment.

In 2012, the HKSAR Government will commence a study on the “Long-term Strategy for Cavern Development in Hong Kong” for completion by late 2015. By adopting a holistic

approach, this should allow rock cavern development to become a sustainable means for increasing land supply.

REFERENCES

- Arup (2011). Executive Summary on Enhanced Use of Underground Space in Hong Kong – Feasibility Study. Ove Arup & Partners for Geotechnical Engineering Office, Civil Engineering and Development Department, Government of the HKSAR, 30p. (May be downloaded at http://www.cedd.gov.hk/eng/underground%20space/doc/Hong_Kong_Underground_Space_Study-Executive_Summary.pdf).
- Chan, R.K.S. (2011). “Planning future cavern development in Hong Kong.” Proceedings of the Hong Kong Institution of Engineers and Hong Kong Institute of Planners Joint Conference on Planning and Development of Underground Space, Hong Kong: 37-43.
- Chan, R.K.S, and Ng, K.C. (2006). “Are we prepared for cavern development in Hong Kong?” Proceedings of the Hong Kong Institution of Engineers Geotechnical Division 26th Annual Seminar, Hong Kong: 53-63.
- Ling, K.K. (2011). “Towards an Underground Development Strategy for Hong Kong.” Proceedings of the Hong Kong Institution of Engineers and Hong Kong Institute of Planners Joint Conference on Planning and Development of Underground Space, Hong Kong: 45-51.
- Pang, P.L.R. and Woodrow, L.K.R. (2009). “A new era of tunnel works in Hong Kong: opportunities, challenges and geotechnical control”. Proceedings of the Institute of Materials, Minerals and Mining (Hong Kong Branch) Conference on Hong Kong Tunnelling, Hong Kong, pp37-46.
- PlanD (2008). Rock Cavern Development. Hong Kong Planning Standards and Guidelines, Planning Department, Government of the HKSAR.

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INTERACTIONS OF SURFACE PROCESSES WITH TECTONICS OF TAIWAN: INSIGHTS FROM SANDBOX EXPERIMENTS

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ABSTRACT

We present the results of 2D and 3D sandbox models designed to investigate the complex deformation characterizing the active Taiwan orogenic wedge. Experiments allow the study of interactions between tectonics and surface processes. Accounting for various factors of surfaces processes and tectonics boundary conditions and parameters such as sedimentation, erosion, basal friction, and décollement level, structural heritage (normal faults or topographic reliefs).

INTRODUCTION

Surface processes include Bioturbation (indicated by B.), Climate (C.), Erosion (E.), and Sedimentation (S.) which interact with tectonic process the interactions among them can be summarized as follow: (Fig.1) (Modified from Willett et al. 2003, Graveleau, 2008)

- (1) Pollution, induce global change, B.->C. (Bioturbation contributes to Climate);
- (2) Landscape modifications. B.-> E., S., T.;
- (3) Ecosystem modifications C., E., S., T.-> B.;
- (4) Physical-chemical weathering C.-> E.;
- (5) Produce sediments & dissolve charge C., E. -> S.;
- (6) Lithologic discharge C., E.->T.;
- (7) Carbon stockage, chemical weathering of silicate S. ->C.;
- (8) Cover protect, change base level S.-> E.;
- (9) Sedimentary dischargement S.->T.;
- (10) Orographic barrier, Albedo, & Others (?) T.-> C.;
- (11) Create potential gravitational slope T.->E.;
- (12) Create sedimentary basins T.-> S.;

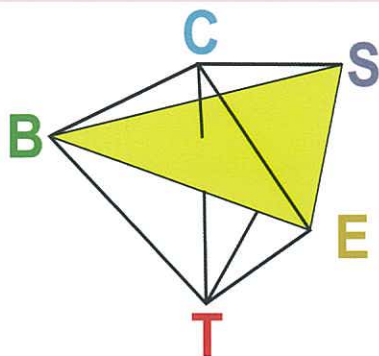


Figure 1: the interaction relationships between surface processes (which include Bioturbation (B.), Climate (C.), Erosion (E.), and Sedimentation (S.)) and tectonic (T.) process.

Deformation of the Taiwan orogenic wedge

In Taiwan today (Fig. 2), the convergence between the Eurasian plate and Philippine Sea plate results in the progressive growth of an active orogenic wedge. It is one of the best places to study the complex relationships that occur between the tectono-metamorphic processes controlling deformation (plate rheology and kinematics) and surface processes (erosion and sedimentation). In the Central Range of Taiwan, foliation and lineation traces outline the geometry and kinematics of deformation in both, the foreland and hinterland of the orogenic wedge. The foliation dip and the strain ellipsoids distribution show the fan shape of a large pop-up structure characterizing the effects of oblique plate convergence. On the eastern flank, regionally developed penetrative cleavage dips gently toward the east. Stretching lineations defined by phyllosilicates lie approximately parallel to the axes of regional folds with varying trends from northeast to east. Geometry of strain shadows indicates that (a) extension directions changed from along-strike toward down-dip and (b) top-to-the southwest or west shearing occurred in the direction of along-strike. The orogen-parallel shearing determined in the hinterland side, which is different from the orogen-perpendicular thrusting observed in the western flank of the Central Range (the foreland side), has to be related with strain partitioning induced by the oblique plate-convergence. The overall shape of the Taiwan orogenic wedge characterized self-similarities of plate boundary between Eurasian plate and Philippine Sea plate and frontal marginal asperities of Chinese continental margin. Erosion rates within the actively deforming mountains are high (3–6 mm/yr) on all time-scales. The purpose of this paper are trying to deal the following problems:

1. How surface processes interact with tectonics in Taiwan?
2. Why metamorphic rocks are exhumed on the eastern flank?
3. Why the foliation distributed into a fan shape?
4. Why the Chelungpu Fault developed as an out-of-sequence thrust?
5. How Taiwan orogenic wedge was built?

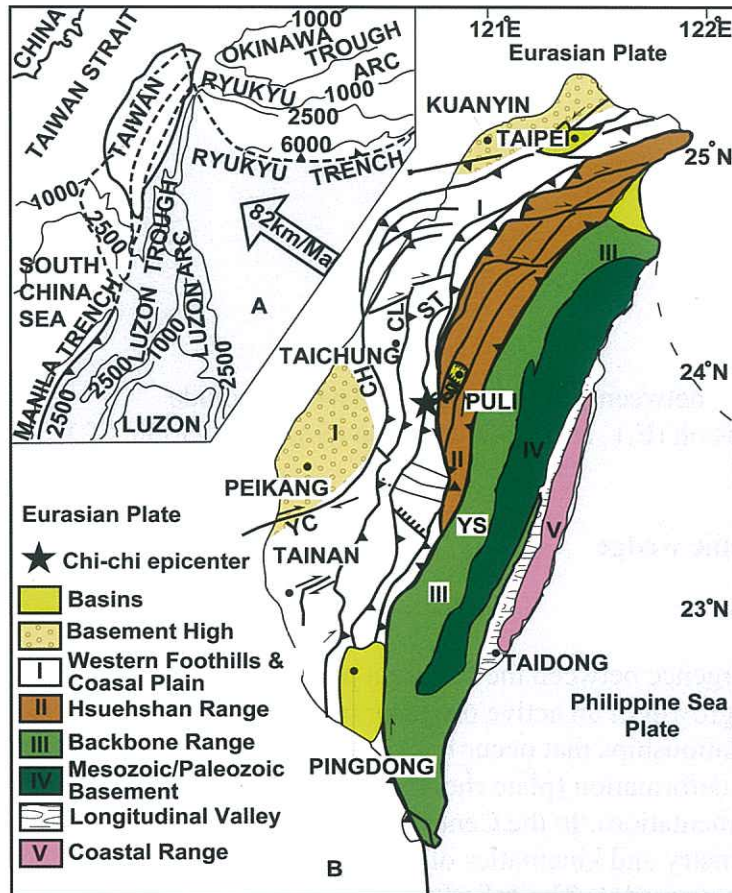


Figure 2. A. Present day tectonics of Taiwan; B. General geologic units of Taiwan

Analog modeling

In recent years attention has been paid on the major role of surface processes in numerous studies dealing with the evolution of orogens at different time scales. For example, the roles of erosion and sedimentation on exhumation and deformation history of accretionary orogens are widely studied through experimental and geological studies. In order to study the kinematics and deformation involved by the rapid convergence between Philippine Sea plate and the Eurasian Plate around Taiwan, we performed 2D and 3D sandbox analog modelling. The experiments have been performed at the Tectonic Modelling Laboratory (Department of Geosciences, National Taiwan University) and at Géosciences Montpellier Laboratory (Montpellier University, France). Coulomb wedge theory assumes that the range mostly grows by frontal accretion of material, distributed shortening and backthrusting at the rear of the wedge to maintain crustal thickening (e.g., Dahlen et al., 1984). Although it accounts globally for most of the long term evolution and shape of Taiwan wedge at wide scale, it fails for explaining tectonic processes at intermediate space and time scales. Indeed, in a natural wedge, the length of thrust sheets, size, nature and rheology of the different tectonic units is determined by material properties of the crust, structural heritage and thermo-mechanical evolution of accreted crustal units, that are independent of critical wedge theory (Platt, 1986). In Taiwan, the accretion of discrete thrust units is controlled by different tectonic processes interacting during wedge growth, following the evolution of geodynamic boundary conditions from oceanic to continental subduction and, in addition, due to the change from submarine to aerial setting that had a great impact on erosion, sedimentation and in return on wedge dynamics. Using insights from models, we aim to better define the main processes that characterize the development of an

orogenic wedge from oceanic subduction to continental subduction. Scaled 2D sandbox simulations (Fig. 3) are used to analyse deformation and exhumation processes occurring in thrust wedges suffering erosion (see details in, Konstantinovskaia and Malavieille, 2005), assuming 1-topographic steady state conditions, i.e., the elevation of Earth's surface does not change with time (Willett and Brandon, 2002) and 2-flux steady state, i.e., the amount of accreted material (input) is equivalent to the amount of material removed by erosion (output). The model materials have frictional properties satisfying the Coulomb theory and thus they are fair analogues of upper crustal rocks (e.g., Lohrman et al., 2003, and references therein). The aeolian sand used is rounded with a grain size of less than 300 μm and a density of 1450 kg/m^3 . The internal coefficient of friction is 0.52 and the cohesion $C_0 = 20 \text{ Pa}$. A basal friction corresponding to these parameters is around 12° for the LF model and around 28° for the HF model. Glass microbeads are used as décollement layers. Resistant layers in the models are made of dry silica powder, which has a significantly higher cohesion (150 Pa) than sprinkled sand (20 Pa). Cohesion and size are scaled with a factor of 10^5 : 1 cm in our experiment is roughly equivalent to 1 km in nature. Models are analyzed using pictures, movies and PIV (Particle Image Velocimetry) software (Fig. 4). We then characterize the exhumation patterns, the mode of fault propagation and displacement patterns by strain partitioning of vertical vs. horizontal displacement and convergent parallel vs. orogen parallel components.

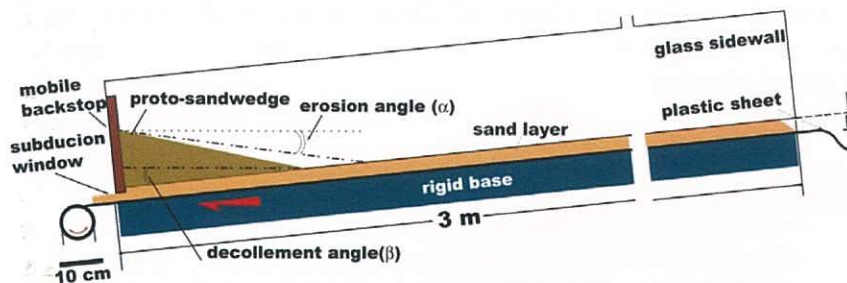


Fig. 3: Sketch of the 2D experimental device. The sand input or initial thickness of sand layers (h) is 4 cm. The angle of erosion α and β are chosen as critical accretion taper angles or overcritical for different experiments.

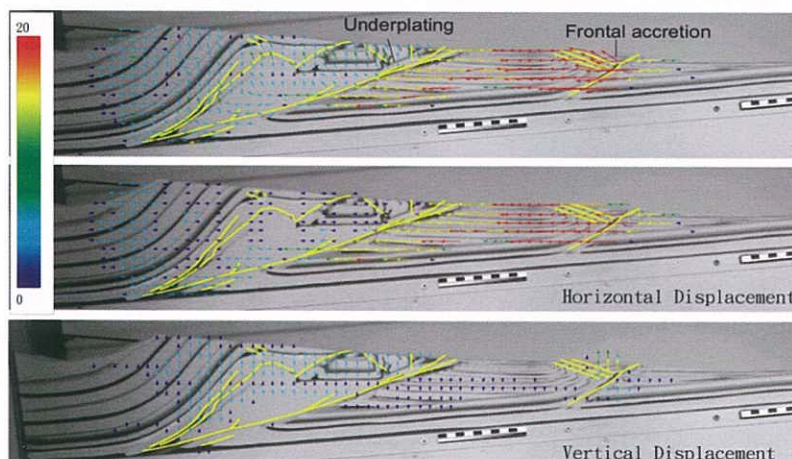


Fig. 4: PIV analysis of the development of out-of-sequence thrusting and underplating-exhumation processes in orogenic wedge submitted to erosion under flux steady state conditions. Thick yellow lines indicate thrust faults. Particle movements are indicated by arrows with scale (pixal) on the upper left.

In this study, we first compare the results of a simple experiment involving erosion only and a décollement layer in the incoming sequence to the present geological structure of the Taiwan orogenic wedge (Fig.5). Modeling reveals that two major types of mechanisms are active simultaneously: frontal accretion in the external parts leading to the development of a foreland imbricate thrust belt and underplating in the internal zones leading to the formation of an antiformal nappe stack. The imbricated units of the antiformal stack are progressively steepened during its development. Analysis of model thrust wedges show that the way of exhumation depends on the internal structure and dynamics of thrust wedges and conversely, on how this dynamics is enhanced by erosion. The diversity of exhumation mode is mainly controlled by the rheology of the crustal sequence involved in continental subduction, the geometry of imbricate faults and the mode of fault propagation. As the entire wedge undergoes internal deformation, erosion controls the lifetime of individual faults, the degree of rotation of the faults and the location of the zone of maximum exhumation. The model outline that the highest rate of material uplift correlate with zones of intense underplating. Thus, although the chosen erosion mode was uniform (similar to diffusion law type), erosion combined with underplating favor a strong exhumation in a restricted area. The extent of basal underplating increases with total shortening. Underplating enhance localized rapid vertical uplift that in feedback favor high denudation rates. This induces a self sustained amplification of exhumation in a specific area of the wedge. The final shape of the wedge reflects these complex interactions, it is characterized by an antiformal stack of duplex units in its rear part, a synformal klippe of thrust units in the slope and imbricated thrust units in the front.

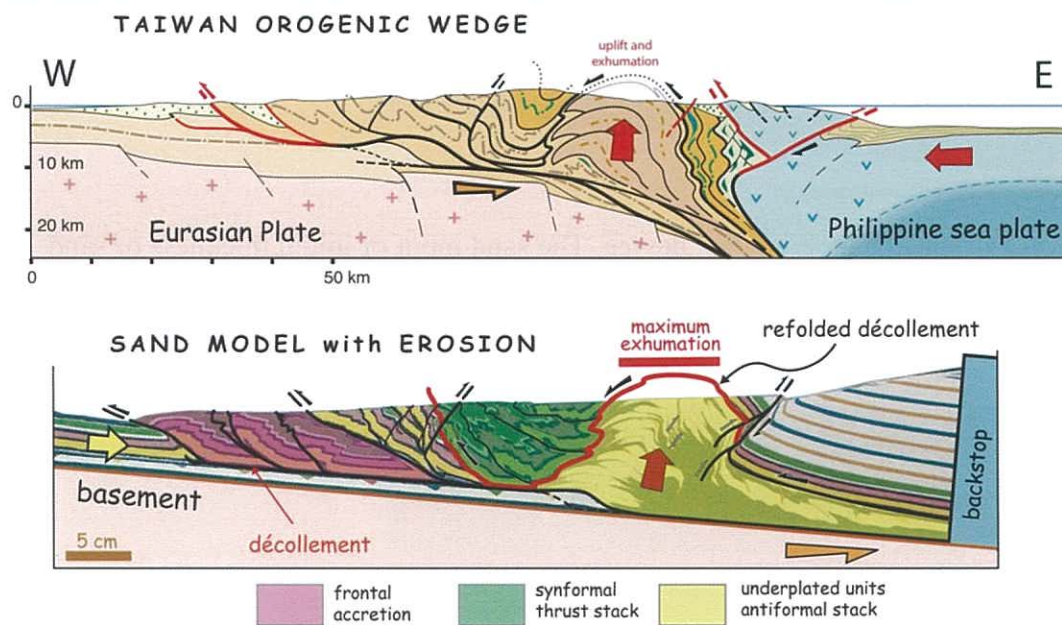


Fig. 5: Interpretive section of the Taiwan orogenic wedge inspired by analog model involving erosion and a décollement layer (experiment from Konstantinovskaia and Malavieille, 2005).

Others complementary experiments accounting for erosion, sedimentation (Fig. 6) and the structural heritage of the Eurasian continental margin show a similar behavior, characterized by the localization of a zone of strong exhumation above the domains of underplating at depth. They emphasise the role played by the geometry of inherited geological structures (inverted basins, basement highs), and the rheology of the

subducting sequence in the development of underplating processes at depth. In Taiwan, the structural heritage and potential décollements occurring in the subducting continental margin exert a regional control on the dynamics of deformation, underplating process and exhumation in the orogenic wedge. In addition, experiments show that important volumes of analogue material are eroded out of the geological record. Indeed, the combined effect of punctuated thrust development (due to frontal accretion) and syndeformational erosion of the foreland sediments leads to an important recycling of sedimentary units constituting the foreland basin. Some of the tectonic structures accommodating the convergence are definitively eroded during mountain growth and there is no remnant of their original lengths. As a consequence, the original lengths and the total shortening determined on restored cross sections are most likely underestimated.

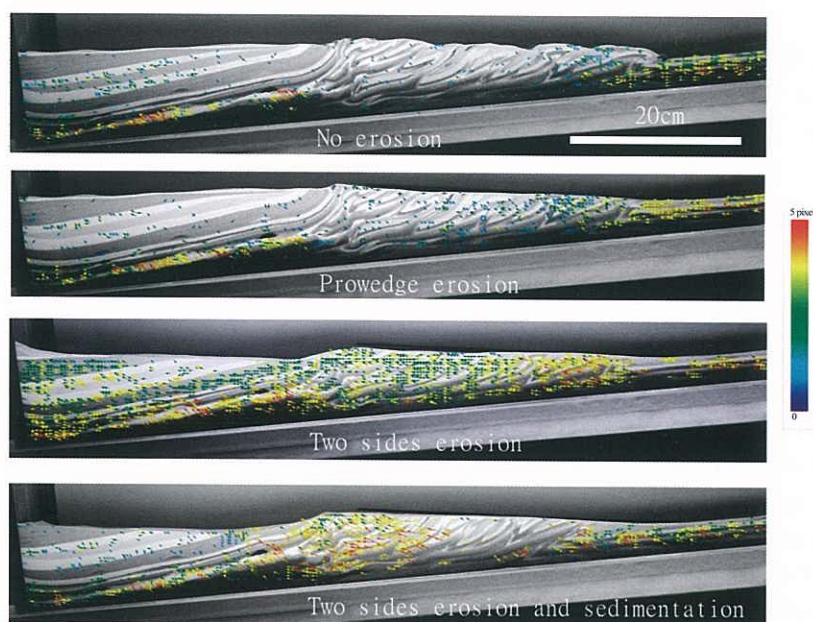


Fig. 6: PIV analysis of the development of subduction wedges and submitted to erosion and sedimentation under high basal friction and flux steady state conditions. Particle movements are indicated by arrows with scale (pixal) on the right.

The 3D experiments (e.g., Lu and Malavieille, 1994) were mainly used to study the complex kinematics and contrasted deformation regimes induced by the indentation of the Eurasian continental margin by the Philippine Sea Plate. Impact of oblique convergence on strain partitioning, geometry of fault networks in the Island and escape tectonics occurring in the middle west and southwestern Taiwan have been demonstrated (Fig. 7). In addition, the subduction of a basement high have been modeled to characterize the effect of a basement topography recognized to the west of Taiwan (Peikang High, Fig. 2) on the deformation of the Foreland thrust belt.

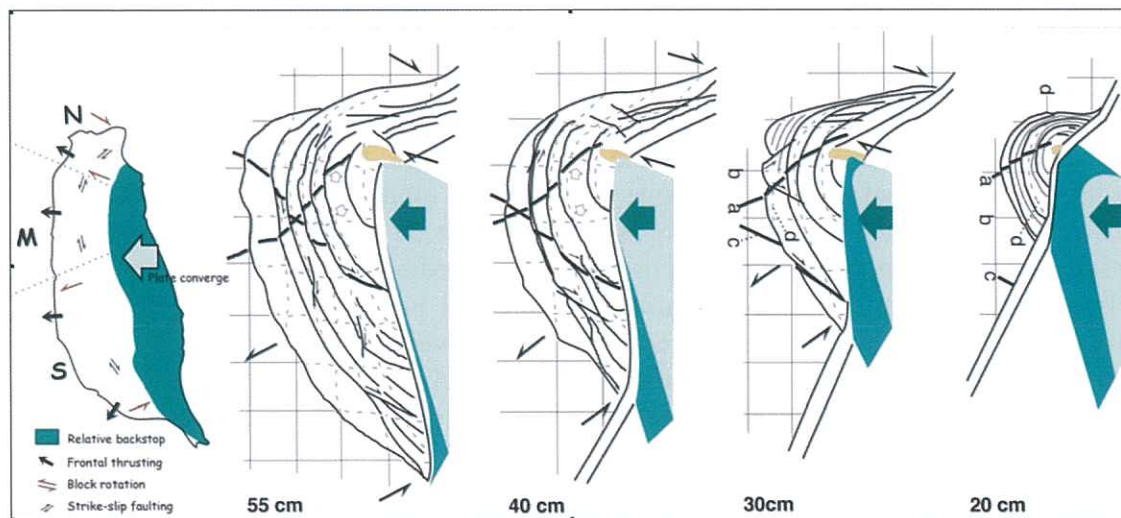


Fig. 7: Sand model showing the impact of oblique convergence on strain partitioning, geometry of fault networks in the Island and escape tectonics occurring in the middle west and southwestern Taiwan

Preliminary conclusions

1. The interactions between tectonics, erosion and sedimentation control geometry and kinematics of the doubly vergent transpressional orogen.
2. Exhumation processes are controlled by the balance between erosion, frontal accretion and underplating in the different structural domains of the wedge.
3. Retroedge erosion favours backfolding and backthrusting, induces flower structures and fan shaped cleavage distribution.
4. Sedimentation promotes underplating and out-of-sequences thrusting.
5. Subduction of the continental margin and associated topographic highs will enhance underthrusting/underplating, thick-skin tectonics and inversion of sedimentary basin.
6. In the Taiwan wedge where surface processes are particularly efficient, total shortening is largely underestimated from balanced cross sections, since a substantial length of imbricated thrust units is removed by erosion.

REFERENCES

- Dahlen F.A., Suppe J. & Davis D.M.; 1984: Mechanics of fold and thrust belts and accretionary wedges: Cohesive Coulomb theory. *J. Geophys. Res.*, 89, 10087-10101.
- Graveleau, F. (2008). Interactions Tectonique, Erosion, Sédimentation dans les avant-pays de chaînes : Modélisation analogique et étude des piémonts de l'est du Tian Shan (Asie centrale) Structure et Evolution de la Terre et des Planètes Montpellier, Dissertation de L'universite Montpellier II 487.
- Konstantinovskaia, E., and Malavieille, J.; 2005: Erosion and exhumation in accretionary orogens : Experimental and geological approaches. *Geochemistry, Geophysics, Geosystems*, Vol. 6, Number 2, 25 pp.
- Lohrmann, J., Kukowski, N., Adam, J. and Oncken, O.; 2003: *The impact of analogue material properties on the geometry, kinematics, and dynamics of convergent sand wedges*. *Journal of Structural Geology*, 25(10): 1691-1711.

- Lu, C.Y. and Malavieille, J.; 1994: *Oblique Convergence, Indentation and Rotation Tectonics in the Taiwan Mountain Belt -Insights from Experimental Modeling*. Earth and Planetary Science Letters, 121(3-4): 477-494.
- Platt J.P.; 1986: *Dynamics of orogenic wedges and the uplift of high-pressure metamorphic rocks*. Geol. Soc. Amer. Bull., 97, 1037-1053.
- Willett S.D. & Brandon M.T.; 2002: *On steady states in mountain belts*. Geology, 2, 175-178.
- Willett, S. D., N. Hovius, et al. (2006). Tectonics, Climate, and Landscape Evolution: Introduction. Special Paper Geological Society of America. S. D. Willett, N. Hovius, M. T. Brandon and D. M. Fisher. Boulder, Colorado, Geological Society of America 398: vii-xi.

CAVERN DESIGN AND CONSTRUCTION IN CHALLENGING GROUND CONDITIONS

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Abstract: *The requirement for new facilities for improving the transport capacities of infrastructures as well as limited space above ground requires new and large underground structures. This paper presents two ambitious underground infrastructure projects in Switzerland. The various challenging geotechnical conditions and the construction of the large caverns are shown for both projects. The geotechnical approach of each underground structure is described.*

The first project describes the so-called Multifunctional Station Faido at the Gotthard Base Tunnel. This complex station contains tunnels, galleries, caverns and tunnel cross overs with large branch-off structures. The station has an overburden of more than 1000 m. Demanding geotechnical phenomena like unexpected fault zones, rock-burst phenomena and micro tremors had to be addressed due to the high overburden.

The second project shows the chip factory "Waferfab". It's an infrastructure project utilizing underground space as a manufacturing facility for sensitive industrial processes. The "Waferfab" is a multiple structure complex with the main offices situated on the surface connected to two large caverns. Due to safety and operational aspects a shallow placement of the cavern was envisioned. The challenges of the project were the excavation of large cross-sections with small overburden and the extremely short construction time of only twelve months.

INTRODUCTION

Nowadays, it is more and more difficult to allocate space for complex infrastructure projects. A possible solution is the realization of such projects underground. This paper shows two examples of large caverns both situated in Switzerland and describes the different construction challenges due to high as well as low overburden.

The Multifunctional Station (MFS) Faido is part of Gotthard Base Tunnel (GBT), the world's longest railway tunnel. The GBT with its more than 57 km length crosses the Alps mostly under very high overburden reaching more than 2.500 m at the maximum. The MFS Faido, one of two such stations, contains galleries, caverns, and tunnel cross overs with large branch-off structures. These cross overs connect the single-track tubes and allow trains in case of an emergency to switch to the adjacent tube. The MFS was excavated by drill & blast and a double shell concrete lining was applied. The construction of the branch-off structures with cross sections up to 330 m² and the geotechnical approach is described in the following sections. The overburden at the MFS Faido ranges from 1.200 m up to around 1.600 m. For caverns with such high overburden the main challenges can be summarised in the reliability of accurately predicting the geological conditions and the occurrence of fault zones. Additionally rock burst phenomena and micro tremors are very likely to occur.

The underground chip factory "Waferfab" is the first underground chip factory in the world. Wafer chip fabrication is a delicate industrial process constrained by vibration, temperature and humidity limits. Underground space provides a stable manufacturing environment in relation to these factors. Furthermore, the safety of an underground chip factory is easier to

ensure and its construction is economically more advantageous. The 'Waferfab' is a multiple-structure complex with the main offices situated on the surface. These are connected to two main caverns serving as production and storage facilities by means of two access galleries. The caverns with lengths up to 100 m were mainly excavated by drill-and-blast method. A single-shell shotcrete lining was applied. Several important aspects for the construction of caverns with low overburden can be listed. Block and wedge failure due to low confining stresses, unfavourable ground conditions due to weathering of ground and ground water have to be considered during design and construction.

THE MULTIFUNCTIONAL STATION, A CAVERN WITH HIGH OVERBURDEN

Layout of the Multifunctional Station Faido

The MFS Faido consists of the two tunnel tubes, which are connected to each other by two tunnel cross overs, the cross cavern for housing the railway infrastructure equipment, the connecting galleries required for construction operations, the cavern for handling logistics in the construction phase, the two emergency stop stations that are connected to the side galleries, and a ventilation tunnel system. Altogether there are about 6 km of tunnels and galleries with cross-sectional areas ranging from 40 m² up to 330 m². The station's overall length is about 2,000 m and the entire MFS was excavated by drill-and-blast method.

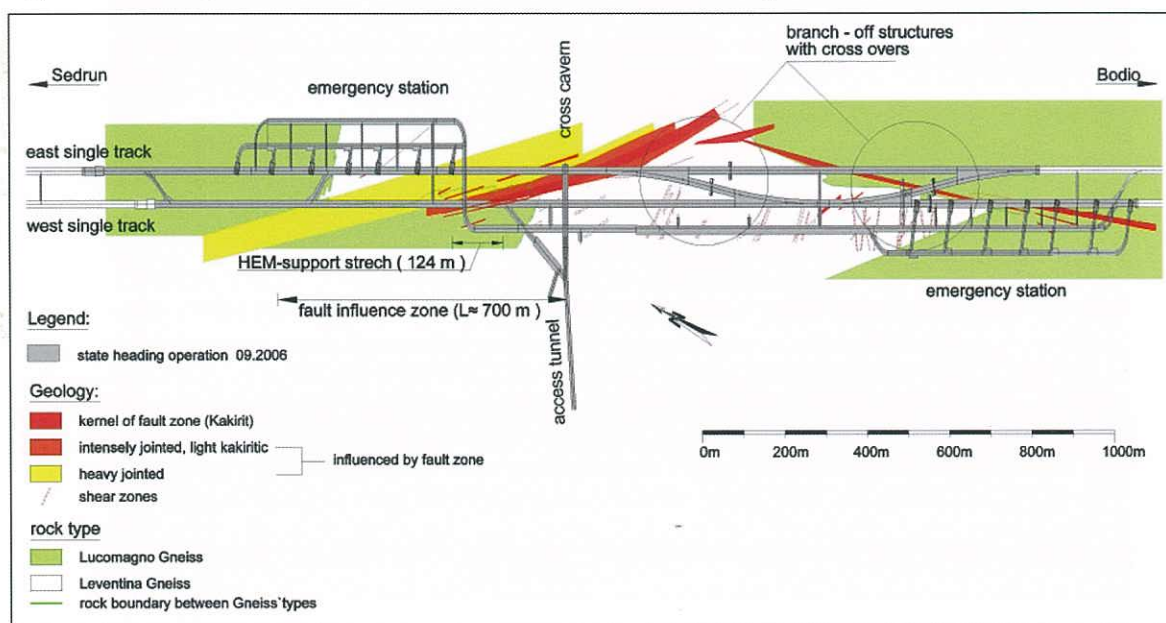


Figure 1. MFS Faido, layout and encountered geological conditions and fault zones

The Impact of Fault Zones crossing the MFS in an acute angle

Individual fault zones were predicted for the southern end of the MFS, but these were not expected to have a significant effect on construction. During excavation faulty gneisses of low strength were encountered and minor instabilities occurred. Intensive seismic and other ground investigations revealed a massive fault zone in the MFS area (see Figure 1).

The actual ground conditions encountered required a critical review of excavation support design. Especially in the immediate vicinity of the fault zone, the initial support with systematic bolting and shotcrete was not appropriate to the conditions with squeezing

behaviour. Radial convergences of more than 70 cm resulted in buckling of the additionally installed steel arches. The rock bolting was increased to over 300 m of heavy steel bolts per meter of tunnel.

In order to understand the ground behaviour intensive measurements and parameter studies were carried out (Stadelmann&Wei, 2010). With the occurrence of the unexpectedly squeezing ground behaviour the original computations based on the ground reaction curve were carefully analysed and verified by back analysis with the actual ground conditions.

From the experiences of deep tunnel constructions it is well known that rock pressure decreases as the amount of rock deformation increases. The analysis showed that the rock pressure in fault zones can only be handled if enough deformations are accepted (Stadelmann et al., 2006).

Rock Burst Phenomena and Micro Tremors

Rock bursts are the immediate failure of the rock under which large amount of stored energy is released and which have high damage potential (see Figure 3).



Figure 2. Damage caused by a rock burst event

In the various tunnel excavations of the MFS Faïdo, rock bursts or similar phenomena occurred in increasing frequency. Three-fourths of all events took place at the face during the first three hours after blasting and were recognised in the form of vibrations and loud cracking or bangs. In May 2004 a rock burst occurred in the side wall of the single-track tunnel east/north that had already been excavated for several months. Rock suddenly detached and the vault was deformed over a distance of about 30 m.

The frequently changing geological conditions could be regarded as a possible cause. Hard, brittle Leventina gneisses are adjacent to more ductile Lucomagno gneisses. Through the nearly parallel orientation of the tunnel axis and the fragmented Lucomagno gneisses, slender

rock wedges of Leventina gneiss are locally formed. These competent wedges take on loads from the Lucomagno-gneiss which causes local stress concentrations that increase as excavation proceeds.

Experience in tunnelling shows that rock burst phenomena can neither be predicted accurately nor prevented by standard excavation support measures (Rehbock et al. 2006). Nevertheless, action must be taken to ensure safety of workforce and equipment. Constructional adaptations of the support and excluding critical tunnel section for access were required. A prognosis of the rock burst risks was undertaken along with the envisioned measures. A rock burst information sheet and lists of preventive measures had been prepared. In addition, excavation support measures were modified to meet the different levels of rock burst risks. Special yielding support elements are used to absorb dynamic loading, such as rock bolts (Swelllex or Yielding Swellex bolts) and flexible steel arches.

Between March 2004 and June 2005 the Swiss Seismological Service (SED) recorded an accumulation of seismic activity in the area of the MFS Faïdo, a region with normally very low seismicity. Many rock bursts at the MFS could have been associated with micro tremors (Rehbock&Stadelmann, 2010). To investigate the correlation between the construction of the GBT and the resulting rock bursts as well as micro-tremors a seismic monitoring programme was initiated. Monitoring results showed that the micro tremors did clearly correlate with excavation activities. After stopping the excavation no more micro tremors have been identified

Extensive calculations were performed for a maximum so-called design micro tremor. The results of the analysis showed that there has been no need for improving (thickness, additional reinforcing) the linings designed for the static load case in the MFS Faïdo. The additional loading due to a spontaneous 'stress drop' due to a micro tremor in the direct vicinity of a tunnel had to be excluded. The case of a stress drop near a tunnel in the MFS Faïdo had been accepted as a residual risk. Therefore the owner of the tunnel decided to install seismic monitoring equipment and vibration sensors in the lining of the tunnels of the MFS Faïdo for a permanent seismic monitoring during operation.



Figure 3. Tunnel branch-off structure with 320 m² cross section

Large Cross Sections at the MFS Faïdo

The cross-section of the branch-off structures at the tunnel cross overs has a maximum size of 330 m² (see Figure 3).

All four bifurcation structures in the MFS are approx. 200 m long. The excavation takes place from north to south, which results in two main excavation types. The cross-section of the tunnel (70 m²) is continually widened till the face of the bifurcation structure (330 m²) is reached. From here on the excavation of the two sections “tunnel” and “tunnel-crossing” is done separately (Stadelmann et al. 2007, 2008). The second way is to start the excavation at the face of the bifurcation structure and reduce the cross-section continually to the standard tunnel section (70 m²).

By means of analytical and numerical methods the rock support types were determined considering the excavation cycle and geological conditions. The calculation results in a rock support type which basically consists of shotcrete reinforced by steel fibers, wire mesh, rock bolting und grouted rock bolts.

Structural safety verification of rock wedges

The analytical verification method was used to determine the safety factor SF as relation of the retaining force of the rock bolts and the propulsive force of the wedge.

The service load of the bolts was determined based on the shear load. The maximum bearing capacity of the bolts was calculated under the assumption of 50% tensile load and 50% shear load. An additional resistance factor of 1.35 was considered. For the structural safety verification a minimum safety factor SF = 1.2 is required. The safety factors were calculated in table form with different types of rock bolts (Fig. 5). The calculation results show that the wedges at the side walls can be stabilized by a light rock support type. The wedges at the crown require a heavier rock support.

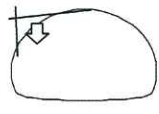
Kluftkörper	Fall Firstauflock. Fallwinkel Volumen Gewicht	Ankertyp	Sicherheitsfaktor für verschiedene Ausbruchsicherungstypen			
			Widerstandbeiwert 1.0		Widerstandbeiwert 1.35	
			Ankerlänge 4m+5m+7m		Ankerlänge 4m+5m+7m	
			leicht	schwer	leicht	schwer
	Fall 1 11°, 90° 16.47 m ³ 45.19 to	Swellex	1.12	1.53	0.83	1.14
		Superswellex	2.25	3.07	1.67	2.27
		Stahlanker	2.48	3.38	1.84	2.50
		Swellex + Stahlanker	1.80	2.46	1.33	1.82
		Superswellex + Stahlanker	2.36	3.22	1.75	2.39
	Fall 2 11°, 81° 26.50 m ³ 71.54 to	Swellex	0.84	1.16	0.62	0.86
		Superswellex	1.68	2.33	1.24	1.72
		Stahlanker	1.85	2.56	1.37	1.90
		Swellex + Stahlanker	1.35	1.86	1.00	1.38
		Superswellex + Stahlanker	1.77	2.44	1.31	1.81

Figure 5. Analytical Method, Extract of the tabular calculation

Numerical Method – Stress redistribution and relaxation

By means of the numerical calculation method the impact of stress redistribution and relaxation were examined considering the differing rock types in the MFS Faïdo.

For the investigation the two-dimensional continuum model (FLAC) was used. The rock consists of heavily jointed Lucomagno- and Leventina-Gneiss. The main joint is of sub vertical orientation with differing angles to the tunnel axis. The bedding is of sub horizontal

orientation with additional joints with sub parallel orientation to the bedding. Two different rock types are defined for the numerical calculation.

Based on the input parameters the resulting internal forces and moments on the lining are determined. Rock bolting is the appropriate means for structural support of wedges. The combination of rock bolting, shotcrete and wire mesh can provide structural safety even for additional hazards like stress related loosening and relaxation.

Monitoring

In the case of the MFS Faïdo the design was carried out by means of previously performed site investigations, structural analyses, comparable experience and essentially with the aid of the observational method. Extensive monitoring provides information on the geotechnical properties and the behaviour of the ground and the structure. This was not only for construction control but most importantly for verifying the assumptions and the results of computation and design.

THE CHIP FACTORY “WAFERFAB”, A CAVERN WITH LOW OVERBURDEN

Overview

The Waferfab manufacturing facility is situated on the western valley flank of the St. Gallen Rhine valley at the foot of the Gonzen. The decision to construct the facility underground was finally based on the economic advantage of decreased installation costs associated with the vibration-sensitive equipment required for chip production.

The facility includes surface office buildings as well as underground manufacturing caverns, connected by two service tunnels on different access levels of the cavern.

Due to the safety and transport requirements, it was necessary to situate the structures near to the surface resulting in the overburden ranging from 20-70m above the main cavern diminishing to 7m at the end of the “Litho cavern”. The dimensions of the main production cavern are 100m*18m*18m (l-s-h) while the “Litho cavern” (56m*18m*10m) is situated perpendicular to the main production cavern (see Figure 4).

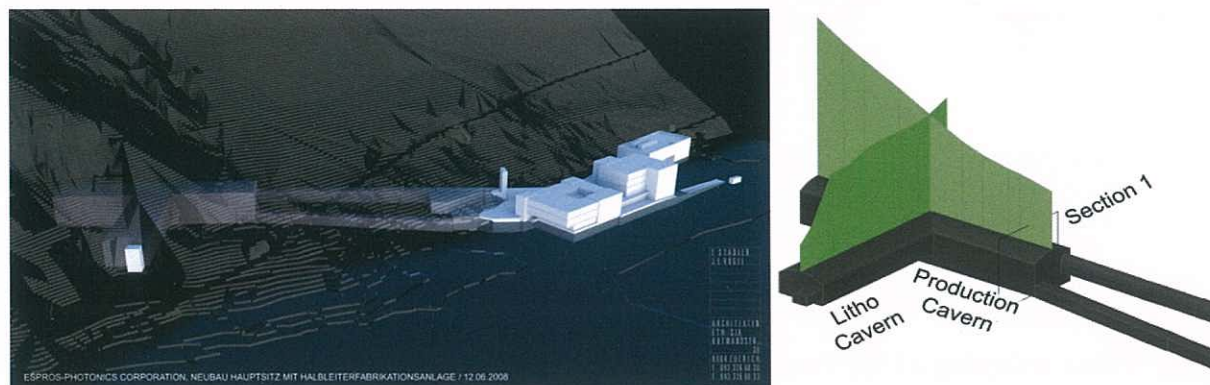


Figure 4. Aerial view of “Waferfab” area (left), caverns with indication of overburden.

Geological Conditions

The underground structure of the Waferfab manufacturing facility is mainly located within the Quinten formation, a fine-grained to compact, thick-bedded limestone.

The Quinten limestone shows a widely differing rock mass behaviour within the area, including gravitational and stress induced block failure at higher stress regimes, buckling as well as spalling phenomena's at bifurcations or pillars at abandoned chambers of the mine.

A geological investigation program was carried out with the purpose of identifying the geological conditions and the rock mass properties, the transition from the valley sediments and in place rock in the access galleries. Two major joint systems were identified. During the excavation of caverns some open joints with apertures ranging from minor centimetres up to 30cm were encountered. The open joints, properly related to large tectonic events, resulted in large and sudden gravitational block falls concurring with the excavation (Wannenmacher et al. 2010).

The local water table is about 2 to 3 m below the invert of the cavern and is connected to the water level of the Rhine valley.

Geotechnical Design and Conditions during Construction

The geotechnical design considers the unsupported underground facility, the stress state and the orientation of the structures as well as groundwater conditions for stability analyses for the identification of hazard scenarios. Due to the local situation a low horizontal stress regime was anticipated for the design. The hazard scenarios are related to rock mass behaviour, representing stable ground conditions with the potential of small local gravity induced falling or sliding of blocks from the crown and side wall, as experience has demonstrated from nearby construction sites.

The primary cavern support for rock mass behaviour type 1 (Figure 5, left) consists of grouted steel and fibreglass rock bolts with lengths varying from 8 to 10 meters as well as a single shell reinforced sprayed concrete lining with a thickness of 20 cm.

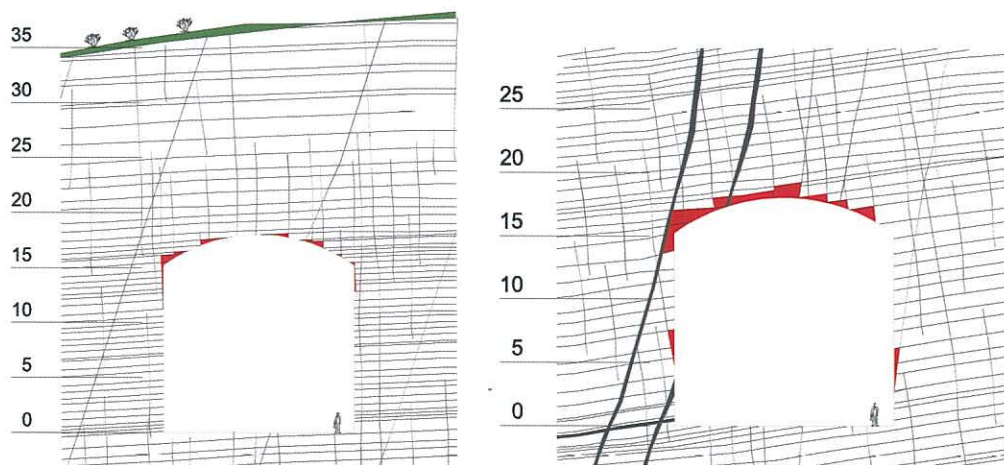


Figure 5. Expected rock mass behaviour Type 1 (left), and encountered behaviour (right).

As the initial widening of the main cavern hall progressed two steeply dipping open joints, with apertures larger than 30 cm and up to 1m locally were found striking at low angle to the axis of the cavern (Figure 5, right). Along the entire intersection in-between these joints, a significant local loss of the horizontal stress component leads to overbreaks extended from 1 to 1.5 meters above the profile. In order to minimize the extent of the overbreaking conditions, the round lengths were reduced and additional bolts installed for short-term protection. Overbreaking conditions extended locally to the southern sidewall where blocks

tended to slide into the excavation on exposed bedding planes. However, the severity of these overbreaks could be minimized with standard protection measures. Open joints extending into the rock mass were backfilled as much as possible with shotcrete, to increase the bearing capacity and stiffness of the rock mass.

Computational Modelling

The choice of calculation model for the geotechnical design at Waferfab manufacturing facility – continuum or discontinuum – are discussed in the following chapter.

The importance of the modelling approach is highlighted by utilising two sections of the cavern focusing on the two rock mass types, differing mainly on the block volume. The parameters for the homogenised, smeared rock mass model were elaborated by scaling the intact rock parameters considering the GSI value and are summarized with Table 1, left part. The representation of the explicit discontinuities of the blocky structure was modelled using Goodman's joint element method (JFEM), a program routine recently offered by Rocscience within the program package phase 2, version 7. No reduction of intact rock parameters, as used with the continuum approach, was considered for this modelling approach. To account for the strength of the discontinuities cohesion and friction were kept identical for both sections investigated. The parameters of the intact rock and discontinuities are as given in Table 1, right part.

Table 1. Parameters used for numerical modelling.

	homogenous model	discontinuum model		
		intact rock	bedding planes	joint sets
Young's Modulus intact [GPa]	-	40		
Young's Modulus rm [GPa]	25	-		
Poisson ratio [-]	0.3	0.3		
GSI / mi	75 / 12	-		
USCi [MPa]	110	110		
UCSrm [MPa]	21	-		
Tensile Strength rm [MPa]	0.96	8	0.9	0
Friction angle [°]	39	45	33	30 / 25
Cohesion [MPa]	8	21	1.5	1.0 / 0
Normal stiffness [MPa/m]	-	-	100'000	35'000
Shear stiffness [MPa/m]	-	-	10'000	7'500

The effect of the local open joints within the first section is considered by low lateral confinement of $K_0=0.3$ for both modelling approaches. The confinement for the section 2 is slightly higher $K_0=0.4$ (since the direct influence of the open joints is not that obvious as for section 1. As stated before, the knowledge of the lateral confinement is of high importance for key block analyses, but can be treated of minor importance since only the differences of the modelling approaches are discussed.

For comparison of the rock mass behaviour only top heading excavation was considered without any support measures. The continuum modelling shows only minor deformation rates due to excavation. The modelling of discrete rock masses emphasises a much higher skill of the geotechnical engineer, since parameters on the strength and stiffness are hardly available for the modelling. The output of such models is always affected of some certain degree of

inaccuracy due to the lack of defined input parameters. Even utilizing simple models as the JFEM by Rocscience give more accurate information and reliability on the expected rock mass behaviour. The excavation influence of the rock mass evaluated by adjacent extensometer readings reaches up to 4 – 6 m in the crown, which matches the modelling of the discontinuum approach with higher accuracy than the continuum model shows (Grossauer&Wannenmacher, 2011).

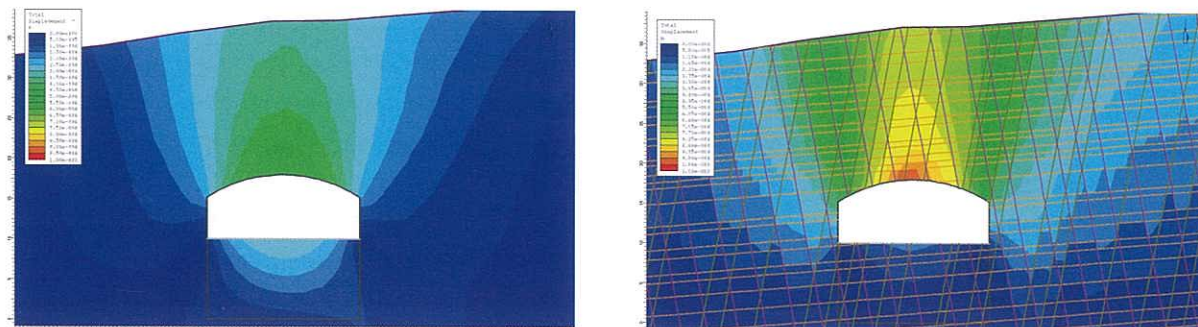


Figure 6. Ground displacements, homogenous model 1 (left), and discontinuum model (right)

CONCLUSION

The paper showed two examples for innovative usage of underground space. The MFS Faïdo as part of the GBT and the chip factory “Waferfab” are ambitious underground projects under challenging conditions. Thanks to the good corporation of all involved parties both projects have been completed successfully.

REFERENCES

- Stadelmann, R. and Wei, Z.Q. (2010). A tunnel and cavern intersection in fault zones at 1240 m depth. EUROCK 2010, Rock Mechanics in Civil and Environmental Engineering, Lausanne, Switzerland
- Stadelmann, R., Rehbock-Sander, M., and Rausch, M. (2006). Crossing of Fault Zones in the MFS Faïdo by using a combination of Geotechnical Computations and the Observational Method . ARMS 2006, 4th Asian Rock Mechanics Symposium, Singapore
- Stadelmann, R., Rausch, M., and Wei, Z.Q. (2008). Design Challenges of the Gotthard Base Tunnel, Pillar Stability in the Multifunction Station Faïdo. ARMS 2008, 5th Asian Rock Mechanics Symposium, Tehran, Iran
- Stadelmann, R., Röthlisberger B., and Wei, Z.Q. (2007). Bewältigung von Querschnitten bis 330 m² beim Gotthard Basistunnel. Felsbau 25 (No. 5), 2007, pp. 121
- Rehbock-Sander, M., Stadelmann, R. and Gerdes, A. (2006). Rock Burst, Experience gained in mines and deep tunnels. ARMS 2006, 4th Asian Rock Mech Symp, Singapore
- Rehbock-Sander, M. and Stadelmann, R. (2010). Gotthard Base Tunnel: Micro Tremors and Rock Bursts encountered during construction. NAT 2010, Portland, USA
- Grossauer K. and Wannenmacher H. (2011). Application of Computational Methods for Design of Rock Caverns. Austrian Society for Geomechanics, workshop on computational methods in geomechanics, Salzburg, Austria
- Wannenmacher H., Grünenfelder F., Amann F., and Button E. (2010). The construction of shallow caverns in blocky ground. EUROCK 2010, Rock mechanics in Civil and Environmental Engineering, Lausanne, Switzerland

Examples of determining sensitive zones of Active reverse fault based on field Observation: case study of the Hukou Fault and the Chihshang Fault in Taiwan

Hao-Tsu Chu¹ and Jian-Cheng Lee²

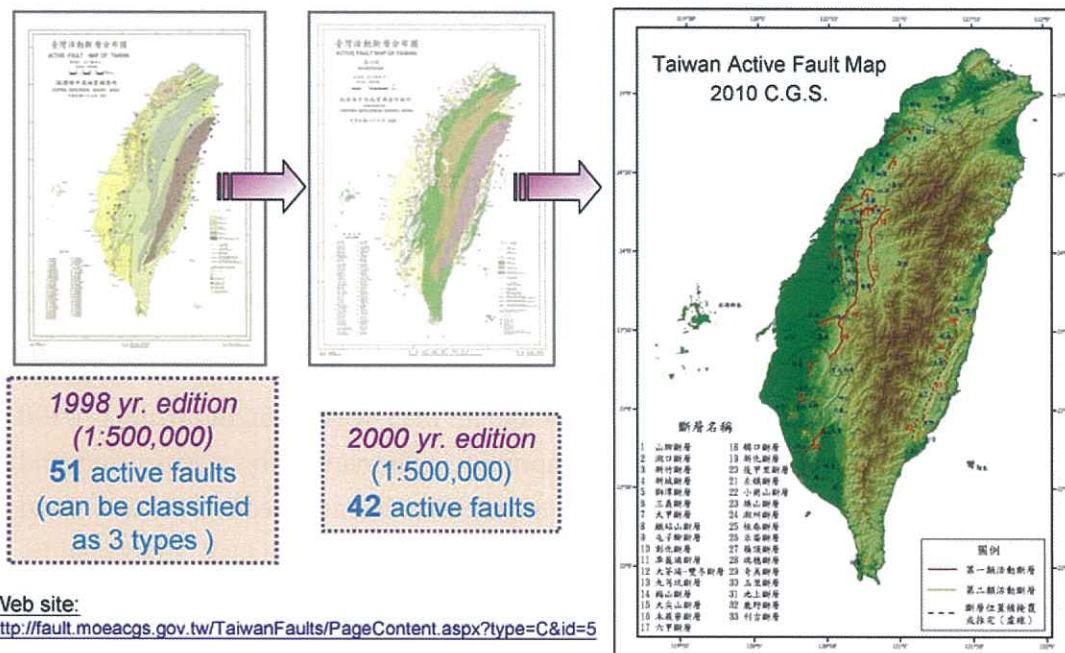
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In Taiwan, geological investigation of active faults in surface rupture, geomorphology, and subsurface trench, on geological map scales ranging from 1:5,000 to 1:25,000, has for long been providing important information for engineering and civil construction projects, migration of earthquake hazard reduction and land demarcation. Since the devastating Chi-Chi earthquake in 1999, the task, supported by a large influx of manpower and resources from the government, has assumed abiding importance. The intensified observation and research on active faults have also included important social applications such as determination of geologically sensitive areas and near surface geological structures of active faults.

In this study, we use the results from recent field investigations on two active faults: the Hukou fault in northwestern Taiwan and the Chihshang fault in southeastern Taiwan, to illustrate that active faults are generally accompanied by other active structures. In the generally compressive tectonic environment in Taiwan, the active anticlinal structure is commonly observed to be closely related to the active faults (usually reverse faults) and blind structures. Based on our observations and structural analyses, we argue that the development of anticlinal structure is strongly controlled by several parameters, including geometry of the fault beneath, near surface locking depth of the fault, and fault branching, especially within the upthrust block. The brittle and ductile deformation of rock formation and near-surface poorly consolidated sediments (induced by active faulting and associated anticlinal fold) is mainly controlled by the mechanical and rheological properties of the fault and the surrounding rock materials. In this study, we employ both the Hukou fault (slip rate < 1.7 mm/y) and the Chihshang fault (slip rate > 20 mm/y), which have great contrast in fault slip rates, as examples to illustrate that the most active region is bounded by the main thrust fault and the main backthrust in the upthrust block in an active compressive tectonic environment. The region delineated by the front fault (main fault) and the rear fault (backthrust) has higher potential of surface co-seismic rupture and is prone to earthquake hazards. Thus it is scientifically judicious to consider demarcating this active region, which resembles an active anticlinal structure, as a “Geological Sensitive Region of Active Reverse Fault”.

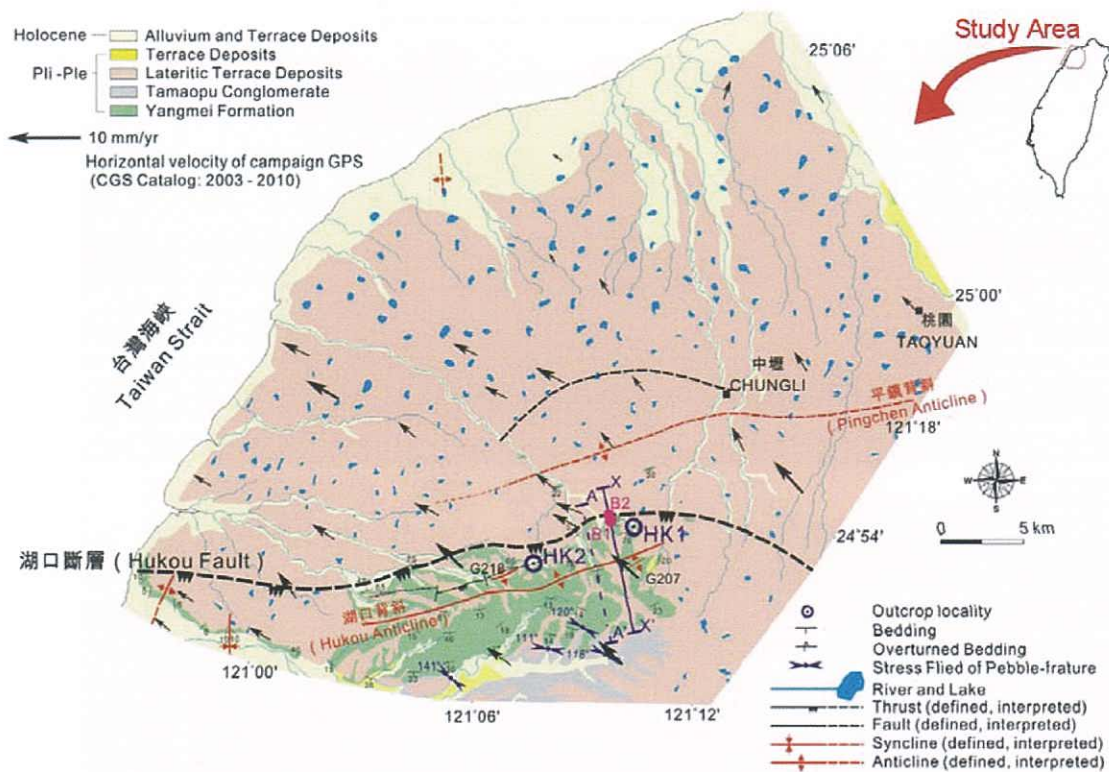
Publication of Taiwan Active Fault Map



- Continue to publish updated versions of Taiwan active fault map with increased relevant information of various kinds of active fault. **33 active faults (2010 yr. web-version)**

Figure 1. Various versions of the Taiwan Active Fault Map since 1998.

Web site: <http://fault.moeacgs.gov.tw/TaiwanFaults/PageContent.aspx?type=C&id=5>



Geological Map and the GPS Velocity (2003-2010) of the Taoyuan Area

Figure 2. Hukou fault and geological map of the Taoyuan area (after Chinese Petroleum Corporation, 1978; Tu and Chen, 1984; Tu and Shao, 2001). The Hukou fault is possibly an active fault in the frontal area of the fold-and-thrust belt in the Taiwan mountain belt. HK1 and HK2 are the Hukou fault outcrops in this study. XX' shows position of the geologic cross-section in figure 5. Black arrows represent the horizontal GPS displacements of Taoyuan area with reference to Penghu island in Taiwan Strait, based on repeated GPS measurements from 2003 to 2010 (Rau, 2010). The slip rate of the Hukou fault is about 1 mm/y (Chen, 2010).

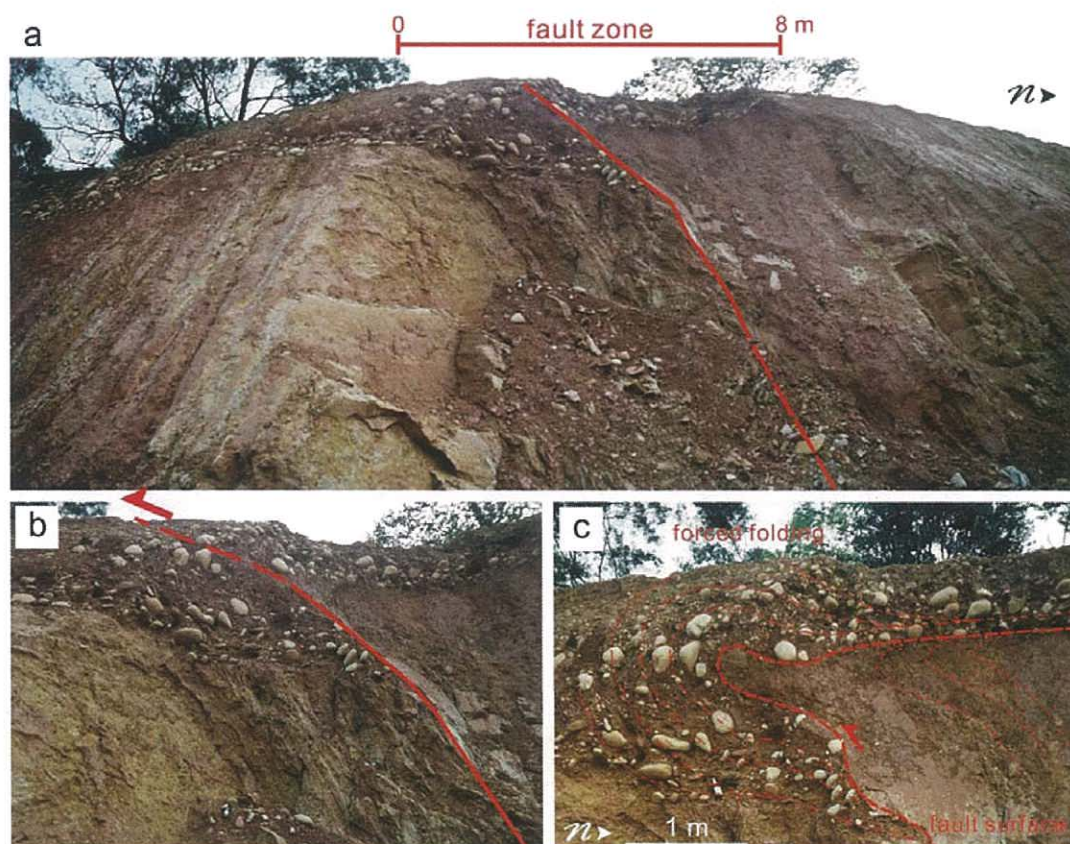


Figure 3. This outcrop at HK-1 shows complex deformation behaviors, both brittle and ductile, around the backthrust of the Hukou fault, which is located about a few hundreds meters away from the main fault in the surface. In this outcrop, we observe that the basal strata, which are composed of alternated thin beds of siltstone and shale of the late Pleistocene Yangmei Formation, lie beneath the angular unconformity. The cover strata are composed of red sand-layers of cobble and boulder conglomerates of terrace deposit of Late Pleistocene-Holocene and the recent organic top soil. The Yangmei Formation is thrust over the covering red soil conglomerate layer towards south along the backthrust with a dip-angle of about 20-50° (a). The fault plane is sub-parallel to the bedding planes of the Yangmei Formation with a net slip of about 8 meters (b). The top covered red soil conglomerate layer was deformed as an inclined drag fold protruding the ground surface (c), which, in rheological terms, can be interpreted as forced folding, intruded by a relative strong rock formation.

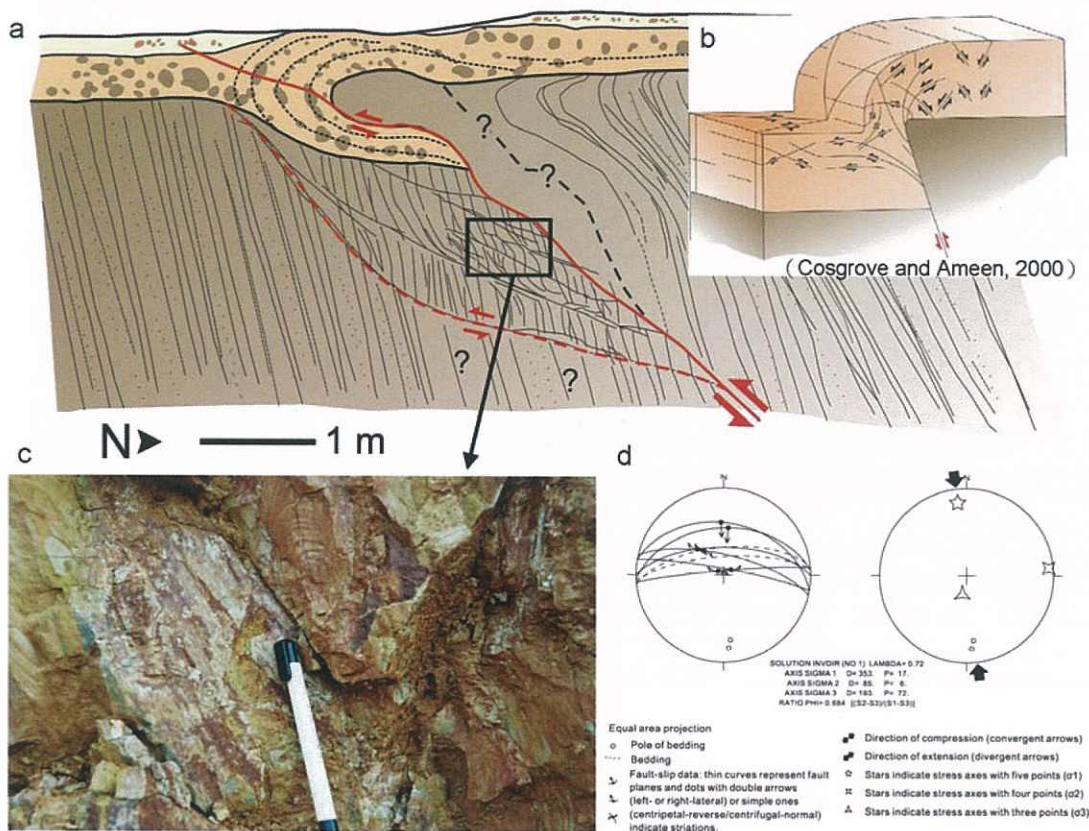


Figure 4. Detailed deformation features at the outcrop of the backthrust of the Hukou fault. (a) The sketch of the outcrop showing that the fault zone, approximately 4 meters wide with vertical throw of about 1.2 meters and horizontal heave of about 1.6 meters is composed of several stacked S-shaped lenticular horses separated by shear planes with slickenside (c). (b) Schematic block diagrams showing potential geometry and sense of movement of macro-faults in experimentally produced forced folds above basement faults (from Cosgrove and Ameen, 2000). (d) Diagram of paleostress analysis based on fault slip data, shown by Schmidt's stereographic projections of lower hemisphere of fault-slip data sets. Faults shown as thin lines; slickenside lineations shown as small dots on fault planes with small, thin inward directed arrows (reverse slip). Computed paleostress axes σ_1 , σ_2 and σ_3 shown as 5-, 4- and 3-pointed stars respectively. Large black arrows indicate computed directions of compression. Open circle indicates the pole of bedding. The compression stress axis σ_1 in N-S direction with a plunge of 18° towards north.

Outcrop HK-2

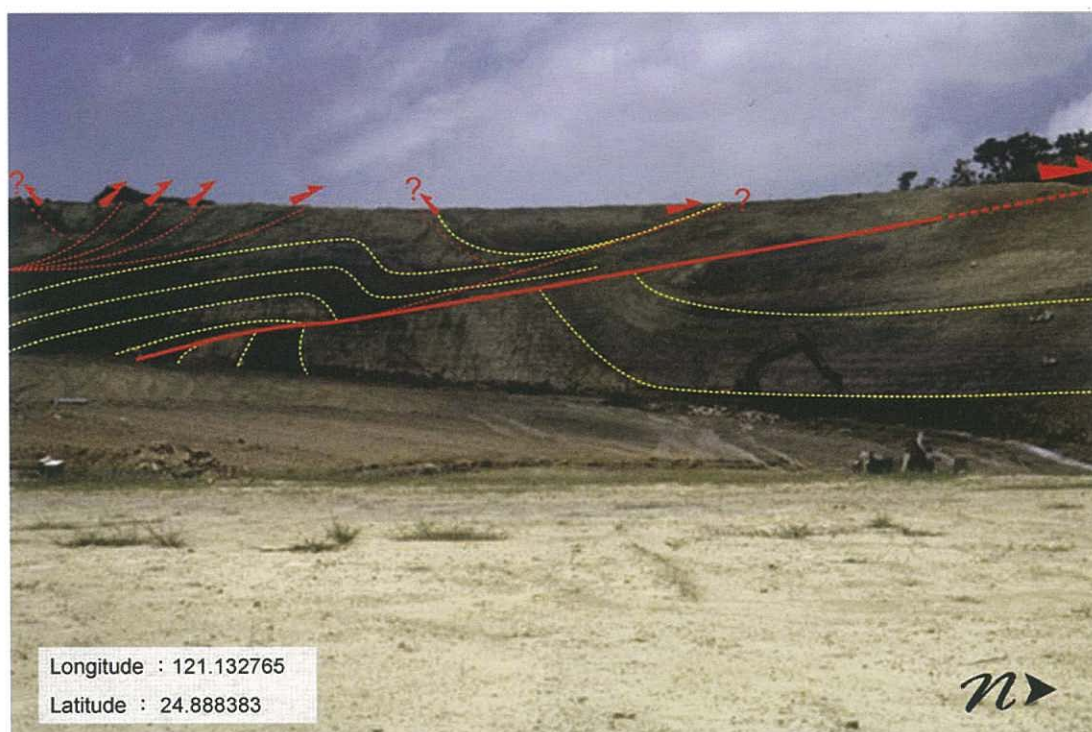


Figure 5. This outcrop at HK-2 site represents a major branch fault in the hanging wall of the Hukou fault. It shows complex deformation structures, including upthrust faults verging towards north with a few branches of fore-thrust as well as back thrust above and drag folds in the footwall. The main Hukou fault is located more than 0.4 km further north from this site.

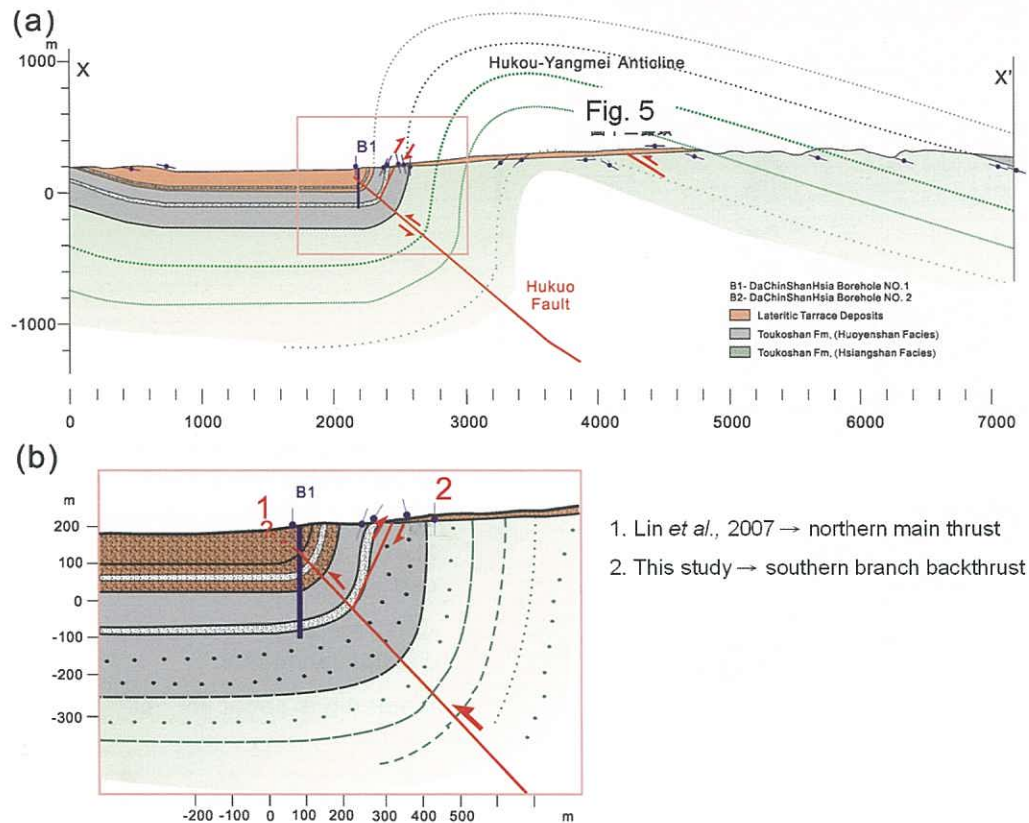
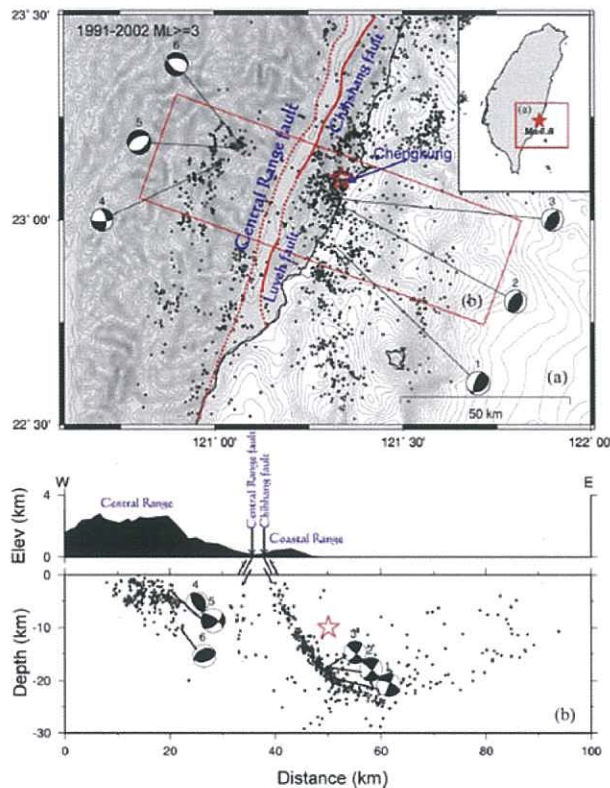


Figure 6. Geological cross section and major structures of the Hukou fault (modified and reconstructed after Lin *et al.*, 2007). The main fault of the northward thrusting Hukou fault appears to be buried by late Quaternary and Holocene alluvial deposits, especially in its footwall side, probably due to relatively low slip rate and rapid erosion and deposition along fault scarp. Based on observations in this study and previous studies, we intend to emphasize a rather wide active deformation zone of a few hundreds meters (i.e., sensitive zone for seismic hazards), which includes a few branches of active thrust and backthrust, occurs in the hanging wall of the Hukou fault.



- An active segment of the Longitudinal Valley Fault
- Ms 7.2 1951 Yuli earthquake and Mw 6.8 2003 Chengkung earthquake.
- Lichi mélange overlaps the alluvial sediments.
- Fault dip is about 45° ~60°

Figure 7. The regional setting of the Chihshang fault. The Chihshang fault is a 35-km active segment of the 180-km Longitudinal Valley fault at the plate suture between the Philippine Sea plate and the Eurasian plate. Along the Chihshang fault, the Luzon arc of the Philippine Sea plate is thrust over the Chinese continental margin of Eurasia. According to interseismic seismicity and aftershocks of the 2003 Chengkung earthquake, the Chihshang fault shows a subsurface listric-shaped geometry with 60-70° dip-angles at the shallow 10 km, changing gradually to 15-20° at the depth of 25 km.



Figure 8. An aerial view looking southward along the Longitudinal Valley above the Chihshang Town. The Central Range is located to the right-hand-side and the Coastal Range is located to the left-hand-side of the Longitudinal Valley, respectively. The surface traces of the Chihshang fault trending N-S generally follow geomorphic scarps and boundary between the rugged hills of the Coastal Range and the flat alluvial deposits of the Longitudinal Valley.

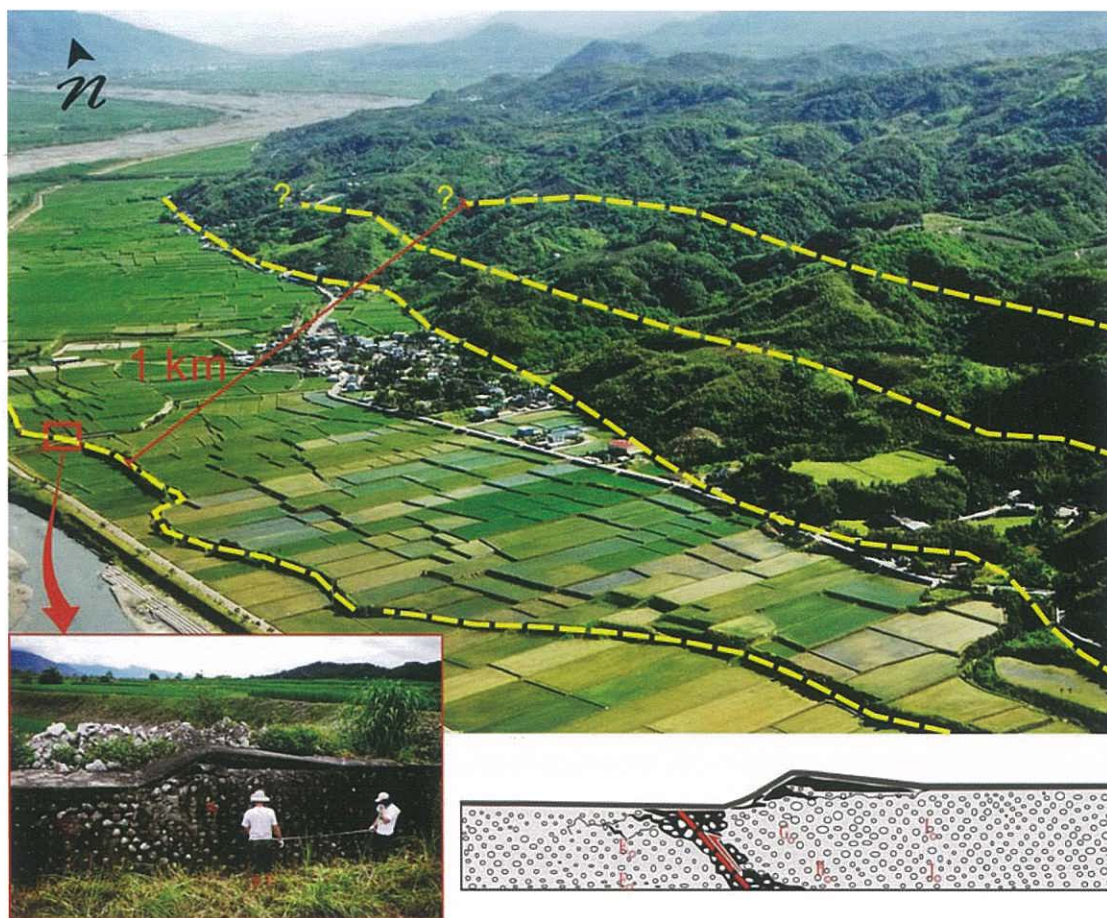


Figure 9. An oblique aerial view looking NNE along the Longitudinal Valley above the Tienkwang Village. The frontal thrust trace of the Chihshang fault (to the left) is marked by a fault scarp of 2-3 meters. This active creeping fault strand has deformed the retaining wall of concreted channels in the rice field as shown in the bottom of the picture and the sketch. Towards east (i.e., right side), another surface fault trace is highly suspected to follow along the boundary of the hills and the rice fields. Two other fault strands (branches) could also exist, based on geomorphic features with similar trend further east in the hanging wall. The total width of the fractures zone between the frontal fault and the easternmost branch (i.e., the sensitive zone for seismic hazards) is estimated to be about 1 km in this area of the Chihshang fault.

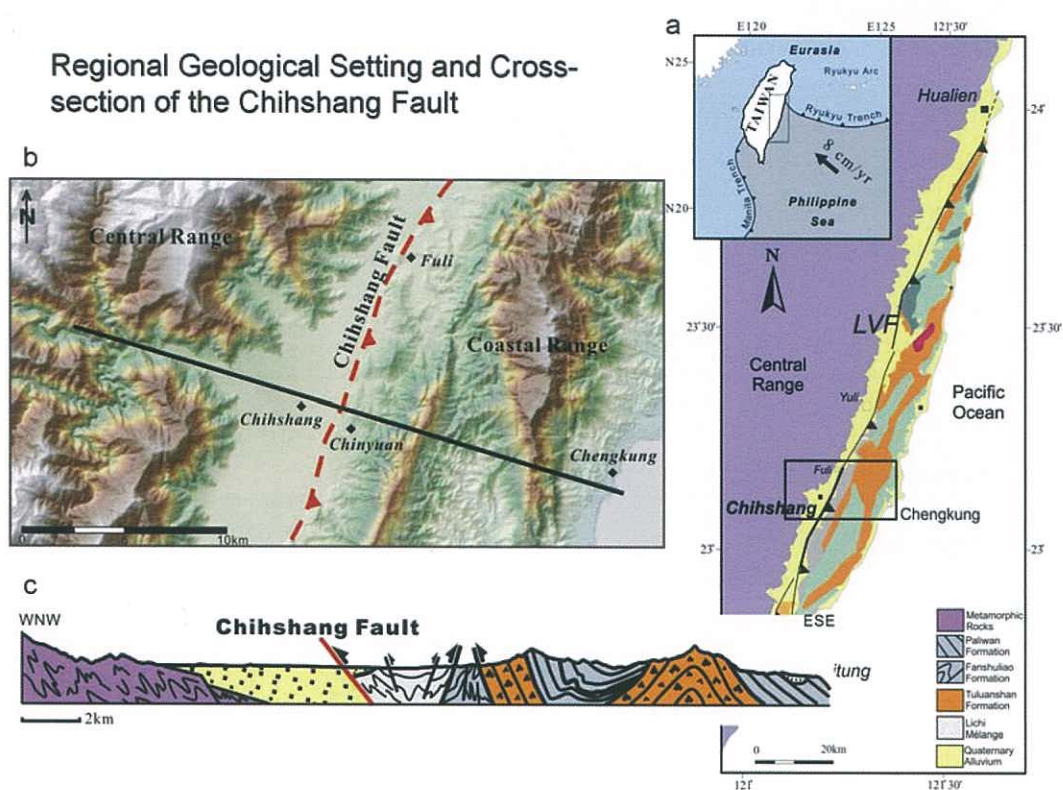
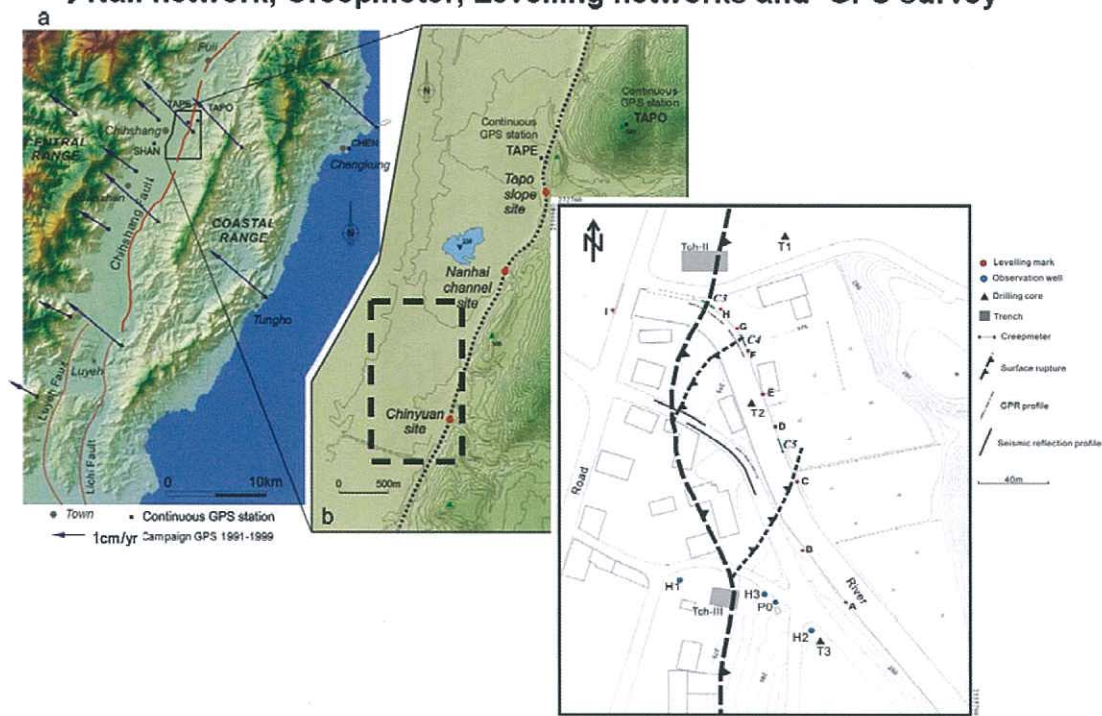


Figure 10. Regional geological setting and geological cross section at the shallow level of the Chihshang fault. Along the surface trace of the Chihshang fault, the Lichi mélange is thrust westward over the fluvial deposit of the Longitudinal Valley.

Geodetic Networks

→ Nail network, Creepmeter, Levelling networks and GPS survey



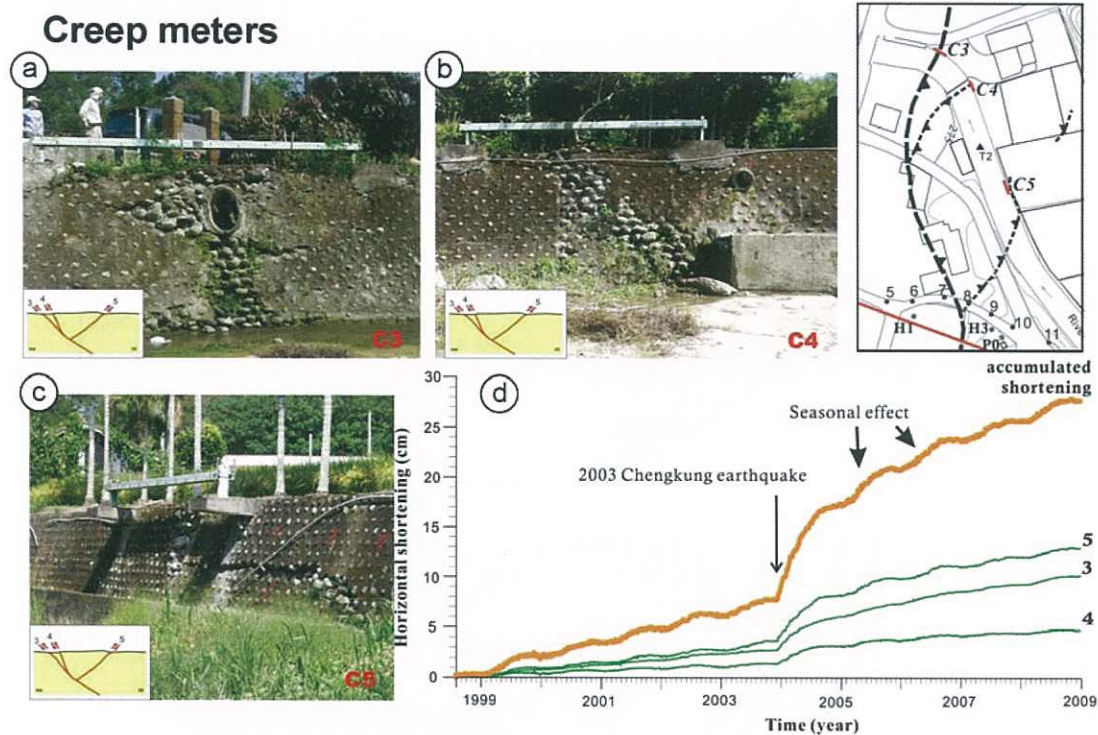


Figure 12. Field photographs of the three surface branches of the Chihshang faults on the retaining wall of the river channel in Chinyuan. (a) W-verging frontal; (b) W-verging middle fault; (c) E-verging backthrust. We installed creepmeter at each branch to record horizontal shortening across the surface faults. (d) Evolution of shortening on three branches of the Chihshang fault at Chinyuan in 1998-2009 from daily creepmeter records (Lee et al, 2003; 2006 Mu et al., 2011). The wave-shaped shortening curve reveals a seasonal shortening variation. Note that the 2003 Mw 6.8 Chengkung earthquake produced a smaller co-seismic shortening coupled with a relatively larger post-seismic shortening.

Fault geometry

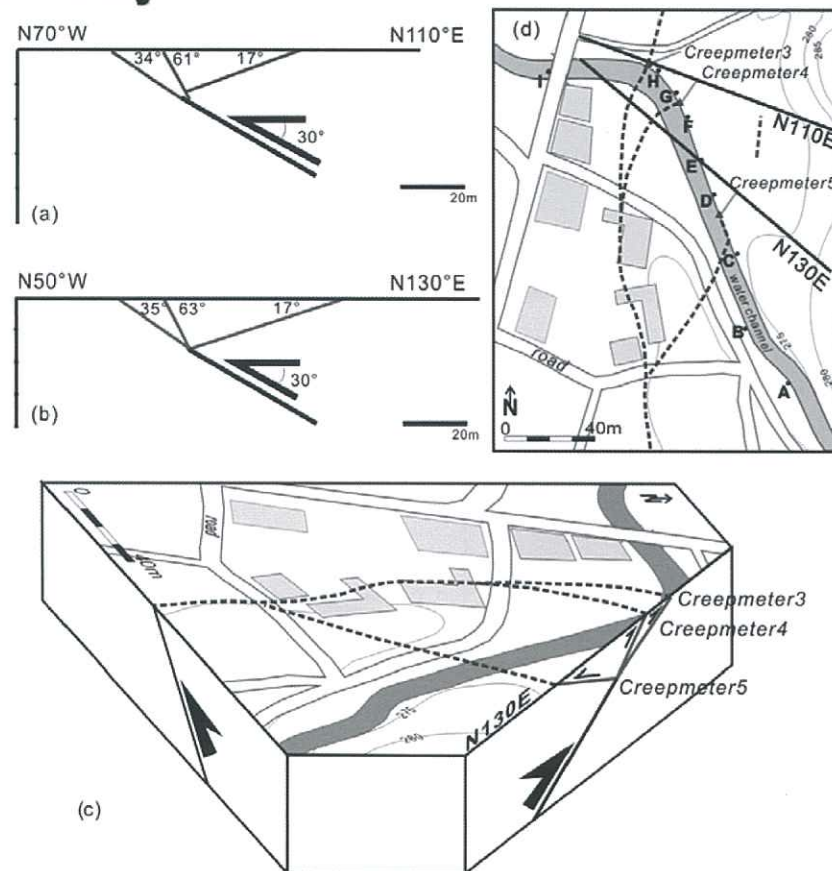


Figure 13. 3-D architecture of the Chihshang fault at the shallow level in Chinyuan. The three-branch fault system, which forms the deformation zone of an anticline up to 100 m wide, developed mainly within the alluvial deposits of the Chinyuan River. In terms of seismic hazard, this 100-m-wide deformation zone should be considered sensitive to active faulting. Outside of the influence of the Chinyuan River, the Chihshang fault generally shows a single fault system with a relative narrow sensitive zone of active faulting.

References

- Angelier, J. (1984) Tectonic Analysis of Fault Slip Data Sets: *J. Geophys. Res.*, 89, 5835-5848.
- Chinese Petroleum Company (1978) Geological Map of Taiwan-Toyuan Map Sheet (1:100,000) Chinese Petroleum Corporation, Miaoli, Taiwan.
- Cosgrove, J. W. and Ameen, M. S. (2000) A Comparison of the Geometry, Spatial Organization and Fracture Patterns Associated with Forced Folds and Buckle Folds. In Cosgrove, J. W. and Ameen, M. S. (eds.), *Forced Folds and Fractures*, Geol. Soc. London, Spec. Publ., 169, 7-21.
- Lee, J.C., Angelier, J., Chu, H.T., Hu, J.C., Jeng, F.S. and Rau, R.J. (2003) Active Fault Creep Variations at Chihshang, Taiwan, Revealed by Creepmeter Monitoring, 1998-2001. *J. of Geophys. Res.*, 108, B11, 2528, doi:10.1029/2003JB002394.
- Lee, J. C., Chu, H.T., J. Angelier, Hu, J.C., Chen, H.Y., and Yu, S.B. (2006) Quantitative analysis of co-seismic surface faulting and post-seismic creep accompanying the 2003, Mw=6.5, Chengkung earthquake in eastern Taiwan, *J. of Geophys. Res.*, 111, B02405, doi:10.1029/2005JB003612.
- Lin, C. W., Lu, S. T., Shih, T. S., Chen, C. S., and Lin, Y. H. (2007) Active Faults of Northern Taiwan with Explanatory Text for the Strip Maps of Active faults (1:25,000) Spec. Publ. Cent. Geol. Surv. 19, 118p. Taiwan.
- Mu, C.H., J. Angelier, J.C. Lee, H.T. Chu, and J.J. Dong (2011) Structure and Holocene evolution of an active creeping thrust fault: the Chihshang Fault at Chinyuan (Taiwan). *J. of Struct Geology*, 33, 743-755, doi: 10.1016/j.jsg.2011.01.015.
- Rau, R. J. (2010) Earthquake Geology and surface deformation and monitoring analysis (4/4) Annual project of the Central Geological Survey, MOEA, 145p.
- Suppe, J. and Namson, J. (1979) Fault-bend origin of Frontal Folds of the Western Taiwan Fold-and-thrust Belt: *Petrol. Geol. Taiwan*, 16, 1-18.
- Tu, M. K. and Chen, W. C. (1984) Geological Map of Taiwan-Chungli Map Sheet (1: 50,000) with Explanatory Text, Central Geological Survey, 53p.
- Tu, M. K. and Shao, P. H. (2001) Geological Map of Taiwan-Chungli Map Sheet (1: 50,000) with Explanatory Text (2nd ed.), Central Geological Survey, 47p.

NEW EVIDENCES OF PALAEVOLCANIC PLUGS IN TUEN MUN AREA, HONG KONG-- DEBATE ON THE VOLCANIC PLUG OR REWORKED PYROCLASTIC DEPOSITS

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ABSTRACT

Over the past ten years the volcanic plug of Hong Kong has been studied in detail, comparison was made with other volcanoes in the world. The existence of a chain of Middle Jurassic volcanic plugs on the east flank of Tsing Shan has been verified. The plugs are composed of andesite--dacite lava with explosive breccia, and surrounded by fallout deposits. Since most volcanic plugs in the world belong to Tertiary to Cretaceous Era, no detailed study has ever been done to palaeovolcanic plug of Middle Jurassic andesitic rock. This research result is therefore a major contribution to geological sciences.

KEYWORDS

Andesite, explosive breccia, palaeovolcanic plug.

INTRODUCTION

The Tuen Mun Formation is composed of basaltic andesite, dacite lava, tuff breccia and tuff with minor tuffaceous sandstone. It occurs in NW Hong Kong between two NNE trending faults from Tuen Mun passing through Lo Wu to Shenzhen (Figures 1-2). The granite occurs in the west whereas the Carboniferous sedimentary rock outcrops in the east. The Ar-Ar dating of andesite indicates ages of 181 ± 3 Ma and 182 ± 3.5 Ma respectively which are of Middle Jurassic age. Owing to the complexity of the pyroclastic rock and rare outcrops, the rock type found in the volcanic plug of Tuen Mun Formation has been misunderstood and intensely debated for a long time.

THE CHARACTERISTICS OF PALAEVOLCANIC PLUG IN THE WORLD

Further to our local study, volcanoes and plugs in other parts of the world were also visited such as Tertiary plugs of Ship Rock in America, Andes in Argentina, Pinatubo and Taal volcanoes in Philippines, kimberlite plugs in China as well as volcanoes in Indonesia, Italy, Iceland and New Zealand, etc. Some Important characteristics of volcanic plugs have been studied and compared with the plugs in Hong Kong. The common characteristics of volcanic plugs in the world are as follows:

- Mode of occurrence -- the shape of plug is circular or elliptical in plane, and cylindrical in cross-section. Generally, the outcrops stand out prominently in the landscape, such as Ship Rock in New Mexico, America. On the contrary, the kimberlite plug formed a circular depression.
- Volcanic facies - the rock in the plug is composed of explosive breccia and lava vein or either one. Generally there were several cyclic eruptions of a volcano. The explosive breccia represents the explosive eruption facies, whereas the lava vein indicates the effusive eruption facies. Surrounding the plugs are airfall deposits which are subject to erosion for a long time, only

their remnants deposit as colluvial boulders at the foothill.

- Pyroclastic fragments -- including the juvenile material and lithic fragments that occur within the plug. The elongated clasts are parallel to the plug. They were formed by explosive eruption or autobrecciation. The lithic clasts are cemented by lava and formed the alteration around their contact margin
- Plug structure -- The plug is associated with parasitic plugs (small plug) and dykes, for example, Ship Rock is associated with six parasitic plugs and six dykes (Figures 3-6). The plugs always occur in a group, such as in Cameroon, Africa.
- Lava and gas flow -- The lava flow and fumarole pipe are parallel to the plug in which the lava and gas move upwards
- Joint pattern -- Forming vertical tabular or concentric circle joints which are also parallel to the plug.

EVIDENCE OF PALAEVOLCANIC PLUGS IN HONG KONG

In order to have a thorough understanding of the Tuen Mun Formation rocks, detailed fieldwork and field inspection have been conducted including re-mapping the area, investigating the outcrops for 110 times. Meanwhile, more than 202 rock samples were collected, 105 thin sections were prepared and identified, 46 rock samples were chosen for chemical analysis. In addition, 11 chemical data were collected from Hong Kong Geological Survey. A chain of ten palaeovolcanic plugs trending NNW has been discovered and verified in the east flank of the hilly area from Tsing Shan Monastery to Por Lo Shan (Figure 2). The interval between two plugs ranges from 20m to 380m. The evidence to support the andesitic plugs in the Tuen Mun area are as follows:

1. Mode of occurrences

Most plugs are circular or elliptical in plane, and cylindrical in cross-section, ranging from 20m to 120m in diameter and 20m to 60m in height. Since the formation belongs to Middle Jurassic age, most of them are subject to weathering for a long period, several hundred metres of volcanic rock have been eroded, leaving only the hard skeletal, palaeovolcanic plugs remain and stand out prominently in the landscape.

2. Volcanic facies

Based on the relative position from source, the volcanic facies can be divided into vent facies, proximal facies and distal facies. Based on the eruptive activity they can also be divided into explosive eruption facies, effusive eruption facies, fallout facies, eruption-sedimentary facies, etc. The important volcanic facies in the study area is plug facies (vent facies). The rocks in the plug are composed of explosive breccia and lava flows produced directly by volcanism. The explosive breccias are the distinctive characteristics for recognition of the plug in the field, which were produced by the explosive eruption of magma. The vent fragments include juvenile lava congealed in early stage, and lithic clasts of Devonian quartzite and Carboniferous marble. The clasts are usually angular, some clasts forming shuttle shape parallel to the plug but in some circumstances may be rounded due to in-vent abrasion during eruption. The plug facies reveal a cyclic eruption starting from violent explosive of pyroclastics to quiet effusion of lava. The parasitic plug has one or two cycles whereas the large plug has multiple cyclic deposits.

The andesite lava in the plug probably reaches a temperature of about 12000 C. The hydrothermal alteration may develop in the contact between the marble clasts and lava forming the skarnization, chloritization and propylitization. Lava flow rises upward and parallel to the plug. The lava flows have a high volatile content resulted in very small fumarole pipes and lithophysaes appeared in the plug.

The group of plugs always occur as a chain which is controlled by a concealed fault. The plug is associated with dykes and parasitic plugs. The dykes occur at Shan King Estate, Por Lo Shan, Yick Yuen Tsuen and Tin Shui Wai. Their length ranges from several metres to more than 100m and 0.5m to 2m wide. At Shan King Estate there are three rounded parasitic plugs of 20m to 50m in diameter.

Around the plug is the fallout facies (airfall facies) which forms the interbedded tuff breccia, crystal ash tuff and lava with localized tuffite. The pyroclastic fragments fallen from eruption cloud or ballistic transportation forming cyclic deposits. The layers close to the crater are thick bedded range from 1m to 4m with a gentle dip angle. The pyroclasts reveal a heterogeneous and poor sorted nature. They contain angular, subrounded and spindle shaped lithic clasts as well as lava spatter which are parallel to the gently inclined layer. The spindle clast and lava spatter suggest that they were attained during flight such as at the south east of Shan King Estate. The fallout deposit can be found adjacent to a fault at Ling To Monastery, a large rock outcrop reveals five eruptive cycles in the interbedded tuff breccia, tuff and lava. Since the deposits are far from the source the layer became thinner ranging from 0.2m to 1m thick. The relationship between the plug and surrounding rock of fallout facies is an intrusive contact.

Effusive eruption facies-mainly forming lava flow near the plug to a widespread area far from the source. The lava is mainly fine-grained or massive basaltic andesite. The thick bedded lava is exposed from Tuen Mun Service Reservoir to Tin Shui Wai.

3. Chemical composition

Hong Kong Geological Survey has conducted 11 chemical analyses on the rocks of Tuen Mun Formation (Langford 1989 and Sewell 1997). These analyses were carried out on samples collected from outside of craters. No samples were collected from plugs.

Due to the aphanitic texture, the volcanic rock of Tuen Mun Formation is very difficult to be identified with naked eyes and microscope. In accordance with the recommendation of International Union of Geological Sciences, 46 rock samples were collected from different volcanic facies including: plug facies, fallout facies and effusion facies. All chemical results were plotted in the TAS (total alkali-silica) diagram to classify different rock types (Figure 34). With respect to the determination of accurate chemical composition, only clean rock samples which are free of metamorphism, weathering, hydrothermal alteration and impurities were used for chemical analysis. Laboratories of Hong Kong University, Guangzhou Institute of Geochemistry and Nottingham University, England were used to conduct the analysis.

The results of the chemical analyses indicate the pattern of volcanic eruption and verified the existence of volcanic plug. 23 lava samples were collected from the plug in which 14 sample results are dacite to trachydacite, 9 sample results are andesite to basaltic andesite. These lava flows with tuff breccia in the plug forms the cyclic eruption. 23 lava samples were taken from outside of the plug, in which 10 sample results are basaltic andesite to andesite, 7 sample results are dacite to trachydacite. These lavas are widespread in the valley and plain representing the quiescent eruption. Other samples are rhyolitic tuff. The crystal ash tuff and tuff breccia were found in the fallout facies around the plug forming the stratovolcanic volcanoes. The primary magma is probably the basalt rising from the mantle which becomes more silica rich by contamination of the basalt with crustal rock of higher silica content forming andesite to dacite

4. Geomechanical behaviour

It is easy to misidentify the tuff breccia as conglomerate due to their similarities in superficial appearance. Nevertheless, the two rock types are very different in terms of geomechanical characteristics. Geomechanical classification was conducted on the Tuen Mun Formation by Irfan (GCO 1990) and Chan and Kwong (2009) in which the uniaxial compressive strength and the elastic modulus of both rocks were very different and they would therefore have different load deformation behaviour. The uniaxial compressive strength of both rock types are tabulated in Table 1 for reference. The marble clast-bearing tuff breccia acquired a UCS about 5 to 10 times stronger than that of sedimentary rock, and 2 to 3 times stronger than that of marble. The UCS of siltstone is approximately 30 MPa which is about 3 to 6 times smaller than that of fine ash tuff. The errors made in rock identification could therefore result in a major impact in the engineering design as these rocks have different geomechanical behaviour. It is therefore strongly suggested that the rock types should be classified carefully with reference to geomechanical characterisation as well.

Table 1: Uniaxial Compression Test Results for Intact Rock Samples

Marble clast - bearing tuff breccia (MPa)	Calcareous conglomerate (MPa)	Clayey Conglomerate (MPa)	Fine ash crystal Tuff (MPa)	Marble (MPa)
a. 150 – 296 ¹	9.3 – 31.2 ³	4.0 -27.4 ⁴	c. 111 - 194 ²	d. 65 - 138 ¹
b. 195 - 329 ²				
Origin: a. Tin Shui Wai b. Tsing Shan Temple c. Tuen Mun d. Yuen Long				
Source of Origin: 1 GCO (1990), 2 Chan and Kwong (2009), 3 Fugro Rock Mechanics Lab. 4 FIGG Rock Mechanics Lab				
Only intact rock samples were tested				

VOLCANIC PLUGS IN THE TUEN MUN AREA

Until now, ten palaeovolcanic plugs and parasitic plugs have been verified in the study area. Some unknown plugs may be discovered in the future. Three typical palaeovolcanic plugs are introduced as follows:

Tsing Shan Monastery Plug (Figures 7-15)

Recently the monastery has been refurbished and 20 boreholes were sunk. After re-mapping the area and studying the borehole data in detail, it is found that the monastery is situated above a palaeovolcanic plug which is a rain drop shaped structure with 120m long and 50m wide. The plug is composed of explosive breccia and andesite lava. The main minerals of andesite are plagioclase and hornblende with minor biotite, augite, quartz and sphene as well as secondary minerals of epidote, chlorite and sericite. Most lava is aphanitic texture, occasionally the prismatic plagioclase is up to 3mm long. Lithic clasts contain sandstone, siltstone and marble of country rock and juvenile andesite fragment congealed in early stage. They are subangular to subrounded, 10mm to 300mm across and cemented by lava. The results of chemical analysis of lava in the plug indicate that three samples are basaltic trachyandesite and three samples are dacite. Contact metamorphism took place between the lava and lithic clast. The ferromagnesian clast formed chloritization or epidotization, the marble clast formed skarnization. The lava flow direction is parallel to the sub-vertical plug. Around the plug is interbedded crystal ash tuff and andesitic lava. The relationship between the plug and tuff is an intrusive contact.

Shan King Estate Plug (Figures 16-23)

This plug is located at 600m west of Shan King Estate. It is elliptical in shape and cylindrical in cross-section, up to 80m long and 50m wide forming a 50m high upstanding outcrop. It is composed of explosive breccia and lava vein. The explosive breccia represents the violent eruption whereas the lava flows indicate the quiescent eruption. The lithic clast is cemented by andesite lava with an altered rim between their contacts. The plug is associated with parasitic plugs and some dykes in the nearby area. The vertical eruptive lava flow and very fine fumarole pipes are parallel to the plug which are typical features indicating past volcanic activity. The vertical cracks produced an irregular columnar or tabular jointing. The fallout deposits exposed at the southeast of the plug, in which the fragment composition is similar to those within the plug but the spindle shape and long axis of clasts are parallel to the gently inclined bedding.

Three parasitic plugs were found in the adjacent area. The Parasitic Plug A forms a 50m diameter, 20m high sub-circle, located 80m east of the main plug. The parasitic plug is composed of explosive breccia and lava flows. The lithic clast is greyish white subrounded to rounded varying from 20mm to 200mm across, occasionally up to 800mm and is cemented by lava. Chemical analysis indicates that the lava is mainly andesite with dacite, most lithic clasts are rhyolitic ash tuff congealed in early stage. A special feature is that the plug reveals a concentric circle joint pattern and the explosive breccia occurs in the core of the plug. The Parasitic Plug B resembles the shape of smaller circle, only 30m in diameter and 20m high, located 35m south of the Parasitic Plug A. The outcrop stands out prominently in landscape. The fragment composition is simple, mainly greyish white subangular to subrounded crystal tuff and dacite. The lava flows upwards inside the plug; the long axis of lithic clasts is also parallel to the flow direction. The fallout deposits with sub-horizontal inclined bedding occur at the SW of Parasitic Plug B.

Por Lo Shan Plugs (Figures 24-29)

Two plugs are situated 550m southwest of Por Lo Shan. The south one is sub-elliptical in shape. It is 85m long, 50m wide and approximately 55m high. This plug comprises explosive breccia and lava of multiple eruptive stages. The chemical analysis result indicates the lava is mainly dacite with andesite. The lithic clasts comprise Devonian quartzite and sandstone, Carboniferous limestone with andesitic fragments. When the lithic clast contacts the hot magma, the margin of limestone is altered to garnet, tremolite, diopside or silicified marble. When subject to ductile deformation, the lithic clast may be flattened and elongated. The north plug has also erupted multiple times producing explosive breccia and lava flows. It forms a 95m long, 45m wide and 20m high ellipse which is 50m apart from the south plug. Both plugs form the upstanding outcrops and have the same lithic clasts; the vertical eruptive lava flow is also evident. The chemical analysis shows the country rock in the eastern and western parts of both plugs are rhyolitic ash tuff.

THE MISUNDERSTANDING OF PYROCLASTIC ROCK AND PLUG IN TUEN MUN AREA

Owing to the heavy vegetation, difficult access and rare outcrops in the hilly area, the pyroclastic rock of the Tuen Mun Formation has been misunderstood which resulted in lengthy debate for the past decade. For example, earliest authors (Allen and Stephens 1971) thought the strata in Tuen Mun area comprised mainly sedimentary rock and water-lain volcanic rock. Arthurton et al (GCO 1988) studied the strata and defined the andesitic strata as Tuen Mun Formation but misidentified the rock in the lower part of the formation was mainly sedimentary rock and showed a layer of conglomerate extending intermittently for nearly 2 km long in the Geological Map of Tsing Shan (Figure 38). Later Sewell et al quoted the obsolete data of the formation in "The Pre-Quaternary Geology of Hong Kong" (GEO 2000 p69). Up to the present some authors still hold the re-sedimentary view, such as in the "Engineering Geological Practice in Hong Kong" (GEO 2007, p.35, Fig. 3.2.3, p105, Fig. 5.5.1 and p140, Fig. 6.2.7) (Figure 37), and in the "Hong Kong Geology Guide Book" (GEO 2008 p52-60), they misinterpreted the lower part of the formation which comprises conglomerate, breccia and fine grained sedimentary rock which might have formed following the collapse of a volcano or by fluvial activity on the margin of a crater lake. Meanwhile, a considerable borehole logs and geological investigation reports of the area has misjudged the tuff breccia as sedimentary rock. These mistakes would greatly influence the accurate geological modeling and geotechnical engineering design in the area of concern.

COMMENT ON THE REWORKING PYROCLASTIC ROCK OF THE TUEN MUN FORMATION

The volcanic rock has a dual character. It reveals a sedimentary nature such as bedding and sorting, it also produces a volcanic character such as high temperature lava containing volatile forming alteration and fumarole structure. If rock classification is just based on one single nature of volcanic rock, it may draw an inaccurate conclusion. The interpretation of a re-sedimentary origin of the conglomerate and breccia in a plug does not accord with facts. The reasons are as follows:

The most important factor is the field observation of the mode of occurrence. Since the field study was not in detail resulted in misjudging the separated cylinder shape plugs as a layer of

conglomerate. The volcanic facies have not been studied by the author of "Hong Kong Geology Guide Book". (GEO 2008). The explosive breccia and lava flows were formed within the plug directly by volcanism. The marble clasts were subject to alteration. The lavas revealed flow structure and fumarole pipes. They are primary volcanic rock. Based on the relative position, the volcanic facies of a contemporaneous eruption can be divided into vent facies (plug facies), proximal facies and distal facies. They cannot demonstrate the relationship between upper or lower strata. The pyroclastic rocks of Tsing Shan Monastery and Por Lo Shan belong to plug facies. The plugs were subject to erosion for 180Ma, most rocks in the surface of the plug were washed out. It is difficult for them to remain as the reworked deposits within the plug.

The pyroclastic rock of Ling To Monastery belongs to proximal facies which are formed in a volcano slope around a volcanic center (Figures 30-33 and 35-36). The facies include rocks deposited from fallout processes and lava flows. The pyroclastic fragments fell from eruption cloud and ballistic transport forming stratified deposits. They occur as interbedded tuff breccias, fine-grained tuff and lava flows, occasionally with localized tuffite forming cyclic eruption. They contain angular, subrounded and spindle shaped lithic clasts as well as lava spatter. The spindle clast and lava spatter suggest that they were attained during flight. The fallout deposits remain in the area because they are located in the downthrow side of a normal fault. The authors with reworked pyroclast view have not done any chemical analysis for the lava flows in the Tsing Shan Monastery Plug and Por Lo Shan Plug. Therefore, they have misunderstood the lava as fine-grain sedimentary rocks, such as sandstone and siltstone, (Hong Kong Geology Guide Book, page 53). They also lacked study and objective review of the published papers and geological maps, such as Frost (1988) and Darigo (1988, 1990), they pointed out the marble clasts--bearing tuff breccia in Tin Shui Wai area was volcanic rock, not sedimentary rock. Irfan (GCO 1990) applied the geomechanic test to verify the tuff breccias were volcanic rock and their strength properties were stronger than those of conglomerate about 5 to 10 times. Lai has not shown the similar rock types as Tsing Shan Formation in the north half part of the same map, the Geology Map of Tsing Shan, Sheet 5 at scale 1:20,000 (Arthurton et al. 1988), but confirmed the rock type in west Tin Shui Wai area belongs to Tuen Mun Formation in the Solid Geological Map of San Tin, Sheet 2 (GEO 1994). Also Kirk et al. (GEO 2000) based on the updated field work data have cancelled and merged the Tsing Shan Formation into Tuen Mun Formation in the Geology Map of Hong Kong at scale 1:100,000. Normally the content of any geological report must agree with the corresponding geological map. Nevertheless, the main editor of the Pre-Quaternary Geology of Hong Kong (2000) has not done any detailed field work in the Tuen Mun area which resulted in selecting outdated data to write the report thus creating contradiction between the report and the corresponding geological map.

CONCLUSIONS

Over the past 40 years, many geologists have spent much of their precious time conducting detailed field mapping and survey in Tuen Mun, Yuen Long and Tin Shui Wai areas. The knowledge of volcanic rock has gradually expanded to reach a comprehensive level of understanding. A change in rock type from stratified conglomerate to cylindrical shape tuff breccia has been identified. Finally, a chain of palaeovolcanic plugs has been verified. The experience of reviewing the

rock types in this area highlights the importance of carrying out detailed field mapping to accurately observe the mode of occurrence of such rocks and conducting chemical analysis for aphanitic rocks to determine their chemical composition as recommended by IUGS, since identification by naked eye alone is extremely difficult.

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REFERENCES

- Allen, P.M. and Stephens, E.A. (1971). Report on the geological survey of Hong Kong. Government Printer, 107p
- Arthurton, R.S., Lai, K. W. & Shaw, R. (1988). Solid and superficial geology map of Tsing Shan (Castle Peak). Map HGM20 Sheet 5. 1:20,000. Geotechnical Control Office, Hong Kong Government.
- Chan, S.H.M. and Kwong, A. K. L. (2009). "Enhanced and systematic classification system for rock types in Tuen Mun and Tin Shui Wai Area, Hong Kong", Proceedings of ISRM-sponsored international symposium on rock mechanics, rock characterization, modeling and engineering design methods.
- Chan, J. Lai, K.W. and Chan, L.S. (2005). "Origin of a chain of clast-bearing cone-shaped rocks within the Tuen Mun andesite in Tsing Shan, Tuen Mun, Hong Kong.", Abstracts of the Conference on Recent Advances in Geological Research of Hong Kong and the Pearl River Mouth Region edited by Switzer, A.D. and Duzgoren-Aydin, N.S. Hong Kong University. 21-22.
- Darigo, N.J. (1988). Deep Bay: Solid Geology. HGP 5B, Sheet 2-SW-C. 1:5,000 Geotechnical Control Office, Civil Engineering Services Department.
- Darigo, N.J. (1990). "Marble-bearing Jurassic volcanics of the western New Territories, Hong Kong" In: Langford R. D., Hansen, A. & Shaw, R. (Eds). Karst geology in Hong Kong. Geological Society of Hong Kong Bulletin. No.4, 61-72.
- Fletcher, C. J. N. (2004). Geology of Site Investigation boreholes from Hong Kong, Double Helix. Hong Kong. 132 p
- Frost, D.V. (1988). Shan Pui: Solid Geology. HGP5B, Sheet 2-SW-D. 1:5,000 Geotechnical Control Office, Civil Engineering Services Department.
- Frost, D. V. (1990). "Geological structure and stratigraphy of the Yuen Long area, Hong Kong" In: Langford, R.D. Hansen, A. & Shaw, R. (Eds). Karst geology in Hong Kong. Geological Society of Hong Kong Bulletin. No.4, 49-60.

- Geotechnical Control Office (1989a). Solid and Superficial Geological Map of San Tin (1:20,000) Map HGM20. Sheet 2.
- Geotechnical Control Office (1989b). Tin Shui Wai: Solid Geology. HGP 5B, Sheet 6-NW-A 1:5,000. Civil Engineering Services Department.
- Geotechnical Control Office (1990). Foundation Properties of Marble and Other Rocks in the Yuen Long–Tuen Mun Area. (GCO Publication No. 2/90), Civil Engineering Department, Hong Kong, 117p.
- Geotechnical Engineering Office (1994). Solid Geological Map of San Tin. Sheet 2. Hong Kong Geological Survey, 1:20,000. Series HGM20S, Civil Engineering Department. Hong Kong Government.
- Geotechnical Engineering Office (2000). Geological Map of Hong Kong. 1:100,000 Series HGM20S Compiled by Kirk, P.A. Sewell, R.J. Campbell, C.D.G. Fletcher, C.J.N. Lai, K.W. & Li, X.C. Hong Kong Geological Survey, Civil Engineering Department. Hong Kong SAR Government.
- Geotechnical Engineering Office (2007). Engineering Geological Practice in Hong Kong. GEO Publication No. 1/2007. Civil Engineering and Development Department, Hong Kong SAR Government, 278p.
- Geotechnical Engineering Office (2008). Hong Kong Geology Guide Book. Geotechnical Engineering Office. Civil Engineering Department, Hong Kong. 173p.
- Lai, K.W. Chan, H.H.K. Choy, C.S.M. & Tsang, A L.Y. (2004). "The characteristics of marble clast-bearing volcanic rock and its influence on foundation in Hong Kong." Proceedings of Conference on foundation Practice in Hong Kong, E1-E10.
- Langford, R.L. Lai, K.W. Arthurton, R.S. & Shaw, R. (1989). Geology of the Western New Territories. Hong Kong Geological Survey Memoir No.3, 140 Geotechnical Control Office, Civil Engineering Services Department, Government Printer, 140p.
- Li, Q W (2010). Discovery of palaeovolcanic plug group of the Middle Jurassic age in Hong Kong and its significance. 3-22 in Proceedings on the Geosciences and Engineering of Guangdong, Hong Kong and Shenzhen. Shenzhen Geological Society (ed). 288p. (in Chinese)
- Sewell, R.J., Campbell, S.D.G. Fletcher, C.J.N. Lai, K.W. & Kirk, P.A. (2000). The Pre-Quaternary Geology of Hong Kong. Geotechnical Engineering Office, Civil Engineering Department, 181p.
- Song S. R. (2006) Volcanoes of Taiwan. Walkers Cultural. 205p

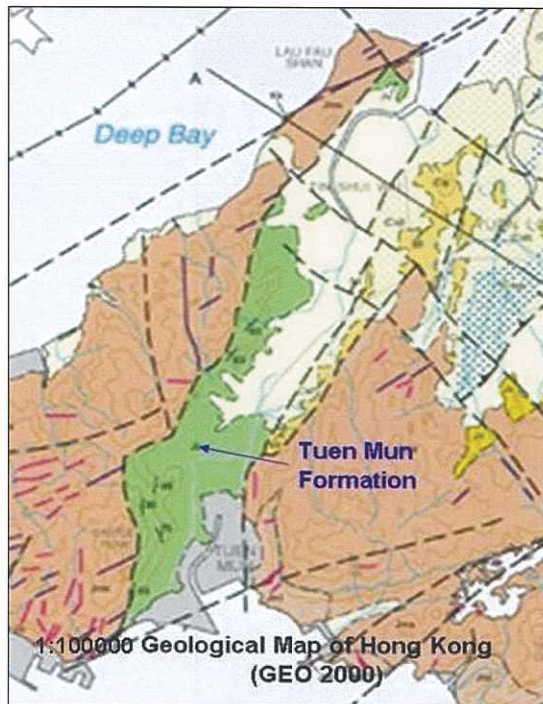


Figure 1 Tuen Mun Formation in geological map of Hong Kong (GEO 2000)

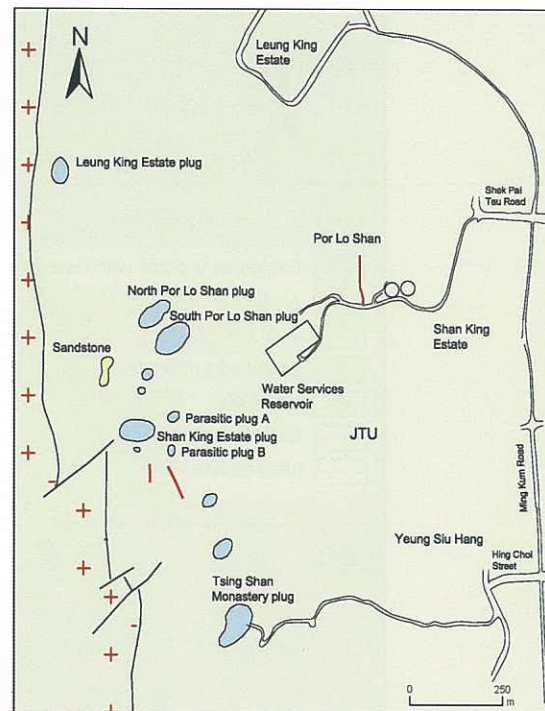


Figure 2 A series of volcanic plugs in the Tsing Shan - Por Lo Shan area

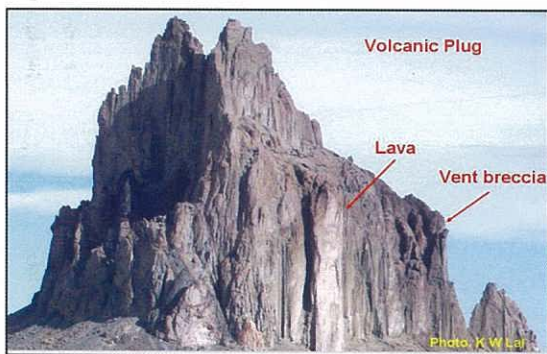


Figure 3 Lava and vent breccia of Ship Rock plug



Figure 4. Three parasitic plugs of Ship Rock, New Mexico, USA



Figure 5 Lava flow and explosive breccia of Ship Rock plug

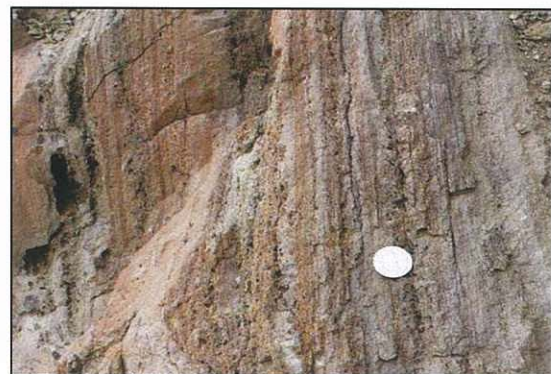


Figure 6 Lava flow of Ship Rock plug

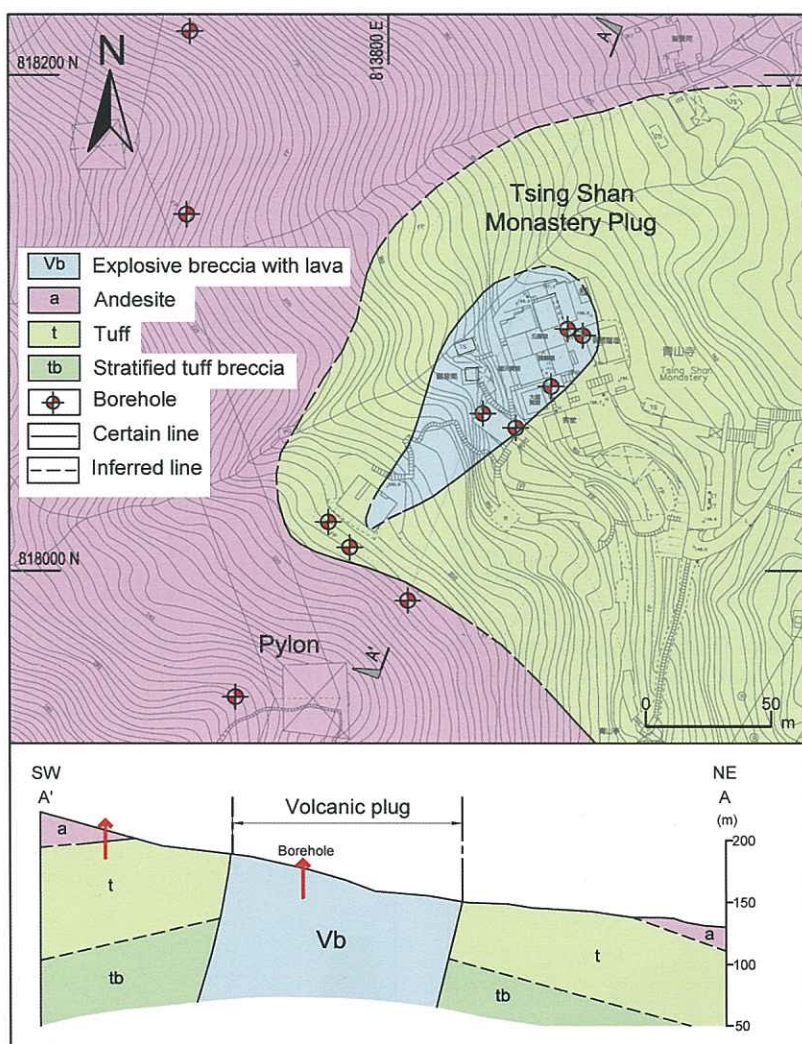


Figure 7 The cylindrical Tsing Shan Monastery Plug surrounded by stratified tuff breccia and andesitic lava

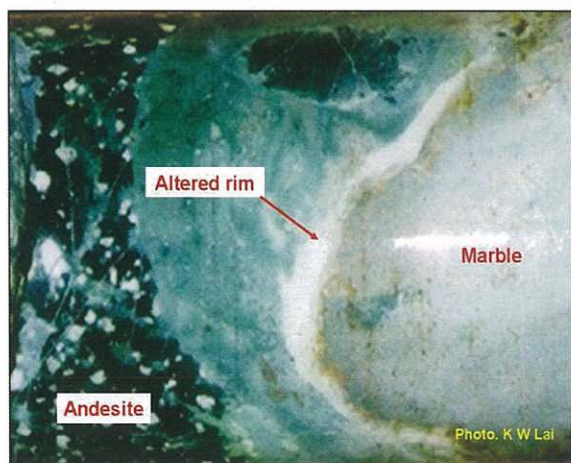


Figure 8 Altered rim between andesite and marble clast of Tsing Shan Monastery Plug

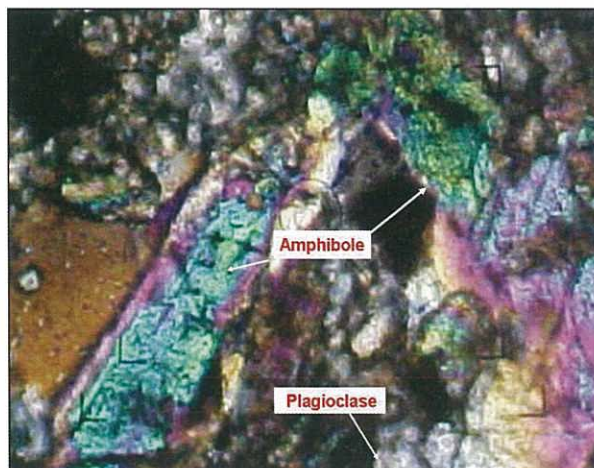


Figure 9 Andesite in thin section under the polarization microscope

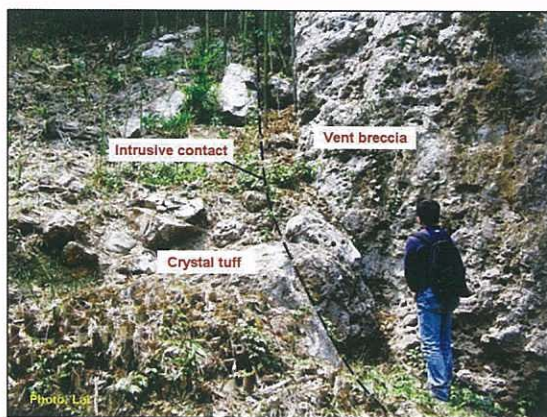


Figure 10 The vent breccia intruded the crystal tuff, Tsing Shan Monastery plug

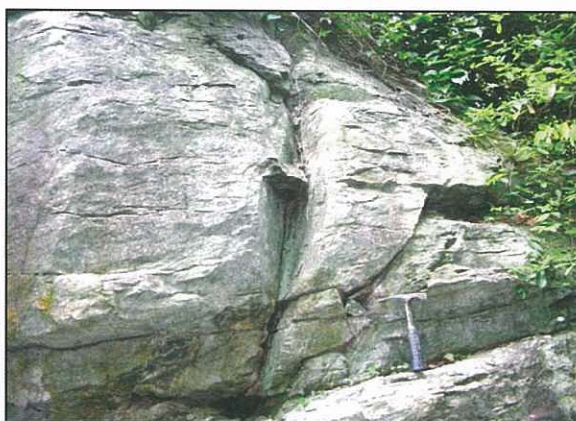


Figure 11 Gently inclined layer of crystal ash tuff around the Tsing Shan Monastery plug



Figure 12 Crystal ash tuff in thin section

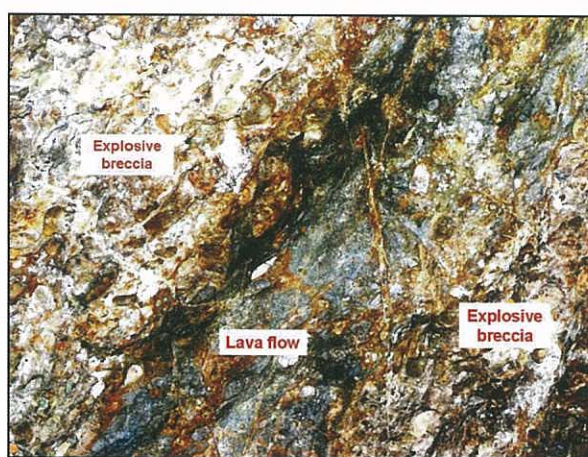


Figure 13 Lava flow and explosive breccia in Tsing Shan Monastery plug

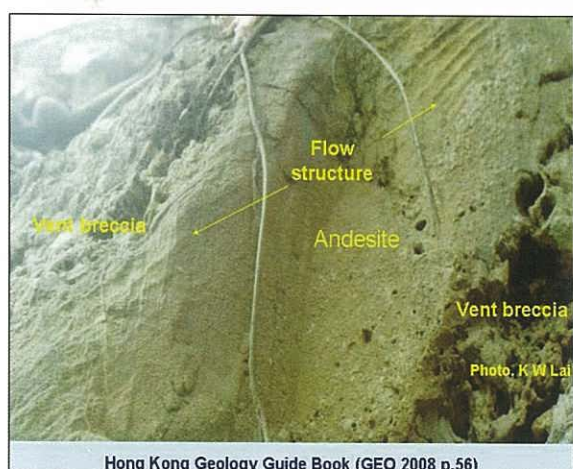


Figure 14 Vent breccia with lava flow which were misjudged as fine-grained banded strata between breccia/conglomerate

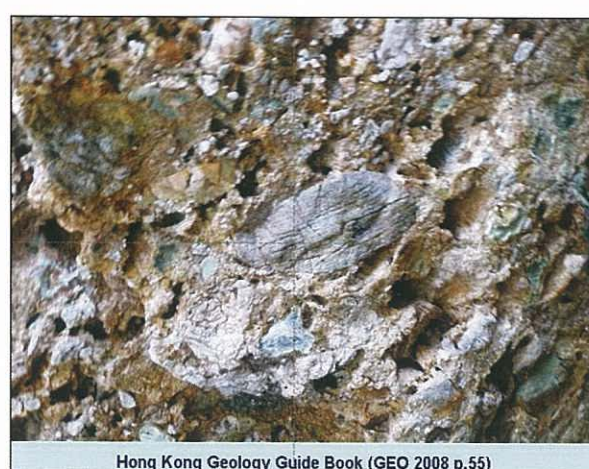


Figure 15 Explosive breccia with lava within a plug which was misjudged as conglomerate, Tsing Shan Monastery

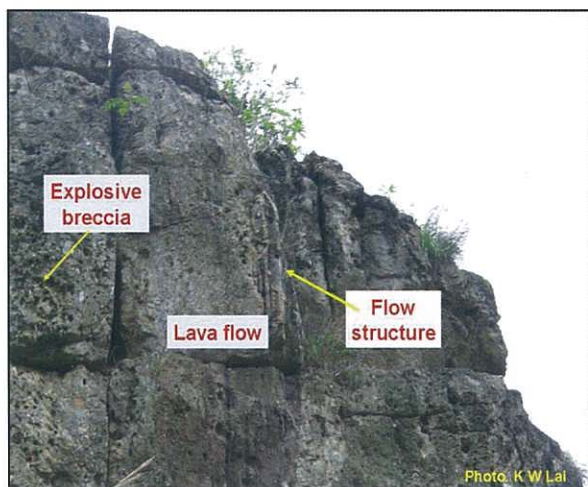


Figure 16 Explosive breccia and lava flow in Shan King Estate plug

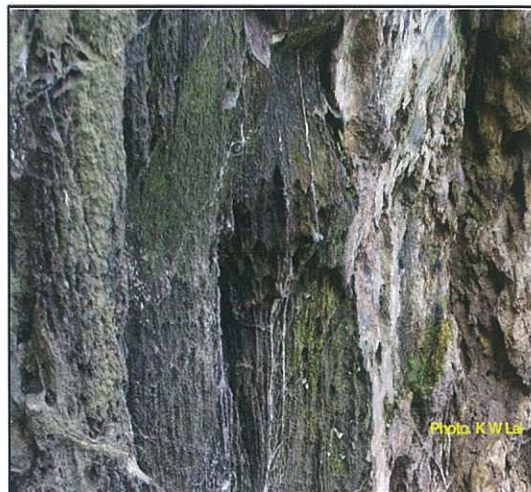


Figure 17 Very fine fumarole pipes in Shan King Estate Plug



Figure 18 Fumarole pipes in Yang Ming Shan crater, Taiwan

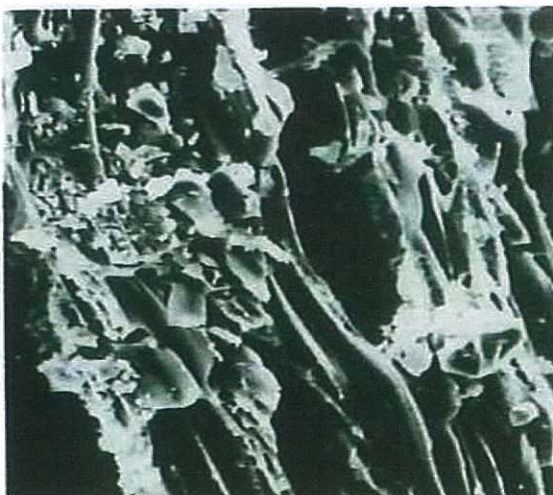


Figure 19 Fumarole pipes under electronic microscope (Song S R)



Figure 20 The explosive breccia in the core of parasitic plug A at 45m NE of Shan King Estate plug

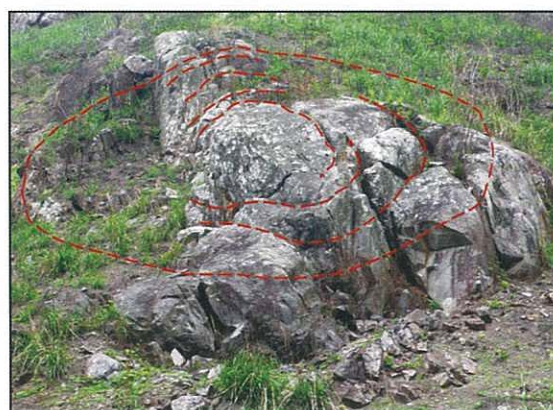


Figure 21 Concentric circular joint of parasitic plug A



Figure 22 Parasitic plug B at 50m SE of Shan King Estate plug

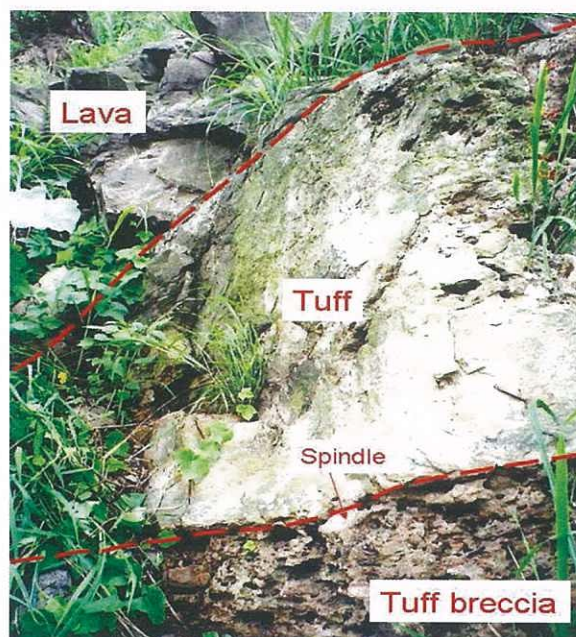


Figure 23 Interbedded tuff breccia, tuff and lava of fallout deposit, at 50m south of Shan King Estate plug

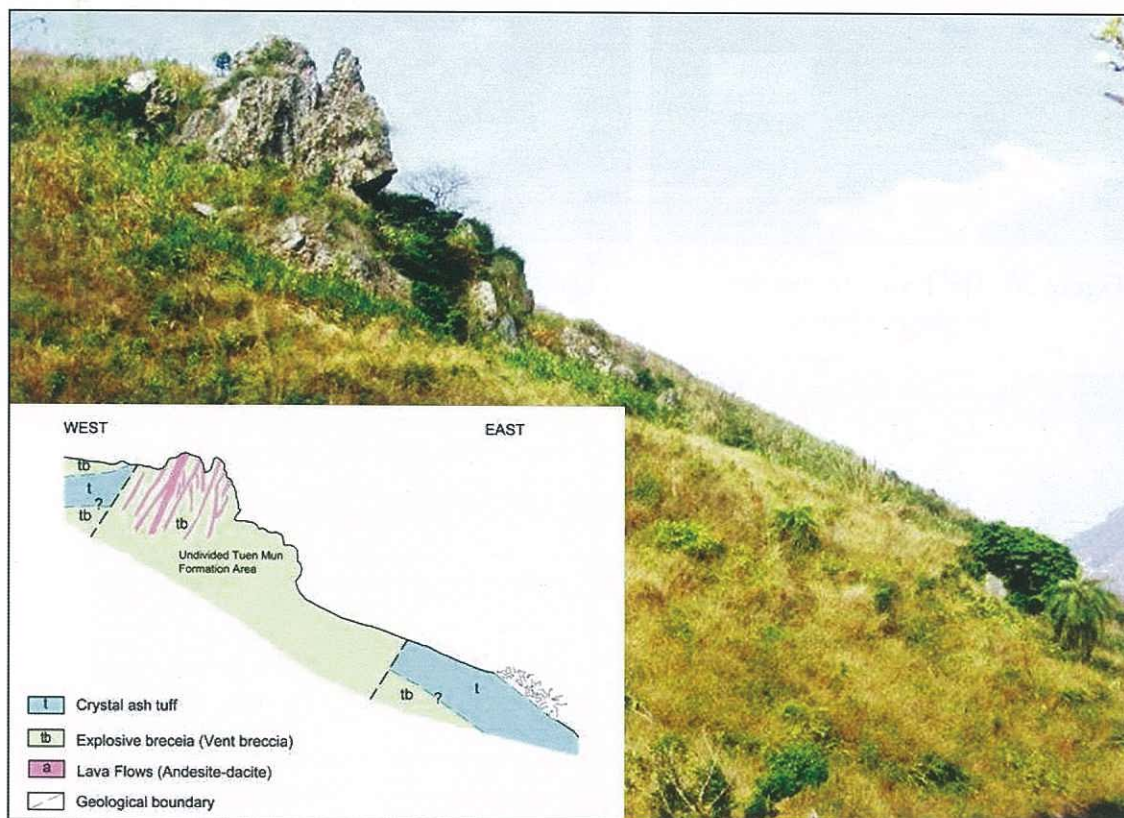


Figure 24 South Por Lo Shan plug

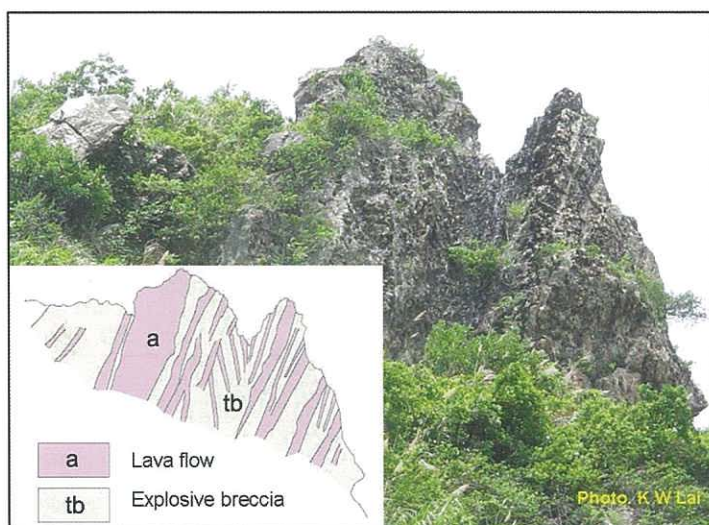


Figure 25 Lava flow and explosive breccia of South Por Lo Shan plug indicating the cyclic explosion

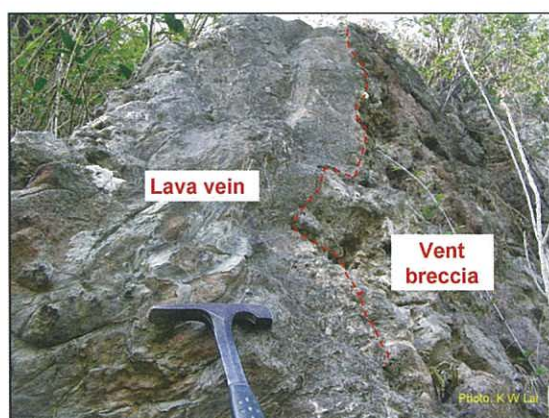


Figure 26 The lava intrudes the Explosive breccia



Figure 27 Explosive breccia in the South Por Lo Shan plug

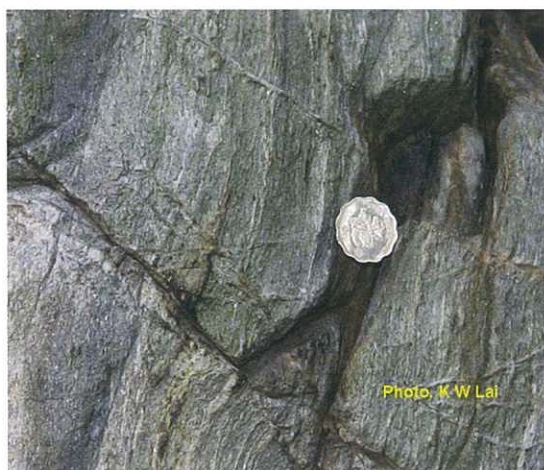


Figure 28 Lava flow structure of South Por Lo Shan plug



Figure 29 The lithophysae indicates the lava containing volatile

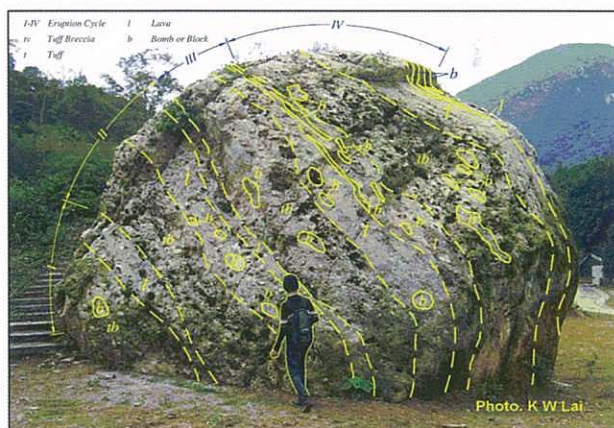


Figure 30 Stratovolcanic deposits at Ling To Monastery

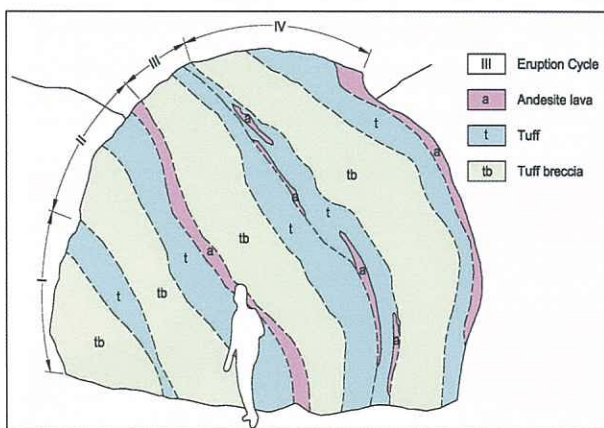


Figure 31 Sketch of the stratovolcanic deposit of Ling To Monastery

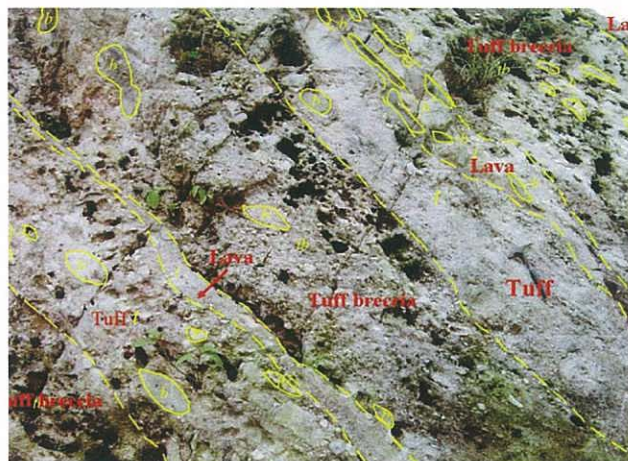


Figure 32 Interbedded tuff breccia, tuff and lava of fallout deposit in Ling To Monastery



Figure 33 Spindle shape lava in the fall out deposit

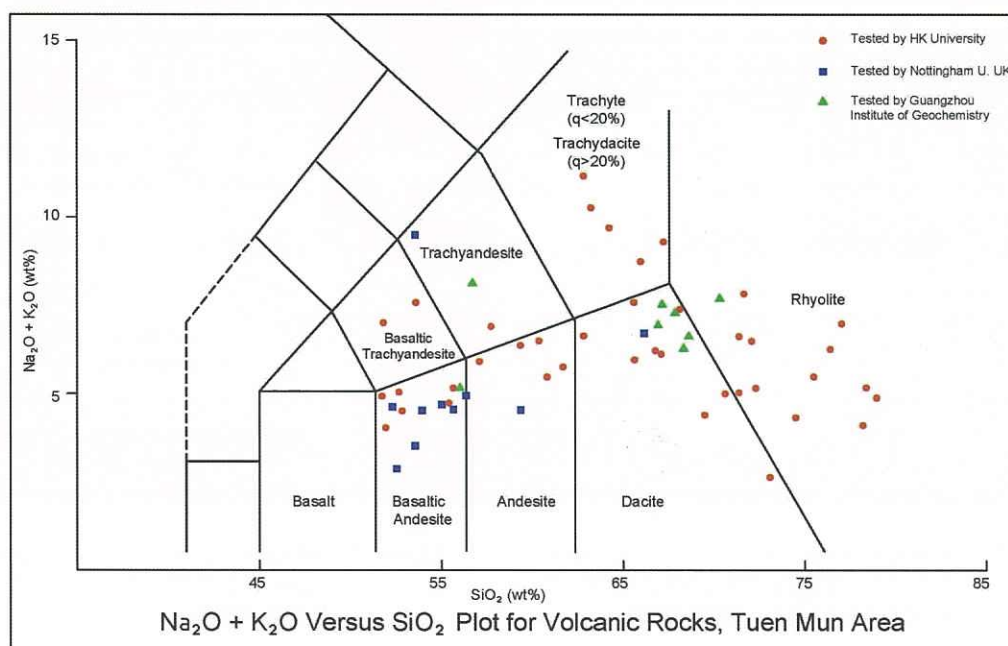


Figure 34 Chemical composition of volcanic rocks in the Tuen Mun Formation

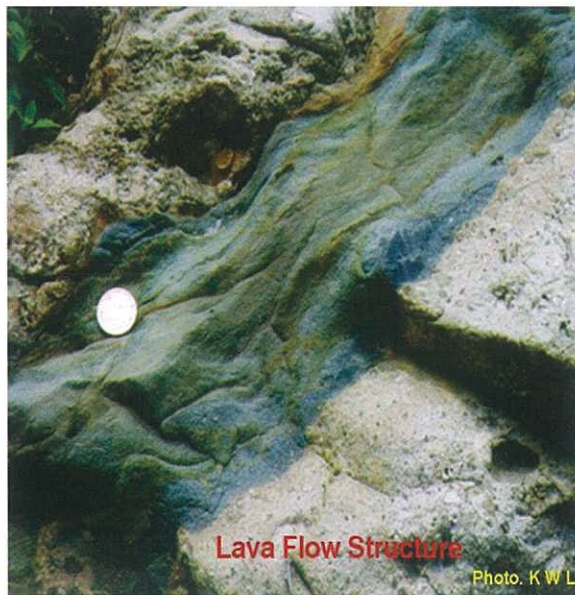


Figure 35 Lava flow structure, Ling To Monastery

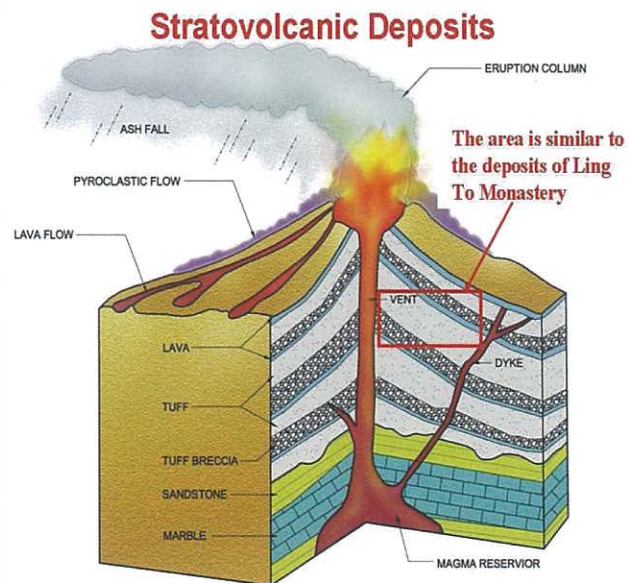


Figure 36 Sketch showing the volcanic plug and stratovolcanic deposits

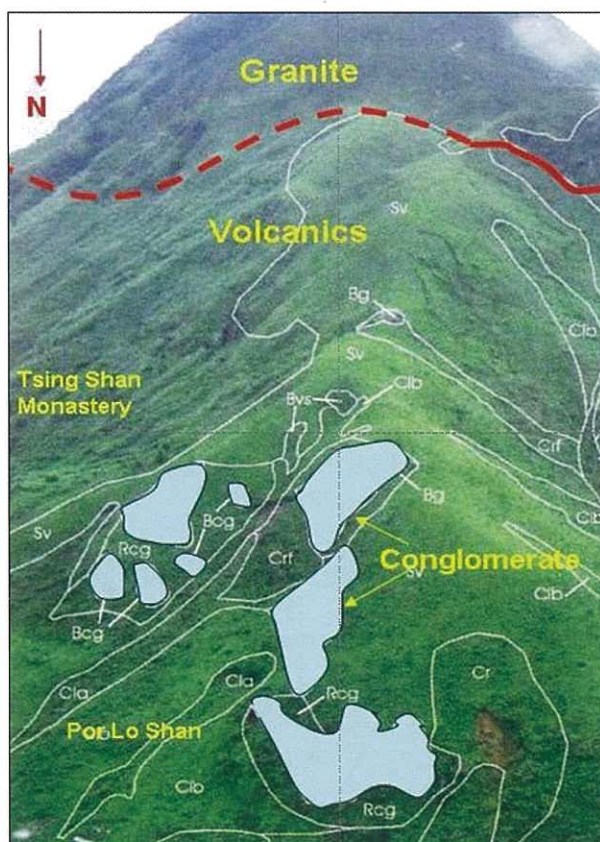


Figure 37 Misidentify conglomerate in the figure of “Engineering geological practice in Hong Kong” (GEO 2007 p35)

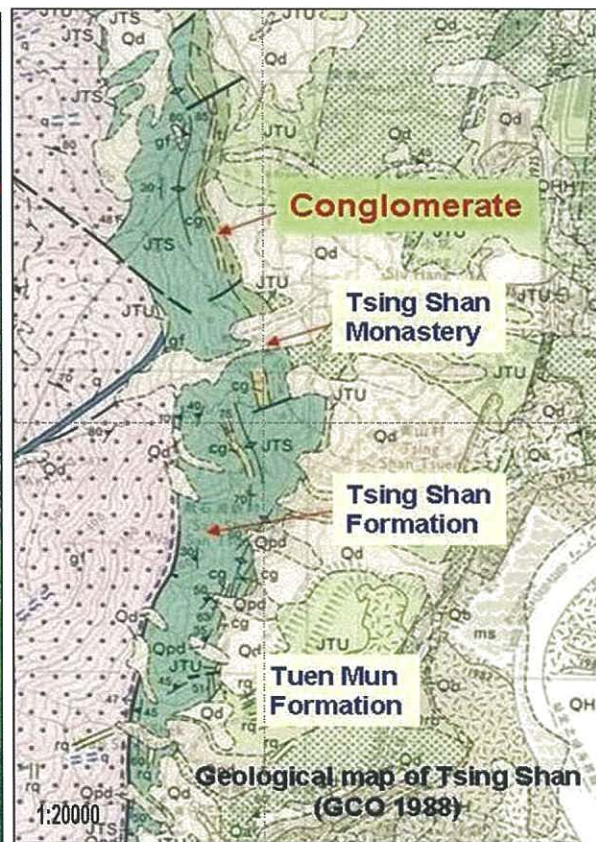


Figure 38 Misinterpretation of a conglomerate layer in published geological map (GCO 1988)

Sustainable Use of Reservoirs in Taiwan - Underwater Tunnel Piercing Method

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Abstract: This study addresses reservoir sediment issues in Taiwan. It is shown that, to install a new desilting tunnel under a reservoir, the underwater tunnel piercing method can be used. The advantage is that there is no need to lower the reservoir's water level or construct a weir. Numerical simulation and a field-blasting test for two cases in Taiwan have been used to explore the feasibility of this construction method in Taiwan.

INTRODUCTION

Due to Taiwan's young geological age, strong geological tectonic effects, torrential rains from typhoons, and frequent earthquakes, the upstream side slopes of water catchment areas of reservoirs in Taiwan may be subjected to avalanches, which cause severe reservoir sedimentation issues. The average lifespan of reservoirs is quite short in Taiwan. Once a reservoir is subjected to sedimentation, its lifespan is reduced, and its storage and flood-control functions decline. In the past, reservoir designs in Taiwan have not been able to solve the reservoir sedimentation problem. Installation of underwater desilting tunnels that can effectively slow reservoir sedimentation has not been accomplished. Extending the lifespan of reservoirs has become an important issue in Taiwan.

The methods for removing sediment from reservoirs can be classified as mechanical dredging and hydraulic flushing. Mechanical dredging encompasses operations that use hydraulic, mechanical, siphoning, or air-lift dredges. Hydraulic flushing can be subdivided further into drawdown flushing, flood flushing, flushing and emptying, density current flushing, and desilting operations. However, studies have indicated that most reservoirs in Taiwan, except for those with small capacities and abundant flows, are not suitable for emptying and flushing operations. Further, most reservoirs in Taiwan have no desilting holes and are located at low elevations so that flushing and desilting operations cannot be performed. Therefore, the underwater tunnel piercing method may serve as an effective method for constructing new underwater desilting tunnels in reservoirs, without having to lower water levels or construct a weir.

However, the implementation of this breakthrough technology, like those in the past, requires the involvement of competent personnel with knowledge and pertinent experience in geology, blasting techniques, and hydraulics when planning and executing underwater tunnel piercing.

RESERVOIR SEDIMENTATION IN TAIWAN

According to information for major reservoirs in Taiwan released by the Water Resources

Agency of the Ministry of Economic Affairs of Taiwan, Taiwan has 39 major reservoirs with a total effective capacity of 2.2 billion m³. Chang (2004), who analyzes statistical data for Taiwan's major reservoirs, has obtained the following analytical results.

- The total water catchment area is 9,414 km² with a total water storage capacity of 2.6 billion m³ originally. Currently, effective total storage capacity is 2.2 billion m³.
- The total sediment accumulated in Taiwan's major reservoirs is approximately 400 million m³, which is equivalent to the total storage capacity of Taipei's Feitsui Reservoir.
- The total amount of sediment in all reservoirs in Taiwan increases by 15 million m³ yearly, and this rate is increasing, which adversely affect water storage capacity and flood-control capability.

THE UNDERWATER TUNNEL PIERCING METHOD

The underwater tunnel piercing method, also called lake tapping, involves running a tunnel toward and under a lake, leaving a short rock-plug on the lake floor beneath the tapping level (Fig. 1). The final plug is then blasted, piercing the lake floor from below. This is an old practice and several hundred lake taps have been carried out in Norway (Palmström, 2005).

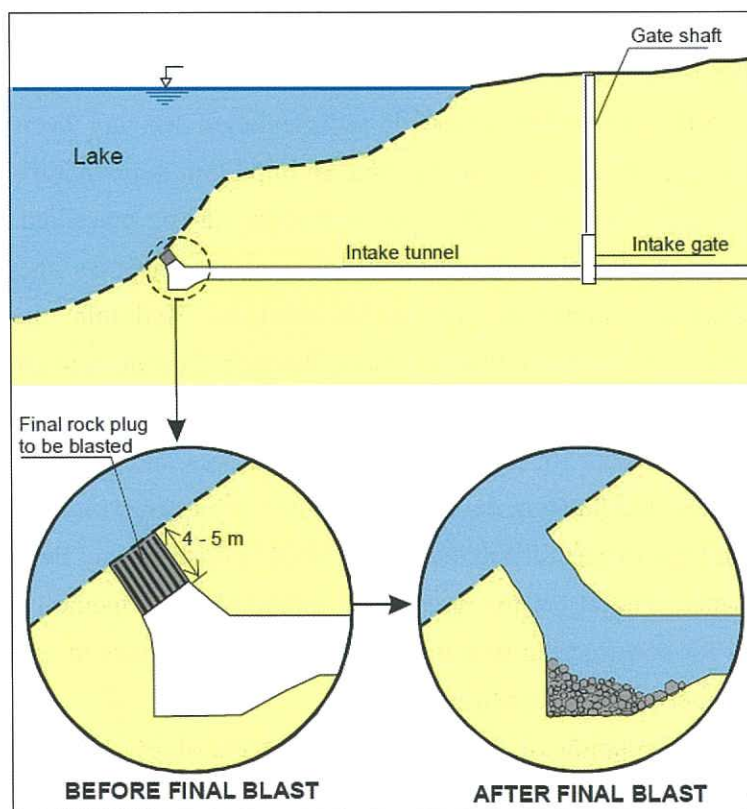


Fig. 1 Principles of the lake tap method for a water tunnel (after Palmström, 2005)

Piercing a sea or lake bottom has been conducted at depths of 120 m below the water level. Over the last 25 years, Norwegian experts have tapped lakes in Norway, Asia, North America, and South America (Palmström, 2005).

Successful construction of a large number of lake taps has been led by highly trained specialists with practical experience. Due to the complexity and risk of damaging existing structures, a thorough and detailed design based on geologic data and experience is a prerequisite for success (Palmström, 2005).

Underwater tunnel piercing is also used in other areas such as flood prevention, shore approaches for oil and gas pipelines from the North Sea, and may in the future be used for fjord or strait crossings by underwater tube bridges (NTNU, 1999).

Underwater tunnel piercings can be divided into two categories (NTNU, 1999).

- Closed system
- Open system

With open-system piercing, communication exists between the tunnel face, the tunnel plug location, and the gate shaft.

With closed-system piercing, the gate is located on the upstream side of the gate shaft. Hence, no communication exists between the plug and gate shaft.

Palmström (2005) noted that careful planning and follow-ups are essential, which have the following features:

- Control of geologic conditions in a rock mass and lake sediment before construction work commences.
- Design of a suitable final blasting method, regardless of whether the so-called “open” or “closed” method is used.
- Control of rock mass and permeability conditions while excavating toward the piercing area and during trimming and designing the final rock-plug.
- Detailed design of all elements in the piercing area with verification of pressures in the final blast, ensuring that that no damage will occur.

NUMERICAL ANALYSIS OF THE UNDERWATER TUNNEL PIERCING

METHOD (Case 1)

Engineering Geologic Investigation

The first study case is located in northern Taiwan. The main lithologic character from top to bottom are alternating sandstone and shale, sandy shale, and sandstone in the rock-plug and tunnel intake. Geologic structures are beddings and joints. No faults or folds were found. The lithologic character of ss/sh2 near the open of plug is alternating sandstone and shale (ss/sh), shale (sh), sandstone (ss) and sandstone interbedded with some shale in 17 layers. Table 1 shows the section, relationship between layers, and thickness. Figure 2 shows the intake geologic profile. Rock classification of the NGI-Q system is 1.75-63.36, which is the range for poor-to-very good grade. The score of the CSIR-RMR system is 50-76, and the rock class is II-III (United Geotech, Inc., 2010).

Table 1 Strata contribution

Formation	Section	Thickness (m)	Section basis
Nankang	ss/sh5	100	alternations of sandstone and shale; easily weathered
	tu1	20	tuff; appeared at 10.9-30.7m in borehole 98-BH-4; upper limit is unknown; thickness is tentative 10 m
	ss-sh2	75	muddy sandstone interbedded with shale, appeared at 30.7-50m
	Mss4	35	massive sandstone, highly strength
	ss/sh4	50	alternations of sandstone and shale; easily weathered
	Mss3	30	massive sandstone, high strength
	ss/sh3	20	alternations of sandstone and shale
	sh3	10	sandy shale; appeared at 4.85-17.3 m in borehole 98-BH-3. The upper limit is unknown. Thickness is a tentative 10 m.
	ss2	30	sandstone occasionally with shale; appeared at 17.3-70 m in borehole 98-BH-3
	sh2	10	sandy shale; appeared at 11.9-13 m in borehole 98-BH-2; upper limit is unknown; thickness is a tentative 10 m.
	ss1	15	sandstone; appeared at 13-57 m in borehole 98-BH-2.
	sh1	10	sandy shale; appeared at 57-70 m in borehole 98-BH-2; lower limit is unknown; thickness is a tentative 10 m.
	ss/sh2	40	alternations of sandstone and shale
	Mss2	110	massive sandstone; appeared at 2.6-50 m in borehole 98-BH-1; occasionally with thin layers of shale
	ss/sh1	70	alternations of sandstone and shale
	Mss1	100	massive sandstone; high strength
Shihti	ss-sh1	>350	sandstone interbedded with shale; gray; with thin layers of coal

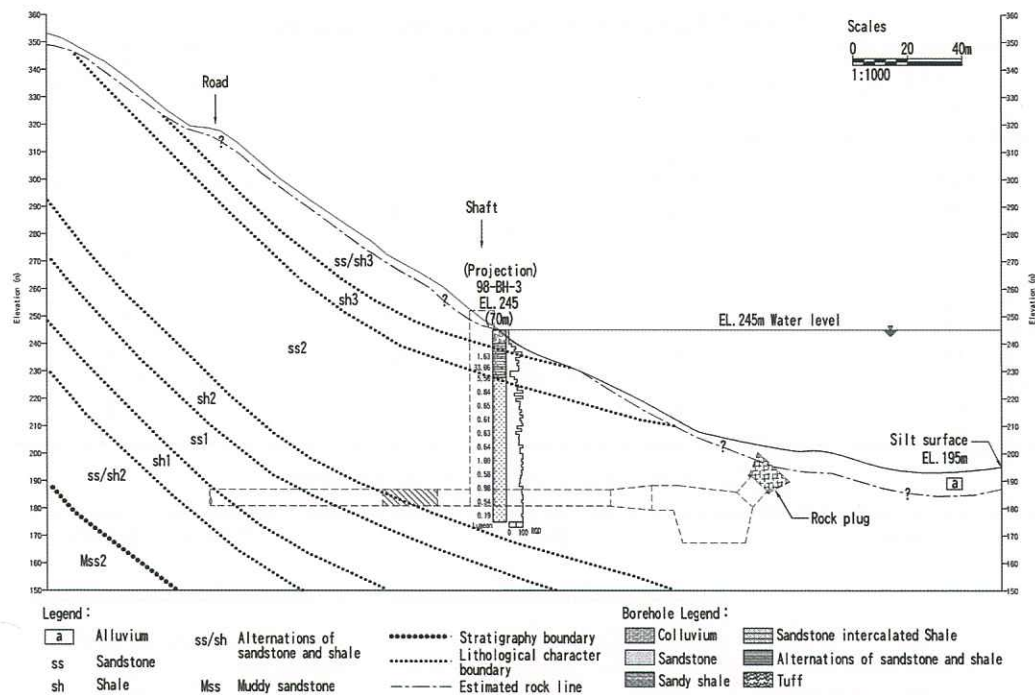


Fig. 2 Intake geologic profile

Numerical Analysis

The simulation uses three-dimensional (3-D) numerical analysis software Midas/GTS for design assessment of three rock-plug sizes to investigate the influence of slope stability on different rock-plug sizes. The centerline of plug plane is fixed at E.L. 195 m. Figure 3 and Table 2 analyze rock-plug sizes and muck-pit sizes, respectively. Table 3 lists the parameters in numerical analysis (United Geotech, Inc., 2010).

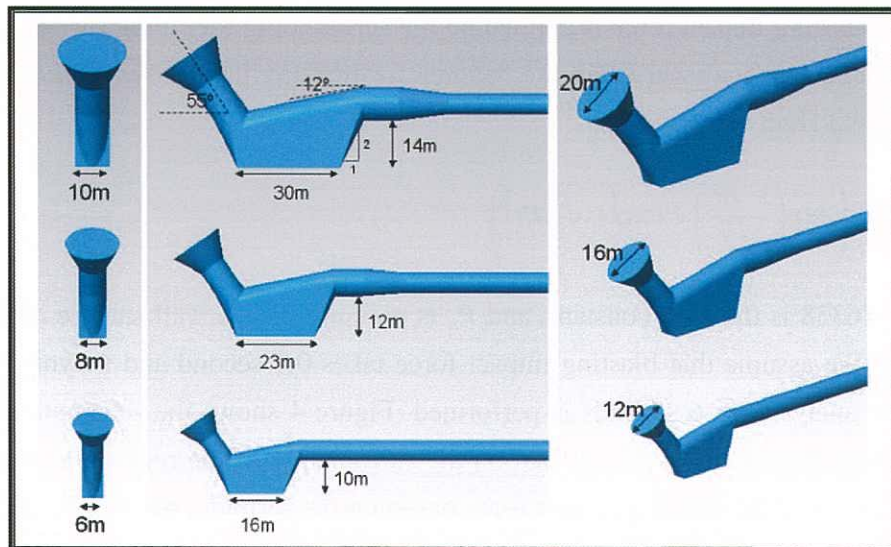


Fig. 3 Different rock-plug sizes and muck-pit sizes

Table 2 Sizes of the rock-plug and muck-pit

Size of rock-plug (m)		Thickness (m)	Diameter/Thickness
Diameter of upper plug	Diameter of lower plug		
20	10	10	1.0
15	15	10	1.5
15	10	10	1.0
16	8	8	1.0
12	6	6	1.0

Table 3 Parameters in numerical analysis

Item	Rock (Mohr-Coulomb elasticity and plasticity)	Concrete lining (plate element, elasticity, 1.5 m thick 1.5m)
Unit weight (MN/m ³)	0.0247	0.0235
Elastic modulus Es (MPa)	819.03	28606
Poisson's ratio (ν)	0.16	0.17
Cohesion (MPa)	0.341	-
Frictional angle (°)	51	-

Dynamic Simulation

We assume blasting impact force is applied on the surrounding rock-plug surfaces in such a way that it can be analyzed using the formula for blasting impact force recommended by the National Highway Institute.

$$P_D(t) = 4P_B \left(\exp\left(\frac{-Bt}{\sqrt{2}}\right) - \exp(-\sqrt{2}Bt) \right)$$

where $B = 16338$ is the load constant, and P_B is pressure on the wall surface of the hole (unit, t/m²). We assume that blasting impact force takes 0.1 second and a dynamic load-time history analysis for 6 seconds is performed. Figure 4 shows the schematic diagram of the blasting impact load force applied on the surrounding of the rock-plug. According to the evaluation of the blasting impact force based on the formula, blasting force reaches roughly 0 at 0.1 second. For the three rock-plug thicknesses, the dynamic deformation distribution after blasting indicates that all deformations are less than 0.1 mm.

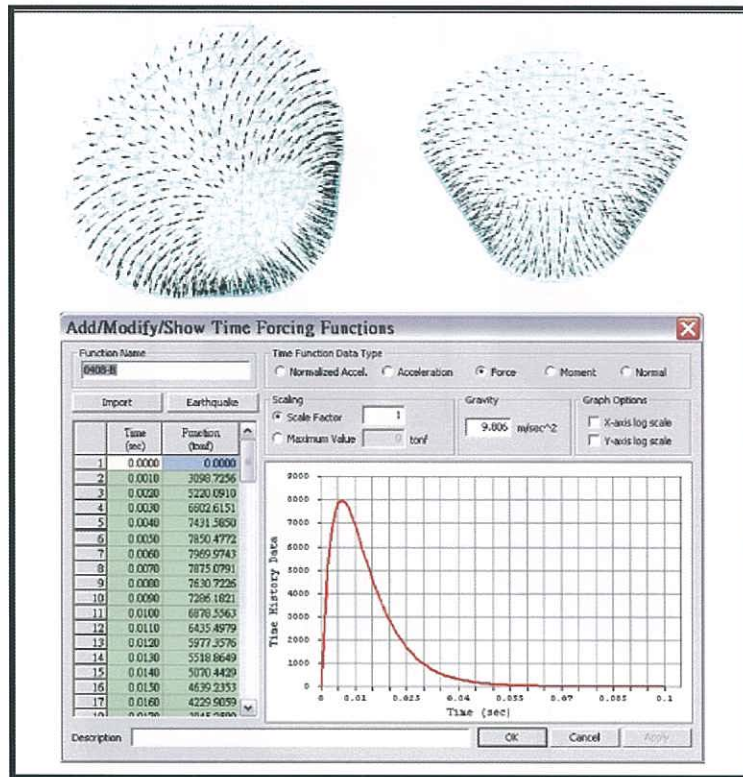


Fig. 4 Schematic diagram of blasting impact force applied to the rock-plug

Figure 5 lists analytical results for the vibration speed distribution. During the first second of blasting impact force, maximum vibration speed of the ground surface on the slope around the rock-plug is less than 20 mm/sec. As the affected area does not exceed the value of five times rock-plug diameter, damage to adjacent structures can be neglected and vibration time does not exceed 2 seconds (United Geotech, Inc., 2010).

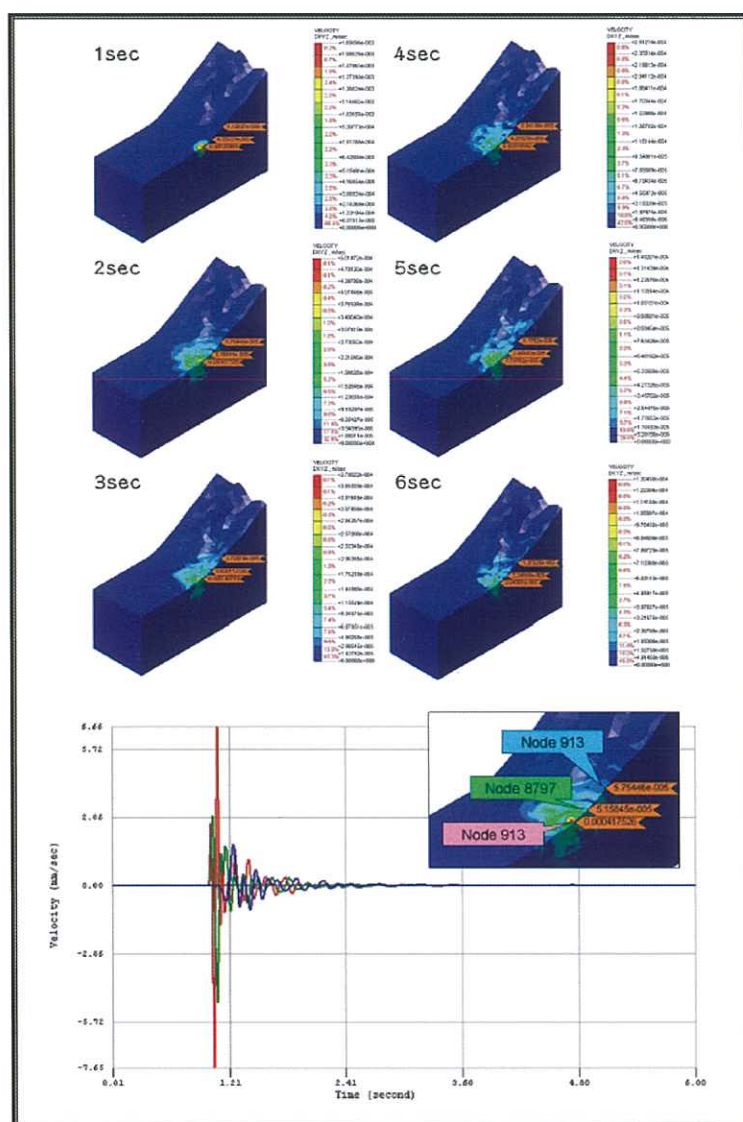


Fig. 5 The distribution of ground vibration speed due to the impact force caused by rock-plug blasting (plug thickness = 6 m)

Remark

According to surface dynamic deformation and velocity of surface vibration due to blasting force by dynamic simulation, all dynamic deformations are <0.1 mm in the three cases after underwater tunnel piercing. All maximum surface vibration velocities are <10 mm/sec during the first second of blasting and are less than the minimum allowable vibration velocity value.

The distances between the rock-plug and spillway, and rock-plug and dam are approximately 1,500 m and 2,000 m, respectively. Monitoring results from the blasting project during construction of tunnels along Highway No. 2 are used to assess particle velocity. To keep particle velocity <1 mm/sec for a distance of 1,500 m, the amount of explosives that can be ignited simultaneously cannot exceed 144 kg.

FIELD BLASTING TESTS (Case 2)

Engineering Geologic Investigation

The second case is located in southern Taiwan. The lithology of the ground surface outcrop of the rock-plug opening is argillaceous sandstone with a strata direction toward 20° northeast with a dip angle of approximately 30° toward the southeast. The rock mass is complete with two high-angle joints with attitudes of N34°W/82°N and N26°E/72°N, respectively. The high-angle joints are approximately 35 m apart. The reservoir sediment level is approximately 176 m. The sediment from the ground surface to approximately 9 m in depth was found to come from Typhoon Morakot. Below this sediment layer is an earlier sediment up to 31.6 m deep. The orientation of the side slope of the rock-plug opening is 45° northwest and the strata form oblique slopes. The side slope has no potential for planar sliding or wedge detachment. Rock strength is reduced because water content increases due to long-term water immersion in the reservoir. The uniaxial compressive strength varies within the range of 36-466 kg/cm², ranging from weak rock to medium strong rock. Water permeability of the rock is very low at approximately 2.86 Lugeon on average. By taking the discontinuities as continuous for conservative assessments, the crown and sidewalls of the rock-plug section may have unstable wedges. Table 4 lists test data for each drilled hole within the rock-plug area. Figure 6 shows the intake geologic profile (United Geotech, Inc., 2011a).

Table 4 Test results for each drilled hole for plug openings

Lithology	Test	Unit weight	Unconfined compression	Triaxial compression		Slake durability
	Unit	γ_t (t/m ³)	q_u (kg/cm ²)	C_p (kg/cm ²)	ϕ_p (°)	-
Argillaceous sandstone	Range	2.47-2.50	36.66-466.01	18.5-26.6	47.2-53.3	Medium – medium high
	Mean	2.49	-	22.6	50.3	-
	Amount	31	31	15	16	23
Lithology	Test	Dynamic	Static	Shear	Lugeon*	Borehole deformation *
	Unit	E_s (kg/cm ²)	E_{s0} (kg/cm ²)	ϕ (°)	Lugeon	E (kg/cm ²)
Argillaceous sandstone	Range	95965-124114	43439-61795	22.8-23.6	1.92-2.67	6722.4-9733.0
	Mean	110040	52617	23.4	2.3	8227.7
	Amount	29	16	14	66	19

*: Field tests

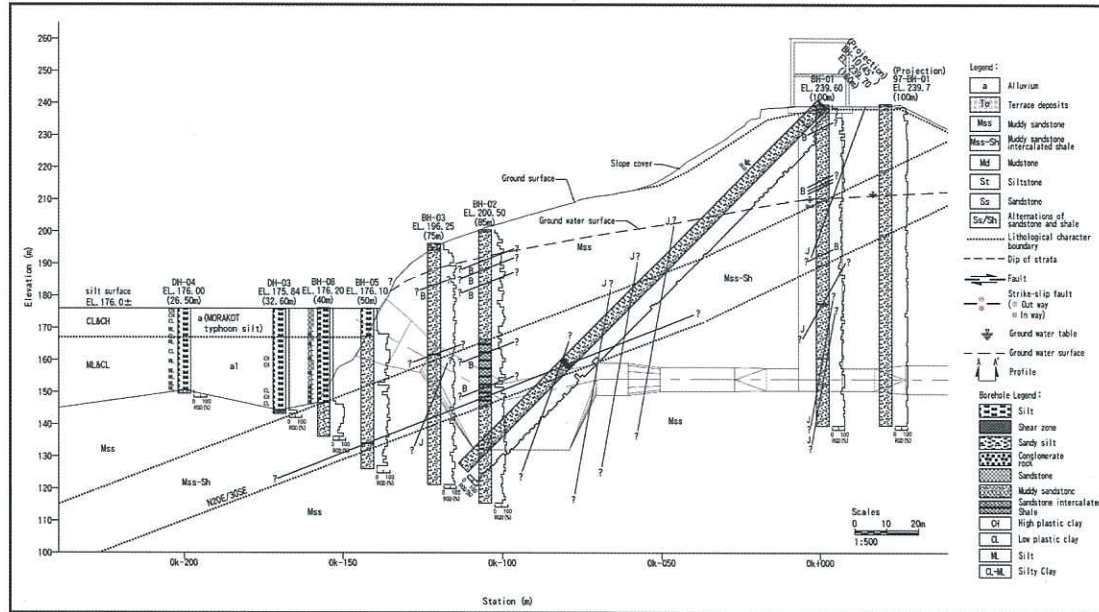


Fig. 6 Intake geological profile

Arrangements of Field-Blasting Holes and Monitoring Points

The field-blasting tests consist of 13 blasting holes with a total drilling depth of 325 m, 310 kg of explosives, and vibration-measurement instruments at 10 locations, including one in the dam. Figure 7 shows the arrangement of field-blasting holes and locations for monitoring field-blasting vibration. Blasting tests were conducted five times. The first three blasting tests were conducted for one signal hole with differing amounts of explosives (15, 20, and 25 kg). The remaining two blasting tests were conducted for five holes with different delay times. Table 5 lists the amounts of explosives, delay time, and relative distances between blasting holes, and monitoring points (United Geotech, Inc., 2011b).

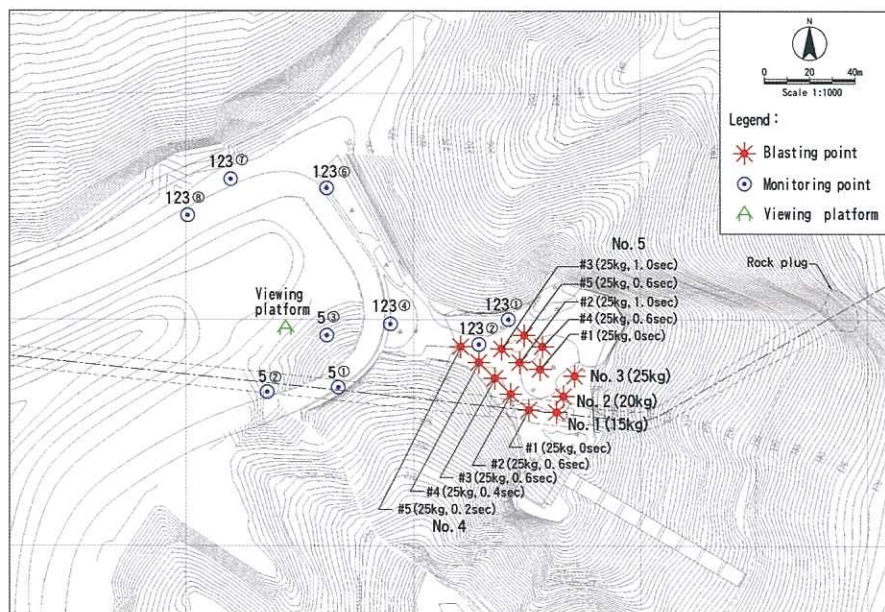


Fig. 7 Arrangement of blasting holes and monitoring points

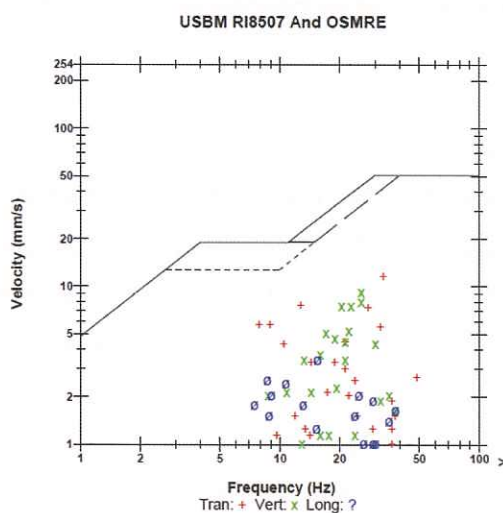
Table 5 Amounts of explosives, delay time, and relative distances between blasting holes and the No. 5 ① monitoring point

No.	1	2	3	4	5
Amount of explosives (kg)	15	20	25	25	25
Delay time (sec)	0.0	0.0	0.0	0.6	1.0
Distance (m)	96.88	102.76	136.74	84.38 (1) 76.45 (2) 76.45 (3) 63.24 (4) 61.07 (5)	58.59 (1) 80.39 (2) 73.71 (3) 92.42 (4) 85.43 (5)

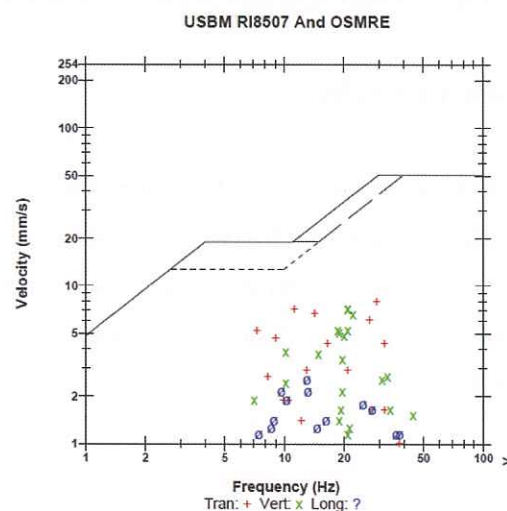
Blasting Vibration Results and Assessment

Analytical software for the InstanTel blasting vibration test used for blasting tests in this study has been used to generate the blasting safety baseline diagram stipulated by USBM R18507. The blasting safety baseline diagram uses the correlation between blasting vibration speed and frequency to determine whether blasting vibration is within the safe range. In this diagram, when vibration frequency at a monitoring point is below the baseline, vibration is below the standard level. Conversely, when it is above the baseline, safety may be compromised.

Figure 8 presents safety baseline diagrams obtained at each test point. The average of the five vibration values for five blasting operations measured at each blasting vibration-monitoring point is below the safe baseline, indicating that the vibration level at each test location by blasting vibration tests does not affect the safety of related structures (United Geotech, Inc., 2011b).



(a) No.1



(b) No.2

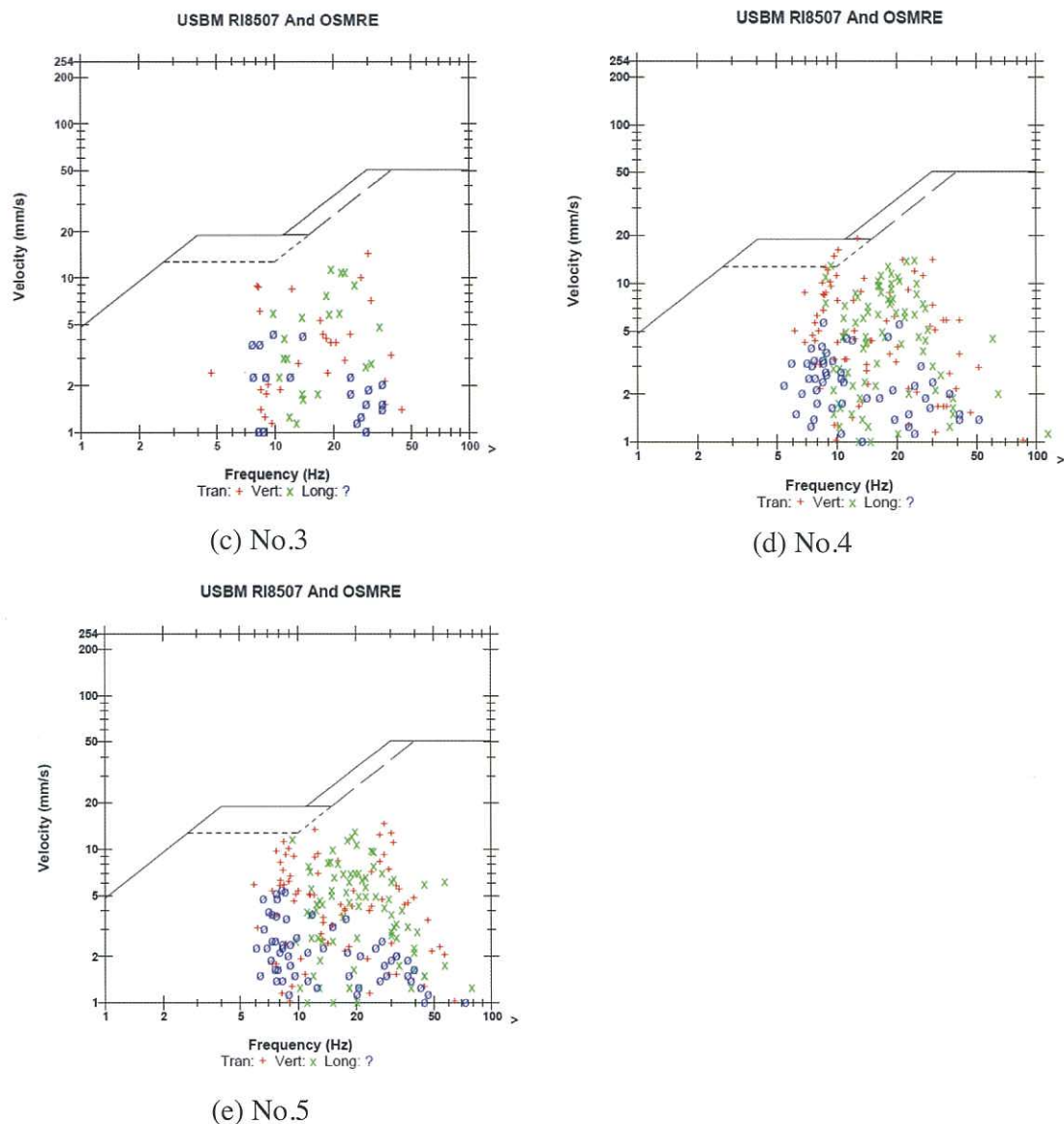


Fig. 8 Safety baseline diagram measured at the No. 5 ① monitoring point for each blasting test

CONCLUSIONS

In Case 1, field-blasting tests have not been performed to obtain the corresponding field parameters for blasting vibration evaluation. On the other hand, actual blasting operations are performed by multi-stage detonation, which differs slightly from the simplified model in the numerical simulation. We recommend conducting numerical simulations based on field-blasting test results to obtain simulation results that fit actual construction conditions.

Case 2: According to the investigation based on the blasting safety baseline stipulated by the USBM R18507, vibration values measured at each monitoring point meet the safety criterion. The maximum amount of explosives used in one hole (single delay) for blasting tests is 25 kg, which is the largest amount of the explosives that can be used for rock-plug

blasting, so that one can ensure that construction by underwater tunnel piercing will not affect structures surrounding the water inlet or dam safety.

Based on simulations and tests for the two cases, the underwater tunnel piercing method for constructing a new underwater desilting tunnel in a reservoir may become an effective method for slowing reservoir sedimentation in Taiwan, rather than slowing reservoir sedimentation by lowering the water level or constructing a weir. However, the underwater tunnel piercing method necessitates the complete removal of all rock-plug material by blasting. Consequently, it is not feasible for constructing external supports and a secondary lining. Future studies should ensure that water tightness, self-reliance, anti-abrasion properties during follow-up flushing, and applicability of sedimentary rocks be verified before blasting.

REFERENCES

- Tung-Chiung Chang (2004): "Water depletion problem in Taiwan and its solution strategy – study of cases in 2002," Journal of Kao Yuan Institute of Technology, Vol. 10, pp. 17–36. (in Chinese)
- NTNU (1999): Project Report 19-99 Underwater Tunnel Piercing.
- Arild Palmström (2005): "LAKE TAP – A well proven solution of a tunnel piercing the lake or sea bottom." (<http://www.rockmass.net/>)
- United Geotech, Inc. (2010): "Preliminary Study of Shihmen Reservoir Upstream Main River Flood Diversion and Anti-silt Project and Hydraulic Model Test - Feasibility Investigation and Assessment of the Rock-Plug Blasting Method," Water Resources Planning Institute, WRA, MOEA. (in Chinese)
- United Geotech, Inc. (2011a): "Supplement Geological Survey Report for Tsengwen Reservoir Silting Control Project," Southern Region Water Resources Office, WRA, MOEA. (in Chinese)
- United Geotech, Inc. (2011b): "Analysis Report of Blasting Vibration Test for Tsengwen Reservoir Silting Control Project," Southern Region Water Resources Office, WRA, MOEA. (in Chinese)

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Thirty Years of Hong Kong Geology

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Introduction

The past 30 years have seen remarkable advances in the study of Hong Kong geology, punctuated by three important milestones: the establishment of the Geological Society of Hong Kong, the Hong Kong Geological Survey and the Department of Earth Sciences at HKU. The quarterly publication of the GSHK Newsletter, commencing in 1982, has provided a platform for geologists to efficiently disseminate their findings. During the same year, the establishment of the Geological Survey of Hong Kong by the Geotechnical Control Office was a most valuable venture. The Survey was tasked with undertaking the systematic geological mapping of Hong Kong at a 1:20,000 scale. The mapping project, founded on work by Davis (1952) and Allen and Stephens (1971) and supplemented with petrographic, geochemical and structural determinations, has provided a framework crucial for the understanding of Hong Kong's geological evolution. The establishment of the Department of Earth Sciences at HKU in 1995 introduced to the geological community a diversity of expertise and instrumental capabilities in geochemistry, age-dating, electron microscopy and geophysics. The Department's collaboration with international and mainland Chinese institutes has also facilitated geological correlation and the interpretation of Hong Kong's geology in a regional context. This paper aims to summarize the key developments and unresolved issues in the study of Hong Kong geology.

Key developments and unresolved issues

This discussion focuses on the following aspects of Hong Kong geology: stratigraphy, igneous units, paleo-environmental reconstruction and structural evolution. Developments in engineering geology and applied geophysics are excluded from the scope of the discussion. The summaries are necessarily brief. For detailed references, readers are directed to the newsletters and bulletins of the GSHK, the Hong Kong Geologist, memoirs and map sheets and the two volumes on the Quaternary and Pre-Quaternary Geology of Hong Kong published by the Hong Kong Geological Survey, and proceedings of conferences organized by universities and professional bodies. Special credit is given to Dick Martin who compiled and reproduced in two CDROMs papers pertaining to Hong Kong geology selected from the above publications. There are controversies over many subjects or aspects of Hong Kong geology, and the discussion presented here is restricted to pre-Quaternary geology. There are necessary omissions; subjects of subtle nature or limited regional significance are also excluded.

(1) Stratigraphy of Hong Kong

While studies by early geologists provided a framework for the stratigraphy of Hong Kong, the ages of several critical geological units remained uncertain for a long time. In the 1980s, assiduous efforts were made by geologists CM Lee, KW Lai, PS Nau and David Workman, among others, to resolve some of the long-standing questions about Hong Kong's stratigraphy. Notably, the discoveries of placoderms in the Bluff Head Formation and insect fossils in the Ping Chau Formation convincingly established Devonian and Cenozoic ages, respectively, which correspond to the oldest and youngest rock units known within Hong Kong. Before 1980, knowledge about late Paleozoic units in Hong Kong was slightly deficient due to their limited surface exposure. The development of new towns and highways in the northwestern New Territories made available numerous boreholes that enabled the Hong Kong Geological Survey to refine the late Paleozoic stratigraphy. The San Tin Group was redefined to comprise the Lok Ma Chau and Yuen Long formations, the latter being a thick sequence of marble correlated with the carbonate unit in southern China (Sewell et al, 2000 and references therein). With this refinement, the stratigraphic framework of Hong Kong was

essentially complete.

Despite the progress described above, several questions regarding Hong Kong's stratigraphy remain unresolved. First, while Cenozoic Era insect fossils were uncovered on Ping Chau, it is not known whether the formation straddles the K/T boundary. Palynological studies have revealed a mixed assemblage of Cretaceous and Cenozoic pollens in the formation. The enigmatic cherty siltstone bed in Lung Lok Shui also presents an intriguing possibility that it may actually represent the K/T boundary (Chan, 2002; discussion to follow). If that is the case, this may be the first place in which the K/T boundary is found in this part of the world. Second, the ages of the Pat Sin Leng and Port Island red-bed formations are still poorly constrained, due to the lack of fossils uncovered. In addition, the sporadic breccias outcrops at Ap Chau, Kat O and Lau Fau Shan are currently grouped with the Upper Cretaceous Kat O Formation. However, these outcrops may represent talus deposits along fault scarps during very different ages.

(2) Igneous units and volcanic stratigraphy

The Hong Kong Geological Survey has made significant progress during the last 30 years on the delineation of igneous units in Hong Kong. While the nomenclature for the volcanic units has been revised several times, the identification is now properly conducted on the basis of stratigraphy, rectifying a caveat in the previous classification by Allen and Stephens (1971) that was based on lithology. Based on detailed geochemical and high precision U-Pb zircon age determinations, the Hong Kong Geological Survey delineated a number of calderas in Hong Kong (Campbell and Sewell, 1997; Davis et al, 1997; Sewell and Campbell, 1997). A cogenic relationship was found to exist between the volcanic groups and the granite suites. Episodic silicic magmatism (volcanic eruptions and granitic emplacements) occurred between 165 Ma and 140 Ma (Davis et al, 1997), which are consistent with the ages of granites in southern Guangdong. Sewell et al. (2012) presented a model of tilted caldera to explain the volcanic facies in the southeastern part of Hong Kong, which was corroborated by the pattern of the spatial distribution of column diameters reported by Cheung (unpublished thesis, 2010).

Some discussion has been directed at the nature of the granitic magmatism. The acidic granites in Hong Kong and the acid dike swarm in northern Lantau may be indicative of magmatism in a back-arc setting. Some granites also contain dioritic xenoliths, which may come from plutons formed during an earlier plate subduction event. Questions continue to linger over the origin and age of the mafic dikes commonly found cutting the granites (Li et al, 2000; Campbell and Sewell, 2007). In many localities around Hong Kong, an earlier phase of mafic dike intrusion has also been observed. Absolute dating of the diorite and the mafic dikes could shed additional light on the precise time of the subduction to extension transition.

(3) Early Cenozoic sedimentary environment and paleogeography

The rock formation on Ping Chau in Mirs Bay always fascinates local geologists; it may hold the key to understanding the paleogeography of the area during the early Cenozoic. The Ping Chau Formation is probably the only formation of this kind exposed in the coastal region of southern China. Sedimentary structures and the presence of evaporate-related minerals in the rock suggest a saline brackish water environment for the formation (Peng, 1971). Our recent study revealed abundant stromatolitic layers and structures in the sedimentary layers (Fig. 1). Organic geochemical determinations show that algae and higher order plants were abundant, suggesting a continental ephemeral sabkha



environment with glauberite and gypsum formed primarily as evaporate minerals (Hu et al, 2005).

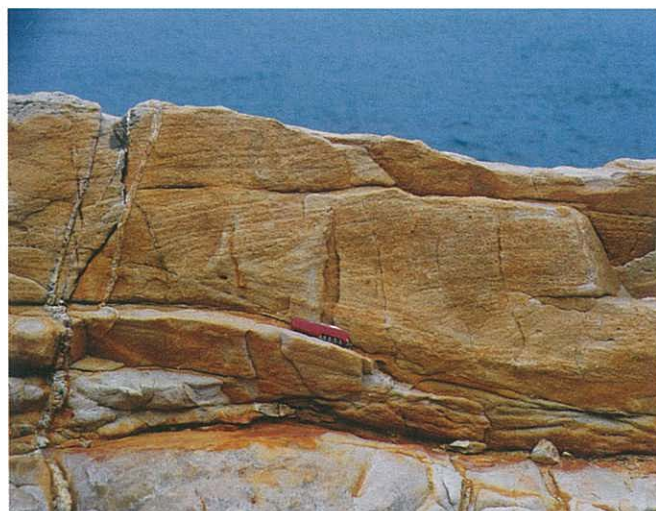
The presence of acmite in the sediment necessarily implies a relatively high diagenetic temperature experienced by the sediment. Consider the typical geothermal gradient of 30°C/km. It would require the formation to have once been buried under several kilometers of sediment. However, available geological evidence does not support this premise; in fact, the entire Mirs Bay basin in which the Ping Chau Formation was deposited appears to be a shallow near-shore basin or was subaerially exposed during the entire Cenozoic Era. The relatively high temperature indicated by the presence of acmite would require an explanation other than burial diagenesis.

Study of the Ping Chau Formation is conducive to the paleogeographic reconstruction of southern China. The Mirs Bay Basin, Sanshui Basin in Guangdong and Zhu-1 and Zhu-2 basins offshore together form a series of early Cenozoic lacustrine basins. The paleogeography could plausibly be depicted by a basin-and-range topography, with ranges separating the lake basins. The deposition of evaporates in Mirs Bay and the Sanshui Basin suggests an ephemeral depositional condition. The Mirs Bay Basin, the smallest in size, also exhibited a hypersaline environment. The paleogeographic reconstruction also has implications for the petrochemical potential of the area, as the Sanshui and offshore basins have been found to possess significant natural gas reserves.

The enigmatic cherty siltstone layer on Ping Chau may hold an important key to understanding the paleotectonic evolution of the area. Several hypotheses have been put forward to explain its origin. The single occurrence of such a layer argues against a volcanic ash origin, because volcanic eruptions tend to recur temporally. For a while, the author considered the possibility that the layer may actually be the K/T boundary (Chan, 2002). However, the preliminary geochemical analysis of samples did not reveal anomalous concentrations of Iridium, an element commonly found in unusual abundance in the K/T boundary layer. In addition, paleomagnetic study of samples from Ping Chau has shown that the rocks possess normal polarity, whereas the K/T boundary is known to possess a reversed magnetic polarity interval. Hence, neither geochemical nor paleomagnetic testing has yielded supporting evidence. We have now identified stromatolitic structures in the cherty layer, indicating that it has a diagenetic nature (Fig. 2). The layer most probably represents a sinter deposit from hot spring activities, probably associated with fault motion during the opening of Mirs Bay. This may also account for the presence of high-temperature minerals in the formation.

(4) Structural evolution

The coast of southern China underwent a transition from an active- to a passive-margin setting during the late Mesozoic-early Cenozoic. This reversal was accompanied by a change in the tectonic principal stress direction. The morphotectonic map of Pubellier et al. (2006) provides a framework for the interpretation of the microstructures of southern China. Our study (Chan et al, 2010) revealed the presence of multiple extension events following the cessation of the Mesozoic arc magmatism. Consequently, many of the



prominent fault systems formed during the Mesozoic Era were reactivated with a different sense of motion in the subsequent deformations. At Fung Wang Wat on the northern shore of Tolo Channel, for example, microstructures in the Tolo Channel Formation reveal an older left-lateral ductile deformation and a younger right-lateral brittle deformation.

Recent studies by Chan and Tang (2004) and Chan (2006) have also shed new light on the origin of some large-scale morphotectonic structures in Hong Kong. Early work by Allen and Stephens (1971) regarded Tolo Channel as an anticline structure. However, detailed mapping by Chan (2006) demonstrated that the Tolo Channel-Bluff Head actually represents a flower structure resulting from a transpressional motion along Tolo Channel (Fig. 3). Sedimentary structures in the Bluff Head Formation show that the entire northwestern section of the fold and fault zone is overturned (Fig. 4). Leung et al. (2003a; 2003b) proposed that the Mirs Bay Basin has a transtensional nature. Chan et al. (2010), however, regarded Mirs Bay to be a rifted basin formed by a NE-SW directed extension.

A key piece of the puzzle pertaining to Hong Kong geology is the age of exhumation of the granites. The nature of the 'thrust' in the northern New Territories, with Jurassic volcanic overlying Cretaceous red beds, is debatable because no regional compressional event is known to have happened during the Cenozoic. This structure actually represents a detachment, with volcanic rock that occupied a higher elevation at the time having slid on top of red beds. Fission track dating results obtained for the Pearl River Delta area show major exhumation at about 30-50 Ma (Tsang, MPhil thesis, 2010; Chan et al., 2011). Similar fission track analysis of the granites in Hong Kong is now being undertaken by the Hong Kong Geological Survey (Tang, personal communication).

Concluding remarks

The foregoing discussion focuses on pre-Quaternary solid geology; notable progress has been made in the study of offshore stratigraphy and the correlation with paleoclimatic events (e.g. Yim et al., 2000). Several papers have contributed to the understanding of the crustal scale structures of Hong Kong (e.g., Darbyshire and Sewell, 1997; Fletcher et al., 2004; Xia et al., 2012). Recent debate has focused on the possible presence of active faults in Hong Kong or its vicinity. To date, however, no such faults have been convincingly identified.

References

- Allen, P.M. and Stephens, E.A., Report on the Geological Survey of Hong Kong. Hong Kong Government Press plus 2 maps, 1971.
- Campbell, S.D.G. and Sewell, R.J., Structural control and tectonic setting of Mesozoic volcanism in Hong Kong. *Journal of the Geological Society*, 154, 1039-1052, 1997.
- Campbell, S.D.G. and Sewell, R.J., 40Ar-39Ar Laser Microprobe Dating of Mafic Dykes and Fault Rocks in Hong Kong, GEO Report No. 206, 78p, 2007.
- Chan, L.S., Is the cherty bed in Ping Chau Formation, Mirs Bay in Hong Kong, the K/T Boundary? The 4th World Chinese Conference on Geological Sciences, pp. 2-3, Nanjing, May 22-24, 2002.
- Chan, L.S., and Tang, L.K., The Geology of Tsing Shan ductile shear zone, Joint Geosciences Assembly, Taipei, Taiwan, p. 46, 17-20 May 2004.
- Chan, L.S., Bluff Head Fold and Thrust Zone: A Positive Flower Structure, HKGS Newsletter, pp. 7-9, 2006.
- Chan, L. S., Shen, W., M. Pubellier, Polyphase Rifting of Greater Pearl River Delta Region (South China): evidence for possible rapid changes in regional stress configuration, *Journal of Structural Geology*, 32, 746-754, 2010.
- Chan, L.S. Tsang, D.P.W., Shen, W., Yan, Y., Fission Track Dating of Rifting Events on the Northern Margin of South China Sea, South China Sea GRI Workshop, Paris, 11-12 February, 2011.
- Cheung, A.K.C., Geometrical study of jointed columns in Sai Kung, Undergraduate thesis, HKU, 2010.
- Darbyshire, D.P.F. and Sewell, R.J., Nd and Sr isotope geochemistry of plutonic rocks from Hong Kong: implications for granite petrogenesis, regional structure and crustal evolution, *Chem. Geol.*, 143/1, 81-93, 1997.
- Davis, D.W., Sewell, R.J., Campbell, S.D.G., U-Pb dating of Mesozoic igneous rocks from Hong Kong, *Jour. Geol. Soc.*, 54/6, 1067-1076, 1997.
- Davis, S.G., The Geology of Hong Kong, 210 pp, HK Government Press, 1952.
- Fletcher, C.N.J., Chan, L.S., et al., Basement heterogeneity in the Cathaysia crustal block, southeast China, *Geological Society Special Publications*, 226, 145-155, 2004.

- Hu, W.X., L.S. Chan, S.P. Yao and D. Zhu, Geochemical features and evolution of the Pingchau Formation of the Ping Chau Island, Hong Kong, in Abstracts Vol (Eds., AD Switzer and NS Duzogoren-Aydin), Conference on Recent Advances in Geological Research of Hong Kong and the Pearl River Mouth Region, Hong Kong, pp. 18-19, Dec 8-10, 2005.
- Leung, K.F., Vohora, V.J., Chan, L.S., and Malpas, J.G., Enhancing Landsat TM to update the structural analysis of the Mirs Bay Basin, Hong Kong China, *Geosciences Journal*, 7, 4, 327-329, 2003a.
- Leung, K.F., Chan, L.S., Pubellier, M., Tectonic evolution of Mirs Bay Basin in Guangdong, South China, *Trans. American Geophysical Union (CDROM)*, Fall Meeting, San Francisco, U.S.A 8-12 December 2003b.
- Li, X.H., Sewell, R.J. and Fletcher, C.N.J., The Dykes of the Northeast Lantau Island, Geological Report GR6/2000, Geotechnical Engineering Office, 2000.
- Peng, C.J., Acmite and zeolite-bearing beds of Hong Kong, a new and unusual occurrence. *Proceedings of the Eighth International Sedimentological Congress, Heidelberg*, pp. 76-77, 1971.
- Pubellier, M., Chan, L.S., Morphotectonic Map of Cenozoic Structures of the South China-Northern Vietnam Coastal Region, Hong Kong, 2006.
- Sewell, R.J. and Campbell, S.D.G., Geochemistry of coeval Mesozoic plutonic and volcanic suites in Hong Kong. *Journal of the Geological Society*, 154, 1053-1066, 1997.
- Sewell, R.J., Campbell, S.D.G., Fletcher, C.J.N., Lai, K.W. & Kirk, P.A., The Pre-Quaternary Geology of Hong Kong, 181p plus 4 maps. Hong Kong Government, 2000.
- Sewell, R.J., Tang, D.L.K. and Campbell, S.D.G., Volcanic-plutonic connections in a tilted nested caldera complex in Hong Kong. *Geochemistry Geophysics Geosystems*, 13, 17, 2012.
- Tsang, D.P.W., Thermochronology inferring post-orogeny exhumation around Pearl River Delta Region, MPhil thesis, HKU, 2010.
- Xia, S., Qiu, X., Tong, C.H., Xu, H. and Zhao, M., Three-dimensional tomographic model of the crust beneath the Hong Kong region, *Geology*, 40/1, 59-60, 2012.
- Yim, W.W.S., The record of the Quaternary on continental shelves - their interpretation, correlation and applications. *Episodes*, 23/1, 32-36, 2000.

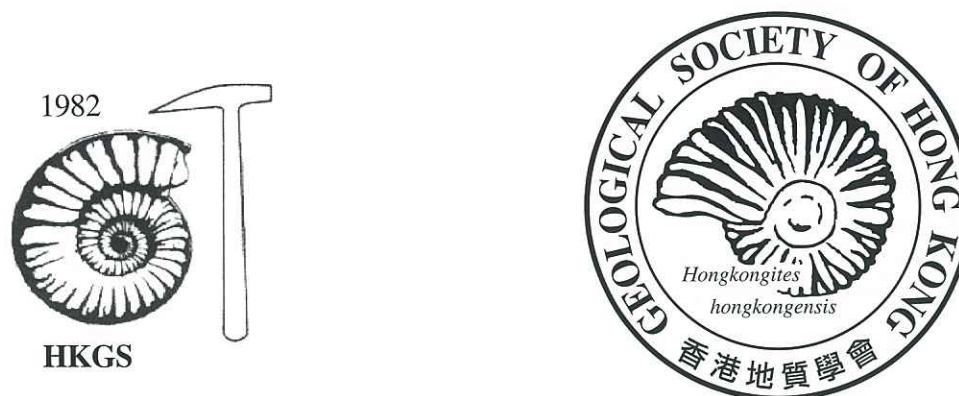
GEOLOGICAL SOCIETY OF HONG KONG

The Geological Society of Hong Kong (GSHK) is a non-profit making organization that promotes geological and earth science studies within Hong Kong and the adjacent regions. For 30 years, the Geological Society of Hong Kong has provided an active forum for amateur and professional geologists alike to exchange ideas on a variety of earth science subjects through regular lectures, conferences, local and overseas field trips, and published journals and bulletins.

The Geological Society of Hong Kong has been very supportive of government's work over the years, particularly in sharing and promoting knowledge of new geological discoveries (e.g. fossil discoveries) which have led to improvements to geological maps and memoirs published by the government. Through a series of training workshops, it has also assisted secondary school teachers with preparation of teaching materials for the New Senior Secondary (NSS) Geography Curriculum on topics of Natural hazards and Earth Science.

Society's History

The logo of the Geological Society of Hong Kong has completely described the Geological Society with a geological hammer and the Hongkongites *hongkongensis* (the first ammonite fossil found in Hong Kong in early 1920s). The original logo served the Society well for our first decade since its establishment in 1982. The Society had then upgraded the logo to make it representative to the Geological Society of Hong Kong in a way that it helps protect our geological assets and environment by taking away the stylized geological hammer in the logo.



The Logo of Geological Society of Hong Kong

The formation of the Geological Society of Hong Kong was first considered back in early 1980. Following a few 'Social' meetings between Maurice Atherton, Peter Randall, David Workman, Andrew Leach and Alistair Burnet, the active members in the geological fields in Hong Kong, set up an 'ad hoc Committee' to organize a few informal field trips and evening talks to bring geologists together. Its purpose was to provide a forum for the exchange of ideas and information amongst geologists in Hong Kong and examine rocks of the local stratigraphical column in the fields.

At about the same time, the Geotechnical Group of the Hong Kong Institution of Engineers (HKIE) was to be formed and it was thought that the geologists could establish a 'Geological Subgroup' of the Geotechnical Group of the HKIE in 1980. Events were organized over the year comprising films at the Hong Kong Polytechnic (the then Hong Kong Polytechnic University), viewing of Allen and Stephen original rock collection at the Hong Kong University, a talk by Brian Ruxton and field trips throughout Hong Kong.

The 'ad hoc Committee' comprised Messrs Burnett, Leach, Hencher, Randall, Workman, Sekura and Atherton met at the beginning of 1981 on 27th January 1981, arranged programme of events for 1981 (lectures, films and field excursions; set up formal and organized system of contacting geologists

and facilitating discussion with the Geotechnical Group of the HKIE through periodic progress meetings.

Disappointed in early 1982, the linking with Geotechnical Group of the HKIE was not successful. It was decided by the ever expanding 'ad hoc Committee' on 22nd February 1982 to start the establishment of a Geological Society of Hong Kong. It was subsequently evidenced that the Constitution and the election of a Steering Group responsible for setting up, registering, establishment and establishing and running the Society for 1 year (until the first fully elected Committee to take over) were approved on 3rd May 1982. The Geological Society of Hong Kong and its Constitution was officially granted registration on 26th July 1982. We must however express our hearty appreciation to the late Dr. Stephen S. F. Hui, well known mining magnate and delegated geologist and mineralogist, that he subscribed a generous donation for the establishment of the Geological Society of Hong Kong.

In order to refresh our memories, the first "Chairman's Message" and "History of the Formation of the Geological Society of Hong Kong" by Dr. A.D. Burnett (the first Chairman of the GSHK) are compiled in the Appendix 1.

At present, the Geological Society of Hong Kong maintains approximately 250 members including professional geologists from the public and private sectors, academia, as well as teachers, students and amateurs. The Society had set up various studies groups in the past 30 years. The first group was Marine Studies Group, which formed in 1984 and was led by Dr. Andrew Malone of the Geotechnical Engineering Office(GEO) for the offshore mapping in GEO and understanding the nearshore geology in Hong Kong and nearby area as well as preparation for the demand of the marine resources for the planned mega reclamation projects.

The Teachers Group was formed in 1985 and was led by Mr. H.M. Keung.. He arranged workshops in earth science teaching for secondary school geography teachers. The Nature Explorer Group was established in 2002 for the young members, which was a subgroup of the Geological Society of Hong Kong and it aims at promoting geological and earth science studies to secondary and tertiary students in Hong Kong. Through various activities like field trips and workshops, students are able to develop their knowledge and attitudes toward our Mother Nature, particularly in geological aspect. We also encourage our members to behave environmental-friendly and to adopt a sustainable lifestyle.

Dr. Raynor Shaw, the past President, formed a Geomorphological Studies Group in 1993 which aimed to systematically document the interesting and varied landforms of Hong Kong in the Journal of the Geological Society of Hong Kong "Hong Kong Geologist" which had been issued from 1995 to 2002.

These formed as part of GSHK's endeavours to reach out to the general public.

GSHK has established the Professional Branch (GSHK-PB) in 2006 to oversee the benefits and professional status of members. GSHK-PB also closely liaises with the geological societies in mainland China, Taiwan and the nearby regions as well as the Geological Society of London in recent years. The logo of GSHK-PB symbolizes the complexity of geology which includes onshore and offshore geology, major rock types and geological structures.



The GSHK has entered a new era. It will continue to promote geological sciences to students, teachers and the general public, in particular, the subject "Geology" has become more familiar to the public in recent years.



Society's Committee

Over the years, the Geological Society of Hong Kong has many enthusiastic members who take part in running the Society's matters with much effort / relentlessly at their free time. We are prepared to give them sincere applause. In the following few pages, we have compiled a summary of the Committee Members of the Society since its establishment of the Geological Society in Appendix 2 for reference.

Publications

The Geological Society of Hong Kong have a wealth of published newsletters, journals, bulletins dealing with a variety of earth science subjects written and compiled by members.

A number of previous publications over the last 30 years had been archived in the web site of the Geological Society of Hong Kong. The publications were focused on the topics of geology of Hong Kong of different topics and localities including Quaternary stratigraphy for Hong Kong, dolomitic limestone in Tolo Harbour, tectonic framework of Hong Kong and vicinity, its relationship to regional seismicity etc. Members and publics are able to retrieve these publications for reference from the web site of the Society. For retrieval the information of Bulletins nos. 1-6 for GSHK seminars/conferences held between 1984 and 2000, it could be recovered from the "Second Collection of Hong Kong Geotechnical Papers, 1984-2007" organized and distributed by The Hong Kong Institution of Engineers.

The publications of GSHK have also contained papers relating landslide incidents / events e.g. Castle Peak Landslide; and the geological structures in the vicinity of Hong Kong territories such as the Pearl River delta. There are some recent reports of field trips prepared by some members in the form of articles which are also recorded in the Society's web site. They are listed below for reference:

Recent Article List

Date:

2003-12-27

2006

2007-05-14

2008-08

2008-11-29

2009-07-18

2009-10-31

2009-10-31

2009-11-07

2011-07-12

Field Trip Reports

Descriptions:

Yunnan Field trip

10 geology spots in HK

Waterfall trees and insects : Patshuiwun - SaiKung (Chinese)

Field trip to Sichuan

Daya Bay Field Trip

North Xinjiang Impressions

Tiu Tang Lung Moon Hike

MoonHikers -Tiu Tang Lung (Chinese)

Recovery of marble core

Tibet Trip 12th ~28th August 2010

As the advance of technology, publishing copies of newsletters were not recommended in the promotion of protecting our environment. Articles of geological topics were posted on the web site of GSHK. The current web site is rich in information and references, which includes the Committee, publication lists, field trip reports and photograph albums, learner's corner etc.

We are also proud of establishing an informative and systematic web site since 2007/08 which maintains update information to members of coming events like seminars, society news, field trips/activities and new articles etc. The valuable archives of Newsletters and publications are also accessible in the web site. Members may wish to visit the website of the Geological Society of Hong Kong at <http://www.geolsoc.org.hk/>.

Field Trips

The Geological Society runs day visits to local (Hong Kong) geological sites of interest, short trips lasting a weekend or a few days to mainland China, Taiwan, the Philipines and Indonesia. Some geological field trips have been organized to farther geological interested locations like Heilongjiang in the Northeast China, ZhangJiang, Tibet, Xinjiang, Yunnan regions etc. which took longer. They are very expeditious and worth visiting with good arrangement for the excursions including accommodation, transport and briefing by local geologists and officials. Local field trips were organized to Lamma Island, Bride's Pool, Fan Lau, Ap Chau/Ledge Point, Port Island, Ping Chau, Nam Chung (Starring Inlet), the Brothers Islands, Kardoorie Farm, Sha Lo Wan and many more. The footprints of our geologists and members cover almost every geological-interested localities of Hong Kong region.

The Society has organized many field trips in the past 30 years. Only some selected photographs of field trips were contained in Appendix 3 due to the limited size of the proceeding, The photographs would be able to retain the memorable moments of our members who participated field trips, let us flip over the pages to recall.

Appendix 1 – First Chairman's Message

Appendix 2 – Summary of Chairmans/Presidents and Secretaries

Appendix 3 – Photographs of Field Trips (Selected)

CHAIRMAN'S MESSAGE

Many of you reading this will remember that Monday evening early in May this year, when at a meeting called to establish the Geological Society of Hong Kong, you voted to accept the proposed draft constitution and elected the Steering Group of which I am Chairman. The Steering Group was charged with the major responsibility of setting up, registering and running the Society until the first elected General Committee comes into being in May 1983.

I am very pleased to report that all has progressed well, the Society having now been officially registered under the Societies Ordinance as of the 26th July, 1982.

This Newsletter, being the Society's first, seems an ideal and timely publication in which to consider how the Society proposes to pursue its prime objective as stated in the Constitution, namely the "Advancement of Geological Science, Particularly in Hong Kong and Nearby Areas."

The Society has already actively embarked on scientific meetings. The nature and frequency of future meetings will depend on members coming forward with firm offers or ideas and also on the Society's ability to obtain the services of experts, visiting or passing through Hong Kong. An interesting prospect is an occasional workshop or symposium. These could range from informal, in-house seminars to symposia with international participation and joint sponsorship. For example, a symposium in Hong Kong on Geology in Urban Development would be sure to attract great regional and even world-wide attention, as would any meeting dealing with the geology of south China.

Organised field trips and site visits have been the mainstay of our activities to date and will probably continue to remain so for some time to come. These activities are particularly popular with our members and afford a marvellous opportunity for informal discussion and friendly argument.

We have high hopes of establishing an interesting and informative newsletter. It is not an easy task to immediately strike the right balance between news, information, articles, etc. and we ask members to be patient while a suitable format is evolved. Other publications will probably be limited in the foreseeable future, to one-off proceedings of special meetings leading to eventually perhaps, a regular journal.

Of particular interest at present is the project of establishing regional contacts with geologists in China, both for unravelling further the geology of Hong Kong and learning more in turn, about the geology of southern China. Visits to China in the form of tours or special trips are a distinct possibility.

Due to the intermittent development of geology in Hong Kong, no comprehensive collections of rocks, minerals or fossils exist, although in recent years both the Government and the academic institutions have started to correct this situation. I am sure all geologists agree that it would be useful to establish such reference collections and have them available for reference and study purpose. In addition, the Society plans to build up its own easily accessible reference library of geological literature relevant to Hong Kong, to be kept at Hong Kong University.

In conclusion, I believe the fact that we already have over 120 members, nearly all of whom are working in a geological capacity, shows that there is strong interest and necessity for the kind of functions a geological society can fulfil. The coming years are sure to be by far the most interesting and fruitful that there have ever been in the history of geology in Hong Kong.

Alistair Burnett

Year	Chairman/President
1982-1987	A. D. Burnett
1987-1988	D. R. Workman
1988-1989	K. W. Lee
1989-1991	M. Atherton
1991-1997	R. Shaw
1997-1998	C. M. Lee
1998-2000	R. B. Owen
2000-2004	L. S. Chan
2004-2007	K. W. Lai
2007-Now	Margie Chen

Year	Secretary
1982-1987	D. R. Workman
1987-1990	R. L. Langford
1990-1992	R. J. Neller
1992-1997	R. B. Owen
1997-1998	William C. H. Chow
1998-2000	R. J. Neller
2000-2007	William C. H. Chow
2007-2012	Patrick C. S. Ho
2012-Now	Felix Lee

Alister Burnett

Y. C. Chan

Maurice Atherton

David Workman

A geological field trip to Daya Bay, 1983



Andrew
Malone

Wyss Yim

C M Lee

Bob Addison

K W Lai



Visit of Honorary fellow Z Liu with D Workman and W Yim 1984



CM Lee during the 3 coast conference field excursion in Hong Kong



Late honorary fellow B Ruxton with W Yim and Mike Rickards on Victoria Peak Hong Kong 1988



YC Chan CM Lee Late M Howat KL Siu A Burnett P Cheung



LS Chan during the 3 coast conference field excursion in Hong Kong



Late honorary fellow Y Huang with K Chen and W Yim at Sheung Wan MTR Station 1986



1984 South China Sea Institute of Oceanology visit
C Dutton Institute director A Malone



1984 Marine Studies Groups visit to
South China Sea Institute of Oceanology



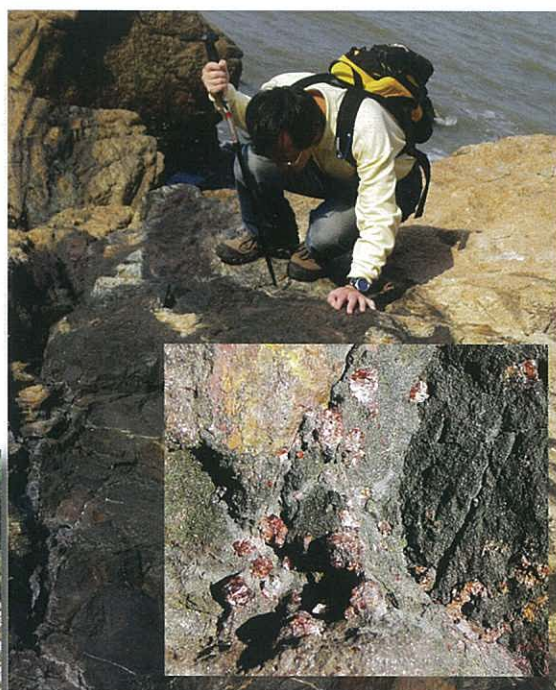
Guangdong Visit to Qujiang 18 April 1987



Yunnan 29 December 2003



Southern XinJiang 14th August 2005



Hong Kong shalowan Lantau 11 Dec 2005



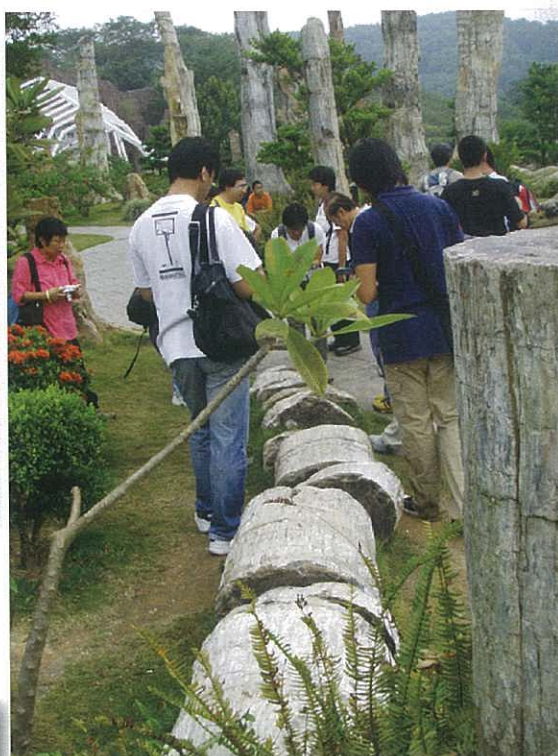
Kwai Chau cavernous limestone 26 March 2005



Hong Kong Columnar joints at Sai Kung 9 Dec 2007



Shenzhen Welcome briefing at
Shenzhen Geological Country Park Management Office Nov 2008



Shenzhen Botany Garden 28 Oct 2007



Panzhihua Sichuan 7th Apr 2007



Philippines volcanoes trip 11 May 2008



Hong Kong Kwun Yin Shan 27 Jan 2008



Heilongjiang Adjacent to a volcano 6 August 2006



Hong Kong Nam Chung NE of Hong Kong 15 Feb 2009



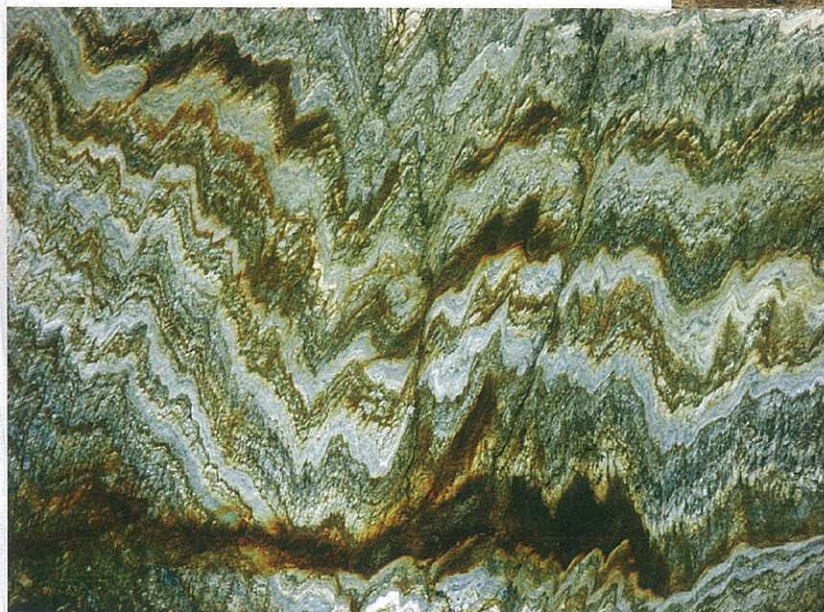
Hong Kong Geology 360 lecture 4 July 2009



Hong Kong Folds at Lai Chi Jong



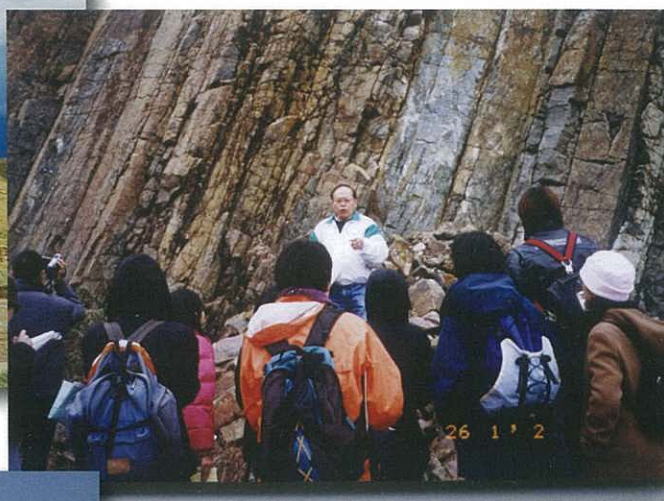
Northern XinJiang 20th July 2009



Taiwan Hualien folding in Marble 2009



Tibet folded mountain



Hong Kong Sai Kung



Shenzhen Rock outcrop near Daya Bay



Shenzhen Plant fossils in a quarry at 水頭沙



Tibet winding road



Zhangjiang inspecting gold pellets from rock cores



Tibet Intrusion of dyke dragged the layers of rocks at Dzong Castle built in AD967



Zhangjiang Snapshot April 2010



Tibet View from a jet plane to Tibet



Tibet Magnificent landscape August 2010



Tibet tight folding on the way from Shigatse to Lhasa
25 August 2010



Tibet from Gyangtse to Shigatse pillow lava
25 Aug 2010



Tibet A look at Mt Qomolangma (5200m at base camp)
August 2010



Tibet Serious discussion before siting for chert
25 August 2010



Tibet A climb adjacent to Saka Monastery August 2010



Tibet Folded mountain August 2010



Tibet Looking for micro-fossiliferous chert 25 August 2010



Tibet Boat trip to Samye Monastery August 2010



*Congratulation
To*

*30th Anniversary
of the Geological Society
of Hong Kong*

AECOM Asia Company Limited

Peako Engineering Co. Limited

SMEC Asia Limited

United Geotech Inc

30th Anniversary Photo Competition

