

**40th Anniversary
of the Geological Society
of Hong Kong**

LIVING GEOLOGY 2022
40th ANNIVERSARY
CONFERENCE

香港地質學會
40週年紀念



香港地質學會40週年誌慶

40th Anniversary of The Geological Society of Hong Kong



Conference Proceeding
26 August 2022

目錄 Contents

	頁 Page
祝賀語 Greeting Messages	3 - 8
前言 Foreword	9
籌備委員會 Organising Committee	10
活動日程 Event Programme	11
會議日程 Conference Rundown	12 - 13
文章目錄 List of Articles	14 - 15
學術報告文章 Paper Articles	16 - 135
參觀及考察資料 Tour and Field Workshop Information	136 - 140
學會歷史及資訊 Society's History and Information	141 - 166
鳴謝及贊助 Acknowledgements and Sponsors	167 - 196

香港地质学会成立四十周年志庆

地负海涵
质直浑厚

中央政府驻港联络办副主任 谭铁牛



广东省地质学会

GEOLOGICAL SOCIETY OF GUANGDONG PROVINCE

贺 信

香港地质学会、尊敬的张志德会长：

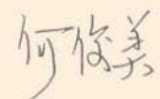
在绿树阴浓夏日长的美好时节，香港地质学会迎来了建会40周年。广东省地质学会理事会和全体会员，向您和贵会全体会员致以热烈的祝贺！

香港地质学会成立40年来，充分发挥全港地质科技爱好者交流平台的作用，通过学术交流、野外考察等多种形式，有力推动了香港地质科学的进展，成效显著，可喜可贺。

广东省地质学会成立70年来，保持与香港地质科技工作者紧密联系，尤其在香港地质学会成立以后，省港两地学会联系更为密切，在科技交流、地学科普、人员互访特别是省港1:50万地质图编图等方面取得很好的成效，建立起兄弟般的友谊，共同为省港两地地质科技工作的健康发展作出了重要的贡献。借此机会，对贵会长期以来为我会发展给予的热忱帮助和大力支持，表示深切感谢！

省港山水相连、人脉相通，同属粤港澳大湾区，给两地地质工作深度合作提供了干事创业的崭新平台，也为我们两个学会科技交流合作提供了更加广阔的舞台。希望贵我两会继续真诚合作，在大湾区建设中携起手来，为建设国际一流的大湾区作出更大的贡献。

广东省地质学会

理事长  恭贺

2022年6月8日

慶祝香港地質學會成立 40 周年賀函

致張志德會長暨全體學會成員

欣逢香港地質學會成立 40 周年，在此獻上最誠摯的祝福，恭祝：會務昌隆、鴻圖大展!!

40 年漫長歲月，貴會披荊斬棘，承先啟後，推動地質教育、辦理論壇文刊、功勳卓著，貴會之成就非凡，實為我輩地質人之翹楚與榜樣。

地質學的教育推展，實為重中之重，也是我輩持續精進之理由與使命，於生活環境的平衡、文明建設之基本，資源礦產之開發、天然災害之趨吉避凶，未來環境之剖析等，皆是以地質學為本之引領與應用，更足見貴會努力推動地質科學的精進，意義重大。

在現今社會新科技新領域不斷發展，對於基礎學門的研究，如何引領更多新進意願投入時間與資源深耕精進，更需要持續的努力，在此情況下，更凸顯貴會之重要性，貴會所抱持之「精深研究、推廣交流」，於我輩實為感同身受、時刻提醒，其中許多舉措，如發行期刊、推廣導覽、廣集心得，言傳身教，能達拋磚引玉、加強資源、交流精進之功效，在兼負重任，百忙之際，也更難能可貴，也讓我輩啟發及效法。

值此緬懷及期勉的 40 周年重大時節，同喜同慶，在此亦表達堅實友誼，期能持續交流，互相激勵，分享成就及共同努力。謹代表台灣的應用地質技師、各公會、理事長暨全體會員再次致上最誠摯之祝賀!!

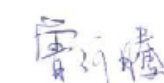
應用地質技師公會聯合會

理事長 王豐仁



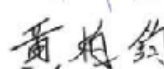
新北市應用地質技師公會

理事長 曾何騰



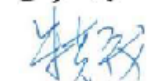
臺北市應用地質技師公會

理事長 黃柏鈞



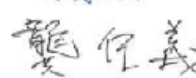
臺中市應用地質技師公會

理事長 朱英茂



高雄市應用地質技師公會

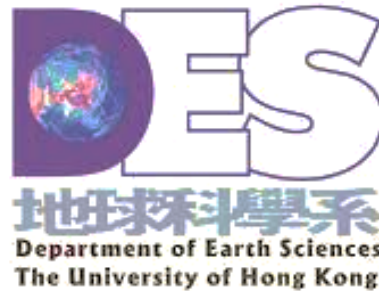
理事長 龔任義



臺灣省應用地質技師公會

理事長 黃柏鈞





Message from the Department of Earth Sciences, The University of Hong Kong

It gives me great pleasure to congratulate the Geological Society of Hong Kong on its 40th Anniversary. Over the past four decades, GSHK has been tireless in its efforts to promote geological interests and studies in Hong Kong and to provide a platform for professionals and amateurs to meet. We are particularly grateful to the GSHK for establishing the Best Student Project Prize in Earth Sciences at HKU since 2015. I wish the GSHK every success in the years to come.

Man Hoi Lee
Head
Department of Earth Sciences
The University of Hong Kong



Message from the Earth System Science Programme, The Chinese University of Hong Kong

On behalf of the Earth System Science Programme and the newly integrated Earth and Environmental Sciences Programme, I would like to express our congratulations on the 40th Anniversary of the establishment of the Geological Society of Hong Kong (GSHK).

Since 1982, the GSHK has offered regular geological conferences, seminars, workshops, and local and overseas field trips to members and non-members. These activities provide a platform to enhance geological interest and knowledge in Hong Kong. The GSHK has made a remarkable contribution to sustainable knowledge exchange in the community, whereby participants from the public, private sectors, and academia could all benefit substantially from the work of the Society. Indeed, I myself joined a fossil workshop organized by the Society in 2017, which has greatly broadened my intellectual horizon and enhanced my understanding of the paleo-environment of the Earth. Such events are a great contributor to the scientific literacy of the general public as well as the advancement of citizen science.

The most interactive learning platform to me is the field excursions organized by GSHK, which establish academic and cultural exchange opportunities for the participants throughout the trips. The natural wonders as documented beautifully in the field trip reports have most certainly attracted people with different backgrounds and reminded us how humans are deeply connected to nature and can do a lot more to preserve our precious Planet.

With the GSHK 40th Anniversary Conference commemorating its achievements in the past 40 years, I would like to send our heartfelt congratulatory message to GSHK with our unwavering belief in its success in the education and advancement of the geological field in the future.

Amos P. K. Tai
Director
Earth System Science Programme, Faculty of Science
The Chinese University of Hong Kong

學會四十
砥礪前行

陳龍生題

The Geological Society of Hong Kong

Since 1982



Foreword

Welcome to this special Conference for the celebration of the 40th Anniversary of the Geological Society of Hong Kong.

The Organising Committee wishes to express our daily life is closely related to the geological environment around us. Hence the theme of the Conference is “Living Geology”. The presentations include latest research works in the Geology of Hong Kong and Kenya, experimental investigation, practical engineering geology, modelling, earthquake, climate changes and dinosaur. I hope this Conference could give you an update on the development of various fields of geological sciences which is highly related to our daily life.

I would like to thank the Liaison Office of the Central People’s Government (中央政府駐港聯絡辦), the Geological Society of Guangdong (廣東省地質學會), the New Taipei City, Taipei, Taichung, Kaohsiung and Taiwan Province Association of Professional Applied Geologists (新北市、台北市、台中市、高雄市、台灣省應用地質技師公會), the Department of Earth Sciences of the University of Hong Kong, the Earth and Environmental Sciences Programme of the Chinese University of Hong Kong, and Professor L. S. CHAN on their greetings. I also express my sincere thanks to all speakers/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 40th Anniversary conference. Last but not least, I must thank the Organising Committee for their great work in making this Conference and other Anniversary activities possible.



Paul CHEUNG
President of the Geological Society of Hong Kong

籌備委員會 Organising Committee

主席：

譚志勤 先生

Chairman:

Mr Kan Tam



委員：

張志德 先生

陳龍生 教授

王毅遠 博士

梁偉健 先生

江志成 博士

陳順明 先生

何照碩 先生

招侃潛 博士

龍德駿 先生

莫翠玲 女士

林憶慈 女士

鄺曉靖 女士

譚佩玉 博士

黃愉晴 女士

何致慇 女士

李卓禧 先生

王澤辰 先生

向婉晴 女士

Members:

Mr Paul Cheung

Prof. L. S. Chan

Dr Louis Wong

Mr W. K. Leung

Dr C. S. Kong

Mr Raymond Chan

Mr Patrick Ho

Dr H. C. Chiu

Mr T. C. Lung

Ms C. L. Mok

Ms Peggy Lam

Ms Trudy Kwong

Dr Tammy Tam

Ms Angie Wong

Ms Sandie Ho

Mr Johnson Li

Mr Spike Wang

Ms Ellie Xiang

活動日程 Event Programme

二零二二年八月廿五日(星期四) 25 August 2022 (Thursday)

時間 Time	活動內容 Activity Descriptions	地點 Venue
14:30 - 16:30	參觀香港科學館展覽 - 地球科學廳及 【八大·尋龍記】專題展覽 Hong Kong Science Museum Tour: Earth Science Gallery and “The Big Eight – Dinosaur Revelation” Special Exhibition	香港科學館 Hong Kong Science Museum

二零二二年八月廿六日(星期五) 26 August 2022 (Friday)

時間 Time	活動內容 Activity Descriptions	地點 Venue
08:45 - 09:00	登記 Registration	香港大學專業進修附屬學院 學院演講廳(九龍東) HKU SPACE College Theatre (Kowloon East)
09:00 - 09:10	開幕儀式 Opening Ceremony	
09:10 - 12:15	演講(上午) Presentations (Morning)	
12:15 - 13:35	午餐 Lunch	
13:35 - 17:20	演講(下午) Presentations (Afternoon)	會所1號德藝會(九龍灣) ClubONE Telford (Kowloon Bay)
18:30 - 23:00	晚宴 Dinner Banquet	

二零二二年八月廿七日(星期六) 27 August 2022 (Saturday)

時間 Time	活動內容 Activity Descriptions	地點 Venue
09:00 - 17:30	野外考察 Field Workshop	鳳凰笏、虎王洲及吉澳 (馬料水碼頭集合) Fung Wong Wat, Fu Wong Chau and Kat O (Gather at Ma Liu Shui Ferry Pier)

二零二二年九月三日(星期六) 3 September 2022 (Saturday)

時間 Time	活動內容 Activity Descriptions	地點 Venue
10:00 - 11:30	參觀寶珊排水隧道山泥傾瀉科技展學館 Visit to Po Shan Drainage Tunnel Landslide Sci-Tech Chamber	寶珊排水隧道 Po Shan Drainage Tunnel

會議日程 Conference Rundown

二零二二年八月廿六日(星期五) 26 August 2022 (Friday)

時間 Time	內容 Descriptions	文章編號 Article No.
8:45 a.m.	Registration	
9:00 a.m.	Opening Ceremony and Welcome Speech	
9:05 a.m.	Start of Morning Session (Chair by Mr Jeffrey Wong) Theme - Recent Advances in Hong Kong Geological Research	
9:10 a.m.	Revisiting the Volcanic-plutonic Connections of Late Mesozoic Silicic Igneous Rocks in Hong Kong Dr Denise L K Tang, Geotechnical Engineering Office	1
9:30 a.m.	Explosion Fractures in Hydrothermal Bodies in Hong Kong: Observations and Implications Prof. L S Chan, Department of Earth Sciences, HKU	2
9:50 a.m.	Key Findings of Hong Kong Geological Survey 1:20,000-Scale Geological Map Sheet 2 Mr Edison Tse, Geotechnical Engineering Office	3
10:10 a.m.	Rhyolite in Po Toi: Implication for Crystal Mush Model Ms Rachel Hung, Department of Earth Sciences, HKU	4
10:30 a.m.	Q&A	
10:45 a.m.	小休 BREAK	
11:00 a.m.	Potential Effects of Climate Change on Landslide Hazards in Hong Kong Mr Steven Williamson, AECOM	5
11:20 a.m.	Field Study of the Hydrothermal Dyke in Kat O Ms Jasmine Song, Department of Earth Sciences, HKU	6
11:40 a.m.	Raman Spectroscopy of Silica-rich, Fine-grained Rocks from Hong Kong Dr Dominic Mok, Asia Gemmological Institute and Laboratory Limited	7
12:00 noon	Q&A	
12:15 p.m.	午餐(自費) LUNCH (NOT INCLUSIVE)	

The Geological Society of Hong Kong - 40th Anniversary

時間 Time	內容 Descriptions	文章編號 Article No.
1:35 p.m.	Start of Afternoon Session (Chair by Dr Louis N Y Wong) Theme - Earth Sciences for Humanity	
1:40 p.m.	A Brief Review of Publication Trends in the Bulletin of Engineering Geology and the Environment Dr Louis Wong, Department of Earth Sciences, HKU	8
2:00 p.m.	Experimental Investigation of Thermal Strengthening in Sichuan Marble Mr Cui Xin, Department of Earth Sciences, HKU	9
2:20 p.m.	Earthquakes in the Weiyuan Shale Gas Field within the Sichuan Basin Dr H F Yang, Earth System Science Programme, CUHK	10
2:40 p.m.	Introduction and Comments on “Guidelines for the Development and Application of Engineering Geological Models on Projects (IAEG C25)” Prof. J J Dong, National Central University, Taiwan (Pre-recorded)	11
3:00 p.m.	Q&A	
3:15 p.m.	小休 BREAK	
3:35 p.m.	Volcanism and Climate Change Prof. Wyss W S Yim, Association for Geoconservation / Formerly Department of Earth Sciences, HKU	12
3:55 p.m.	African Palaeoenvironments and Mammal-Hominin Evolution Prof. Bernie Owen, Hong Kong Baptist University (Pre-recorded)	13
4:15 p.m.	A Geologist Plays a Key Role in Construction Projects Mr Lih Luor, Sinomac Engineering Consultants Limited (Pre-recorded)	14
4:35 p.m.	The Evolution of Flight in Dinosaurs Dr Michael Pittman, School of Life Sciences, CUHK	-
4:55 p.m.	Q&A	
5:10 p.m.	CONCLUDING REMARKS	
5:20 p.m.	END OF CONFERENCE	

文章目錄
List of Articles

Article No.	Author	Title	Pages
1	D L K Tang	Revisiting the Volcanic-plutonic Connections of Late Mesozoic Silicic Igneous Rocks in Hong Kong	16 - 18
2	L S Chan	Explosion Fractures in Hydrothermal Bodies in Hong Kong: Observations and Implications	19 - 24
3	E T K Tse and D L K Tang	Key Findings of Hong Kong Geological Survey 1:20,000-scale Geological Map Sheet 2	25 - 29
4	C W Hung, L S Chan and D L K Tang	Rhyolites in Po Toi: Implications for Crystal Mush Model	30 - 34
5	S Williamson	Potential Effects of Climate Change on Landslide Hazards in Hong Kong	35 - 40
6	J S Song and L S Chan	Field Study of The Hydrothermal Dyke in Kat O	41 - 47
7	D W K Mok and S S M Cheung	Raman Spectroscopy of Silica-rich, Fine-grained Rocks from Hong Kong	48 - 53
8	L N Y Wong	A Brief Review of Publication Trends in the Bulletin of Engineering Geology and The Environment	54 - 57
9	C Xin, L N Y Wong, Y H Zhang, Z J Wu and T Y Guo	Experimental Investigation of Thermal Strengthening in Sichuan Marble	58 - 60
10	H F Yang, J P Zi and J W Zhang	Earthquakes in the Weiyuan Shale Gas Field within the Sichuan Basin	61 - 67
11	J J Dong	Introduction and Comments on “Guidelines for the Development and Application of Engineering Geological Models on Projects (IAEG C25)”	68 - 72
12	W W S Yim	Volcanism and Climate Change	73 - 78
13	R B Owen	African Palaeoenvironments and Mammal-hominin Evolution	79
14	羅立	地質師在土木工程建設的關鍵角色	80 - 92
15	Y Y Zhang and M Sun	Molybdenum and Boron Isotopic Evidence for Carbon – Recycling via Carbonate Dissolution in Subduction Zones	93 - 96

The Geological Society of Hong Kong - 40th Anniversary

Article No.	Author	Title	Pages
16	馬秋柱	非洲納米比亞矽藻土的工程特性	97 - 108
17	K H T Tseng	A Simple Tectonic Map as Learning Aid to the Complex Geology of China	109 - 112
18	顏一勤、葛岳淵、 李彪、黃能偉	從雙極排列直流電阻法探究地下地質構造模式	113 - 114
19	S C Chang and J P Wang	Active Volcanoes around the Taipei Metropolis – Hazard Identification and Risk Assessment	115 - 118
20	J G Zhang	Detailed Exploration QA/QC Plan for Andranovato Gibbsite Bauxite, Madagascar	119 - 126
21	M Y H Li and H C Chiu	Mobilization of Rare Earth Elements along Hillslope during Sub-tropical Weathering: Insight from Hong Kong	127 - 130
22	K W Lai	The Characteristics of Cretaceous and Paleogene Fault Basins in Hong Kong	131 - 135

REVISITING THE VOLCANIC-PLUTONIC CONNECTIONS OF LATE MESOZOIC SILICIC IGNEOUS ROCKS IN HONG KONG

Denise L K Tang

Hong Kong Geological Survey, Geotechnical Engineering Office,
Civil Engineering and Development Department, HKSAR Government

INTRODUCTION

The late Mesozoic igneous rocks in Hong Kong comprise dacitic to rhyolitic ignimbrites and lavas with intercalated tuffaceous sedimentary units, as well as intrusions of granodiorite, granite, quartz monzonite and minor dykes of various compositions (Sewell et al., 2000; 2012a). The volcanic and plutonic rocks were considered to be largely co-genetic representing ancient caldera-related large-scale silicic magmatic systems (Campbell & Sewell, 1997). Spatial and temporal distributions of the silicic volcanic and their sub-volcanic plutons were constrained by detailed mapping (Campbell & Sewell, 1997 and references therein), supported with ID-TIMS zircon geochronological data (Davis et al., 1997; Campbell et al., 2007; Sewell et al., 2012b). Four volcanic-plutonic assemblages, corresponding to temporally distinct magmatic episodes were identified (Davis et al., 1997; Sewell et al., 2000; 2012b). The genetic correlations of the volcanic groups and igneous suites were established on the basis of broadly coeval eruption and intrusion ages, and similarities in whole-rock geochemical signatures (in particular whole-rock TiO_2 versus Zr concentrations, Figure 2 in Sewell & Campbell, 1997). It is noteworthy that matching of individual volcanic units to specific plutons was not explicitly done, and that a sub-volcanic equivalent might not be identified for each volcanic unit, and vice versa (Sewell & Campbell, 1997; Tang et al., 2017). This paper aims to re-examine the connections of the paired volcanic-plutonic units in Hong Kong, with a particular focus on the two Early Cretaceous magmatic assemblages, in light of the emerging concept of large silicic magmatic systems.

VOLCANIC-PLUTONIC CONNECTIONS

Large silicic magmatic systems are commonly described through the generalised crystal mush model, in which volcanic rocks and sub-volcanic plutons are considered to be genetically related and share a common magmatic origin (e.g. Bachmann & Bergantz, 2004; Hildreth, 2004; Hildreth & Wilson, 2007). In this model, silicic magmatic systems are inferred to be dominated by a crystal mush that contains $\geq 50\%$ crystals and is thus theologically locked (Brophy, 1991; Bachmann & Bergantz, 2004; Huber et al., 2011). When the crystal content of the magma is $<45\%$, the crystals are suspended in the melt, allowing convection, mixing and stirring of the magma. Once the crystallinity reaches a threshold of $\sim 45\text{--}50\%$, wholesale melt convection is hindered owing to the rheological locking of the crystal mush, but the permeability remains sufficiently high for melt extraction from the rigidified crystal framework by crystal compaction and settling. Further increases in the crystal content gradually reduce the permeability of the mush and eventually stop the melt-crystal separation processes. The crystal mush model suggests that the sub-volcanic granitic plutons represent in part either the completely solidified non-erupted crystal mush, or the remnant, crystal-dominated part of the system after the withdrawal of rhyolitic melt (e.g. Bachmann et al., 2002; Bachman & Bergantz, 2004).

The volcanic products of the High Island caldera complex ranging from crystal-rich dacitic to rhyolitic ignimbrites (of the Repulse Bay Volcanic Group, RBVG) to trachytic to high-silica rhyolite ignimbrites (of the Kau Sai Chau Volcanic Group, KSCVG) are inferred to represent the evacuation of different parts (in space) or development stages (in time) of a long-lived (>3 Myr) magmatic system. The

divergence in volcanic lithologies suggests that there were separate modes of volcanic-plutonic connections which co-existed and spatially overlapped in the High Island caldera system.

The magma reservoir(s)¹ of the earlier units of the RBVG, i.e. Long Harbour and Mount Davis formations, are characterized by their dacitic composition, high crystal contents, and relatively high proportion of inherited zircons (see Tang et al., 2017). The system is inferred to have been sourced from partial melting of older Yanshanian granites (the magmatic roots) and basement rocks, and assembled into a crystal-dominated system, with only small or negligible proportion of a rhyolitic melt-dominated cap. The eruptions of the Long Harbour and Mount Davis formations are interpreted as reflecting the intermittent ‘defrosting’ and evacuation of parts of the crystal mush. They can be considered as equivalent to the ‘monotonous intermediates’ summarized by Hildreth (1981).

Subsequent eruptions of the RBVG, i.e. the Ap Lei Chau, Che Kwu Shan and Pan Long Wan formations, show evidence for additional input from less evolved, hotter sources. These volcanic units are linked through their abundance of inherited zircon core with the earlier granites (Shui Chuen O Granite). The compositions of the Ap Lei Chau and Che Kwu Shan units reflect a progressive involvement and interaction of mafic magma with the magma reservoirs. As the mafic influx heightened, melts are extracted from the crystal mush and/or crystal root where zircons from the earlier granites and/or basement rocks were released into the newly assembled melts. The Pan Long Wan trachydacitic lava is interpreted as the product of the invigorated magmatic system, with a geologically rapid (less than $\sim 10^2$ to 10^3 years) ascent, assembly and storage of the melts.

The eruptions of the KSCVG are considered to represent a state where a large body of crystal-poor rhyolite, probably sustained by underlying less-evolved crystal-rich magma, was developed beneath the High Island caldera system. The magmas are inferred to have generated directly from fractionation of a mafic, mantle-derived source. This interpretation is supported by the whole rock geochemistry of the KSCVG units, which show fractionation trends from intermediate to highly-evolved silicic compositions from the Pan Long Wan trachydacite through the Clear Water Bay Formation to the High Island Tuff.

The Sok Kwu Wan Granite and D'Aguilar Quartz Monzonite are considered to be coeval and probably co-magmatic with the KSCVG on the basis of their similarity in zircon trace element characteristics and age spectra from zircon U-Pb SIMS analysis (Tang et al., 2017). These two intrusive units are exposed close to the caldera margin of the High Island caldera and are interpreted to have intruded along the caldera bounding faults following caldera collapse. Their zircon trace element characteristics suggest that there was either a relatively limited degree of melt fractionation during zircon growth in the magma bodies, or that the magma completely solidified with a narrow span of melt evolution (Tang et al., 2017).

The Kowloon and Mount Butler granites are inferred to be sourced from recycling of pre-existing crustal materials, which included older Yanshanian granites and much older basement rocks (Tang et al., 2017). The latest geochronological data suggests that these granites (~ 139 - 138 Ma, Tang et al., 2017) were emplaced ~ 1 - 2 Myr after the eruption of the KSCVG, and therefore were independent of the magmas that fed the KSCVG. These granites were probably crystallised from high-evolved melts at or near solidus temperature, and have never supported any significant eruption products. They were emplaced within 2-3 km of the surface into the base of the RBVG units. Their cooling and crystallisation is considered to indicate the final state of shallow crustal magmatic activity in the High Island caldera system.

¹ Here, a magmatic reservoir is defined as comprising two different physical sub-domains, i.e. the crystal-dominated “mush” zones and the melt-dominated “magma chambers” that contain rhyolitic melts extracted from the “mush”. See Sparks et al. (2019) for a detailed overview.

REFERENCES

- Bachmann, O. and Bergantz, G.W., 2004. On the origin of crystal-poor rhyolites: Extracted from batholithic crystal mushes. *Journal of Petrology* 45, 1565-1582.
- Bachmann O., Dungan, M.A. and Lipman, P.W., 2002. The Fish Canyon magma body, San Juan volcanic field, Colorado: Rejuvenation and eruption of an upper-crustal batholith. *Journal of Petrology* 43, 1469-1503.
- Brophy, J.G., 1991. Compositional gaps, critical crystallinity, and fractional crystallization in orogenic (calc-alkaline) magmatic systems. *Contributions to Mineralogy and Petrology* 109, 173-182.
- Campbell, S.D.G. and Sewell, R.J., 1997. Structural control and tectonic setting of Mesozoic volcanism in Hong Kong. *Journal of the Geological Society, London* 154, 1039-1052.
- Campbell, S.D.G., Sewell, R.J., Davis, D.W. and So, A.C.T., 2007. New U-Pb age and geochemical constraints on the stratigraphy and distribution of the Lantau Volcanic Group, Hong Kong. *Journal of Asian Earth Sciences* 31, 139-152.
- Davis, D.W. Sewell, R.J. and Campbell, S.D.G., 1997. U-Pb dating of Mesozoic igneous rocks from Hong Kong. *Journal of the Geological Society, London* 154, 1067-1076.
- Hildreth, W., 1981. Gradients in silicic magma chambers: Implications for lithospheric magmatism. *Journal of Geophysical Research* 86, 10153-10192.
- Hildreth, W., 2004. Volcanological perspectives on Long Valley, Mammoth Mountain, and Mono Craters: Several contiguous but discrete systems. *Journal of Volcanology and Geothermal Research* 136, 169-198.
- Hildreth, W. and Wilson, C.J.N., 2007. Compositional zoning of the Bishop Tuff. *Journal of Petrology* 48, 951-999.
- Huber, C., Bachmann, O. and Dufek, J., 2011. Thermo-mechanical reactivation of locked crystal mushes: Melting-induced internal fracturing and assimilation processes in magmas. *Earth and Planetary Science Letters* 304, 443-454.
- Sewell, R.J. and Campbell, S.D.G., 1997. Geochemistry of coeval Mesozoic plutonic and volcanic suite in Hong Kong. *Journal of the Geological Society, London* 154, 1053-1066.
- Sewell, R.J., Campbell, S.D.G., Fletcher, C.J.N., Lai, K.W. and Kirk, P.A., 2000. The Pre-Quaternary Geology of Hong Kong. Civil Engineering Department, Hong Kong SAR Government, Hong Kong.
- Sewell, R.J., Tang, D.L.K. and Campbell, S.D.G., 2012a. Volcanic-plutonic connections in a tilted nested caldera complex in Hong Kong. *Geochemistry, Geophysics, Geosystems*, 13, Q01006.
- Sewell, R.J., Davis, D.W. and Campbell, S.D.G., 2012b. High precision U-Pb zircon ages for Mesozoic igneous rocks from Hong Kong. *Journal of Asian Earth Sciences* 43, 164-175.
- Sparks, R.S.J., Annen, C., Blundy, J.D., Cashman, K.V., Rust, A.C. and Jackson, M.D., 2019. Formation and dynamics of magma reservoirs. *Philosophical Transactions of the Royal Society A* 377, 20180019.
- Tang, D.L.K., Wilson, C.J.N., Sewell, R.J., Seward, D., Chan, L.S., Ireland, T.R. and Wooden, J.L., 2017. Tracking the evolution of Late Mesozoic arc-related magmatic systems in Hong Kong using in-situ U-Pb dating and trace element analyses in zircon. *American Mineralogist* 102, 2190-2219.

ACKNOWLEDGMENTS

This paper is published with the permission of the Director of Civil Engineering and Development and the Head of the Geotechnical Engineering Office, the Government of the Hong Kong Special Administration Region.

EXPLOSION FRACTURES IN HYDROTHERMAL BODIES IN HONG KONG: OBSERVATIONS AND IMPLICATIONS

Chan, Lung Sang
Department of Earth Sciences, HKU

Abstract: Field observations of the hydrothermal breccias in Kat O, Crescent Island, and Hung Shek Mun in northern New Territories of Hong Kong reveal the presence of explosion fractures in the hydrothermal bodies. The fractures probably resulted from expanding vapor explosions when superheated fluids ascended rapidly along crustal fractures and encountered the water saturation line in the subsurface ground. The fracturing occurred in multiple phases of the hydrothermal injection process and at relatively shallow depths of about 150 m. The findings from this study are conducive to the understanding of the P-T paths of hydrothermal fluids as well as formation of hot springs in amagmatic regions.

INTRODUCTION

Silica-rich hydrothermal breccias are found to exist at 14 localities in the northeastern part of Hong Kong. These hydrothermal bodies, occurring in forms of pipes, dikes and veins, and varying in size from a few meters to over a hundred meters, are intensively silicified and generally lack metallic mineralization. The breccia bodies commonly consist of a massive, texture-less core zone of completely silicified rocks fringed by marginal zones of stockworks and silica veins. The brecciation evidently formed in a fluid-assisted process by injection of superheated, over-pressurized fluids from the deeper part of the crust into rock formations at shallow depths. The rapid ascent of the superheated fluids led to depressurization of the fluids and subsequent expanding vapor explosions (EVEs) when the ascending fluids reached the water saturation line. This study reports the morphology of the explosion fractures observed in the hydrothermal bodies as well as their hydro-thermodynamic implications.

FORMATION OF HYDROTHERMAL BRECCIAS

The occurrences of hydrothermal bodies in the northern part of Hong Kong appear to center about the western side of Mirs Bay, with the largest bodies exposed in Kat O, Crescent Island, and Double Island (Fig. 1). While hydrothermal events are mostly associated with volcanogenic or magmatic processes, the Hong Kong area did not experience any magmatic activities during the past 100 m.y., and an alternative explanation is needed to account for the hydrothermal events. Chan (2019) and Chan et al. (2022) showed that hydrothermal injections could be attributed to a sudden deepening of the brittle-plastic (B-P) boundary in the crust. The crust is known to comprise an upper brittle zone and a lower plastic zone, separated by a brittle-plastic (B-P) transition at a depth of 10-15 km (Sibson, 1977). A fair amount of water is probably trapped in the plastic lower crust (Bailey, 1990; Cheng & Ben-Zion, 2019). The low permeability of the plastic zone effectively isolates the trapped water from the fractures in the brittle zone, maintaining the water at lithostatic pressure of about 27 MPa/km. A sudden deepening of the B-P boundary can result in the liberation of the trapped fluids into the brittle zone in which ground water is subject to the much lower hydrostatic pressure of 10 MPa/km. Such fluctuations of the B-P boundary can be caused by crustal cooling around a magmatic body (Fournier, 1999) or triggered by temporary extensions of crustal faults into the plastic zone (Zielke et al., 2018). In both cases, the over-

pressured fluids may ascend into the brittle zone along crustal discontinuities, resulting in brecciation and silicification of rocks along the injection paths.

EXPLOSION FRACTURES

Explosion fractures are often produced in rock quarry blastings (Loorents et al., 2000). In a rock blasting the conversion of chemical energy into gaseous expansion can produce a shock wave with a pressure in the range of 0.5-50 GPa, readily overcoming the tensile strength of the rocks (Saharan et al. 2006). As shown in Fig. 2, an explosion fracturing pattern generally comprises a cavity in the center, a crushed annulus with dense fractures and an exterior zone with radial cracks (e.g. Mitelman & Elmo, 2014). Unlike geological discontinuities formed by kinematic processes, the radial cracks extend in all directions for a finite distance from the crushed annulus. A damage boundary marking the extent of the radial cracks is sometimes present.

Over 30 explosive fractures were recorded in the hydrothermal dike in Kat O Island. Many of the fractures are present in the massive parts of the silicified rock and exhibit an axisymmetric pattern (Fig. 3a-c). The central cavity is generally equidimensional, with a diameter ranging from 1 cm to over 5 cm. In a few instances, the central cavities are filled by secondary materials (Fig. 3d). The crushed annulus containing dense fractures vary in width in the range of 1-3 cm. The radial cracks generally extend for less than 20 cm and occasionally show a damage boundary (Fig. 3e). When the EVE occurs along a pre-existing fracture, the fracturing pattern is affected by the local anisotropic stress configuration due to the fracture (Fig. 3f). In the hydrothermal dike in Kat O, the explosion fractures are located mainly in the core zone, suggesting the occurrence of the highest fluid velocity there in the hydrothermal injection process. Multiple stages of hydrothermal injection, brecciation and silicification are evident, since many explosion fractures are found to occur in silicified rocks formed in earlier stages.

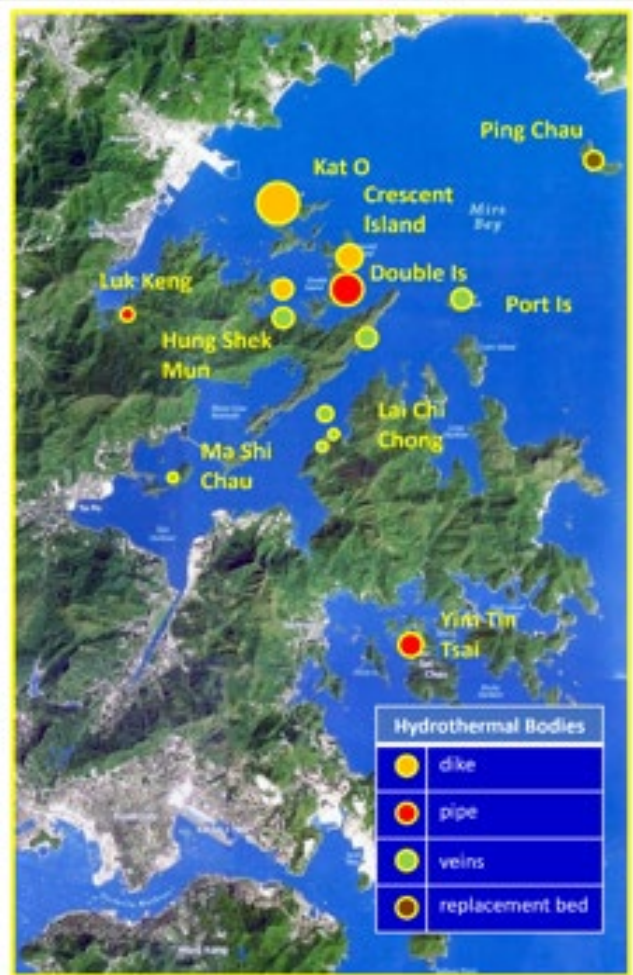


Fig. 1. Occurrences of hydrothermal bodies in northeastern Hong Kong, with size of symbol roughly proportional to size of the body

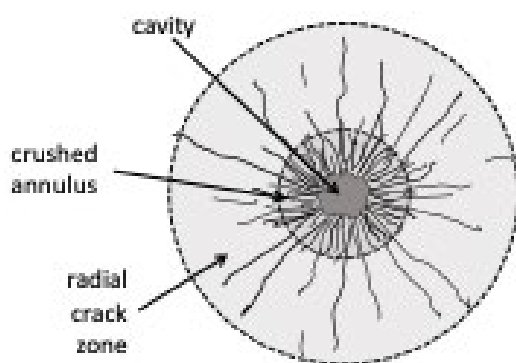


Fig. 2. a: Structure of explosion fracture; b: blast-induced explosion fracture in Lantau, Hong Kong

IMPLICATIONS FOR P-T PATHS OF HYDROTHERMAL FLUIDS

The explosion fractures were formed as superheated hydrothermal fluids encountered the water saturation line in the subsurface ground, as rapid depressurization of the fluids led to EVEs similar to the explosion of a fractured gas tank. Alvarez et al. (2016) and Chan et al. (2022) pointed out that such a conversion from liquid to gas could produce a substantial volumetric change and pressure. As shown in Fig. 4, the liquid-gas transformation must occur at temperatures below the supercritical temperature of water of 374°C, since above that temperature water and steam are indistinguishable from each other. Assuming a depth of 10 km for the B-P transition and a geothermal gradient of 25°C/km, the temperature and pressure for the trapped water are 250°C and 270 MPa respectively. At that temperature, liquid boiling occurs at about 4 MPa, equivalent to a crustal depth of about 150 m. At the liquid-vapor boundary, the specific volume is 0.050 m³/kg and 0.0012 m³/kg respectively for steam and water, yielding an expansion ratio of 42. The sudden increase in pressure associated with the expanding vapors can probably produce rupture patterns oblivious to the local deviatoric stress configuration in the surrounding rocks.

The presence of explosion fractures in a rock formation is conducive to the determination of the P-T path of the over-pressured hydrothermal fluids. Vaporization occurs when the over-pressured fluids reach the water saturation line as shown in the phase diagram of water (Fig. 4). For P-T Path A in Fig. 4, the fluids ascend very quickly through fractures to reach the saturation line, maintaining a steady temperature at close to 250°C. The vaporization is essentially incurred by the reduction in the pressure, with no or little loss of heat. For P-T Path B, the ascending fluids suffer some heat loss during their ascent and meet the boiling curve at a shallower depth than that for Path A. Ironically, the expansion pressure is greater since the specific volume of steam increases with decreasing temperatures, resulting in a greater expansion ratio. In this case more intense formations of explosion fractures are expected. For P-T Path C, the over-pressured fluids ascend through the brittle zone with a velocity sufficiently slow to enable the fluids to emerge on the surface as hot spring water without vaporization. No explosion fractures are produced in the process. In summary, explosion fracturing must have occurred in the subsurface ground when the fluids reach the water saturation line in a rapid depressuring process and at relatively shallow crustal depths.

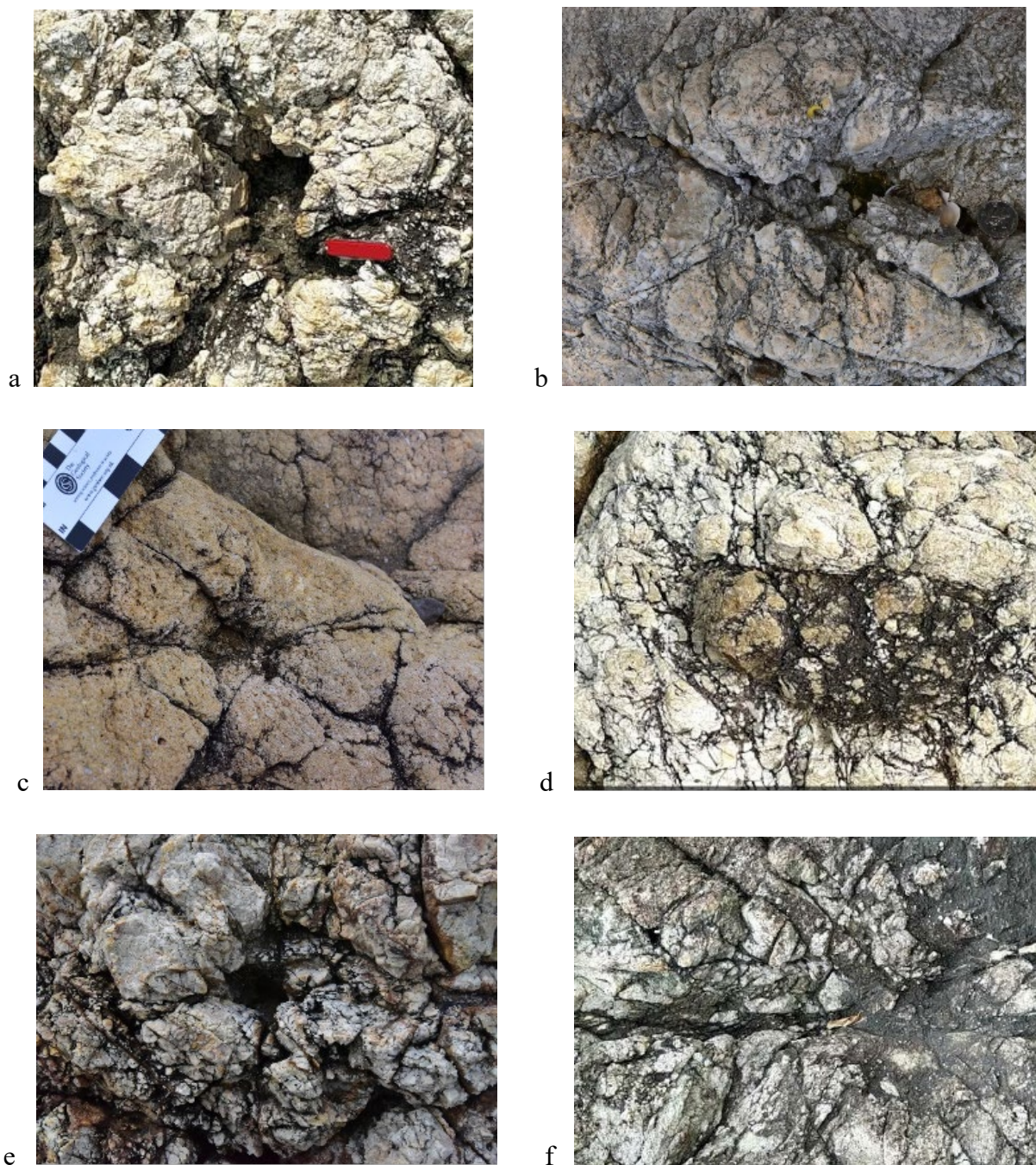


Fig 3 Explosion fractures in Kat O Island; a-c: explosion fractures displaying a clear central cavity, crushed annulus and radial cracks, d: explosion fracture with cavity filled, e: explosion fracture with a marked damage radius, f: explosion fractures developed along pre-existing cracks

CONCLUSIONS

The conclusions of this study are as follows.

1. Explosion fractures observed in the silicified rocks were formed by expansion vapor explosions as ascending superheated water reached the boiling point during the depressurization of the fluids.
2. The explosion fracturing occurred at shallow depths of about 150 m.
3. The rapid depressurization process was associated with limited heat loss during the fluid ascent, allowing the fluids to reach the boiling curve before emerging onto the surface and hence implying a relatively fast fluid velocity in the hydrothermal injection.
4. The presence of expansion fractures can facilitate determination of the P-T paths of hydrothermal fluids as well as provide an explanation for hot spring formations in non-volcanogenic regions.

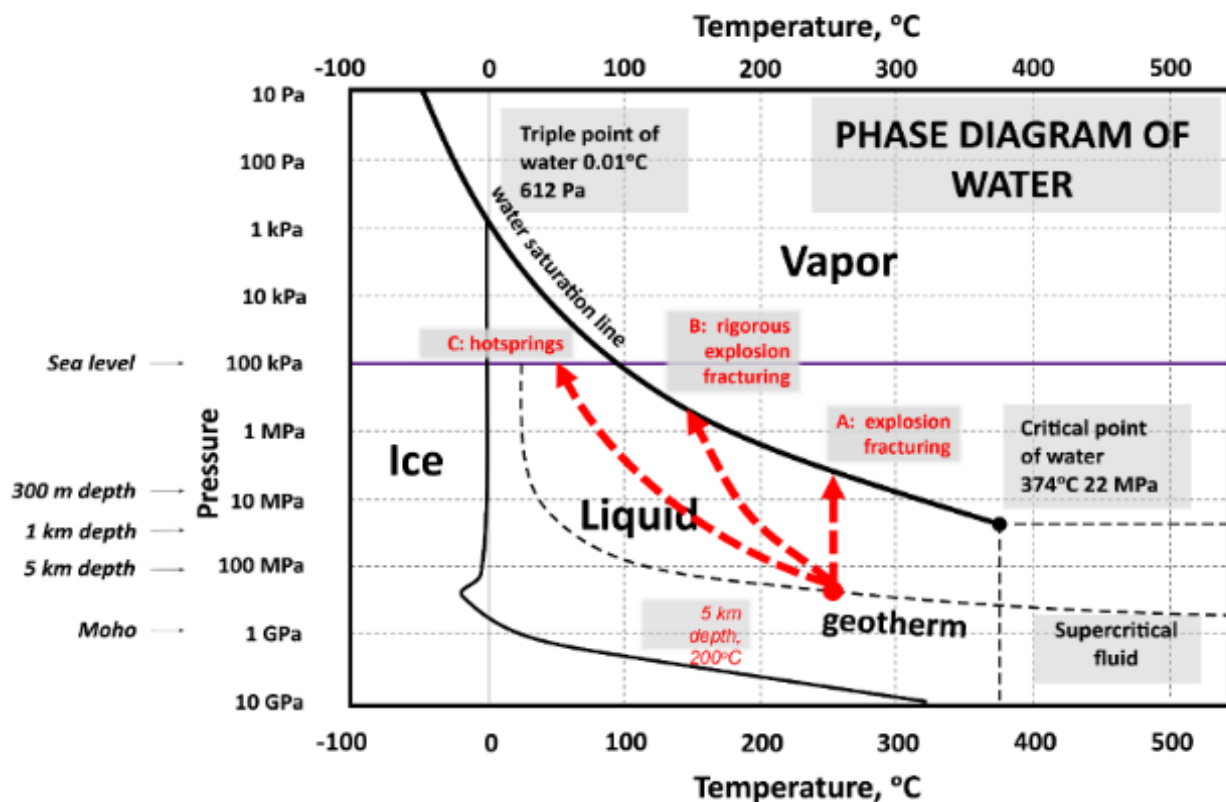


Fig. 4. P-T paths of hydrothermal fluids plotted on the phase diagram of water. Explosion fractures will form for fluid Paths A and B, with B having more rigorous explosion fractures due to greater expansion ratio at a lower temperature. Fluids following Path C will emerge as hot springs on the surface.

REFERENCES

- Alvarez, W., Belza, J., Peacock, D., Claeys, P. & Tavarnelli, E., 2016, Expansion Breccias in Carbonate Rocks, Geological Society of America Abstracts with Programs. Vol. 48, No. 7 doi: 10.1130/abs/2016AM282404
- Bailey, R.C., 1990, Trapping of aqueous fluids in the deep crust, Geophysical Research Letters, 17, 8, 1129-1132
- Chan, L.S., 2019, A Model for the Formation of Hot Springs in Coastal Area of Guangdong, Conference Proceed., The 9th World Chinese Conference of Geological Science, June 1-2, 2019, Jilin, China

- Chan, L.S., Alvarez, W., Geiser, P., and Tavarnelli, E., 2022, Fluid-assisted brecciation of Lower Cretaceous Maiolica limestone in the Umbria-Marche Apennines: Hydrodynamical implications, in Koeberl, C. et al. (eds), From the Guajira Desert to the Apennines, and from Mediterranean Microplates to the Mexican Killer Asteroid: Honoring the Career of Walter Alvarez: Geological Society of America Special Paper 557, p. 1–16, [https://doi.org/10.1130/2022.2557\(07\)](https://doi.org/10.1130/2022.2557(07))
- Cheng, Y. and Ben-Zion, Y., 2019, Transient brittle-ductile transition depth induced by moderate-large earthquakes in southern and Baja California, *Geophys. Res. Lett.*, doi: 10.1029/2019GL084315
- Fournier, R.O. 1999, Hydrothermal processes related to movement of fluid from plastic into brittle rock in the magmatic-epithermal environment, *Econ. Geol.*, 94, 8, 1193-1211
- Loorents, K.J., Björklund, L. & Stigh, J., 2000, Effect of induced fracturing based on a natural fracture system in a dimension stone quarry in the Offerdal Nappe, Sweden, *Bull Eng Geol Env*, 58: 215–225
- Mitelman, A., & Elmo, D., 2014, Modelling of blast-induced damage in tunnels using a hybrid finite-discrete numerical approach, *Journal of Rock Mechanics and Geotechnical Engineering*, 6, 565-573
- Saharan, M.R., Mitri, H.S. & Jethwa, J.L., 2006, Rock fracturing by explosive energy: review of state-of-the-art, *Fragblast*, 10:1-2, 61-81
- Sibson, R.H., 1977, Fault rocks and fault mechanisms, *Journal of the Geological Society*, 133, 191-213
- Zielke, O., Mai, M. & Schorlemmer, D., 2018, Postseismic deepening of the brittle-ductile transition zone depth, *Geophysical Research Abstracts*, EGU General Assembly 2018, vol. 20, EGU2018-2362

ACKNOWLEDGEMENT

The author is indebted to Projectterrae for financial support of field work for the project.

KEY FINDINGS OF HONG KONG GEOLOGICAL SURVEY 1:20,000-SCALE GEOLOGICAL MAP SHEET 2

Tze-kei Tse and Denise L K Tang
Hong Kong Geological Survey,
Geotechnical Engineering Office, Civil Engineering and Development Department

Abstract: *The updating of the 1:20,000-scale HKGS geological map sheet 2 has been recently completed. Key revisions to the updated map include: (i) reinterpretation of the stratigraphy of the San Tin Group; (ii) recognition of a Mesozoic sedimentary sequence in the district; (iii) subdivision of the Tuen Mun Formation; (iv) inference of possible presence of the Shing Mun Formation; (v) revision of the extent of Kat O Formation; and (vi) identification of an undifferentiated granite. The updated map is published in digital format with an accompanied geological report on the major findings.*

INTRODUCTION

In 1989, the Hong Kong Geological Survey (HKGS) published the first edition of the 1:20,000-scale geological map Sheet 2 – San Tin, with an accompanying geological memoir (Langford et al., 1989). Updating of the map sheet in digital format, including the preparation of a solid geology map (Figure 1), has recently been completed. Apart from standardising with the latest stratigraphic nomenclature, key updates of Sheet 2 include re-interpretation of the San Tin Group, identification of a Mesozoic sedimentary sequence in the Ma Tso Lung area, reassignment of various Mesozoic volcanic units, identification of Cretaceous redbeds in the offshore area, and identification of an undifferentiated granite subcrop. A full report documenting the findings and updates of Sheet 2 is published as a GEO internal report (Tse & Tang, 2022). This paper will focus on the findings associated with the stratigraphic and structural interpretation of the San Tin Group, the identification of a Mesozoic sequence in the district, and its contact relationship with the Tai Mo Shan Formation.

REINTERPRETATION OF THE SAN TIN GROUP

The Carboniferous San Tin Group includes two formations, the lower Yuen Long Formation and the upper Lok Ma Chau Formation, which comprise dominantly marbles and metasedimentary rocks (Langford et al., 1989). These two formations were each subdivided into two members (Frost, 1992). The stratigraphy of the San Tin Group has been reviewed under the map updating exercise for Sheets 6 and 2 (So & Sewell, 2019; Tse & Tang, 2022). In the previous interpretation of the Yuen Long Formation, the Ma Tin member was underlain by the Long Ping member. Under the latest interpretation, the stratigraphic relationship of these two members are reversed, i.e. the Ma Tin member is considered to be the older unit, and they essentially form a conformable succession (Figure 2a).

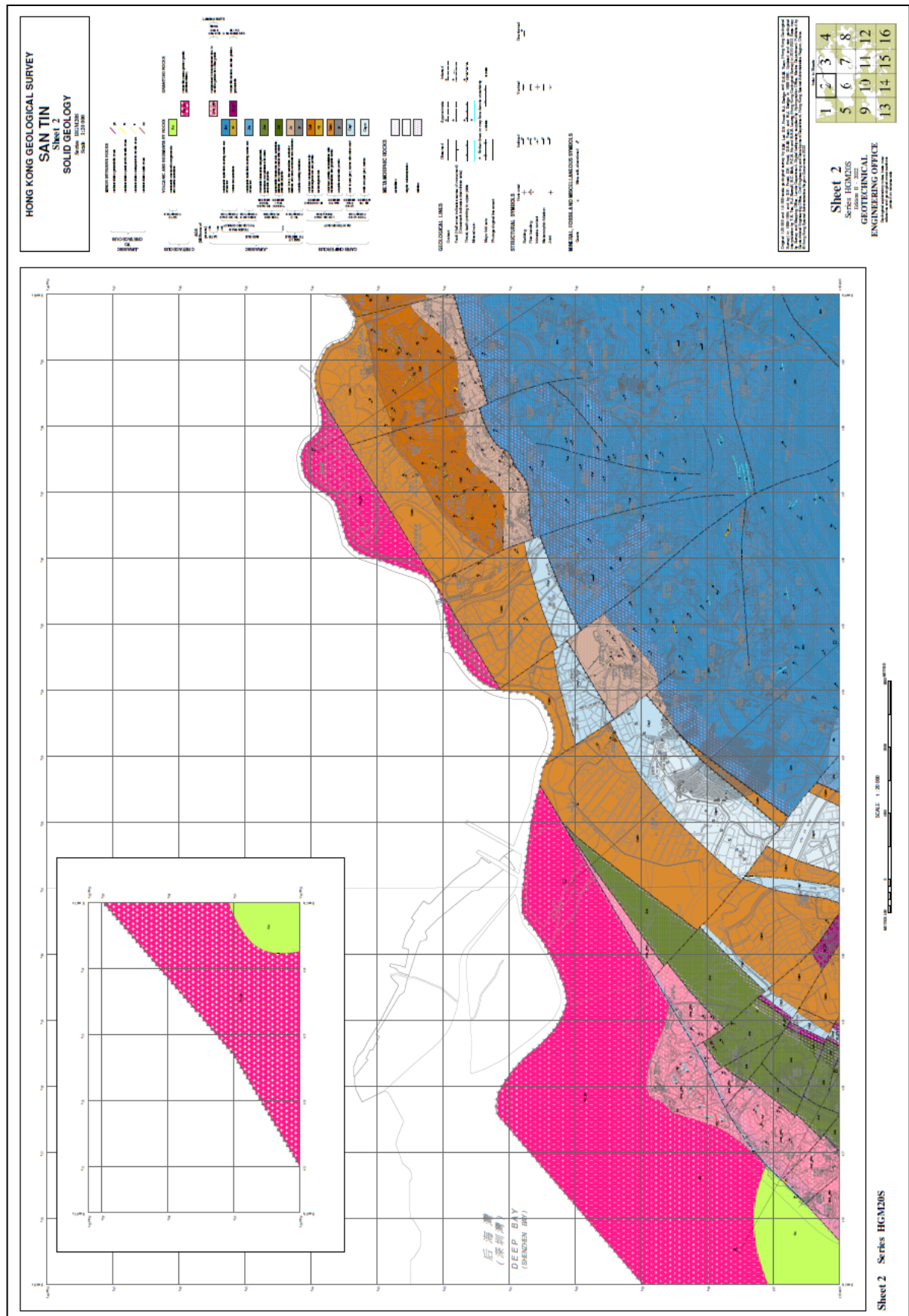


Figure 1 Updated 1:20,000-Scale HKGS Solid Geology Map Sheet 2.

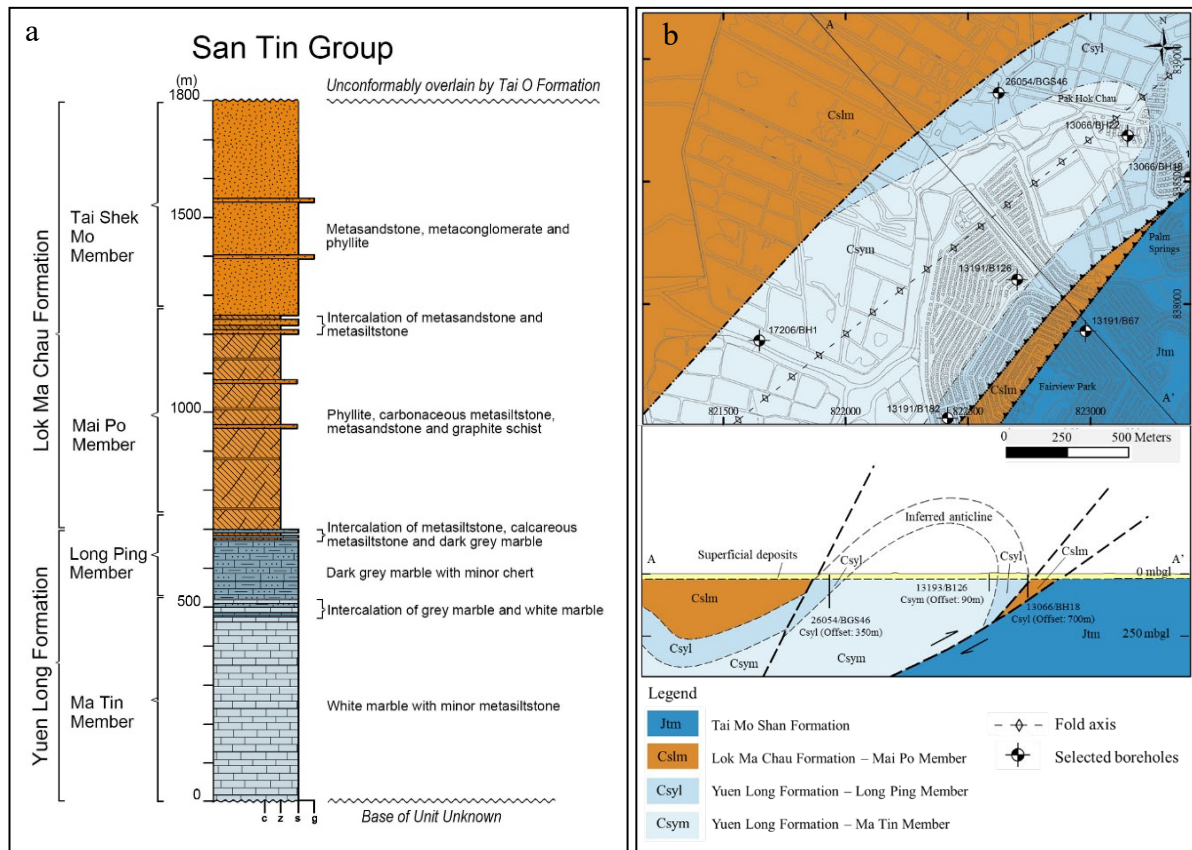


Figure 2 (a) Updated Stratigraphic Column of the Carboniferous San Tin Group; (b) Inferred Anticline near Fairview Park

Based on existing borehole data, additional marble subcrops, dominantly impure or dolomitic marbles (of the Long Ping member), are confirmed in the Lut Chau – Tung Chan Wai, and Shan Pui River areas (Figure 1). In addition, dark grey impure marble, either interbedded with or in transition to metasiltstone, has been encountered at relatively shallow levels near Mai Po, the Yuen Long Sewage Treatment Works and Hong Kong Wetland Park. The interbedded and transitional sequences are interpreted to represent the uppermost part of the Long Ping Member. Based on the spatial relationship of the Long Ping and Ma Tin members, an anticline is inferred with the fold axis trending northeast (Figure 2b). However, there is insufficient evidence to support whether overfolding has occurred in the district.

The outcrops of the Lok Ma Chau Formation was originally mapped apparently as a repeating sequence exposed between Lo Wu and Lok Ma Chau (Langford et al., 1989). The two members (i.e. Tai Shek Mo and Mai Po members) were interpreted to have a thrust contact close to the border at Lecky Pass and Ping Hang to Lok Ma Chau. This contact relationship was based on a presumption that the sedimentary sequence was younging towards the northwest and that the Mai Po member was repeated by faulting (Langford et al., 1989). A conformable contact between the two members, on the other hand, was mapped to the southwest (Langford et al., 1989). This previous structural interpretation has been reassessed with consideration of a contrasting model proposed earlier by Allen & Stephens (1971).

Allen & Stephens (1971) proposed that the metasedimentary and volcanic sequence in the district possibly represented the underlimb of an overfold, implying a southeasterly younging direction of the metasedimentary sequences. Based on the findings of the map updating exercise, we consider that Allen & Stephens' "fold" model is more probable and better in explaining the distribution of the Mai Po and Tai Shek Mo members, which are now considered to have a conformable contact in the district.

Nonetheless, the scale of regional folding remains doubtful due to the lack of consistent evidence across the northern New Territories.

PRESENCE OF MESOZOIC SEDIMENTARY SEQUENCE

Detrital zircon dating was conducted for seven samples of metasandstone and metasiltstone collected from the Ma Tso Lung area (Sewell et al., 2016; Figure 3a). The results have revealed the presence of two sample groups with distinct zircon age spectra (Figure 3b). The first group, including four samples (left panel in Figure 3b), yielded detrital zircons ranging from Palaeoarchean to Silurian-Devonian ages, indicating a maximum depositional age of about 440 Ma. These four samples are considered to represent the Carboniferous Lok Ma Chau Formation. The other group, including three samples (right panel in Figure 3b), contains Mesoarchean to Triassic detrital zircons, suggesting that these sediments must be deposited during or after the Triassic. The detrital zircon age spectra of these three samples are comparable with that of a sample (HK13496) collected near the type locality of the Tai O Formation at San Shek Wan, Lantau Island (Sewell et al., 2016). Based on these findings, the sedimentary succession, which includes metasandstone, metasiltstone with graphite interbeds, exposed near Ma Tso Lung (formerly mapped as the Mai Po Member, in conformable contact with the Tai Shek Mo Member) is now tentatively reassigned from the Mai Po member to the Lower to Middle Jurassic Tai O Formation.

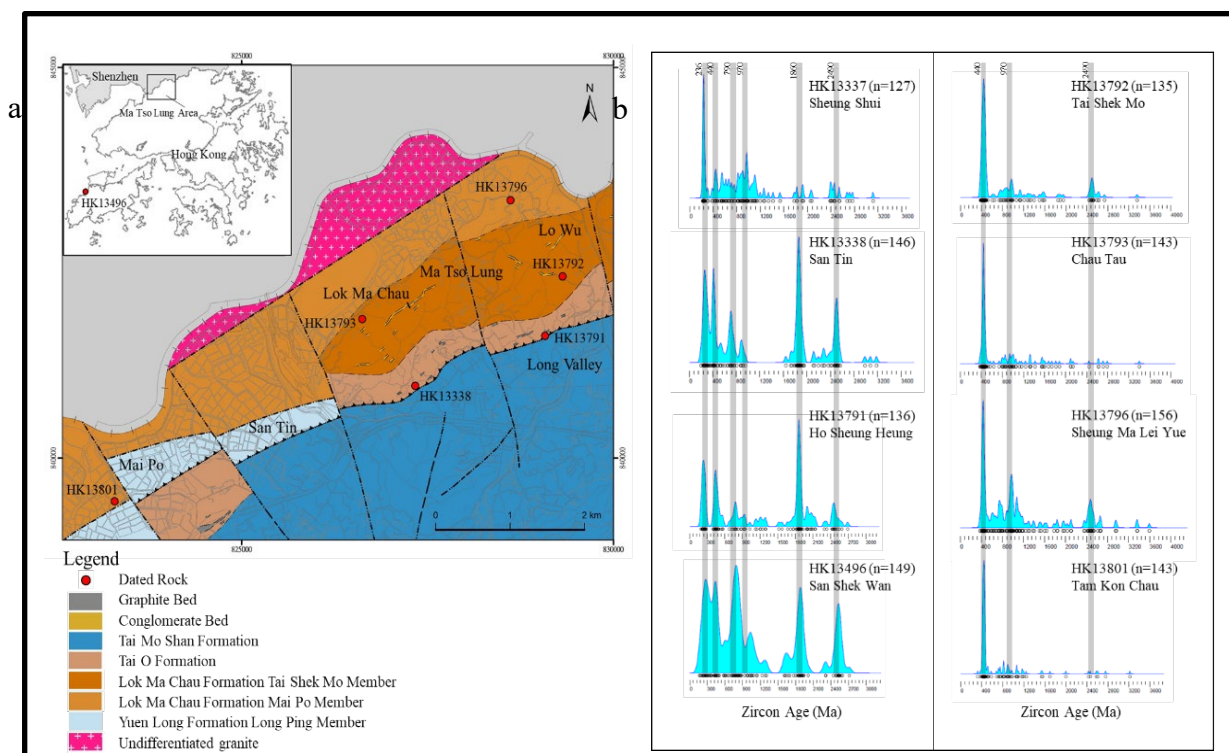


Figure 3 (a) Sample Location of Detrital Zircon Analysis; (b) Detrital Zircon Age Spectra (KDE Plots). KDE Plot of Sample HK13496, which is from San Shek Wan, Lantau Island for Comparison (Modified from Sewell et al., 2016)

In line with this re-assignment, the contact between the newly-assigned Tai O Formation and the overlying Tai Shek Mo Member is now reinterpreted to be an unconformity. Near the contact, metasandstone of the Tai Shek Mo member often shows signs of silicification, and is associated with quartz veins or quartzite. These features may be interpreted as a lag deposit and possibly represent a disconformity between the Lok Ma Chau and Tai O formations, but they are not always recognised.

The contact between the Tai O and Tai Mo Shan formations is interpreted to be essentially a conformable contact, but locally sheared along the San Tin Fault. Their contact relationship is evident in several existing drillholes at Tsung Yuen to Chau Tau and Mai Po San Tsuen to Wo Shang Wai areas, as well as in the field near Fung Kong Shan and Tit Hang. Near Pak Shek Au, the intermittent outcrops of the two formations are mylonitised along the San Tin Fault, such that the exact contact between the meta-sedimentary rocks and meta-volcanics cannot be traced with certainty.

Based on the field observations from some recent exposures near Ho Sheung Heung, the S-C fabrics developed on the meta-sedimentary rocks show sub-horizontal to gently-inclined, northwesterly dipping cleavages, with shear fabric suggesting a normal dip-slip motion. This zone of intense shearing is coincident with the interpreted alignment of the San Tin Fault, which has been traditionally considered as a thrust fault. As such, the nature of this fault warrants further investigation.

CONCLUSIONS

The geological map Sheet 2 is the fifth map updated under the map updating programme currently being conducted by the HKGS. Apart from producing geological maps in digital format, a comprehensive set of databases containing drillhole records, geotechnical data, geophysical data, and well as information of rock samples, fossil and mineral occurrences etc. are being established. The HKGS has continued to undertake various geological studies to improve our understanding of Hong Kong's geological history, and thereby to produce more accurate geological maps.

REFERENCES

- Allen, P.M. & Stephens, E.A. (1971). Report on the Geological Survey of Hong Kong. Government Printer, Hong Kong, 107 p.
- Frost, D.V. (1992). Geology of Yuen Long. Hong Kong Geological Survey Sheet Report No. 1. Geotechnical Engineering Office, Hong Kong, 69 p.
- Langford, R.L., Lai, K.W., Artherton, R.S. & Shaw, R. (1989). Geology of the Western New Territories. Hong Kong Geological Survey Memoir No. 3, Geotechnical Control Office, Hong Kong, 140 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, Hong Kong, 181 p. plus 4 maps.
- Sewell, R.J., Carter, A. & Rittner, M. (2016). Middle Jurassic collision of an exotic microcontinental fragment: Implications for magmatism across the southeast China continental margin. *Gondwana Research*, vol. 38, pp 304-312.
- So, K.W.F. & Sewell, R.J. (2019). Updating of Hong Kong Geological Survey 1:20,000-scale Maps, Major Findings and Revisions Map Sheet 6 – Yuen Long. Geological Report No. GR 4/2019, Geotechnical Engineering Office, Hong Kong, 58 p.
- Tse, T.K & Tang, D.L.K. (2022). Updating of Hong Kong Geological Survey 1:20,000-scale Maps, Major Findings and Revisions Map Sheet 2 – San Tin. Geological Report No. GR2/2022. Geotechnical Engineering Office, Hong Kong, 37 p.

ACKNOWLEDGMENTS

This paper is published with the permission of the Director of Civil Engineering and Development and the Head of the Geotechnical Engineering Office, the Government of the Hong Kong Special Administration Region.

RHYOLITES IN PO TOI: IMPLICATIONS FOR CRYSTAL MUSH MODEL

HUNG, Chiu Wing, CHAN Lung Sang

Department of Earth Sciences, the University of Hong Kong

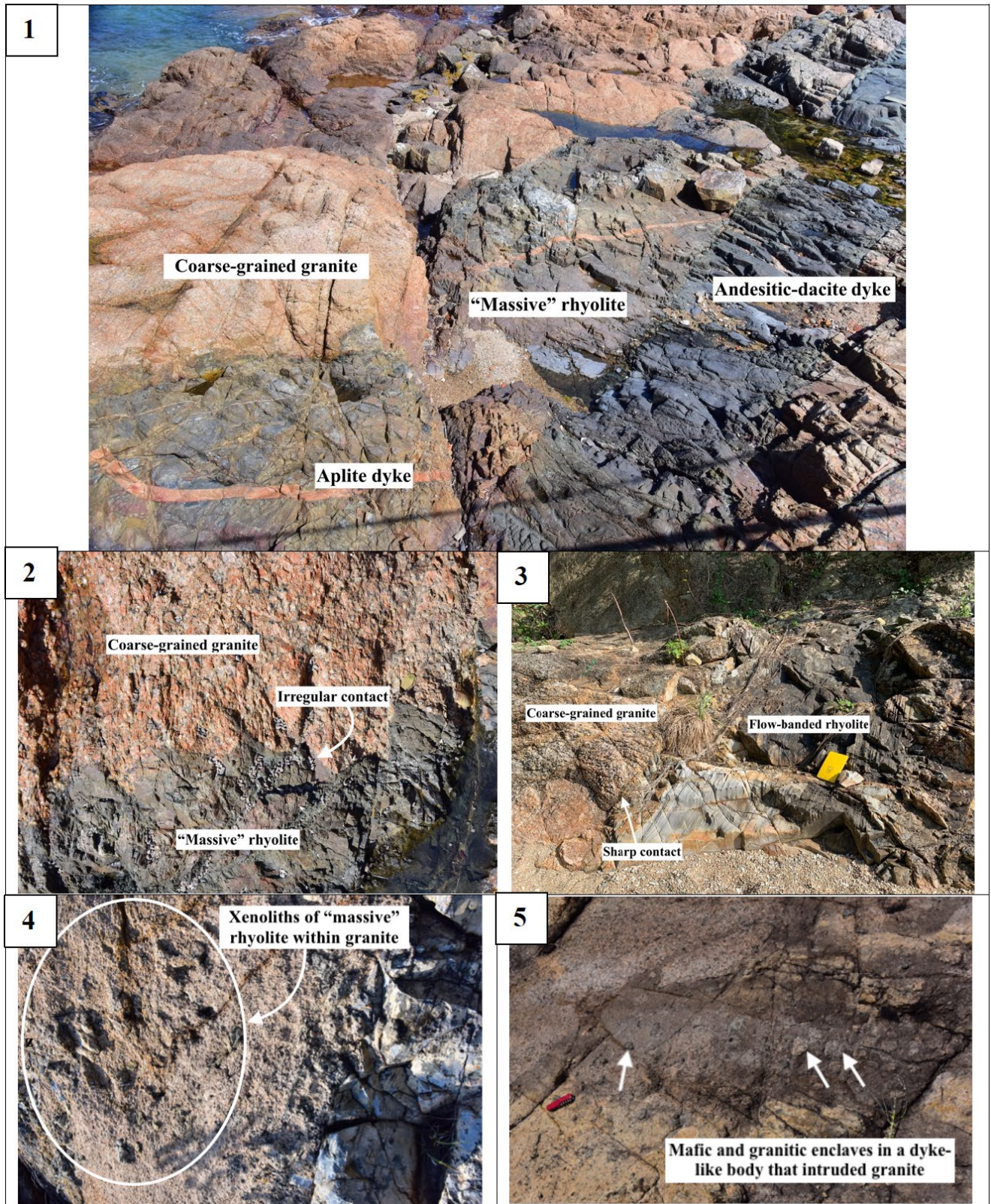
Denise LK TANG

Hong Kong Geological Survey, Geotechnical Engineering Office,
Civil Engineering and Development Department, HKSAR Government

The Po Toi Granite is a subcircular granite pluton formed during the late Mesozoic magmatism in Hong Kong (Sewell et al., 2000). A well-exposed section near the pier of Po Toi Island is a popular field trip location for geology students to study cross-cutting relationship and relative age of rocks (Plate 1). The section contains most of the lithological units that are exposed on the island, including coarse-grained granite (the Po To Granite), feldspathic porphyry and several types of rhyolites. A major unresolved question regarding this section is the relative age of the granite and a light-grey, “structureless” rhyolite (called “massive rhyolite” in this abstract). The contact of the massive rhyolite with the granite is irregular and strikes approximately towards the northwest (Plate 2). Along the contact, features that may be indicative of their relative age, such as chilled margins, flow bands, xenoliths, or apophyses, are absent. In addition, a set of aplite dykes which apparently extend from the granite is found to have cut the massive rhyolite. The ambiguous contact and cross-cutting relationship preclude a definitive determination of age relation of the two units. Other rhyolite units in the vicinity, on the other hand, display prominent flow bands and sharp and well-defined contacts with other units (Plate 3).

Based on the field study, we propose that the granite and the massive rhyolite were coeval and formed by solidification of different sub-domains within a single crystal mush zone. A crystal mush is a partial crystal, partial liquid system that is permeable and semi-consolidated where the melts and the crystals together form a network (Fig. 1a). The crystal mush model has been used to explain many magmatic phenomena such as remobilization of magma, formation of microgranite enclaves, generation of magmas with different compositions, mingling of mafic and intermediate magma, and extraction of rhyolite and aplite from interstitial melts (Bachmann & Bergantz, 2004, 2008; Garibaldi et al., 2018; Lipman & Bachmann, 2015; Schaen et al., 2018; Sliwinski et al., 2017).

We hypothesize that the Po Toi Granite cooled and crystallised from a crystal mush (Fig. 1a). In a crystal mush, interstitial melt is distributed either in the crystalline framework on a micro-scale that is comparable to the crystal dimensions, or coalesces into veins, lenses and/or pockets of melt (Fig. 1b; +Sparks et al., 2019). Because water tends to escape from the crystal framework, the interstitial rhyolite melt becomes water-rich, at 4–6 wt % H₂O (Miller et al., 2003). The granite-massive rhyolite-aplite units in this study likely formed in a similar manner. The water-rich, rhyolitic melt probably cooled at a faster rate than the enclosing crystal mush and had a lower viscosity. The rapid crystallisation of this rhyolitic melt within the solidifying crystal mush (later became the Po Toi Granite) generated the massive rhyolite in the granite (Fig. 1c). Several aplite dykes were emplaced along preexisting lines of weakness, with their crystallization facilitated by the presence of volatiles (Fig. 1d). The absence of chilled margin and the irregular contact between the massive rhyolite and granite could be explained by the inference that the crystal mush was still warm and not fully crystallised by the time when rhyolite completely solidified.



Plates. 1) Rock exposures near the pier at Po Toi Island; 2) Ambiguous contact between coarse-grained granite and rhyolite, as if the rhyolite is “squeezing out” from the granite; 3) Sharp contact between flow-banded rhyolite dyke (right) and coarse-grained granite (left); 4) Co-mingling of rhyolite (right) and granite. Fragments of the “massive” rhyolite can be seen inside the granite (left); 5) Dyke-like body with granitic and mafic enclaves embedded in a fine-grained matrix.

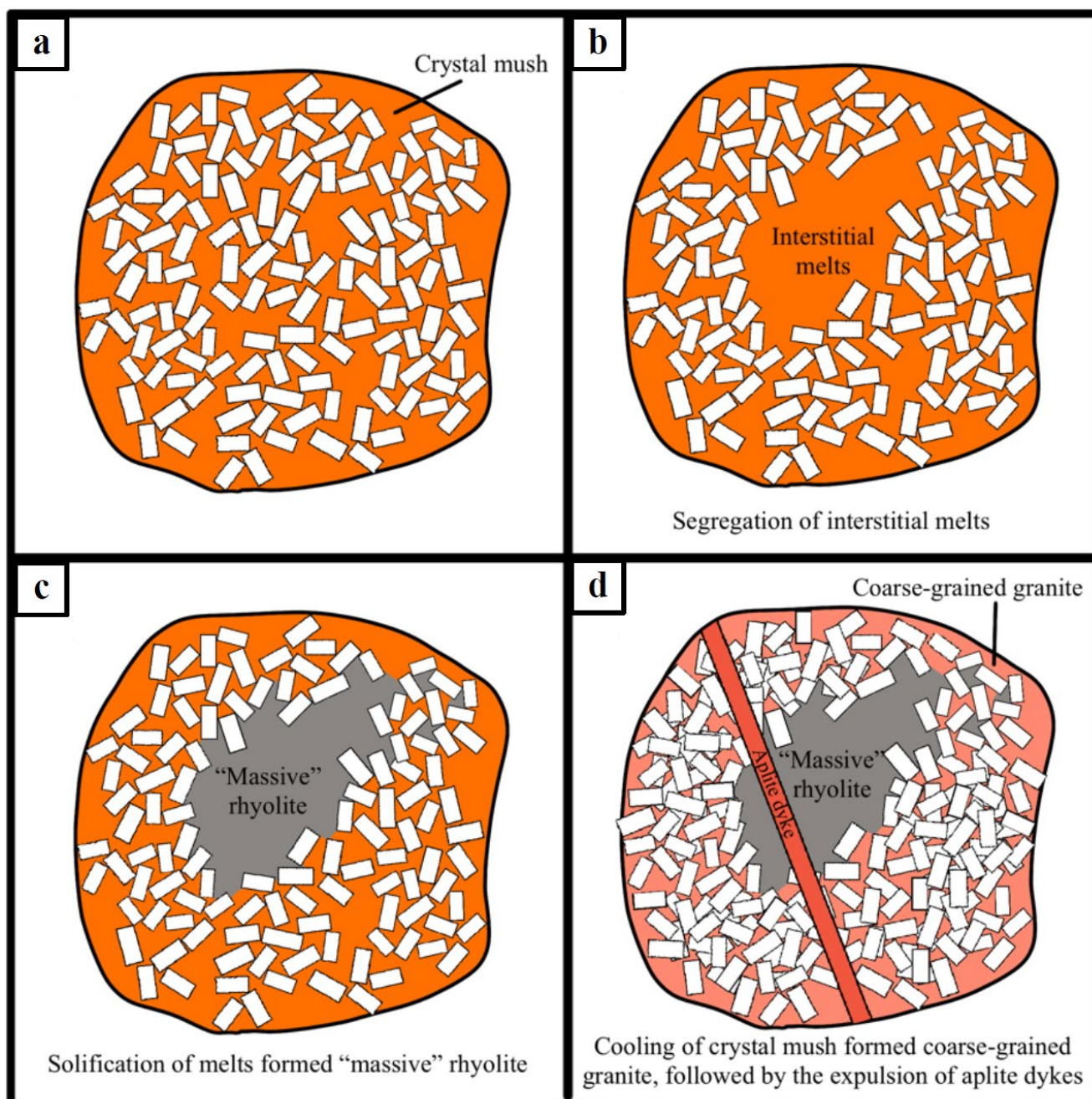


Fig. 1 Illustration of the crystallisation and emplacement of the Po Toi Granite and "massive" rhyolite from a crystal mush zone. (a) The crystal mush comprised a rheologically-locked crystal framework surrounded by interstitial, high-silica melt. (b) The interstitial melt coalesced into pockets of melt in the mush zone, (c) and crystallised rapidly to form the "massive" rhyolite. (d) Subsequent degassing of the crystal mush when it is almost solidified led to the expulsion of the aplite dykes that cut across the "massive" rhyolite.

A rhyolite body exposed at a separate locality about 500 m from the pier provides additional evidence for the coexistence/co-emplacement of the granite and the rhyolite. As shown in Plate 4, the rhyolite is found to have 'intruded' into the granite, while at the same time, the granite contains fragments of the rhyolite as 'xenoliths'. The observations can be explained under the framework of the mush model that some of interstitial melts crystallised and emplaced ("intruded") in the crystallised mush, whereas some solid fragments solidified earlier were captured by the cooling/crystallising mushy granite. Nearby, there is a dyke-like structure with mafic and granitic enclaves embedded in a fine-grained matrix. The feature

resulted where blocks from one magma were incorporated into another granitic magma where they were quenched and hybridized (Plate 5).

In conclusion, we suggest that the rock exposure near the Po Toi pier exhibits various features that provide evidence for the occurrence of a crystal mush during the formation of the massive rhyolite. The Po Toi Granite is inferred to cool and crystallize from a crystal mush, from which water-rich, rhyolitic melts were separated. The extracted rhyolitic melt then cooled rapidly and formed the massive rhyolite within the crystallizing mush. Field observations supporting this interpretation include 1) the absence of chilled margin, 2) lack of internal structures and flow bands of the rhyolite; 3) lack of xenoliths near the contact; and 4) presence of co-mingling structures. Therefore, the massive rhyolite and the granite (Po Toi Granite) are considered to be coeval and co-emplaced within a crystal mush zone. The crystal mush model can be used to explain many features observed in the granites in Hong Kong, including the presence of mafic enclaves in the granite, melt extraction, and megacrysts alignment.

References

- Bachmann, O. & Bergantz, G. W. (2004). On the origin of crystal-poor rhyolites: extracted from batholithic crystal mushes. *Journal of Petrology*, 45, 1565–1582.
- Bachmann, O. & Bergantz G. W. (2008). Rhyolites and their source mushes across tectonic settings. *Journal of Petrology*, 49(12), 2277–2285, <https://doi.org/10.1093/petrology/egn068>
- Garibaldi, N., Tikoff, B., Schaen, A. J., & Singer, B. S. (2018). Interpreting granitic fabrics in terms of rhyolitic melt segregation, accumulation, and escape via tectonic filter pressing in the Huemul pluton, Chile. *Journal of Geophysical Research: Solid Earth*, 123, 8548–8567. <https://doi.org/10.1029/2018JB016282>
- Jellinek, A. M. & DePaolo, D. J. (2003). A model for the origin of large silicic magma chambers: Precursors of caldera-forming eruptions. *Bulletin of Volcanology*, 65, 363–381.
- Koyaguchi, T. & Kaneko, K. (1999). A two-stage thermal evolution model of magmas in continental crust. *Journal of Petrology*, 40, 241–254.
- Lipman, P.W., & Bachmann, O. (2015). Ignimbrites to batholiths: Integrating perspectives from geological, geophysical, and geochronological data. *Geosphere*, 11.
- Marsh, B. D. (1981). On the crystallinity, probability of occurrence, and rheology of lava and magma. *Contributions to Mineralogy and Petrology*, 78, 85–98.
- Miller, C. F., Meschter McDowell, S. & Mapes, R. W. (2003). Hot and cold granites? Implications of zircon saturation temperatures and preservation of inheritance. *Geology*, 31, 529–532.
- Schaen, A. J., Singer, B. S., Cottle, J. M., Garibaldi, N., Schoene, B., Satkoski, A. M., & Fournelle, J. (2018). Textural and mineralogical record of low pressure melt extraction and silicic cumulate formation in the late Miocene Risco Bayo-Huemul Plutonic Complex, southern Andes. *Journal of Petrology*. <https://doi.org/10.1093/petrology/egy087>
- 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.
- Shaw, H. (1972). Viscosities of magmatic liquids. *American Journal of Science*, 272, 870–893.
- Sliwinski, J. T., Bachmann, O., Dungan, M. A., Huber, C., Deering, C. D., Lipman, P. W., et al. (2017). Rapid pre-eruptive thermal rejuvenation in a large silicic magma body: The case of the Masonic Park Tuff, Southern Rocky Mountain volcanic field, CO, USA. *Contributions to Mineralogy and Petrology*, 172(5), 30. <https://doi.org/10.1007/s00410-017-1351-3>

- Sparks, R., Annen, C., Blundy, J. D., Cashman, K. V., Rust, A. C., & Jackson, M. D. (2019). Formation and dynamics of magma reservoirs. *Philosophical transactions. Series A, Mathematical, physical, and engineering sciences*, 377(2139), 20180019. <https://doi.org/10.1098/rsta.2018.0019>
- Weinberg, R. F., Vernon, R. H., & Schmeling, H. (2021). Processes in mushes and their role in the differentiation of granitic rocks. *Earth-Science Reviews*, 220, 103665. <https://doi.org/10.1016/j.earscirev.2021.103665>

ACKNOWLEDGEMENTS

We thank Dr. Martin Li and Mr. Matthew Chung for assistance in the field and petrographic works. DLKT published this abstract with the permission of the Director of Civil Engineering and Development and the Head of the Geotechnical Engineering Office, the Government of the Hong Kong Special Administration Region.

Potential Effects of Climate Change on Landslide Hazards in Hong Kong

Steven Williamson
AECOM Asia Co. Ltd

ABSTRACT

The predicted changes in rainfall patterns due to climate change is subject of interest to those involved in landslide assessment and mitigation and in Hong Kong, the frequency and intensity of heavy rainstorm is predicted to increase. The Hong Kong Observatory predicts that under the least favourable greenhouse gas emission scenarios, the projected change in annual rainfall (relative to average rainfall between 1995-2014) is 4.6% between 2041-2060 and 9% between 2081-2100.

In a typical year, Hong Kong can have over 300 reported landslides, occurring on man-made slopes and natural hillsides. Most of these landslides were triggered by heavy rainfall during the wet season. Some of these landslides resulted in casualties, significant economic loss and even fatalities. Inevitably, such predicted changes in rainfall characteristics due to climate change will have a long-term effect on the risk of landslides in Hong Kong and thus, the resilience of facilities at risk. With respect to natural terrain landslides in the past few decades, some very intense rainstorms, and the associated occurrence of landslide clusters or individual large magnitude landslides may indicate future trends.

1. Introduction

The current policy trend of national and local governments in addressing climate resilience to infrastructure potential effects of climate change, and in particular rainfall on landslide hazard and risk has been a subject of interest to stakeholders in slope safety management.

Based on the UN Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report [AR6], it has been predicted that the frequency and intensity of heavy rainstorms in Hong Kong will generally increase in the 21st century. Heavy rainfall has been a key triggering factor to landslides in Hong Kong and some correlations between rainstorm intensity and the potential to trigger landslides have been established by GEO.

Systematic studies and works programmes have been implemented by the Geotechnical Engineering Office (GEO) to identify, understand and manage the risks arising from natural terrain landslides in Hong Kong. However, these are typically based on past landslide evidence dating back to the early 1960's and the possibility of more intense rainfall and extreme weather in the remaining part of 21st century due to climate change provides further challenges to our predictive and risk management strategies.

2. Natural Terrain Landslide Setting in Hong Kong

Hong Kong has a population of 7 million people living in a total land area of about 1,100 km² of which about 60% comprises hilly, undeveloped terrain. Thus, it has one of the highest population densities in the world with much of the urban development encroaching into the steep hillsides. It is geologically diverse and suffers severe tropical storms during the summer months which trigger landslides.

Natural terrain covers over 60% of the total land area of Hong Kong. Some 70% of the natural terrain is steeper than 15 degrees and over 30% is steeper than 30 degrees. The present-day landscape is thought to have been formed mainly during the Quaternary Period over the past 1.4 million years. Although the

The Geological Society of Hong Kong - 40th Anniversary

landscape has experienced a long history of landscape evolution, the hillsides remain highly susceptible to rain-induced landslides.

Over 100,000 recent and relict natural terrain landslides have been categorised in the Enhanced Natural Terrain



Figure 1 – Proximity of Urban Development to Steep Hillside Terrain

Landslide Inventory (ENTLI) of GEO. Most of these are relict landslides, being observed as historical landslides from 1963 aerial photographs, but over 300 landslides affecting the public are reported to GEO in an average year. These are mainly near the interface of the built environment and steep hillsides (Figure 1) and although the large majority of these commonly involve man made features, many are natural terrain landslides which tend to occur most frequently during heavy rainstorms.

Notable natural terrain studies were conducted by the Geotechnical Engineering Office (GEO) of the government since the 1980s and these works led to the launch of the Government's Landslip Prevention and Mitigation Programme (LPMit) in 2010, one of the core components of which is to tackle natural terrain landslide hazards.

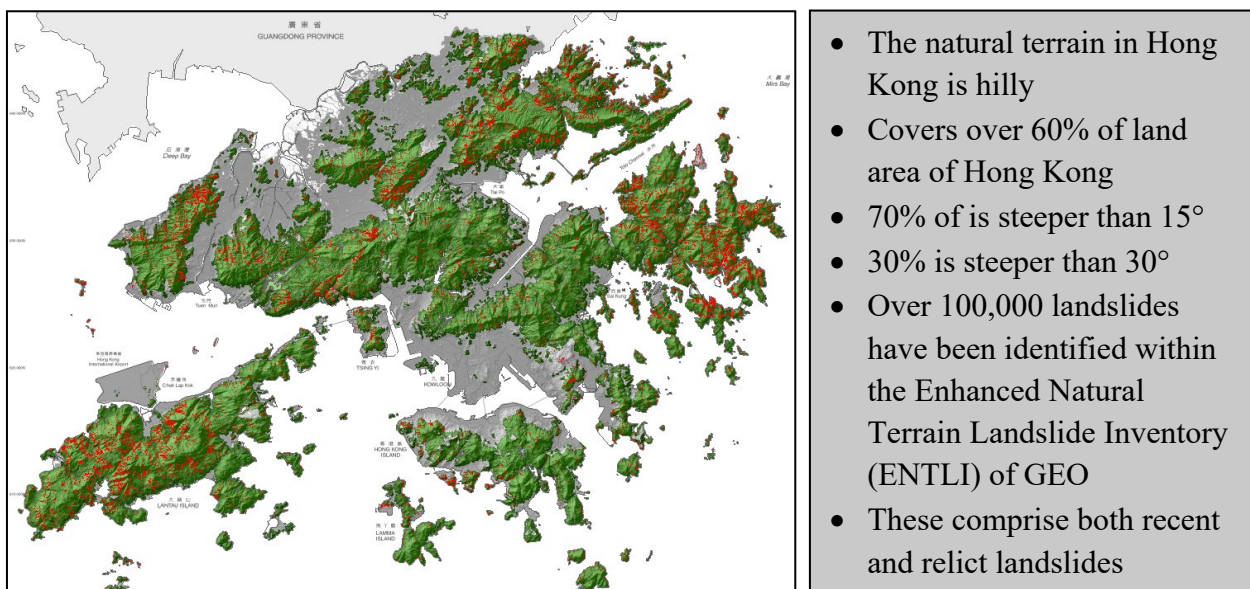


Figure 2 – Coverage of hilly terrain and ENTLI database in Hong Kong

The LPMit programme predicts natural terrain hazard location and magnitude based on the ‘react to known hazard principle’ which is largely based on the pattern of past landslide records from the ENTLI, and so relies on the landslide data of the past 60 years or so. In the past 30 years or so several notable CDF landslides associated with severe rainstorms have occurred with source volumes exceeding 2000m³. In many of these cases, they have not been predicted by ‘react to known hazard principle’.

3. Natural Terrain Landslides

Natural terrain hazards include debris avalanches, debris flows, rockslides and boulder/rockfall. The most hazardous type of landslide is a channelised debris flow (CDF) which can attain large magnitude and velocity, and thus energy, due to the confined nature of the debris trail. Notable such landslides in the past include the 1990 Tsing Shan debris flow which was triggered by a 340 m³ source which impacted upon and mobilised about 2,000 m³ of loose colluvium. The subsequent debris flow mobilised and entrained about 20,000 m³ of material and travelled more than 1 km from the landslide source. The possibility of a similar flow occurring above a densely packed urban area has given increased impetus to the study of natural terrain hazards in Hong Kong. The 1999 debris flow at Sham Tseng San Tsuen gave further impetus when a landslide source of only 600 m³ travelled down a rocky ravine as a highly mobile debris flow which resulted in one fatality and 13 injured persons needing to be rescued. More recent cases include the 2002 Lei Pui Street CDF, a number of large CDF’s triggered by the June 7 2008 severe rainstorm, the 2016 Sai Kung Sai Wan Road CDF and the 2018 Fan Kam Road landslide cluster /CDF.



Figure 3– Large CDF generated by the June 7 2008 Rainstorm at Yu Tung Road, North Lantau.

Although it is too premature to make definite judgements, the perceived increase in the frequency of relatively large natural terrain landslides may be reflecting changes in typical ground conditions in the hillsides which may be responding to increased rainfall due to climate change.

4. Rainfall Intensity and Density of Landslides

The relationships between rainfall intensity and density of landslides has been the subject of several studies by GEO in Hong Kong including using the maximum rolling 24-hour rainfall normalised against the mean annual rainfall to correlate natural terrain landslide occurrence in Hong Kong which indicated that the density of natural terrain landslides increases exponentially with rainfall intensity. As most natural terrain landslides are very shallow (of the order of 0.5 m to 3 m deep) and are relatively sensitive to short duration increases in pore water pressure, it is not surprising that a good overall correlation between rainfall intensity and landslide density exists. However, in terms of susceptibility of natural terrain, it has been observed that during moderate rainfall intensities with a relatively frequent return period, landslides tend to occur predominantly on the more susceptible terrain, while more intense and 'extreme' rainstorms tend to generate a higher proportion of landslides on the less susceptible terrain. One implication is that if more frequent 'extreme' events are experienced during the remaining part of the 21st century, the historical landslide record for the past 60 years may under-represent the frequency and magnitude of landslides that could be expected in future. This would apply to the less susceptible terrain as well as to the terrain with the highest susceptibility.

GEO's Landslide Potential Index (LPI) estimates the number of landslides that can be triggered by a rainstorm based on rainfall characteristics and spatial distribution of slopes in Hong Kong. The LPI can be used to help predict the potential of a rainstorm to generate landslides.

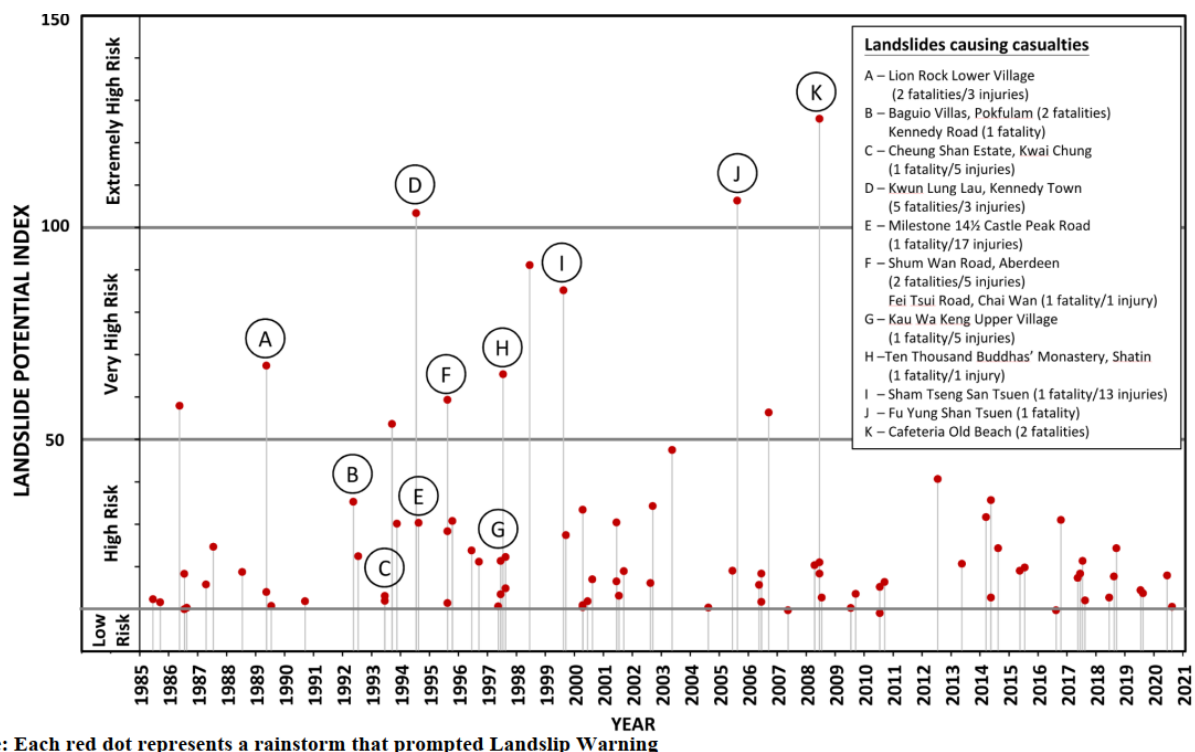


Figure 4– Landslide Potential Index of every Rainstorm that prompted Landslip Warning between 1985 and 2020

5. Predictions of Temperature and Rainfall

Some of the questions that are relevant to the use of existing recent and relict landslide inventories for forecasting future landslide frequency:magnitude are as follows:

- How much has the climate changed over the past 100 years or so?
- How much might it change over the next 100 years?
- What were the likely prevailing conditions during the Holocene which might be relevant to the existing relict landslide inventory?

Short term predictions

In the context of this document plus/minus 100years is considered 'short term'. Based on information from HKO the following data is obtained:

Temperature

- The mean annual temperature has risen by about 2° C from the year 1885 to the year 2021.
- The average rise in temperature per decade has increased to 0.31° C per decade between 1992 and 2021.
- Based on IPCC AR6, 2022, the projected change in annual mean temperature relative to 1995-2014 is up to 1.7° C by the 2041-2060 period and up to 3.6° C by the 2081-2100 period, depending on the greenhouse gas emission scenarios.

It can therefore be concluded that the temperature has risen over the past 100 years and that it is likely to continue rising, at an increasing rate, over the next 100 years.

Rainfall

- According to HKO, during the period 1884 to 2021 there was an average rise of 2.3 mm per year.
- According to HKO, for the annual number of heavy rain days (hourly rainfall > 30 mm), there was an average rise of 0.2 day per decade from 1884 to 2021
- The above are statistically significant at 5% level
- The strength of the El Niño oscillation and the preceding winter monsoon are important factors and also the urban 'heat-island' effect which will tend to induce more rainfall.
- Based on IPCC AR6, 2022, the projected % change in annual rainfall relative to 1995-2014 (2456 mm) is up to 6.4° C by the 2041-2060 period and up to 9.0° C by the 2081-2100 period, depending on the greenhouse gas emission scenarios.

The measured and projected trends in increase of average annual rainfall and temperature with time show an increasing rate of change under differing greenhouse gas emission scenarios. The frequency of extremely wet years is predicted to increase.

6. Implications

If we assume that the climate will get warmer over the next 100 years and that increased rainfall intensity is a likely response to this environmental change, then there are some possible implications to the assessment of landslide hazard and risk in Hong Kong that may be prudent to consider:

- A hotter/wetter climatic regime is forecast to occur
- Frequency and intensity of rainfall (short term duration) likely to increase
- Implication on landslide frequency and magnitude relationship (larger landslides more frequently)
- Implications for Assessment of landslide hazard and debris mobility
- Implication for Large magnitude:low frequency landslide cases
- Implications for landslide clustering events.

7. Landslide Hazard Potential Under Predicted Climate Change Effects

The assessment of landslide hazard potential depends largely on robust engineering geomorphological assessment of the terrain and identification of relict and recent landslides and any relevant local factors such as past landslide activity which might indicate a predisposition to a higher or lower frequency of different types of landslides. Provided that the evidence of the relict landslide record is duly taken into account when making these assessments, including the possibility of reactivation of relatively 'dormant' areas of hillside, then at least some of the problem will have been addressed. The problem of assessment of landslide hazards from relatively 'dormant' areas of hillside could be addressed by considering the landslide susceptibility of a much larger, area with similar attributes (e.g. slope angle, geology etc.) on a regional basis to establish an overall 'background' landslide frequency:magnitude relationship. This relationship could then be scaled according to the size of the local area and then by consideration of the local engineering geomorphological conditions.

In addition, more attention could be applied to identify the sites of relict low frequency, large magnitude landslides and to assess the potential of other areas of hillside to produce similar landslides under the assumed wetter conditions in the 21st century. Further work might include:

- Enhanced aerial photograph interpretation, assessment of high-resolution LiDAR generated DTM maps and engineering geomorphological mapping to identify evidence of former large-scale landsliding such as:
- relict source scars or deposits, unusually large colluvial lobes, fans and aprons, concentrations of alluvium and signs of disturbed drainage patterns.
- Undertaking further landslide dating studies of the sites identified, and
- the systematic production of landslide hazard maps.

8. Debris Mobility Assessment Under Predicted Climate Change Effects

Given the forecasts for more frequent 'extreme' rainfall events and taking into account the high mobility of the debris from some landslides during past extreme rainfall events, the possibility of larger source areas, more highly mobile debris, clustering and cumulative debris effect of landslides converging from tributary drainage lines, may need to be considered to cater for the expected wetter conditions.

9. Conclusions

The climate in Hong Kong is forecast to become hotter and wetter in the next 100 years. Landslide activity is expected to increase along with a higher frequency of relatively large landslides and landslide cluster events. The relict landslide record and enhanced engineering geomorphological interpretation is likely to become increasingly more important for a more appropriate assessment of landslide hazard and risk.

FIELD STUDY OF THE HYDROTHERMAL DYKE IN KAT O

Jasmine Sherry Song, Chan Lung Sang

Department of Earth Sciences, The University of Hong Kong

Abstract: The rock formations in the northern headland of Kat O in Hong Kong are intensely affected by upwelling and intrusion of silica-rich hydrothermal fluids. Field mapping, thin sections and geochemical analyses were conducted to determine the morphology and composition of the altered rocks. The silica-rich fluids are found to have produced chalcedonic veins, chaotic and mosaic breccias, and various hydrothermally incurred structures. Based on the intensity of the hydrothermal alteration, the study area was delineated into a core zone, a stockwork zone, and a marginal zone. The core zone is a massive and thick body, with completely silicified fragments embedded in silica matrix. The stockwork zone shows a dense mesh of silica veins with original rock fabrics and clasts preserved. The rocks in the marginal zone are affected only locally by seepage of silica-rich fluids and controlled by contrasts in the permeability of the rock units.

INTRODUCTION

Hydrothermal systems are closely related to formation of metallic ores, providing insights into mineral resources yet to be explored. In many localities in Hong Kong, rocks are found to have been hydrothermally altered. However, little about the role of hydrothermal fluid intrusion is discussed in existing publications on Hong Kong geology. A hydrothermal body exposed in the headland of Kat O Island in northern New Territories of Hong Kong allows us to study in detail the geological characteristics of hydrothermal bodies. In this study, an integrated field and petrographic survey was conducted to determine the morphology and structures of the hydrothermal body, as well as factors controlling the silicification and brecciation of the host rock.

GEOLOGY OF STUDY AREA

The Kat O headland is made up primarily of the Carboniferous Lok Ma Chau formation (Cmp), the Jurassic Ngo Mei Chau formation (JNM) and the Cretaceous Kat O formation (KKO) as shown in Fig. 1 (Lai et al., 1996). Cmp comprises a series of mudstone and limestones showing soft-sediment formation, with the limestones embedded in the mudstone as boudins. JNM consists of tuff breccias with intercalated volcanoclastic sediments. KKO is a series of reddish terrigenous sediments. In Cheung Shek Tsui, a silicified body about 5 m wide is exposed (Fig. 2); the body was mapped as a fault breccia in the previous mapping by Lai et al (1999).



Fig. 1 Geological map of Kat O headland (Lai, Campbell & Shaw, 1996)

Detailed field study of the area, however, reveals no kinematic structures in support of a fault origin of the body. The body is found to be intensely silicified and extend across the headland in a E-W direction. We interpret the body as a hydrothermal dike resulting from injection of over-pressured, silica-rich fluids into the host rocks. The structure postdated the Cretaceous formation and resulted in extensive silicification of the rock formations in the area. Based on the extent of silicification, we have also delineated the area into three zones: 1) a core zone of complete silicification; 2) a stockwork zone, and 3) a marginal zone with minimal silicification.

Fig. 2. Hydrothermal dike at Cheung Shek Tsui, Kat O



CORE ZONE

The core zone of the hydrothermal body has the highest degree of silicification, where rocks are completely replaced by silica. A 5-m wide, wall-like structure extends in an easterly direction into the sea on the eastern side of the headland. Boulders from the similar unit are found on the western side of the headland. Most of the rocks are pale and greyish white color. They are massive and structureless. Both the matrix and the clasts in the rocks are silicified and do not retain any original fabrics. Due to

intense silicification, the rocks in the core zone are very resistant compared to other rocks in the study area.



Fig. 3 Silicified rocks in the core zone that is massive and structureless

STOCKWORK ZONE

Stockworks are network-like, interconnected silica veins formed by hydrothermal fluids seeping along cracks. A stockwork zone is present on the northern side of the core zone of the hydrothermal body. In the stockwork zone, the rocks are semi-silicified, whereas only the matrix is replaced by silica. The more resistant silica veins form web-like patterns on the rock surface. Mosaic-type breccias showing limited movements of the clasts within the fluid system are commonly present. Some breccia fragments show silica rims around less altered clasts, suggesting silicification of the matrix before the clasts (Figs. 4-6).

Fig. 4 Silica rims around clasts. The clasts are semi-silicified



Fig. 5 Silica stockwork with web-like structures



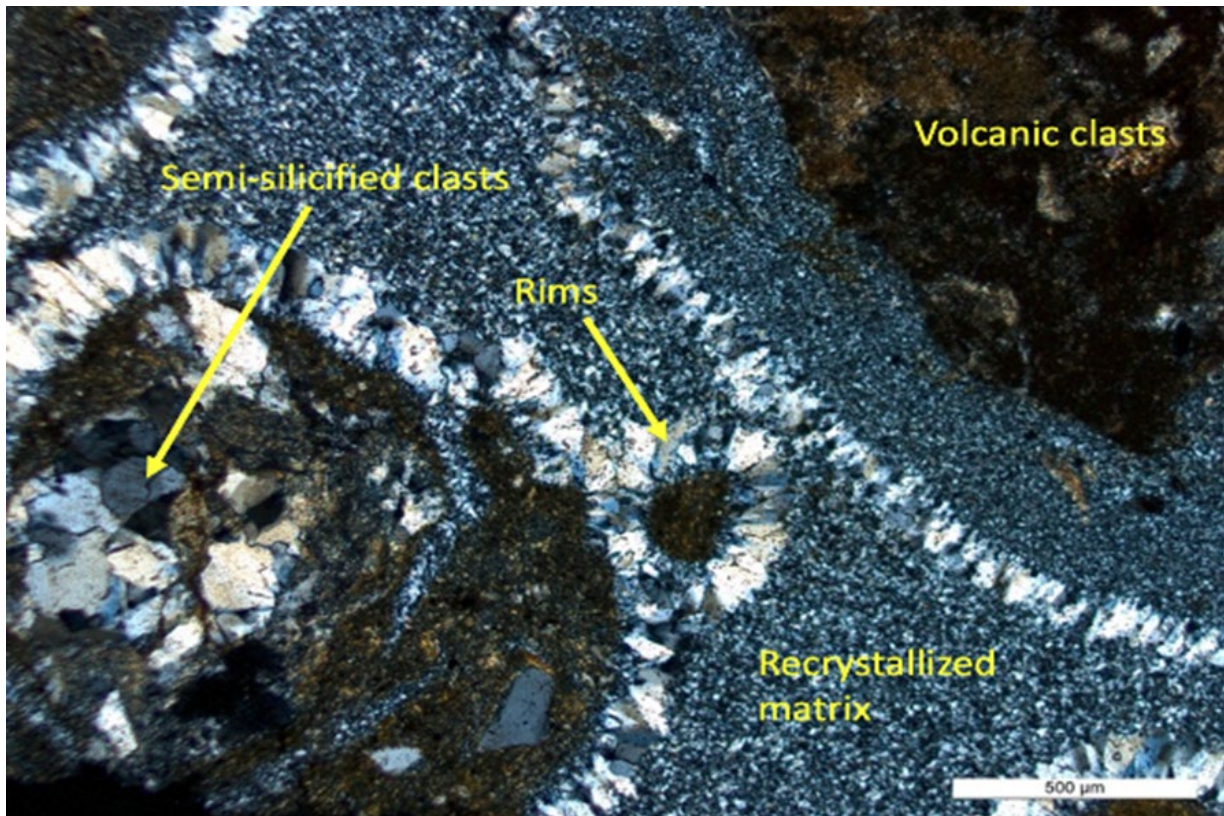


Fig. 6 Thin section of quartz and chalcedony rims wrapping around semi-silicified clasts. Recrystallized quartz can be observed in the matrix.

MARGINAL ZONE

The marginal zone is composed of mostly red beds. The rocks show minimal extent of silicification and are altered only locally by seepage of silica-rich fluids. The rocks retain original fabrics and structures, with discernible matrix and clasts. It is worth noting that seepage of silica fluid is controlled by the distribution of mud contents in the rock. Due to its low permeability, the mudstone often marks the extent of alteration of the red beds (Fig. 7). In some rock boulders, the extent of fluid penetration and alteration are clearly visible (Fig. 8).

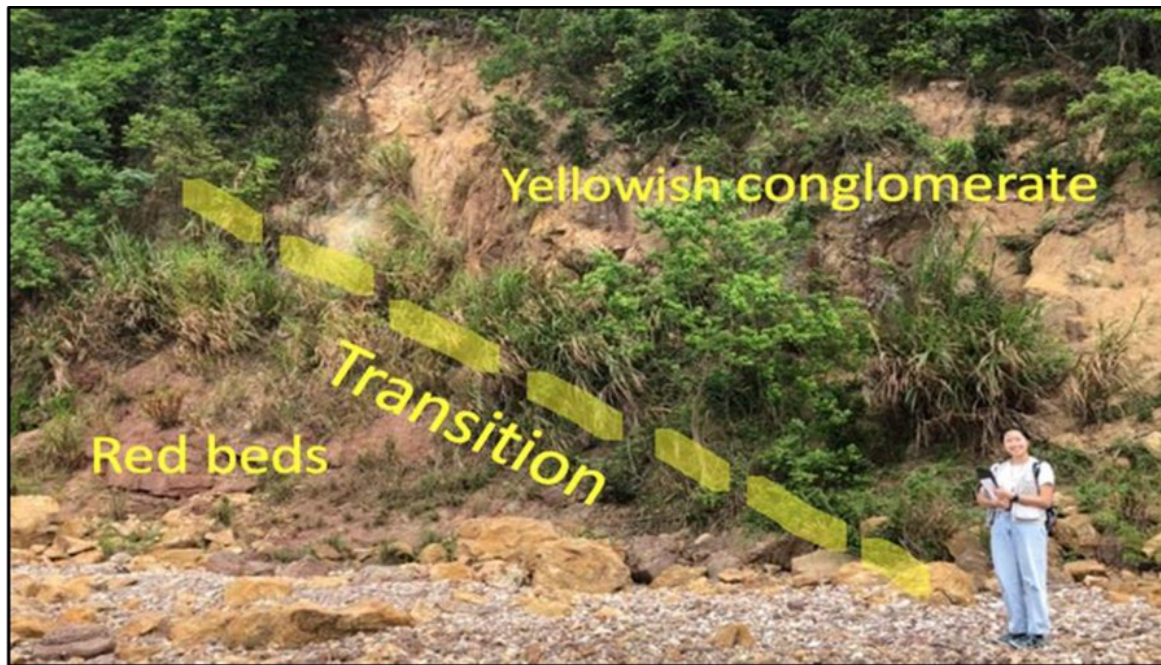
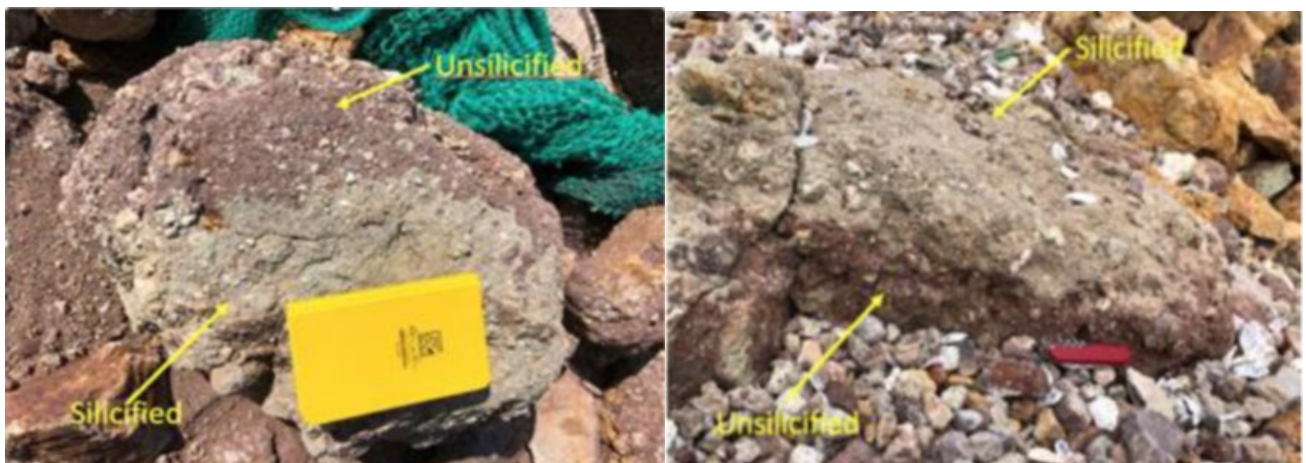


Fig. 7 Contact of unsilicified (left) and semi-silicified yellowish conglomerate (right).

Fig. 8 Minor seepage of silica-rich fluid in the red beds, displayed in greyish color. The rock permeability along the transition boundary might be low, limiting silicification in certain parts of the rocks.



SILICIFICATION CONTROLLED BY PERMEABILITY

The distribution of the silicification zones is not symmetrical about the hydrothermal dike. The gradual decrease in the intensity of silicification north of the hydrothermal dike is not found in the south. The southern boundary of the hydrothermal dike is marked by a sharp contact with the Cmp mudstone (Fig. 9). Conceivably, the silicification was controlled by the permeability of the rocks. The low permeability of the mudstone precluded percolation of the hydrothermal fluids. Thus, neither the mudstone nor limestone was silicified. The clastic sediments of the Kat O formation to the north of the hydrothermal dike, on the other hand, were highly pervious, enabling extensive silicification of the rock layers. Whereas a mudstone was present in the sediment, the contrast in permeability also resulted in selective silicification of local layers.

Fig. 9 Contact between dark mudstone (lower) and silicified rocks of the hydrothermal dike (upper)



The various zones of silicification are shown in the summary map in Fig. 10.

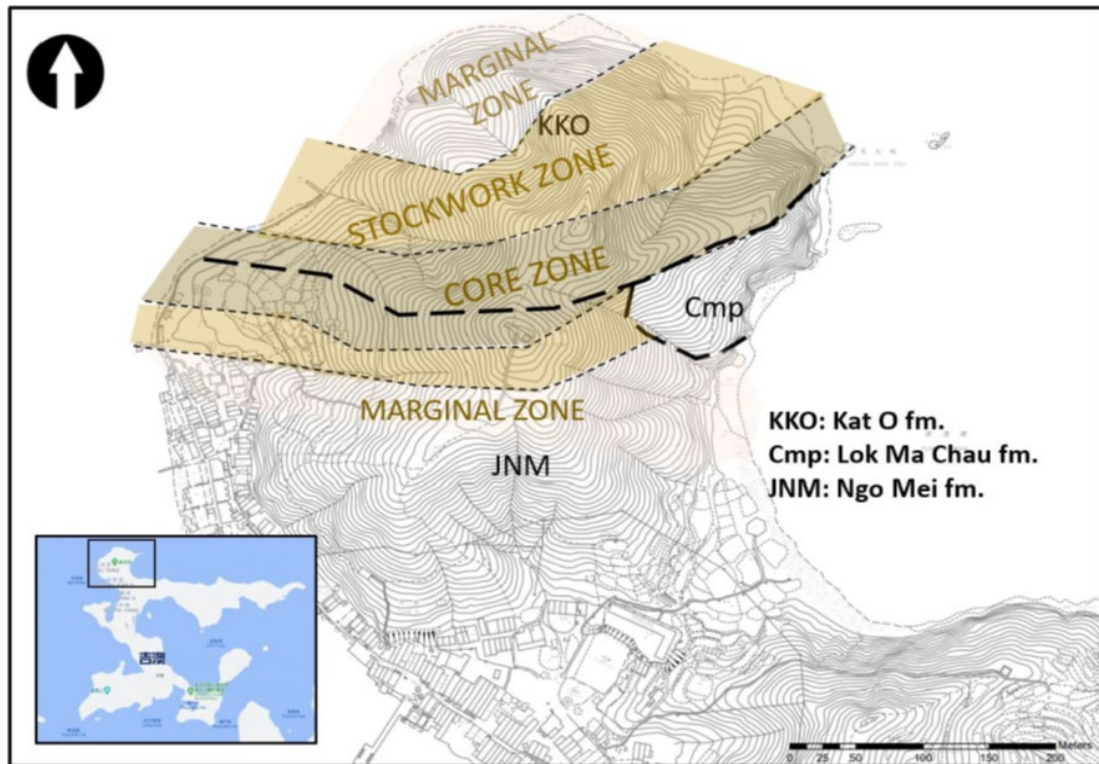


Fig. 10 Interpretation map of silicification zoning

CONCLUSION

This study has contributed to the understanding of the geology of Kat O. The summary findings are as follows.

- (1) Hydrothermal intrusion has highly altered and masked the original host rocks in the northern part of the island.
- (2) The silicification shows a gradational pattern from the core to the margin. An asymmetrical distribution of the silicification zones was mapped based on field and petrographic evidence.
- (3) The hydrothermal alteration was controlled by the permeability of rocks.

REFERENCES

Lai, K.W., Campbell, S.D.G. and Shaw, R., 1996, Geology of the Northeastern New territories, 1:20,000 Sheets 3 and 4, HK Geological Survey Mem. No. 5, 144 p. GEO, HK Government.

RAMAN SPECTROSCOPY OF SILICA-RICH, FINE-GRAINED ROCKS FROM HONG KONG

Dominic WK Mok, Sharon SM Cheung
Asia Gemmological Institute and Laboratory, Hong Kong

Chan Lung Sang
Department of Earth Sciences, The University of Hong Kong

Abstract: Raman spectra of 28 samples of tuff, lava, siliceous mudstone, and biogenic mudstone from Hong Kong were obtained using a 785 nm excitation laser. The results show that the four different rock types can be distinguished by Raman spectroscopy. This study represents a first attempt in establishing a Raman database for local rocks, which can be used for field identification of rock types using portable Raman systems.

INTRODUCTION

The identification of silica-rich, fine-grained rocks sometimes poses challenges for geologists in the field, especially in the absence of diagnostic features such as flow bands or bedding laminations. Several rock types in Hong Kong such as rhyolite, ash tuff, and cherty mudstone, may have similar chemical composition, rendering difficult their identification by whole rock geochemical analyses alone. Even conventional petrographic determinations may not always yield unambiguous identification due to the fine-grained nature of the rocks. In recent years, in part due to the needs for the Martian explorations, Raman spectroscopy, among others, has become a key technique used for identifying natural rocks and potential signs of life in remote manners (Berlanga et al., 2019; Marshall et al., 2010).

Raman spectroscopy is an analytical technique based on the inelastic photo scattering (Raman scattering) of material when hit by a monochromatic beam of light (see Vašková, 2011, for an easy overview of the method). The difference in wavelength of the scattered light and the incident laser, expressed in term of wavenumber/cm, form a spectrum with band positions at frequencies corresponding to the energy levels of characteristic vibrational modes of the study sample. The spectrum is compared to that from reference standards for the identification of the study material. For geological material, the spectral range of 100-1800 wavenumber/cm is particularly useful for the determination of minerals. The method is useful in discerning the chemical composition of volcanic glasses (Di Genova et al., 2015; Giordano, et al., 2020), the presence of carbon in chert (Bowers et al., 2015), water content in volcanic glasses, (Kotov et al., 2021), as well as maturity of organic matter in sediments (Henry et al., 2019).

While the Raman spectra of individual minerals are readily available, the Raman spectra of a particular rock type can be highly varying, since the composition and impurities of the mineral constituents in a rock can affect its characteristic Raman scattering spectrum. In this study, we have attempted to determine the Raman spectra of several groups of fine-grained rocks, which may serve as a criterion for delineating the rock types. Supplementary geochemical determinations using EDXRF were conducted to obtain the whole rock major element abundances of the samples.

METHODOLOGY

The four groups of samples studied are (1) tuffs, (2) lavas, including rhyolite, dacite and andesite, (3) siliceous mudstones (impure chert) and (4) biogenic mudstones. A total of 28 samples were selected for the geochemical and Raman determinations (Table 1). Petrographic thin sections were prepared for some of the samples to facilitate their identification. Raman spectroscopic measurements were done using a 785 nm laser source on a ProTT-UID-G6 Dual made by United ID Lab. Calibration is done using a diamond sample. The results are plotted baseline-corrected for the range 100-2000 cm⁻¹. Energy dispersive X-Ray fluorescence determinations were also done for the major elements using a Gemray 5000.

Table 1. Rock types, locations and silica and alkali contents (in percent) of studied samples

Sample	Rock type	Location	Silica	Al ₂ O ₃	K ₂ O+Na ₂ O
T1-1	Eutaxitic tuff	Unknown	77.7	14.3	4.5
T1-2	Eutaxitic tuff	Unknown	83.1	9.6	3.7
GS13441	Ash tuff	Tung Lung Chau	79.3	13.0	4.1
GS13742	Ash tuff	Ap Chau	80.1	9.7	2.8
GS11052	Ash tuff	Tung Chung	79.7	14.9	3.1
GS12070	Ash tuff	Lantau	77.3	15.8	3.7
GS1XXX2	Ash tuff	unknown	60.0	18.2	3.8
ED1	Ash tuff	Sai Kung	77.8	13.5	3.5
T21	Lapilli tuff	Shum Chung	81.6	11.7	3.6
ED8	Mafic rock	Sai Kung	57.4	16.9	1.7
TM20-8	Andesite	Tuen Mun	69.6	15.8	1.5
TM20-9	Andesite	Tuen Mun	68.7	13.7	2.2
TM20-10	Silicified andesite	Tuen Mun	73.2	18.5	3.5
TM20-11	Silicified andesite	Tuen Mun	83.9	9.2	1.2
PT0226A	Rhyolite	Po Toi	74.1	16.8	3.4
PT0226B	Andesite	Po Toi	60.5	18.3	2.2
PTA	Rhyolite	Po Toi	74.1	15.6	4.4
PTK	Dacite	Po Toi	66.2	18.7	2.8
PC8	Biogenic mudstone	Ping Chau	47.2	15.1	3.6
PC10-1	Biogenic mudstone	Ping Chau	63.0	20.9	5.6
PC10-2	Biogenic mudstone	Ping Chau	67.5	20.4	3.7
PC13	Biogenic mudstone	Ping Chau	55.4	17.3	4.2
SC1	Impure chert	Shum Chung	70.1	23.6	2.8
SC2	Impure chert	Shum Chung	85.2	9.7	2.5
CLP	Impure chert	Che Lei Pai	86.4	8.3	0.7
FNS1	Impure chert	Fei Ngo Shan	83.4	11.6	3.1
WDT1	Impure chert	Wong Dei Tung	79.1	14.1	4.7
WDT2	Impure chert	Wong Dei Tung	72.2	16.1	5.5

ELEMENTAL ABUNDANCES AND RAMAN SPECTRA OF SAMPLES

The abundances of SiO₂, Al₂O₃ and alkaline oxides of the samples determined by the EDXRF analyses are also shown in Table 1. Other than the biogenic sedimentary rocks, the samples have silica contents in the range of 57-86%. The variations in silica contents of samples from a rock type may be due to varying concentration at the sample points. In general, the ash tuffs are andesitic to rhyolitic in composition and contain small visible felsic crystals. Based on the silica contents, the samples are classified into rhyolite, dacite and andesite. The siliceous mudstones or impure chert samples have high silica contents in the range of 70-86%. They are dark-colored, massive and indurated, sometimes showing conchoidal fractures on broken faces. The samples from Wong Dei Tung and Fei Ngo Shan exhibit thin laminations a few mm thick and extensive slump structures. The sample from Che Lai Pai represents a product of hydrothermal alteration as shown by the extensive presence of chalcedony in the photomicrographs. The samples from Ping Chau are brownish dolomitic mudstone that formed in a saline lake environment. Geochemical results of the samples reveal markedly varying silica and relatively high Al₂O₃ contents, indicative of the abundance of clay minerals in the rocks.

The Raman spectroscopy in this study focuses on the T-O band of the Raman spectra (Low wavenumber: ~470–570 cm⁻¹; middle wavenumber: 570–850 cm⁻¹; and high wavenumber: ~850–1250 cm⁻¹), since this region of the spectrum depends on the contents of silica and other anhydrous components of the sample, and is relatively unaffected by the water content. In particular, the peaks in the LW region are caused by the presence of tetrahedra rings in the aluminosilicate network, common to quartz and feldspars. The HW region, on the other hand, is influenced more by symmetric and asymmetric stretching in the Al-Si-O network (Le Losq et al., 2012). Raman shifts above 2800 cm⁻¹ are caused by high frequency C-H stretching and not relevant to mineralogical study. We used in this study a Raman spectrometer with a near-infrared 785 nm excitation wavelength which is less susceptible to fluorescent effects than the 532 nm, hence producing less noisy spectra and a bigger measurement spot size.

As shown in Fig. 1, the Raman spectra of the four groups of rocks illustrate patterns distinctively different from each other. Multiple peaks are present in the LW region of all samples, and few peaks are present in the band of the spectrum with wavenumbers above 2800 cm⁻¹, which is associated with molecular stretching of various function groups of organic compounds such as proteins, lipids and nucleic acids. The intensity and sharpness of a peak are, respectively, indicative of the relative abundance and degree of crystallinity of the associated material. The peaks in the LW and HW ranges are probably caused by minerals commonly present in acid igneous rocks, such as quartz (466 cm⁻¹), orthoclase (474 cm⁻¹, 512 cm⁻¹), albite (478 cm⁻¹, 762 cm⁻¹), biotite (718 cm⁻¹), muscovite (263 cm⁻¹), as well as alteration products such as chlorite (382 cm⁻¹, 662 cm⁻¹) based on the RRUFF Database (Database of Raman spectroscopy, X-ray diffraction and chemistry of minerals, <https://rruff.info/>). More intense peaks in the MW region (570–850 cm⁻¹) are present in the rhyolite samples than in the ash tuff.

The tuff and lava samples show marked peaks at about 466 cm⁻¹, which are characteristics of quartz, and broad multiple peaks in the range of 1000–1500 cm⁻¹, which are characteristics of the albitic constituents. The fine ash tuffs (Fig. 1a) show prominent peaks at about 1180–1 to 1182 cm⁻¹, followed by secondary peaks at about 1392–1 to 1396 cm⁻¹. The lava samples (Fig. 1b) show a broad peak at 1224–1 to 1226 cm⁻¹, and secondary peaks at about 1400 cm⁻¹, 1520 cm⁻¹ and 1690 cm⁻¹ in the HW region. The different Raman peaks of the tuff and lava samples may be used as a criterion for differentiating the two groups of volcanic rocks.

The siliceous mudstone samples (Fig. 1c) show Raman spectra distinctively different from those of the volcanic rock samples. In addition to a prominent peak at 466 cm⁻¹, the spectra possess a pair of sharp and distinct peaks at 1350 cm⁻¹ and 1600 cm⁻¹. The two peaks correspond to the D-band and G-band of carbonaceous material and are probably associated with organic contents carried by the samples.

These two peaks are commonly observed in cherts and siliceous mudstones (Schopf et al., 2008). The samples in this group also exhibit a peak at about 100 cm⁻¹, which is attributable to the clay minerals in the samples (Saikia et al. 2016).

The biogenic sedimentary rocks from Ping Chau do not exhibit prominent peaks corresponding to the D or G bands. The broad peaks observed at wavenumber shifts below 300 cm⁻¹ are attributable to the presence of clay minerals. Also, a peak centering about 2190 cm⁻¹ is observed in the samples. The origin of this peak is enigmatic since it falls within the ‘silent range’ of the Raman spectrum. It is plausibly associated with some thermally altered hydrocarbons in the sediment. The two broad peaks at below 300 cm⁻¹ and 2190 cm⁻¹ may be characteristics of the biogenic sediment.

DISCUSSION

The results from this study show that Raman spectroscopy provides a method for rapidly identifying fine-grained rocks. The following criteria are proposed for the identification of the various rock types.

- (1) Acid volcanic rocks show prominent intensities and broad peaks in the HW region, which are characteristic features of albitic glasses.
- (2) Fine ash tuffs have a prominent Raman peak slightly below 1200 cm⁻¹, while lavas have Raman shifts at about 1220 cm⁻¹.
- (3) Acid lavas consisting of fine-grained crystals exhibit multiple peaks in the LW and MW regions, probably caused by a greater abundance of plagioclase and biotite in the rock.
- (4) The D-band and G-band peaks in the siliceous mudstones suggest the presence of carbonaceous matter in the sample.
- (5) The biogenic sedimentary rocks contain a peak at about 2150 cm⁻¹ that is absent in the other groups of samples. For that, it can be used for a first-order distinction between igneous and sedimentary rocks, as igneous rocks are depleted in organic material.
- (6) The peaks in the 100-200 cm⁻¹ region are indicative of the presence of clay minerals, which are characteristics of sedimentary rocks.

The Raman spectroscopy is non-destructive and requires only a small amount of sample. While it may not replace conventional methods for determining whole-rock chemistry or rock textures, Raman spectroscopy provides a rapid means of detecting natural material by remote manners (e.g., Jehlicka et al., 2009; Giordano et al., 2020; Guimbretiere et al., 2016; Berlanga et al., 2019). It is even possible to estimate the chemical composition of the volcanic rocks from the Raman peaks (Gonzalez-Garcia, et al., 2020).

CONCLUSION

This study represents a first step in establishing a Raman spectra database for the rocks in Hong Kong. A set of criteria are now developed to delineate various rock types based on the Raman spectra. With continuing advancements in portable Raman spectroscopic systems and accumulation of characteristic Raman spectra for local rocks, this method may potentially become a novel method for determination of rock types in the field.

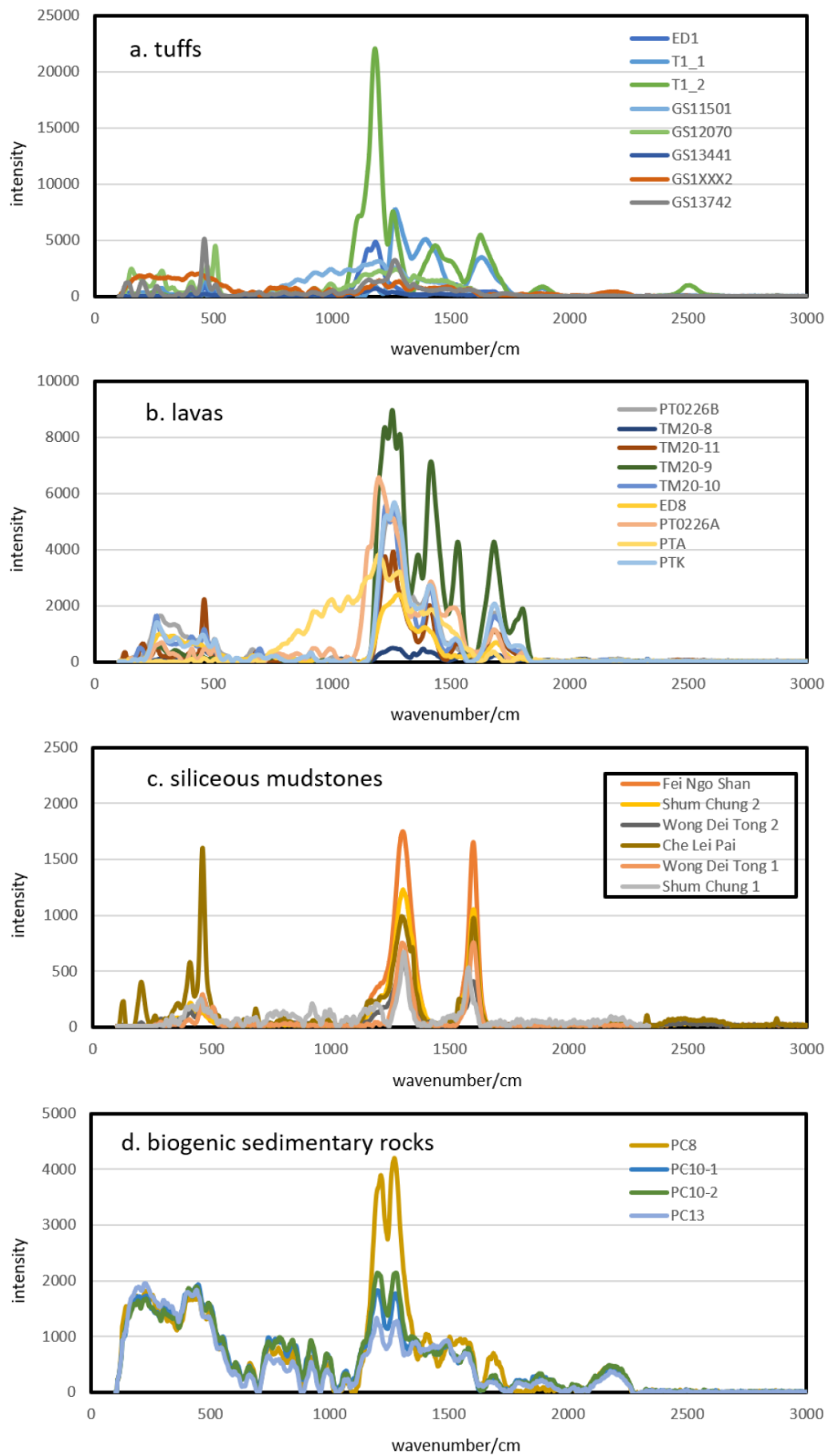


Fig. 1 Raman spectra obtained for four groups of fine-grained silica-rich rocks

REFERENCES

- Berlanga, G., Acosta-Maeda, T.E., Sharma, S.K. and 5 others, Remote Raman spectroscopy of natural rocks, *J. Applied Optics* Vol. 58, Issue 32, pp. 8971-8980, 2019
- Bowers, D.M., Steele, A., Fries, M.D., Green, O.R. and Lindsay, J.F., Raman imaging spectroscopy of a putative microfossil from the 3.46 ga apex chert: insights from quartz grain orientation, *Astrobiology*, 16, 2, 169-180, 2016
- Di Genova, D. and 6 others, Approximate chemical analysis of volcanic glasses using Raman spectroscopy, *J. Raman Spectroscopy*, 46, 1235-1244, 2015
- Giordano, D., Russell, J.K., and 4 others, Raman Spectroscopy from Laboratory and Proximal to Remote Sensing: A Tool for the Volcanological Sciences, *Remote Sens.*, 2020, 12(5), 805; <https://doi.org/10.3390/rs12050805>
- Guimbretière, G., Canizarès, A., Finizola, A. and 6 others, Raman spectroscopy as suitable tool for the field study of recent volcanic environments, *J. Raman Spectroscopy*, 47, 740–742, 2016
- González-García, D., Giordano, D., Russell, J.K. and Dingwell, D.B., A Raman spectroscopic tool to estimate chemical composition of natural volcanic glasses, *Chem. Geol.*, 556, (119819), 2020
- Henry, D.G., Jarvis, I., Gillmore, G. and Stephenson, M., Raman spectroscopy as a tool to determine the thermal maturity of organic matter: application to sedimentary, metamorphic and structural geology, *Earth-Science Rev.*, 198, 2019, 102936. 410–419, 2009
- Kotov, A.A., Smirnov, S.Z., Plechov, P.Y. et al. Method for Determining Water Content in Natural Rhyolitic Melts by Raman Spectroscopy and Electron Microprobe Analysis. *Petrology*, 29, 386–403, 2021
- Le Losq, C., Neuville, D.R., Moretti, R. and Roux, J., Determination of water content in silicate glasses using Raman spectrometry: Implications for the study of explosive volcanism, *American Mineralogist* 97, 5-6, 779-790
- Marshall, C.P., Edwards, H. G. M. and Jehlicka, J., Understanding the Application of Raman Spectroscopy to the Detection of Traces of Life, *Astrobiology*, 10, 2, 229-43, 2010
- Saikia, B.J., Parthasarathy, G., Borah, R.R. and Borthakur, R., Raman and FTIR Spectroscopic Evaluation of Clay Minerals and Estimation of Metal Contaminations in Natural Deposition of Surface Sediments from Brahmaputra River, *International Journal of Geosciences*, 7, 873-883, 2016
- Schopf, J.W, Tewari, V.C. and Kudryavtsev, A.B., Discovery of a New Chert-Permineralized Microbiota in the Proterozoic Buxa Formation of the Ranjit Window, Sikkim, Northeast India, and Its Astrobiological Implications, *Astrobiology*, 8, 4, 2008, DOI: 10.1089/ast.2007.018
- Vašková, H., A powerful tool for material identification: Raman spectroscopy, *International Journal of Mathematical Models and Methods in Applied Sciences*, Issue 7, Volume 5, 2011

ACKNOWLEDGEMENTS

We thank Denise L.K. Tang and Martin Y.H. Li for providing some of the samples for the analyses in this study.

A BRIEF REVIEW OF PUBLICATION TRENDS IN THE BULLETIN OF ENGINEERING GEOLOGY AND THE ENVIRONMENT

Louis N.Y. Wong

Department of Earth Sciences, The University of Hong Kong, Pokfulam Road, Hong Kong, China
Editor-in-Chief, Bulletin of Engineering Geology and the Environment

1. Introduction

Bulletin of Engineering Geology and the Environment (BOEG) is the official journal of the International Association for Engineering Geology and the Environment (IAEG). Starting as a simple artisanal publication in 1970, the Bulletin became a scientific reference among the most respected journals in the fields of engineering geology, the environment and other geosciences. Part of this presentation is based on the article entitled “Celebrating the 50th anniversary of bulletin of engineering geology and the environment” by Ulusay and Wong (2020). By compiling and analysing data over the past five decades, the publication trends in engineering geology are revealed and discussed.

2. Scope of the Bulletin

According to the IAEG amendments to the statutes, which came into effect in August 1974, and were published in Bulletin No. 10 in December 1974, the purpose of the Bulletin was: “*To inform members and to promote publication for the worldwide dissemination of new engineering geological knowledge and techniques. The publication of the Bulletin is particularly devoted to this purpose*”. This confirmed the statement in the first editorial in Bulletin No. 1 that it was initially envisaged as a cross between a newsletter and a scientific journal. The IAEG statutes of 1992 stated that one of the aims of the IAEG was to, “*...evaluate and disseminate the results of engineering geological activities on a worldwide basis by ... the publication of the scientific and technical achievements of members of the IAEG in the IAEG's own periodical and relevant news in the IAEG newsletter*”. Here there is a clear distinction between scientific publication and news.

Engineering geology is defined in the statutes of the IAEG as the science devoted to the investigation, study and solution of engineering and environmental problems which may arise as the result of the interaction between geology and the works or activities of man, as well as of the prediction of and development of measures for the prevention or remediation of geological hazards. The scope of the Bulletin is as follow, which can also be found in the following link:
<https://www.springer.com/journal/10064/aims-and-scope>

- (a) the applications/implications of the geomorphology, structural geology, and hydrogeological conditions of geological formations;
- (b) the characterization of the mineralogical, physico-geomechanical, chemical and hydraulic properties of all earth materials involved in construction, resource recovery and environmental change;
- (c) the assessment of the mechanical and hydrological behavior of soil and rock masses;
- (d) the prediction of changes to the above properties with time;
- (e) the determination of the parameters to be considered in the stability analysis of engineering works and earth masses.

3. Hans Cloos Medal Lecture Papers Published in the Bulletin

In BOEG, an important development took place in 2003. Since 1977, the IAEG had awarded its most prestigious medal, the Hans Cloos Medal, approximately every two years. From 2002, it was decided

The Geological Society of Hong Kong - 40th Anniversary

that the medal winner should present a Hans Cloos Lecture and that a paper, resulting from the lecture, would be published in the Bulletin. The first Hans Cloos Lecture paper, written by John Knill, was published in 2003. A list of the Hans Cloos Lecture papers is provided in Table 1.

The titles of the Hans Cloos Lectures provide clues on the state-of-the-art engineering geology research and practice. Most of early ones focused on the engineering geological aspects of landslides, with the recent emphasis shifted to a variety of other important engineering geological issues.

Table 1. Hans Cloos Lecture papers published in BOEG

Year	Hans Cloos lecturer	Title of the paper	Publication details (year, volume, pages)
2002	John Knill	Core values: the first Hans Cloos Lecture	2003, V.62, 1-34
2004	Vincenzo Cotecchia	The Second Hans Cloos Lecture. Experience drawn from the great Ancona landslide of 1982	2006, V.65, 1-41
2006	Robert Schuster	The Third Hans Cloos Lecture. Urban landslides: socioeconomic impacts and overview of mitigative strategies	2007, V.66, 1-27
2008	Wang Sijing	The 2008 Hans Cloos Lecture. Seismic geo-hazard assessment of engineering sites in China	2009, V.68, 145-159
2010	Martin Culshaw	The 2010 Hans Cloos Lecture. The contribution of urban geology to the development, regeneration and conservation of cities.	2011, V.70, 333-376
2012	Victor Osipov	The 2012 Hans Cloos Lecture. Physico-chemical theory of effective stress in soils	2014, V.73, 903-915
2014	Roger Cojean	The 2014 Hans Cloos Lecture. Engineering Geology—some feedback regarding the practice of a scientific and technical discipline	2015, V.74, 1087-1103
2016	Resat Ulusay	The 2016 Hans Cloos Lecture. Geo-engineering aspects on the structural stability and protection of historical man-made rock structures: An overview of Cappadocia Region (Turkey) in the UNESCO's World Heritage List	2018, V.77, 457-488
2018	Runqiu Huang	The 2018 Hans Cloos Lecture*	Not yet published

* Not submitted by the author yet

4. Contribution of submissions from different countries/regions.

As summarized in Table 2, around 80% of the papers in 2020 came from Asia, followed by Europe (around 10%). The top four countries were China, Iran, India and Turkey. Most notably, more than half of the submissions came from China.

Table 2. Number of papers submitted to the Bulletin in 2020 with respect to countries (the top 20 countries) and the Continent

Number of papers submitted to BOEG for the top 20 countries/regions (2020)			Classified by continent (2020)	
Rank	Country/Region	Percentage (%)	Continent	Percentage (%)
1	China	57.76	Asia	80.44
2	Iran	9.87	Europe	10.69
3	India	5.22	Africa	4.09
4	Turkey	4.06	S America	1.96
5	Brazil	1.51	N America	1.67
6	Pakistan	1.40	Aus/NZ	1.15
7	Poland	1.11	Total	100.00
8	Egypt	1.08		
9	Malaysia	1.05		
10	Australia	1.02		
11	Italy	0.99		
12	Algeria	0.88		
13	Nigeria	0.86		
14	Canada	0.82		
15	USA	0.72		
16	United Kingdom	0.65		
17	Japan	0.61		
18	Taiwan	0.52		
19	Spain	0.51		
20	Iraq	0.50		

5. List of papers arranged by decades

When BOEG celebrated its 50th Anniversary in 2020, 15 papers were selected by the Editors-in-Chief of BOEG for free access during September – October 2020. The selection comprises three papers published in each decade (5 decades in total) with the highest number of citations. Most of the papers over the years were concerned with landslides, while some recent foci include rock mass characterizations and application of artificial neural network.

Decade 2010-2019

- 1) Corominas, J., van Westen, C., Frattini, P., Cascini, L., Malet, J.P., Fotopoulou, S., Catani, F., Van Den Eeckhaut, M., Mavrouli, O., Agliardi, F., Pitilakis, K., Winter, MG, Pastor, M., Ferlisi, S., Tofani, V., Hervás, J., Smith, J.T. (2014) Recommendations for the quantitative analysis of landslide risk. *73*(2), pp.209-263.
- 2) Chapuis, R.P. (2012) Predicting the saturated hydraulic conductivity of soils: a review *71*(3). pp.401-434.
- 3) Hajihassani, M., Armaghani, D.J., Marto, A. and Mohamad, E.T. (2015). Ground vibration prediction in quarry blasting through an artificial neural network optimized by imperialist competitive algorithm. *74*(3), pp.873-886.

Decade: 2000-2009

- 4) Van Westen, C.J., Van Asch, T.W. and Soeters, R. (2006) Landslide hazard and risk zonation—why is it still so difficult?. *65*(2), pp.167-184.

The Geological Society of Hong Kong - 40th Anniversary

- 5) Marinou, V., Marinou, P. and Hoek, E. (2005). The geological strength index: applications and limitations. *64*(1), pp.55-65.
- 6) Marinou, P. and Hoek, E. (2001) Estimating the geotechnical properties of heterogeneous rock masses such as flysch. *60*(2), pp.85-92.

Decade: 1990-1999

- 7) Aleotti, P. and Chowdhury, R. (1999) Landslide hazard assessment: summary review and new perspectives. *58*(1), pp.21-44.
- 8) Hoek, E., Marinou, P. and Benissi, M. (1998) Applicability of the Geological Strength Index (GSI) classification for very weak and sheared rock masses. The case of the Athens Schist Formation, *57*(2), pp.151-160.
- 9) Cruden, D.M. (1991) A simple definition of a landslide. *43*(1), pp.27-29.

Decade: 1980-1989

- 10) Savage, W.Z. and Varnes, D.J. (1987) Mechanics of gravitational spreading of steep-sided ridges («sackung»). *35*(1), pp.31-36.
- 11) Matula, M. (1981) Rock and soil description and classification for engineering geological mapping report by the IAEG Commission on Engineering Geological Mapping. *24*(1), pp.235-274.
- 12) Canuti, P., Focardi, P. and Garzonio, C.A. (1985) Correlation between rainfall and landslides [Corrélation entre chutes de pluie et glissements de terrain], *32*(1), pp.49-54.

Decade: 1970-1979

- 13) Matula, M. (1979) Classification of rocks and soils for engineering geological mapping: part I: rock and soil materials. *19*(1), pp.364-371.
- 14) Radbruch-Hall, D.H., Varnes, D.J. and Savage, W.Z. (1976) Gravitational spreading of steep-sided ridges («sackung») in Western United States. *13*(1), pp.23-35.
- 15) Hutchinson, N.N. (1977) Assessment of the effectiveness of corrective measures in relation to geological conditions and types of slope movement. *16*(1), pp.131-155.

REFERENCES

Ulusay, R., & Wong, L. (2020). Celebrating the 50th anniversary of bulletin of engineering geology and the environment. *Bulletin of Engineering Geology and the Environment*, *79*(7), 3285-3287.

Experimental investigation of thermal strengthening in Sichuan marble

^{1,*} Xin Cui, ¹ Louis Ngai Yuen Wong, ¹ Yahui Zhang, ² Zhijun Wu, ³ Tianyang Guo

¹ Department of Earth Sciences, the University of Hong Kong, Hong Kong, China

² School of Civil Engineering, Wuhan University, Wuhan, China

³ Department of Civil and Environmental Engineering, The Hong Kong Polytechnic University, Hong Kong, China

* Corresponding author: Xin Cui (Email: u3005741@hku.hk)

Extended Abstract

It is well documented that temperatures higher than 400 °C can significantly lower rock strength due to thermally induced decomposition and microcracks. However, rock strength increase between 25 °C and 400 °C has also been reported in a number of previous studies. Such a temperature range encompasses most underground rock engineering projects, therefore the thermal strengthening phenomenon, if exists, may have profound engineering implications.

Three key research gaps are identified in previous studies associated with the thermal effect on rock strength. (1) Heterogeneity is a typical attribute of rock material but it was not well controlled/understood in previous studies. It remains elusive if thermal strengthening does exist or it is just an illusion caused by rock heterogeneity. (2) Most of the previous studies investigated a too wide temperature range (25 to 1000 °C) and thus compromised the resolution of temperature increment, which is insufficiently fine to convincingly reveal the thermal effect on rock strength in the moderate temperature range. (3) Thermal treatment, where rock specimens are annealed before applying mechanical loading, is frequently reported in previous studies, while laboratory experiments associated with real-time thermo-mechanical loading are very rare.

In this study, we performed triaxial compression tests on Sichuan marble in the temperature range 25 °C - 200 °C to bridge the abovementioned three research gaps. We chose Sichuan marble as the testing material because it was simple in mineral composition (calcite and dolomite) and relatively homogeneous in texture. As such, Sichuan marble could well suppress heterogeneity and expose the thermal effect on rock strength. In addition, we focused on the narrow moderate temperature range and implemented a temperature increment of 25 °C, which was sufficiently fine to explore the thermal effect on rock strength. In particular, we used a triaxial compression apparatus (Figure 1) with real-time thermo-mechanical loading capability, which was in more fidelity to the *in-situ* condition. The purposes of this study are two-fold: (1) explicitly confirm if thermal strengthening does exist, and (2) unveil the mechanism of thermal strengthening if (1) is justified.

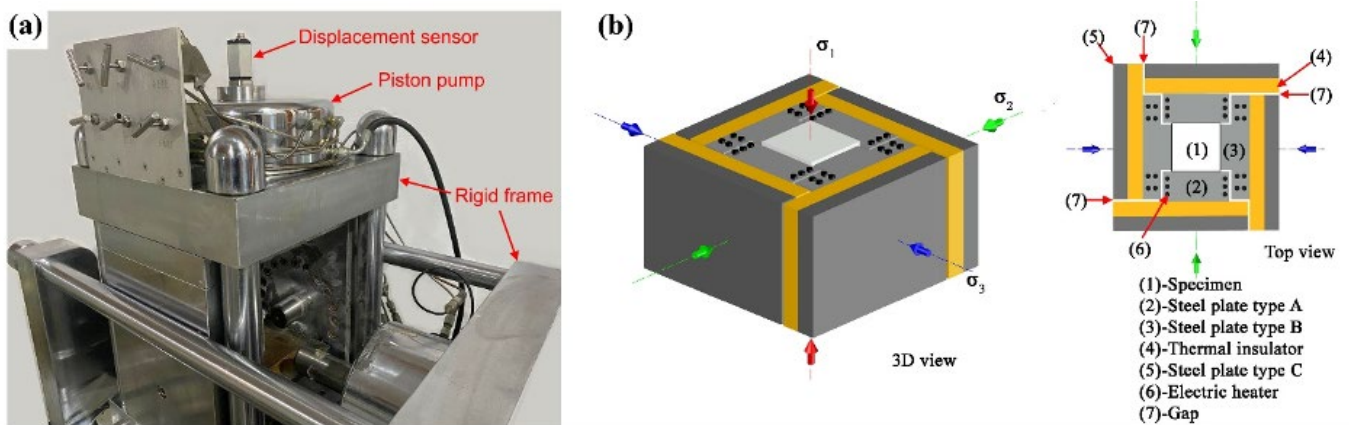


Figure 1 (a) True triaxial compression apparatus with real-time heating function, and (b) the corresponding thermo-mechanical loading rationale.

We performed eight groups of real-time heating experiments ranging from 25 °C to 200 °C with a temperature increment of 25 °C. In addition, one thermal treatment group was also tested under 175 °C. Confining pressure of 20 MPa was applied in all cases. Data dispersion in our experiments is limited (Figure 2), while we observe a clear trend of strength increase along with temperature. Therefore, thermal strengthening does exist in Sichuan marble. Unexpectedly, the thermal treatment group does not show strength increase.

To unveil the mechanism of thermal strengthening, we investigated five factors, namely water content, thermal decomposition, thermal cracks, twin lamella and thermal expansion, which were of high potential to affect rock strength under thermal-mechanical loading. Note that it is no guarantee that the above five factors are thorough enough; they are comprehensive to our best knowledge. For the water content, we pre-dried a number of specimens and measured the specimen weight before and after drying. The water content of Sichuan marble is extremely low ($< 0.05\%$), thus it has limited influence on rock strength.

Thermal decomposition of carbonate rocks (marble in our case) releases gaseous CO_2 , which reduces the carbon element in rock material. Based on this rationale, we used EDX (Energy-dispersive X-ray Spectroscopy) to analyze the carbon element in the rock specimens before and after heating under 25 °C, 100 °C, 175 °C and 200 °C. We do observe a decreasing trend of the carbon element in Sichuan marble as temperature increases, but the extent is very limited ($< 1.5\%$ under 200 °C). Thus thermal decomposition is unlikely to be the leading factor of thermal strengthening in Sichuan marble.

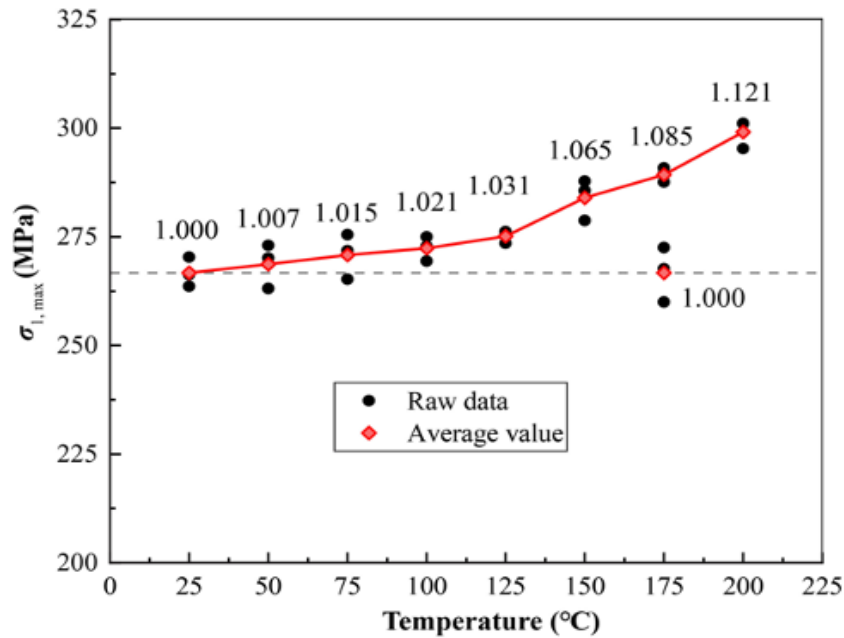


Figure 2 Normalized peak stresses at different elevated temperatures relative to room temperature. The degree of increase was gentle below 125 °C but accelerated thereafter. The increasing trend well extrapolated beyond 200 °C. Since the data dispersion is limited, thermal strengthening in Sichuan marble can be confirmed. However, for the thermal treatment group at 175 °C, thermal strengthening was absent.

We fabricated thin-sections of Sichuan marble at room temperature and that heated up to 200 °C, respectively. Thermal cracks were insignificant in both cases. SEM image examination further proved that thermal cracks at 200 °C could not be easily perceived with the room temperature case as a benchmark. Previous studies report visually striking twin lamellae (twins) in Carrara marble subject to thermal and/or mechanical loading. However, in our study, twins were very sparse (< 1% in terms of grains) even under the cooccurrence of pressure and elevated temperatures. Thermal cracks and twins are not the main factors of thermal strengthening in Sichuan marble either.

We infer that thermal expansion is the leading mechanism of thermal strengthening in Sichuan marble due to the following two reasons. (1) When the specimens were heated in the temperature range 25 °C - 200 °C, thermally induced cracks were very limited, but thermal expansion was bound to take place. (2) Thermal expansion might result in tighter compaction between grains. Consequently, the normal stresses applied on the faces of microcracks may be enhanced, which increases rock strength on the macroscale. The first point above plausibly explains why thermal strengthening did not occur in the thermal treatment group. That is because the compaction caused by thermal expansion disappeared after the quench. The second point indicates that tighter compaction caused by thermal expansion was able to strengthen rock, which led to the strengthening phenomenon in the real-time heating groups.

The recent rock engineering focus has shifted to great depth, featuring multiphysics and a prolonged lifetime. Heating and cooling are critical processes associated with these engineering activities, and the working temperature thereof typically falls in the range investigated in this experimental study. Our research outcome implies that temperature tends to be a favorable factor to enhance the integrity of rock material during the heating process (e.g. early stage of nuclear waste disposal), but may generate adverse effects during the cooling process (e.g. Enhanced Geothermal Systems).

Earthquakes in the Weiyuan shale gas field within the Sichuan Basin

Hongfeng Yang^{1,2}, Jinping, Zi¹, and Jiewen Zhang²

¹Earth System Science Programme, The Chinese University of Hong Kong

²Shenzhen Research Institute, The Chinese University of Hong Kong

Abstract: As one of the major shale gas blocks in China, the Weiyuan shale gas field has been actively developed since 2010, accompanying numerous hydraulic fracturing (fracking) activities. Accordingly, the number of earthquakes has been increasing drastically, with a few damaging earthquakes ($M > 4$) since 2019, some of which led to fatalities. However, it remains unclear how these earthquakes might have been induced. We derived high-resolution tomographic structure and earthquake location using data recorded at dense arrays. High-resolution locations of seismicity exhibit clear lineation and temporal migration parallel to the horizontal wells, indicating a causal relationship. Most earthquakes are concentrated near the depth of fracking. However, the largest earthquakes occur on basement faults, 3 km below the injection layer. In comparison, one deadly earthquake struck above the injection layer at 1-km depth that had long been considered aseismic. Stress drops of earthquakes increase slightly with depth and exhibit heterogeneous spatial distribution, with a median value of 0.96 MPa in the southwest and 0.82 MPa in the northeast. Our high-resolution source parameters indicated a mixture of mechanisms that can induce earthquakes in the region, providing critical insights for hazard assessment of induced earthquakes in the Sichuan Basin.

INTRODUCTION

It was well known that anthropogenic processes can trigger earthquakes large enough to harm infrastructure and people (Ellsworth, 2013; Grigoli *et al.*, 2017; Yang *et al.*, 2017). In particular, recent heightened concern had been raised in a number of places where unconventional energy production took place, such as geothermal development (Grigoli *et al.*, 2018; Kim *et al.*, 2018), shale gas production (Atkinson *et al.*, 2016; Bao and Eaton, 2016; Clarke *et al.*, 2014), underground gas storage (Zhou *et al.*, 2019; Jiang *et al.*, 2020), and so on. As one critical technique, hydraulic fracturing (HF), also termed fracking, had been extensively used to extract resources from unconventional reservoir such as low-permeability shale rocks. Accompanying HF, numerous earthquakes with moment magnitudes (M_w) less than 0 were induced, which were valuable to monitor fracture growth. However, damaging earthquakes with $M_w > 4$ triggered by HF had been reported recently, with notable examples in north America (Wang *et al.*, 2020; Babeie Mahani *et al.*, 2019), United Kingdom (Eyre *et al.*, 2019), and China (Lei *et al.*, 2017; Meng *et al.*, 2019). By far the largest HF induced earthquake (the 2018 Xingwen earthquake with a local magnitude (M_L) 5.7) occurred in the southern Sichuan Basin (Lei *et al.*, 2019a), where the Changning-Weiyuan shale gas block (Fig. 1a) had been discovered and developed since 2011.

The Weiyuan shale gas field (WSGF), had a few damaging events since 2019. Historical seismicity in the WSGF was sparse, with very few earthquakes with magnitudes larger than 1 before 2015 (Fig. 1c). Then earthquakes occurred more often, and the total number increased drastically from 2018 (Fig. 1c). On 25 February 2019, an M_w 4.3 earthquake struck the region at 1:15 pm with a reported intensity of VI (Fig. 1a). Immediately after the quake, fracking activities nearby were temporally shut down, because the earthquake caused 2 fatalities and 12 injuries. This was the first deadly earthquake associated with fracking (Yang *et al.*, 2020). Moreover, on 8 September 2019, an M_w 5.0 earthquake occurred in the Weiyuan county (Fig. 1a) and claimed one death and more than 60 injuries (Lei *et al.*, 2020). Another M_w 4.1 earthquake occurred on the same day, very close to the epicentres of the February earthquakes

(Fig. 1a), demonstrating the urgent need of better evaluating seismic hazard in the Weiyuan region for purposes of mitigating their effects.

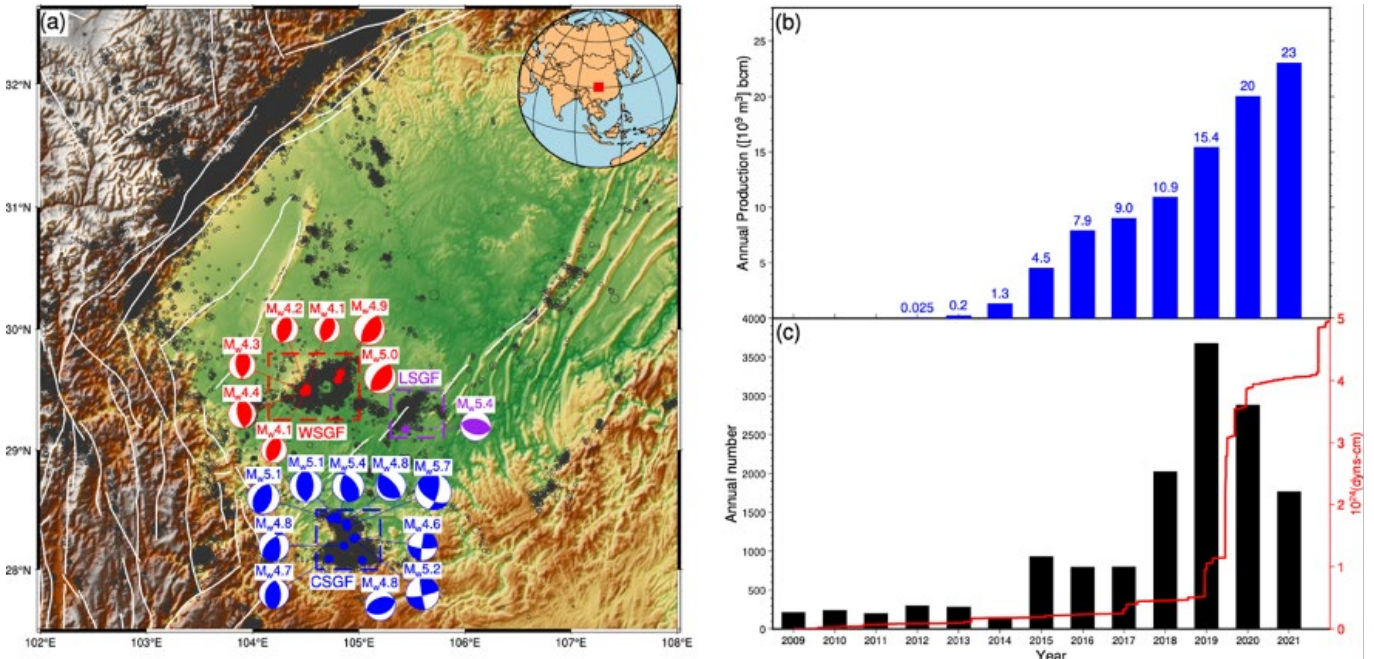


Figure 1. (a) A map showing catalog seismicity from December 2008 to December 2021 from the China Earthquake Network Center (CENC), with local magnitudes larger than 1. Moment tensor solutions represent large earthquakes in the Changning Shale Gas Field (CSGF, blue), Weiyuan Shale Gas Field (WSGF, red), and Lu County Shale Gas Field (LSGF, purple) with their moment magnitudes labelled. Inset map denotes the location of the Sichuan Basin. **(b)** Annual production of shale gas in China in billion cubic meters. **(c)** Number of earthquakes per year since 2009 in the three shale gas fields and cumulative released seismic moments that were calculated from local magnitudes and M_L - M_w relationship [Yi *et al.*, 2020].

Although the earthquakes in the WSGF had been investigated with different methods, there are considerable discrepancies in their source parameters, pose challenges in elucidating mechanisms of their occurrence and source faults. For instance, the focal depths of the two largest earthquakes in the WSGF were in debate, probably due to the limited station coverage. On September 8, 2019, an M_w 5.0 earthquake occurred in the east cluster to Weiyuan (Fig. 2a). Using the crust 1.0 velocity model, Wang *et al.*, (2020) constrained the focal depth at 5 km, close to the result (4.5 km) using another velocity model that was derived from relocated local earthquakes (Yi *et al.*, 2020). However, two other studies resolved its focal depth at 2.5 km (Lei *et al.*, 2020) and 2.9 km (Sheng *et al.*, 2020), respectively, which were slightly shallower than the injection depth (3.0 km). Similarly, the focal depths of the 18 December 2019 M_w 4.9 earthquake differed from 4 km (Yi *et al.*, 2020), 3 km (Sheng *et al.*, 2020), to 2.5 km (Lei *et al.*, 2020). Resolving earthquake source parameters in high resolution is necessary to infer whether and how these earthquakes were induced by fracking activities in the WSGF.

In this study, we derived high-resolution earthquake location and tomographic images using permanent stations in the WSGF and a dense temporary seismic network that was deployed in the region for one year. We also obtained stress drops of the earthquakes and investigate their distribution pattern in the region. Our new results not only delineated the responsible faults for the damaging earthquakes in the WSGF, but also shed critical lights on understanding the mechanisms leading to these events.

2. Method and Dataset

Two local earthquake datasets were used in this study. One is recorded by a dense temporary seismic network that was deployed from 2015 to 2016 in northeast Weiyuan (Zhou et al., 2021). The other one is constructed from records at the permanent stations of the Sichuan Earthquake Agency, which were expanded to deploy 25 more stations after the 2019 February Mw 4.3 earthquake.

2.1. Double difference tomography

We use the event-pair tomoDD method to invert the 3-D velocity model (Zhang and Thurber, 2006). In order to obtain accurate absolute locations, we also include absolute travel times in addition to differential times. To get more accurate absolute travel times, we then improve the absolute location for the events in the catalog using the HYPOInverse algorithm (Klein, 2002) with a newly refined velocity model (Zhou et al., 2021). In total there are more than 90 stations from both the temporary seismic network and permanent stations within 100 km of the WSGS. The spatial resolutions of our model grid are ~ 4 km in lateral directions and 1.5 km in depth, which are estimated from checkerboard tests.

2.2. Stress drop calculation

We implement Brune's source spectrum model to estimate the earthquake stress drops for small earthquakes (Brune, 1970). In this model, the far-field displacement spectrum of an earthquake can be represented as a function of the seismic moment and corner frequency of the earthquake. By assuming a simple circular rupture for a small earthquake, the corner frequency f_c can be derived from the source dimension and the rupture speed (Brune, 1970; Madariaga, 1976). Then the stress drop can be calculated from seismic moment and source radius (Eshelby, 1957).

3. Results

3.1 Relocated earthquakes

After conducting double-difference tomography, we obtain high-resolution earthquake locations in the region. Compared with previous results of double-difference earthquake relocation using a 1D velocity model (Yang et al., 2020), our results exhibit higher resolution and delineate a number of clusters with north-south and northwest-southeast orientations (Fig. 2). However, they do not correlate with mapped faults. Some clusters last for a few weeks, consistent with the typical time windows of fracking. Most earthquakes are concentrated at depths of 3-5 km, slightly below the depth of fracking.

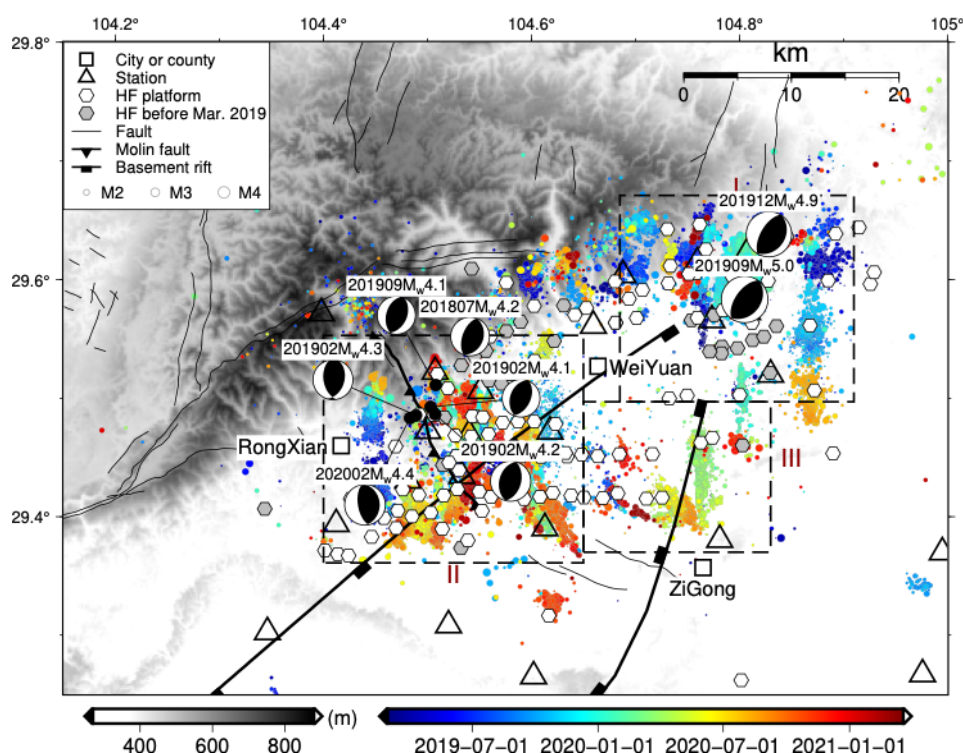


Figure 2. Earthquake distribution after relocation, coloured by their occurrence time. Focal mechanisms of the largest earthquakes in the region were displayed with their magnitude and occurrence time in year and month. Solid lines represent the identified faults.

We inspect depth cross sections of the seismicity and infer that most of these earthquakes are likely induced by pore pressure diffusion. Furthermore, we do not observe clearly sequential migration of seismicity, the typical indicator of slow slip. The largest earthquake (M_w 5.0) in WeiYuan nucleated at a depth of 6.2 km in the Precambrian basement, well below the fracking depth. Small magnitude events extended to the basement depth before the M_w 5.0 event, showing a potential channel of fluid migration. Thus we infer that the M_w 5.0 earthquake may have been caused by long-distance (>4 km) fluid migration.

3.2 A new tomographic model in WeiYuan

Here we present a new tomographic model in the WSGF (Fig. 3). At shallow depths of 2 km, there is a prominent low V_p zone extending from the WeiYuan anticline to the Molin fault where the 2019 M_w 4.3 earthquake occurred. At greater depths, the most distinct feature is the low velocity zone between the two basement faults that were formed during the rifting process in the Proterozoic era. Such low-velocity feature emerges at 4.0 km depth, and extends to 8 km. In comparison, the low velocity zone associated with the Molin fault did not extend beyond 4 km depth, consistent with that the Molin fault was formed as a small tear fault when the WeiYuan anticline was lifted due to the India-Asia collision (Wang et al., 2020).

3.3 Stress drops of earthquakes in WeiYuan

Using the above method, we obtain stress drop of $>12,000$ earthquakes in the WSGS from March 2019 to April 2020. We divide the WeiYuan Region into western and eastern WeiYuan by longitude line 104.65 degrees, and demonstrate the stress drop patterns in the two areas respectively. In western WeiYuan, the median stress drop is 0.96 MPa, slightly larger than that in the eastern WeiYuan region

which is 0.82 MPa. More specifically, in the western Weiyuan region, there is no apparent dependence of stress drop on depth. However, in the eastern Weiyuan region, significantly lower stress drops at 3–4 km depth is found than those at deeper depths; the median value of stress drop between 3 km and 4 km depth is about 0.48 MPa, while the median below 4-km depths is 0.95 MPa, nearly twice of that in the shallower depths. The gap in stress drop values at 4 km depth coincides with the injection activities in this region.

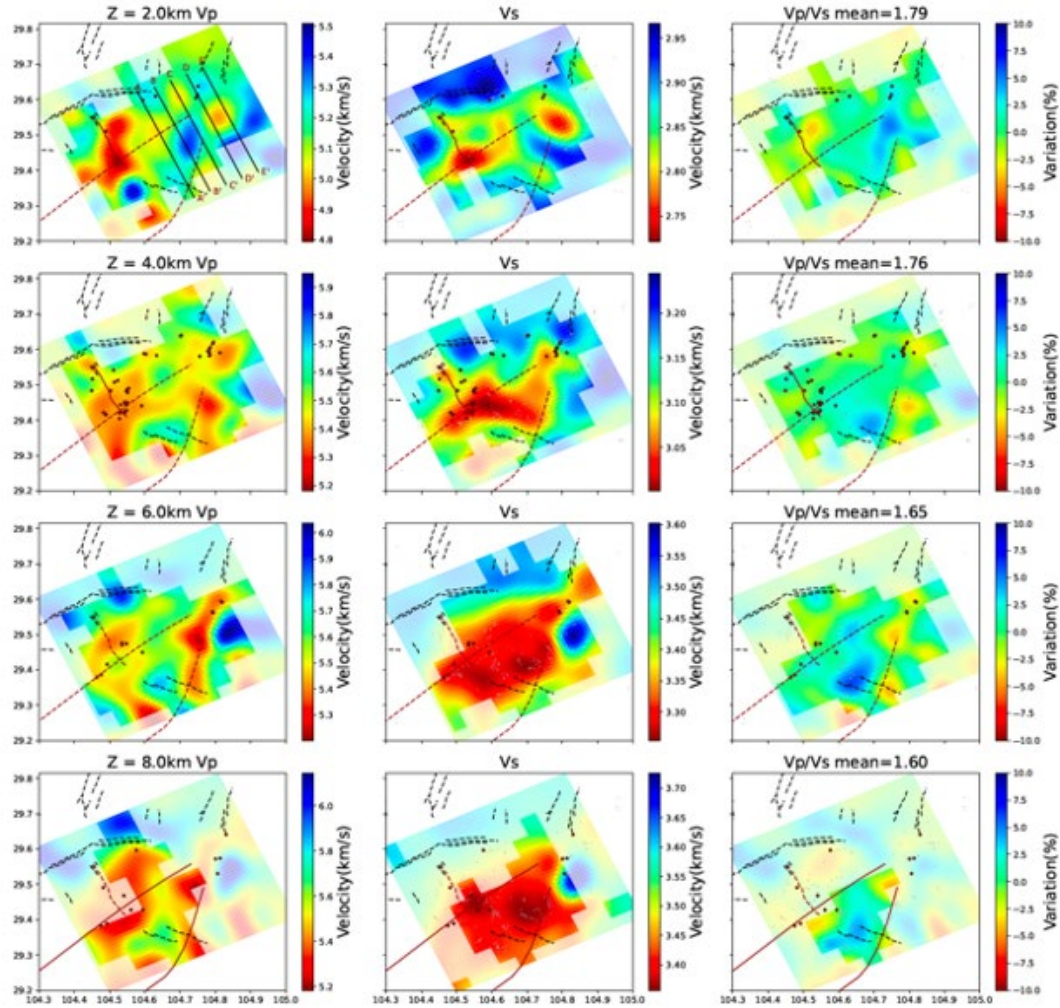


Figure 3. tomographic results of Vp (left), Vs (middle), and Vp/Vs (right) in the study region, from 2 to 8 km in depth (top to bottom). Triangles denote permanent stations and black circles show relocated earthquakes. Solid and dashed lines represent identified faults in the region.

4. Conclusions

Here we conduct high-resolution double-difference tomography in the WSGF. Distinct low velocity zones are found in central Weiyuan, which corresponds to the rift bounded by extensional faults in the Precambrian basement. At shallow depths, low velocity zones are associated with the Molin fault where the 2019 Mw 4.3 earthquake occurred. High-resolution earthquake locations exhibit clear spatial and temporal clusters, most of which are concentrated at depths slightly below the fracking depth and are likely caused by pore pressure diffusion. The largest earthquake initiates at the basement and ruptures to shallow depth. Stress drop values show a clear spatial variation in the WSGF, but most earthquakes tend to have relatively low values of stress drops (<1 MPa).

Acknowledgements

This study is supported by National Science Foundation of China (U2139203) and Hong Kong Research Grants Council (14303721).

References

- Atkinson, G. M., D. W. Eaton, H. Ghofrani, D. Walker, B. Cheadle, R. Schultz, R. Shcherbakov, K. Tiampo, J. Gu, R. M. Harrington, et al. (2016). Hydraulic fracturing and seismicity in the Western Canada Sedimentary Basin, *Seismol. Res. Lett.* 87, no. 3, 631–647, doi: 10.1785/0220150263
- Babaie Mahani, A., H. Kao, G. M. Atkinson, K. Assatourians, K. Addo, and Y. Liu (2019). Ground motion characteristics of the 30 November 2018 injection-induced earthquake sequence in northeast British Columbia, Canada, *Seismol. Res. Lett.* 90, no. 4, 1457–1467.
- Bao, X., and D. W. Eaton (2016). Fault activation by hydraulic fracturing in western Canada, *Science* 354, no. 6318, 1406–1409, doi: 10.1126/science.aag2583.
- Brune, J. N. (1970), Tectonic stress and the spectra of seismic shear waves from earthquakes, *J. Geophys. Res.*, 75(26), 4997–5009, doi:10.1029/JB075i026p04997
- Clarke, H., L. Eisner, P. Styles, and P. Turner (2014). Felt seismicity associated with shale gas hydraulic fracturing: The first documented example in Europe, *Geophys. Res. Lett.* 41, 8308–8314, doi: 10.1002/2014GL062047.
- Ellsworth, W. L. (2013). Injection-induced earthquakes, *Science* 341, no. 6142, 1225942, doi: 10.1126/science.1225942
- Eyre, T. S., D. W. Eaton, D. I. Garagash, M. Zecevic, M. Venieri, R. Weir, and D. C. Lawton (2019). The role of aseismic slip in hydraulic fracturing-induced seismicity, *Sci. Adv.* 5, eaav7172.
- Grigoli, F., S. Cesca, E. Priolo, A. P. Rinaldi, J. F. Clinton, T. A. Stabile, B. Dost, M. G. Fernandez, S. Wiemer, and T. Dahm (2017). Current challenges in monitoring, discrimination, and management of induced seismicity related to underground industrial activities: A European perspective, *Rev. Geophys.* 55, no. 2, 310–340, doi: 10.1002/2016RG000542.
- Grigoli, F., S. Cesca, A. P. Rinaldi, A. Manconi, J. A. López-Comino, J. F. Clinton, R. Westaway, C. Cauzzi, T. Dahm, and S. Wiemer (2018). The November 2017 Mw 5.5 Pohang Earthquake: A Possible Case of Induced Seismicity in South Korea. *Science* 360 (6392): 1003–6. doi:10.1126/science.aat2010.
- Guo, H., and H. Zhang. (2017). Development of Double-Pair Double Difference Earthquake Location Algorithm for Improving Earthquake Locations. *Geophysical Journal International* 208 (1): 333–48. doi:10.1093/gji/ggw397
- Jiang, G., X. Qiao, X. Wang, R. Lu, L. Liu, H. Yang, Y. Su, L. Song, B. Wang, and T. Wong (2020). GPS observed horizontal ground extension at the Hutubi (China) underground gas storage facility and its application to geomechanical modeling for induced seismicity, *Earth Planet. Sci. Lett.* 530, 115943.
- Kim, K.-H., J.-H. Ree, Y. Kim, S. Kim, S. Y. Kang, and W. Seo (2018). Assessing whether the 2017 Mw 5.4 Pohang earthquake in South Korea was an induced event, *Science* 360, 1007–1009, doi: 10.1126/science.aat6081.
- Lei, X., D. Huang, J. Su, G. Jiang, X. Wang, H. Wang, X. Guo, and H. Fu (2017). Fault reactivation and earthquakes with magnitudes of up to Mw 4.7 induced by shale-gas hydraulic fracturing in Sichuan Basin, China, *Sci. Rep.* 7, 7971, doi: 10.1038/s41598-017-08557-y.
- Lei, X., Z. Wang, and J. Su (2019a). The December 2018 ML 5.7 and January 2019 ML 5.3 earthquakes in South Sichuan Basin induced by shale gas hydraulic fracturing, *Seismol. Res. Lett.* 90, no. 3, doi: 10.1785/0220190029.
- Lei, X., J. Su, and Z. Wang. (2020). Growing Seismicity in the Sichuan Basin and Its Association with Industrial Activities. *Science China Earth Sciences*. doi:10.1007/s11430-020-9646-x.
- Madariaga, R. (1976). Dynamics of an expanding circular fault. *Bulletin of the Seismological Society of America*, 66(3), 639–666

- Meng, L., A. McGarr, L. Zhou, and Y. Zang (2019). An investigation of seismicity induced by hydraulic fracturing in the Sichuan Basin of China based on data from a temporary seismic network, *Bull. Seismol. Soc. Am.* 109, no. 1, 348–357, doi: 10.1785/0120180310.
- Sheng, M., R. Chu, S. Ni, Y. Wang, L. Jiang, and H. Yang. (2020). Source Parameters of Three Moderate Size Earthquakes in Weiyuan, China, and Their Relations to Shale Gas Hydraulic Fracturing. *Journal of Geophysical Research: Solid Earth* 125 (10). doi:10.1029/2020jb019932.
- Wang, B., R. M. Harrington, Y. Liu, H. Kao, and H. Yu (2020). A Study on the largest hydraulic-fracturing-induced earthquake in Canada: Observations and static stress-drop estimation, *Bull. Seismol. Soc. Am.* doi: 10.1785/0120190261.
- Wang, M., H. Yang, L. Fang, L. Han, D. Jia, D. Jiang, and B. Yan (2020). Shallow fault activation induced by hydraulic fracturing: The 2019 Weiyuan earthquake sequences in Sichuan, China, *Seismol. Res. Lett.* doi: 10.1785/0220200174
- Yang, H., Y. Liu, M. Wei, J. Zhuang, and S. Zhou (2017). Induced earthquakes in the development of unconventional energy resources, *Sci. China Earth Sci.* 60, no. 9, 1632–1644, doi: 10.1007/s11430-017-9063-0.
- Yang, H., P. Zhou, N. Fang, G. Zhu, W. Xu, J. Su, F. Meng, and R. Chu (2020). A Shallow Shock: The 25th February 2019 ML 4.9 Earthquake in the Weiyuan Shale Gas Field in Sichuan, China. *Seismological Research Letters*. doi:10.1785/0220200202.
- Yi, G., F. Long, M. Liang, M. Zhao, and S. Wang (2020). Geometry and Tectonic Deformation of Seismogenic Structures in the Rongxian-Weiyuan-Zizhong Region, Sichuan Basin: Insights from Focal Mechanism Solutions. *Chinese Journal of Geophysics (in Chinese)* 63 (9): 3275–91. doi:10.6038/cjg202000095
- Zhang, M., W. L. Ellsworth, and G. C. Beroza (2019). Rapid earthquake association and location. *Seismol. Res. Lett.*, 90(6), 2276–2284. doi:10.1785/0220190052
- Zhang, H., and C. Thurber (2006). Development and Applications of Double-Difference Seismic Tomography. *Pure and Applied Geophysics* 163 (2-3): 373–403. doi:10.1007/s00024-005-0021-y
- Zhou, P., W. L. Ellsworth, H. Yang, Y. J. Tan, G. C. Beroza, M. Sheng, and R. Chu. (2021). Machine-Learning-Facilitated Earthquake and Anthropogenic Source Detections Near the Weiyuan Shale Gas Blocks, Sichuan, China. *Earth and Planetary Physics* 6, 501-519. doi: 10.26464/epp2021053.
- Zhu, W. Q., and Beroza, G. C. (2019). PhaseNet: a deep-neural-network-based seismic arrival-time picking method. *Geophys. J. Int.*, 216(1), 261–273. doi:10.1093/gji/ggy423
- Klein, Fred W. (2002). User's Guide to HYPOINVERSE-2000, a Fortran Program to Solve for Earthquake Locations and Magnitudes. US Geological Survey

Introduction and Comments on “Guidelines for the Development and Application of Engineering Geological Models on Projects (IAEG C25)”

Dong, Jia Jyun

Graduate Institute of Applied Geology, National Central University, ROC

Abstract: Commission 25 (C25) of the International Association of Engineering Geology (IAEG) proposed a first draft of “Guidelines for the Development and Application of Engineering Geological Models (EGM) on Projects” in early 2022. This guideline includes: Introduction, EGM Development Principles, EGM Development Process, Assembly and Communication of EGMs, Managing EGM Uncertainty, Ensuring EGM Quality, EGM and Project Management, EGMs related to project stages, and Application and Outputs of EGMs. This paper briefly introduces this Guideline and some comments and suggestions related to uncertainties of EGMs are proposed.

INTRODUCTION

C25 is one of a number of IAEG commission established as a result of wide-ranging discussions following the First Hans Cloos Lecture (Knill, 2001). One of the aims of C25 is to develop guidelines for the preparation and use of engineering geological models. After the documentation of first report “Engineering Geological Models: an Introduction: IAEG Commission 25” has been published in Bulletin of Engineering Geology and the Environment (official journal of IAEG; Parry et al., 2014), a draft of “Guidelines for the Development and Application of Engineering Geological Models (EGM) on Projects” has been release for discussion in early 2022. This paper try to briefly introduce this Guideline. Comments focusing on the Chapter 5 “Managing EGM Uncertainty” are provided and hope the discussion can beneficial to the Guideline modifications.

CONTENTS OF IAEG GUIDELINE

The contents of this Guideline are summarized as follows. Most of the text came from the Guideline directly with minor modifications.

Introduction

This Guidelines can be used in a wide range of fields including: civil engineering, mining, geo-hazard studies, land-use planning and environmental assessment, to reduce the adverse influences on quality and reliability of EGM due to overlook the fundamental principles of engineering geology. The EGM is not simply a 2D or 3D visualization of a data set. It is a comprehensive knowledge framework for the logical evaluation and interpretation of all the geological conditions and their engineering characteristics that are of significance to the project, so that appropriate engineering decisions during the life cycle of project can be made based on an appropriate EGM.

EGM Development Principles

Definitions of several models including: Model, EGM, Conceptual Model, Observational Model, Geotechnical Model, Analytical Model, Software Model, and Software Model are provided. There are two key elements should be considered when developing an EGM – (a) the project and (b) the ground.

EGM can be totally different at an identical site if different engineering projects such as buildings, tunnel, or bridge are considered.

The EGM is developed by combining: (a) Conceptual Model, which involves making judgements based on knowledge, experience, intuition, ingenuity and vision in the generation of ideas to explain the observed engineering and geological conditions and processes and the interpreted site total geological history; and (b) Observational Model, which is an developed using accumulation and processing of large quantities of factual information that focusses on describing materials and mass condition, geological structures, groundwater conditions, characterizing behavior and performance and developing plans, sections and 3D visualizations. They form two different but essential and complimentary tools that must be combined at all stages of the project to generate an appropriate EGM. Only when conceptual ideas and observational data have been reconciled should engineering analysis proceed.

EGM building is essentially about practicing the scientific method: (a) define / identity problem, (b) form hypothesis, (the conceptual model); (c) collect data to test, disprove, or prove hypothesis, (the observational model); (d) refine hypothesis depending on collected data; (e) draw conclusions, (f) communicate results. The operating rules and common mistakes made during the development of the EGM are listed.

EGM Development Process

The EGM development process involves several essential steps, including: (a) assemble team, define scope and purpose; (b) assemble relevant engineering and geological information of significance to the project in a desk study; (c) conceptualize the possible engineering geological conditions using the desk study, knowledge and experience; (d) combining Conceptual Models and Observational Models into an EGM; (e) define engineering geological units and their engineering characteristics and zone the ground; (f) identify significant uncertainties, gaps and discrepancies in the knowledge framework; use these findings to define an appropriate/specific ground investigation to minimise or eliminate unknowns or risks; (g) acquire further knowledge to improve the framework, or reduce the risks, facilitate upgrade to design or deal with claims. These steps are repeatedly iterating during the life cycle of projects. The details of each step are provided.

Assembly and Communication of EGMs

The knowledge framework has to be collated and assembled within a reporting format that can be used to document and communicate the various parts of the EGM. The report content should be clearly differentiated into factual information and observations, interpretations, and opinions. It is important to note that scale is fundamental. EGM is only accurate for the scale at which the data were collected.

This Guideline acknowledged that software visualizations has been increasingly used by diverse communities, often unfamiliar with geological concepts. There is a real danger that users will produce wildly inaccurate models by combining diverse data sets in ways that do not follow geological logic. The Guideline indicated that “Implicit realism can produce misplaced trust”. Challenges remain in producing models and visualizations that clearly incorporate and display uncertainties in data or interpretation especially for the 3D software models.

Data management includes many issues surrounding ‘versioning’ of the EGM outputs and its components – including data sources. Each stage of the EGM should be documented and retained for future reference. A record of changes to the EGM, including reasons for major changes, should be recorded. A process required to ensure design teams are using the most up-to-date EGM.

Managing EGM Uncertainty

The aleatory and epistemic uncertainties are defined first. Then the biases relevant to EGM development are introduced. Sources of uncertainty in EGM came from: (a) the appropriateness of the concepts underlying the EGM; (b) the quality of the available data; (c) the spatial relevance of the data to the

project – location and scale: (d) The quantity of available data; (e) the ground complexity – more complexity requires more data; (f) the understanding of those undertaking the work.

A qualitative approach using the relative reliability of data can be applied to EGMs to classify datasets reliability (in order of certainty from least to most) under the headings “Implied, Qualified, Justified and Verified”. The identifying and documenting uncertainty within software models are highlighted in this Guideline.

Ensuring EGM Quality:

The EGM must satisfy a number of objectives which are listed below: (a) Is it robust? (b) Is it transparent (easily looked into and understood even by non-technical people)? (c) Is it defensible, consistent and is it free of flaws? (d) Performance - does it do the job well enough? (e) Sufficiency - is everything essential there? (f) Necessity - are there things in it which aren't essential?

Data validation, which checking of the accuracy and quality of source data before using, importing or otherwise processing data, is a form of data cleansing. Verification is a process in which different types of data are checked for accuracy and inconsistencies after data migration is done.

This Guideline provided valuable QA/QC checklist for the EGM development process. Approaches to assessing or measuring the effectiveness of the EGM are introduced: (a) the EGM is ultimately informing engineering decisions, analysis and design, and it is an effective model if it meets these needs to the appropriate level given the project stage. (b) comparison of EGM predictions of ground conditions with the “as encountered” conditions as a project proceeds (an ongoing process) determines the EGM reliability, even though not always precisely accurate geometrically.

EGMs and Project Management:

EGM documentations related to project include: Contract, Factual and Interpretative Reports, and Geotechnical Baseline Reports (GBR). The cost estimate in Contract reflects an understanding of the geological conditions that are of engineering significance to the project. The Factual Reports are usually regarded as ‘Rely Upon Data’, whilst the Interpretative Reports are usually ‘For Information Only’. As a result of this separation, the generation of a high quality EGM may not be a priority. However, developing an EGM should become a priority, mainly of the need for information from the EGM to undertake design. Thus, alongside the Factual and Interpretive Report, to incorporate a high quality EGM as a separate scope item into the project documentation is necessary.

The baseline statements in GBR establish what is ‘foreseen’ and provide a contractual test for what might be claimed to be ‘unforeseen’ in relation to the ground conditions encountered during construction. An EGM based on observational data within a realistic and appropriate conceptual framework is the ideal tool to support the development of all components of GBRs. As a result, the EGM is a part of the GBR and can be directly linked to contractual clauses.

This Guideline provided the source of geotechnical risks (project management, contractual, and technical issues related to geology, parameters, analysis). Many of them relate to an inadequate understanding of the ground i.e. they reflect epistemic uncertainty resulting from an inadequate EGM. EGM performs different functions within project risk management such as: (a) documentation of identified hazards; (b) identification of discrepancies in conceptual/observational models (known unknowns); (c) documenting what all parties should reasonably know so that anything that is encountered that is a true “unknown unknown”; (d) illumination of risks generated by shortcomings in the EGM development such as lack of competencies in the team.

EGMs related to project stages:

The EGM plays a key role in the whole life cycle of an engineering project. The Engineering Geologist is not just a data gathering function but plays a role in all stages of a project, including: concept/pre-feasibility, feasibility, schematic design/tender design, detailed design, and construction. The

importance roles of EGM are indicated in the Guideline and the EGM used in site investigation, analysis and design, and construction are introduced in more detail.

Application and Outputs of EGMs:

EGM applications and outputs for a variety of key project types (rock engineering and soil engineering projects, hydrogeological studies and contaminated land projects, landslide studies, and offshore project) are introduced.

COMMENTS ON “CHAPTER 5 MANAGING EGM UNCERTAINTY”

The wide-ranging discussion following the First Hans Cloos Lecture posed the question: “do practitioners need guidelines for the preparation of models and how should uncertainty be addressed within such models?” (Parry et al., 2014) and motivated the idea to prepare a guideline for EGM development. Therefore, “uncertainty” is one of the key elements of this Guideline.

To broadly discuss the first draft of Guideline, C25 Guideline Workshop took place on Wednesday 6th October, during the 3rd European Regional Conference of IAEG. Many questions from the participants focused on EGM uncertainties are attracted:

- (1) Purpose is the most important consideration element for documenting the EGM uncertainty.
- (2) There is an inverse relationship between spend on ground investigation and the uncertainty in the EGM. GI work is often awarded on cost increasing risks
- (3) Is it proposed to develop a standard way of describing risk and uncertainty that is presented alongside every EGM?
- (4) Measures of uncertainty are themselves often highly uncertain and when portrayed in models may give false impressions, but are useful indicators nonetheless.
- (5) If there is uncertainty there must be certainties. Is there certainties in natural ground? Can we put numbers on them that will be CERTAIN along space and time?
- (6) Should we distinguish bias from uncertainty? Bias and uncertainties are hard to distinguish when not enough data. So can we define the minimum explorations (ex. boreholes) needed to build a feasible EGM?
- (7) The section on uncertainty is very detailed. Perhaps it would be more beneficial to provide guidance on how to communicate 'limitations' of each EGM to users?
- (8) Should we address each type of uncertainty individually and then combine?
- (9) For simple projects EGM uncertainty should be presented in a risk assessment alongside other project risks so EGM risks are treated equally with other risks.
- (10) We talked about uncertainties of the data we derived from both field and laboratory. Can we put a back analyses section into the software modeling?

The author was invited to provide comments on Chapter 5 “Managing EGM uncertainty” during this workshop. The key observation is the EGM uncertainty do properly incorporated into this Guideline. The EGM uncertainty is highlighted using one isolated chapter and “Uncertainty” or “Uncertainties” appeared 105 times; “Risk” or “Risks” appeared 97 times, and “Reliability” appeared 39 times. The existence, importance, and identification of uncertainty have been indicated in Sections 2.3, 3.1, and 3.7. Sections 2.4 and 6.3 mentioned uncertainty documentation, QA/QC, and communication. Uncertainty zoning is introduced in Section 3.6. In Chapters 7 and 8, the EGM uncertainty and risk management (Sections 7.3) and EGM uncertainty in different project stages are carefully illustrated. Notably, the Software models uncertainty is stressed in many places (Sections 4.7, 6.4, 6.5). Some suggestions are summarized as follows:

- (1) “Uncertainty” can be defined in the beginning of Chapter 5 such as: *Uncertainty - The lack of certainty, a state of limited knowledge where it is impossible to exactly describe the existing state, a future outcome, or more than one possible outcome.* (Hubbard, 2014)
- (2) There are three important elements of EGM uncertainty: Identification (source, type), Documentation, and Communication (risk). One section related to risk communication can be added in Chapter 5.
- (3) Consider including the type of uncertainty (Wellmann et al., 2010): (a) Type 1 (error, bias, and imprecision): uncertainty in all types of raw data that are used for modelling, like the position of a formation boundary or the orientation of a structure. (2) Type 2 (stochasticity, and inherent randomness): this commonly shows up as the uncertainty in interpolation between (and extrapolation from) known data points. (3) Type 3 (imprecise knowledge): applies to incomplete and imprecise knowledge of structural existence, general conceptual ambiguities and the need for generalizations.
- (4) The lines and symbols on maps and sections to represent formation boundaries and structural features proposed by FGDC (2006) could be useful to indicate the EGM uncertainty, qualitatively. The lines may be solid, long dash, medium dash, or short dash, with or without question marks to portray combinations of scientific confidence and location accuracy.
- (5) The roles of EGM uncertainty on reliability-base design of geotechnical engineering can be enhanced.

CONCLUSIONS

Commission 25 of IAEG proposed a first draft of “Guidelines for the Development and Application of Engineering Geological Models (EGM) on Projects”. One of the key features are the EGM uncertainty do properly incorporated into this Guideline. The comments on EGM uncertainty are provided and hope the comments are of use for the Guideline modification.

REFERENCES

- IAEG C25. (2022). Guidelines for the development and application of engineering geological models on projects. First Draft.
- Knill, J.L. (2003). Core values: the First Hans Cloos Lecture. *Bulletin of Engineering Geology and the Environment*, 62(1), 1-34.
- Parry, S., Baynes, F. J., Culshaw, M. G., Eggers, M., Keaton, J. F., Lentfer, K., Novotny, J., Paul, D. (2014). Engineering geological models: an introduction: IAEG C25. *Bulletin of Engineering Geology and the Environment*, 73(3), 689-706.
- Hubbard, D. W. (2014). How to measure anything: finding the value of “intangibles” in business. Wiley.
- Wellmann, J. F., Horowitz, F. G., Schill, E., Regenauer-Lieb, K. (2010). Towards incorporating uncertainty of structural data in 3D geological inversion. *Tectonophysics*, 490(3-4), 141-151.
- FGDC (2006). FGDC digital cartographic standard for geologic map symbolization. US Geological Survey Geologic Data Subcommittee, Federal Geographic Data Committee Document Number FGDC-STD-013-2006, 33.

ACKNOWLEDGEMENTS

The financially supported by Taiwan ministry of science and technology (MOST108-2638-E-008-001-MY2, MOST110-2123-M-008-001-) and the earthquake disaster & risk evaluation and management center (E-DREaM) from the featured areas research center program within the framework of the higher education sprout project of the ministry of education (MOE) in Taiwan are gratefully acknowledged.

VOLCANISM AND CLIMATE CHANGE

Wyss Yim

Association for Geoconservation, Hong Kong /
Institute of Space and Earth Information Science, Chinese University of Hong Kong /
Guy Carpenter Asia-Pacific Climate Impact Centre, City University of Hong Kong /
Department of Earth Sciences, The University of Hong Kong

Abstract: *Satellites since the early 1980s and ARGO ocean profiling floats since the early 2000s, are providing observation records of terrestrial and submarine volcanic eruptions. Both cooling and warming of the atmosphere and the hydrosphere as well as severe weather events may be caused by volcanic eruptions. Local climatic impacts include the cooling effect and extreme rainfall variability. Regional climatic impacts include the formation of hot blobs beneath the ocean surface, the retreat of polar sea ice and the long-lasting and strong 2014-2016 ENSO. For illustration, Hong Kong's rainfall during 1982 and the 2014-2016 ENSO are presented in greater details. Studies on naturally released geothermal heat from volcanism which is underestimated at present should improve our understanding on the causes of climate change.*

INTRODUCTION

Volcanism driven climate change are based on the plate climatology theory introduced by Kamis (2014). Unlike the Sun which is the first order driver of earth's climate, it is an underestimated second order driver which can contribute significantly to regional natural variation. The overall theory contends that periods of active earth tectonics and volcanism can be correlated to periods of active climate change and/or climate related events.

Geothermal heat is released into the atmosphere and hydrosphere together with gases including carbon dioxide, in variable amounts through volcanic eruptions. It's role in raising temperature may be mistaken for anthropogenic greenhouse gas-driven global warming. In this paper, case studies of local and regional climatic impacts will be used to highlight the role played by volcanoes.

MODELS OF VOLCANIC ERUPTIONS

Volcanic eruptions can be classified into three model types:

(1) Terrestrial/sub-aerial model

The main features of the terrestrial model are shown in Figure 1A. This type of eruptions switches on hot air followed by cooling. The injection of ash, gases and aerosols cause shortwave radiation blockage; pressure changes; moisture redistribution; continental cooling; ozone depletion; circulation changes including changes to jet streams, and severe weather events. Lava flows entering the sea is a cause of warming of coastal waters. For measurement, the Volcanic Explosivity Index (VEI) introduced by Newall and Self (1982) on a scale ranging from 0 to 8 based on the volume of erupted tephra discharged shown in Figure 2 is used.

(2) Submarine model

The main features of the submarine model are shown in Figure 1B. This type of eruptions switches on hot seawater causing ocean warming; pressure changes; circulation changes including changes to jet streams; moisture redistribution; continental warming, and severe weather events. There is no scale available for measurement at present but basaltic magma is known to be at between about 1000-1200°C while acidic counterparts are lower in temperature and are much more explosive.

(3) Mixed submarine and terrestrial model

This type of eruptions is initially submarine and later terrestrial following the birth of new volcanic islands rising above the sea level. Their impacts on weather are a combination of (1) and (2).

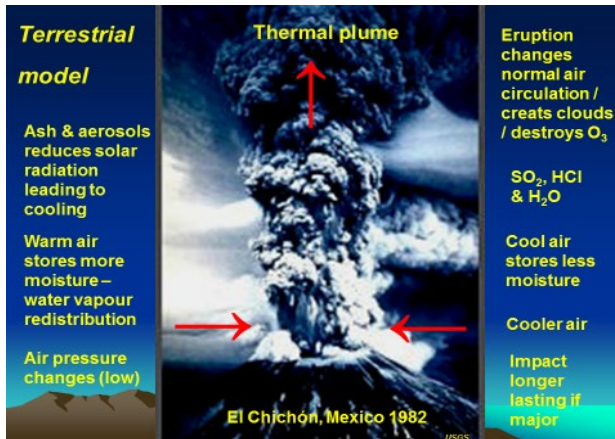


Figure 1A Terrestrial model.

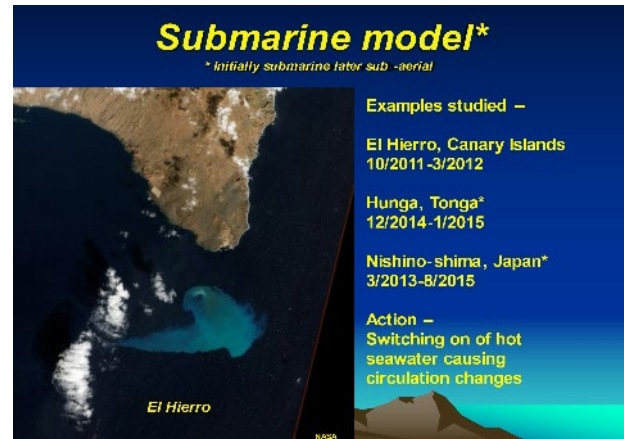


Figure 1B Submarine model.

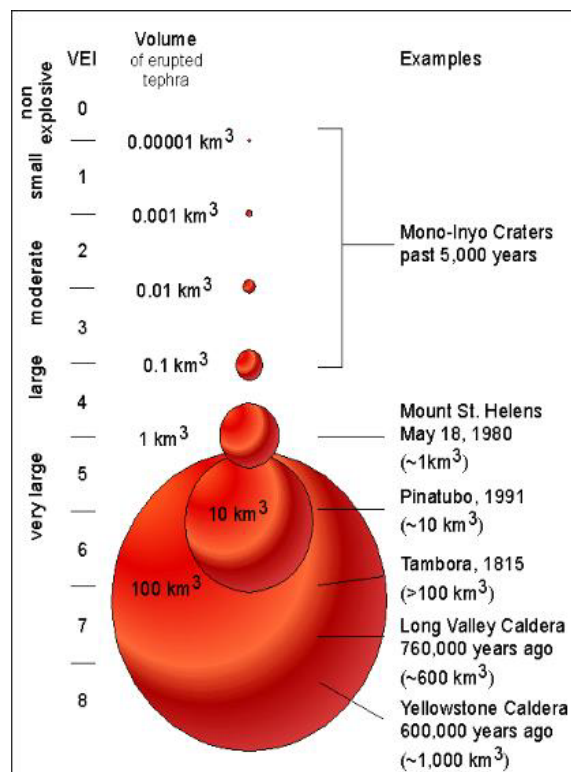


Figure 2 Volcanic Explosivity Index (VEI) of Newhall and Self (1982).

EXAMPLES OF CLIMATE CHANGE IMPACTS

A summary table of volcanic eruptions studied and their climate change impacts is shown in Table 1. Out of these, two case study examples one local and one regional are presented in greater detail.

Table 1. Summary table of volcanic eruptions studied and their climate change impacts.

Volcano(es)	Month/year	Type	Climate change impact(s)	Source
Agung, Indonesia	2/1963	Terrestrial	Driest year in Hong Kong since record began with water supply reduced to 4 hours in four days	Yim (2012)
El Chichón, Mexico	3/1982	Terrestrial	Second wettest year in Hong Kong since record began with numerous floods and landslides	Yim (2021)
Pinatubo, Philippines	6/1991	Terrestrial	Eleventh driest year in Hong Kong since record began	Yim (2011)
Chaitén, Chile	5/2008	Terrestrial	Sixth wettest year in Hong Kong since record began; wettest June on record; record rainstorm 384 mm in 4 hours on June 7 th triggering 2400 landslides on Lantau Island	Yim (2010); Zhang et al. (2016)
Eyjafjallajökull, Iceland	4/2010	Terrestrial	Wettest year in Slovakia since record began; severe flooding in Slovakia/Czech Republic/Germany/Poland	Yim (2018a)
Soufrière Hills, Montserrat	2/2010	Terrestrial	Disastrous storms in Madeira and western France (Cyclone Xynthia)	Yim (2016a)
El Hierro, Canary Islands	2011-2012	Submarine	Arctic sea ice and Greenland ice sheet retreat; floods and record rainfall in United Kingdom; Hurricane Sandy	Yim (2013); Yim (2018b)
Nishino-shima, Japan	Late 2013	Mixed	North Pacific Blob causing two years without winters in western North America; biodiversity changes; important role in the long-lasting and strong 2014-2016 ENSO	Yim (2016b); Yim (2017)
Mayotte, Indian Ocean	2018	Submarine	South Indian Ocean Blob causing a record-breaking year of disastrous tropical cyclones affecting southeastern Africa	Yim (2019)
Volcano F and Lateiki, Tonga; White Island, New Zealand	8-12/2019	Mixed	South Pacific Blob causing sea-surface temperature of over 5°C above normal 1 million square km ² in surface area; record Antarctica temperature and sea ice retreat	Wong & Yim (2020)

HONG KONG'S RAINFALL DURING 1982

The late March to early April eruption of the El Chichón volcano in Mexico was responsible for the second wettest year in Hong Kong on record during 1982 in spite of the city's location over 14,000 km across the Pacific Ocean. The VEI was ranked 5 and maximum cloud height reached 26 km above sea level while 7 million tonnes of sulphur dioxide and 20 million tonnes of particulates were estimated to be ejected into the stratosphere. Satellite tracking showed westerly drift of the volcanic cloud at an average rate of 20 m/second and was above Hong Kong after eleven days, completely circling the globe in 21 days (Figure 3).

The arrival date of the stratospheric cloud above Hong Kong on 16th April, 1982 coincided with the record low relative humidity measured at ground level (fifth lowest according to the Hong Kong Observatory). This is consistent with the stratospheric influence of aerosols, ice crystals and particulates settling through the troposphere providing condensation nuclei for rain. On 19th April the first trace of rainfall was detected becoming heavier on 22nd April with 70.9 mm.

During 1982 rainfall distribution in Hong Kong shows a bimodal distribution pattern with a first peak in May followed by a second stronger peak in August both accompanied by widespread disastrous floods and landslides. The first peak can be explained by the first- and second-time drift around the globe of the El Chichón eruption cloud while the second peak shows subsequent drifts at least several more times around the globe contributing anomalously large amount of rain and extending the rainy season until November 1982. A total of 6 days with rainfall exceeding 100 mm was recorded, 3 times each during the months of May and August.

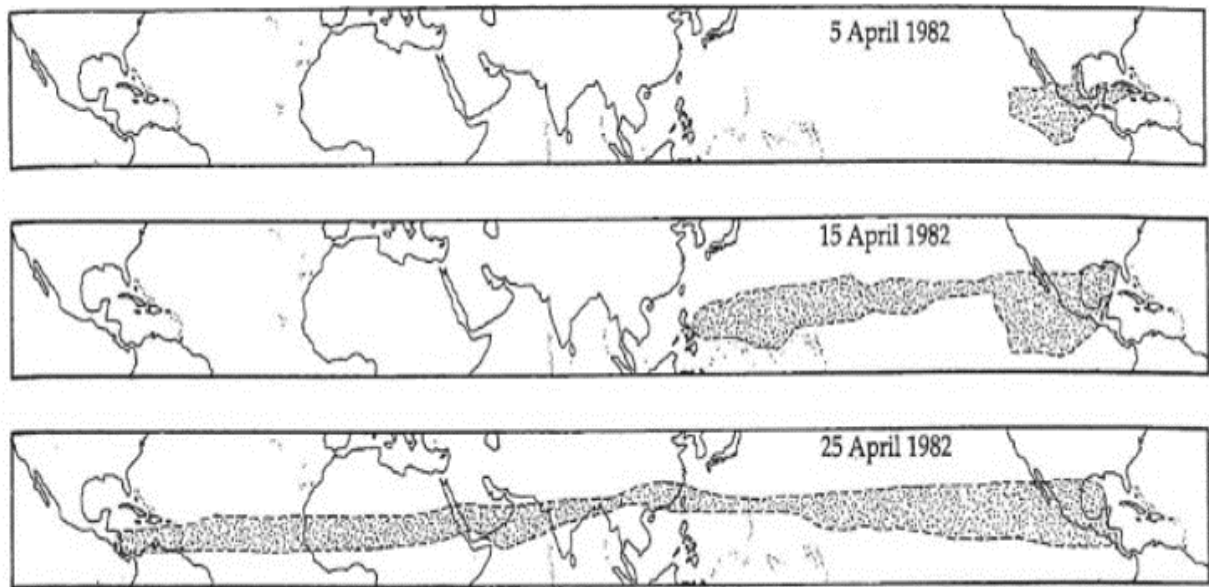


Figure 3 Satellites tracked the westerly drift of the El Chichón eruption cloud reaching above Hong Kong after 11 days and completely circling the globe in 21 days. [Source: Rampino and Self, 1984.]

2014-2016 ENSO

Three volcanic eruptions (Figure 4) releasing geothermal heat into the Pacific Ocean from before November 2013 until November 2015 acting in combination with the Sun was found to be responsible for the longest lasting and strong El Niño this century. Two of the eruptions were initially submarine followed by terrestrial eruptions after new islands were created while the third eruption was entirely terrestrial with basaltic lava flows at $\sim 1000^{\circ}\text{C}$ entering the ocean. Important regional impacts included the suppression of heat loss from the ocean during winter, record high summer temperatures over parts of the land in the Pacific northwest, record sea-surface temperatures in the Pacific northwest for February since the 1980s, record high sea-surface pressure for the years 1949-2014, acceleration in the contraction of Arctic sea ice during the summers of 2014 and 2015, ecological damage including algal blooms and coral bleaching, and, the return to La Niña conditions after sea-surface temperature returned to equilibrium during 2016.

Events in chronological order attributable to the three volcanic eruptions contributing to the development of El Niño conditions include:

- (1) March 2013 Submarine eruption of Nishino-shima - Warming first detected in sea-surface temperature anomalies maps.
- (2) November 2013 Submarine and terrestrial eruption of Nishino-shima - During the northern hemisphere based on Wikipedia.
- (3) February 2014 Sea-surface temperature measurement - 2.5°C above normal.
- (4) June 2014 Island ~ 2.3 km in diameter ~ 110 m above sea level was created - 'Blob' dimension reached 1600 km by 1600 km and 91m deep; spread to the coast of North America with patches off Alaska, Victoria/California and Mexico.
- (5) July-September 2014 Coral bleaching in Hawaii - Reported by the University of Queensland; area of warm water exceeded 9 million km^2 during the peak stage; rapid contraction of Arctic Sea ice during summer and early autumn.
- (6) January-August 2014 Episodic eruption of Nishino-shima with lava flow - Increase in island area; onset of El Niño conditions; abnormally hot summer in Pacific northeast.
- (7) December 2014 Submarine and subaerial eruption of Hunga volcano, Tonga - Occurred during

southern hemisphere summer; year without winter in the Pacific northeast.

- (8) January 2015 Hunga eruption ends - Forecast of strong El Niño conditions; coral bleaching in northern part of Great Barrier Reef.
- (9) March 2015 Severe tropical cyclone Pam - Most intense tropical cyclone of the South Pacific in terms of sustained wind; worst natural disaster in Vanuatu.
- (10) May-June 2015 Eruption of Wolf volcano, Galapagos - Lava flows entered the sea exacerbating the already strong El Niño conditions.
- (11) Early 2016 Blob dissipation - Change to La Niña conditions.

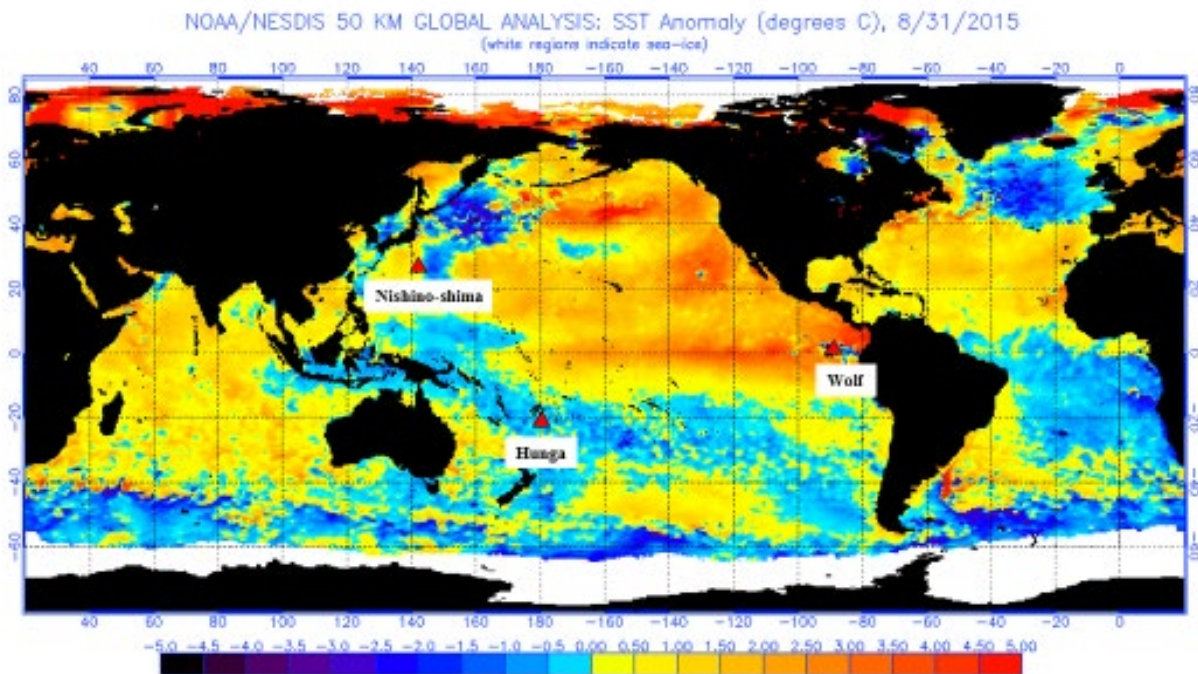


Figure 4 Global map of sea-surface temperature anomalies showing the El Niño conditions on August 31, 2015 under the influence of the North Pacific blob and further exacerbated by the May 25, 2015 Wolf eruption with lava flows into the sea. The locations of the Nishino-shima, Hunga and Wolf volcanoes are also shown. Arctic sea ice retreated further towards the North Pole in the north Pacific compared to the north Atlantic. [Source: NOAA]

CONCLUSIONS

Volcanic eruptions are underestimated as a natural cause of climate change in contrast to the exaggerated but minimal impact of anthropogenic carbon dioxide emissions. Further case studies on volcanic eruptions supported by empirical evidence are needed to change this situation. Climate change is unfortunately politicized by the United Nations and numerous governments and there is no longer any debate based on scientific truth. Hopefully more Earth scientists in the future will continue this important research work to improve our understanding on the causes of climate change.

REFERENCES

- Kamis, J. (2014). Plate climatology (<https://www.plateclimatology.com>).
- Newhall, C.G. and Self, S. (1982). The Volcanic Explosivity Index (VEI): An estimate of explosive magnitude of historical volcanism. *Journal of Geophysical Research* 87(C2): 1231-1238.

The Geological Society of Hong Kong - 40th Anniversary

- Rampino, M.R. and Self, S. (1984). The atmospheric effects of El Chichón. *Scientific American* 250/1: 34-43.
- Wikipedia. Nishinoshima ([https://en.wikipedia.org/wiki/Nishinoshima_\(Ogasawara\)](https://en.wikipedia.org/wiki/Nishinoshima_(Ogasawara))).
- Wong, A. and Yim, W. (2020). 2019-2020 South Pacific Blob and Antarctica warming in February 2020. Saltbush Club. <https://saltbushclub.com/2020/04/28/south-pacific-blob>.
- Yim, W. (2010). Chilean volcano produces trail of destruction. *Imperial Engineer* 11, Spring, 10-11.
- Yim, W. (2011). Volcanic eruptions and climate change: past to present. *Imperial Engineer* 14, Autumn, 12.
- Yim, W. (2012b). Science Focus: How volcanic activity has influenced our rainfall. *South China Morning Post*, April 8, 2012.
- Yim, W. (2013). Climatic impact of the El Hierro eruption from October 2011 to March 2012. *Imperial Engineer* 18, Autumn, 12-13.
- Yim, W. (2016a). Volcanoes and disastrous storms. *Imperial Engineer* 23, Spring, p. 19.
- Yim, W. (2016b). Explanation for the northern Pacific Blob. *Imperial Engineer* 24, Autumn, p. 15.
- Yim, W. (2017). Geothermal heat: an episodic heat source in oceans. *Imperial Engineer* 25, Spring, 14-15.
- Yim, W. (2018a). Geothermal heat and climate variability. *Imperial Engineer* 28, Autumn, p. 24-26.
- Yim, W. (2018b). Geothermal heat and Arctic Sea ice variability. *Imperial Engineer* 27, Spring, p. 26.
- Yim, W. (2019). Climatic impacts of the SW Indian Ocean Blob. *Imperial Engineer* 30, Autumn, p. 24-25.
- Yim, W. (2021). Impact of a volcanic eruption in Mexico on Hong Kong rainfall. *Imperial Engineer* 35, Autumn, p. 14-15.
- Zhang, Y., J.Y. Tsou, Z. Huang, J. Hu and W.W.-S. Yim (2016). Chapter 3 Monitoring of the 2008 Chaitén eruption cloud using Modis data and its impacts. *Intech: Geospatial Technology – Environmental and Social Applications*, 57-73.

ACKNOWLEDGEMENTS

This paper is a contribution by the Hong Kong Volcanoes Study Group. I would like to thank the Organizing Committee of the Geological Society of Hong Kong 40th Anniversary Conference 2022 for inviting me to present this paper.

African Palaeoenvironments and Mammal-hominin Evolution

R.B. Owen

Quaternary deposits in the south Kenya Rift preserve a one-million-year record of environmental change driven by climatic, volcanic and tectonic controls. Climate varied between wet and dry on differing times scales with an overall progressive increase in aridity documented in the Olorgesailie, Magadi and Koora Basins which were particularly wet between about 750–500 ka, dry around 450 ka and subsequently characterised by multiple wet-dry cycles. Volcanism introduced tephra that infilled basins with geothermal fluids influencing microfossil preservation. Tectonism changed basin configurations, overflows and drainage networks.

The Hominin Sites and Paleolakes Drilling Project (HSPDP) under the direction of Prof. Andy Cohen also compared long cores from these basins with other parts of Africa to develop a Plio-Pleistocene record of environmental variability with negative implications for the application of the variability selection hypothesis as a possible driver of hominin change.

地質師在土木工程建設的關鍵角色
A GEOLOGIST PLAYS A KEY ROLE
IN CONSTRUCTION PROJECTS

羅 立

興澳工程顧問有限公司 總經理

摘要

地質學常被認為只是一門基礎科學，對土木工程建設僅止於大地工程資料的提供，然而，土木工程建設常常是需要地質學的專業學養來解決自然界原本就存在的土木工程問題，這邊就以一條經過複雜地質條件的高速公路建設案例來說明，地質學的知識與經驗如何協助土木工程師處理遭遇活動斷層與邊坡滑動等地質問題，地質師亦在此工程建設中扮演了相當重要的關鍵角色。

前言

台灣中部一條東西向的高速公路，稱為國道6號公路南投段，自東向西穿過了盆地、丘陵及山間盆地不同的地形區，也穿過了數條古老斷層與近代斷層，施工過程中遭遇了無法避免的天然與人為的地質災害，整體檢討來說，這個工程初期輕忽了地質條件，引發了不少的地質災害，災後則充分利用地質專業技術，配合適切的工程考量，順利完成道路工程的建設，。

國道6號公路南投段自東行經寬廣的河谷，大部份都在地勢較平坦之河岸階地；往東開始穿過地勢起伏較大之丘陵地形；再往東則進入山間盆地。全路線穿過台中盆地、八卦山中寮丘陵及埔里盆地3地形分區（圖1）。從地形地質條件來看，這條公路以雙冬斷層為界，西邊穿過地質年代較年輕的西部麓山帶地質區，主要由第四紀未膠結或膠結鬆散的沈積層與第三紀碎屑狀沉積岩組成，由於砂岩、頁岩及泥岩岩層抵抗侵蝕能力差異甚大，加上構造運動造成的傾斜排列的地層；東段則通過較老的西部麓山帶地質區東緣、雪山山脈帶地質區西緣及埔里盆地，主要由第三紀碎屑狀沉積岩、輕度變質沉積岩及第四紀未膠結或膠結鬆散的沈積層組成 [3]。就構造地質條件而言，這些地質分區界線是不同地質時代地層的接觸，代表著過去構造活動的位置；地形分區則往往代表著近期構造活動的結果。

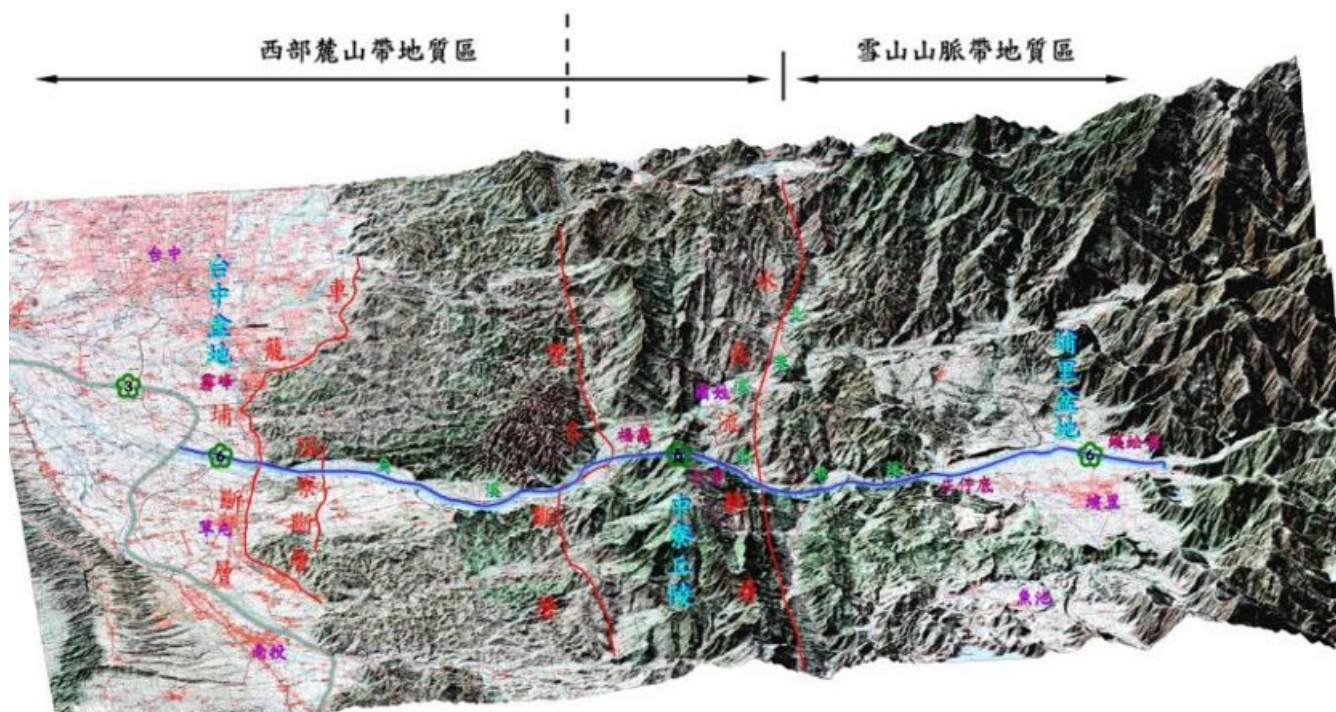


圖1 國道6號公路南投段地形與地質分區

活動斷層

1999年9月21日凌晨，臺灣中部發生芮氏規模為7.3的強烈地震，震央定位於南投縣集集鎮北緯23.85度、東經120.82度位置，後續的研究分析認為此地震係由車籠埔斷層與大茅埔-雙冬斷層2條活動斷層再次活動引起[4]，這個地震不但在不同地區造成長100公里餘的破裂帶，地表隆起高度達 10 公尺[5]，最大垂直位移約達 8公尺，最大水平位移超過 5.8公尺[6]。地震後地質調查資料顯示，這條公路無法避免通過車籠埔斷層，然而此路段是地震地表變位最明顯的區域（圖2、圖3），意味著未來也可能再次遭遇同樣的地質災害。

地震前此路段經過低位河階且需跨越河床，故設計以高架橋形式通過，地震後避免斷層再次錯動造成重大損害與傷亡，以及迅速修復通車的考量，通過斷層帶路段由高架橋變更設計為路堤。然而，變更路堤段的範圍與長度如何決定呢？

參與本工程的地質師利用震後補充地質鑽探資料描繪出車籠埔斷層地下主要錯動位置，配合震後地表變形、張裂、錯動位置分布（圖4），加入地質資料的不確定性與可能風險考量，評估未來斷層再活動可能影響的區域，最後配合地形條件與橋梁單元決定路堤長度，其中，車籠埔斷層西側地表破裂分布已鄰近臺3線，故路堤段西端就以臺3線為界；路堤段東端則至少涵蓋地

表破裂分布範圍，並配合西側銜接橋梁整體單元擬定（圖5），目前該路段已增設舊正交流道（圖6）[7]。另外，地震斷層錯動時，鄰近區域均有明顯地震動增益現象，本路堤段距離車籠埔斷層地表破裂線10公里範圍內，故設計地震力考量近斷層效應，並綜合考量路權用地範圍、路基穩定及填土材料本身特性等因素，就近以路塹、基礎或隧道開挖料作為路堤填料。

這個案例來看，活動斷層再次活動的影響絕非土木工程師可以利用工程技術處理，反而需要靠地質學的專業本能，以及對地質資料的不確定性與地質行為重現偏差的瞭解，方能因應活動斷層再次活動引發的地質災害。

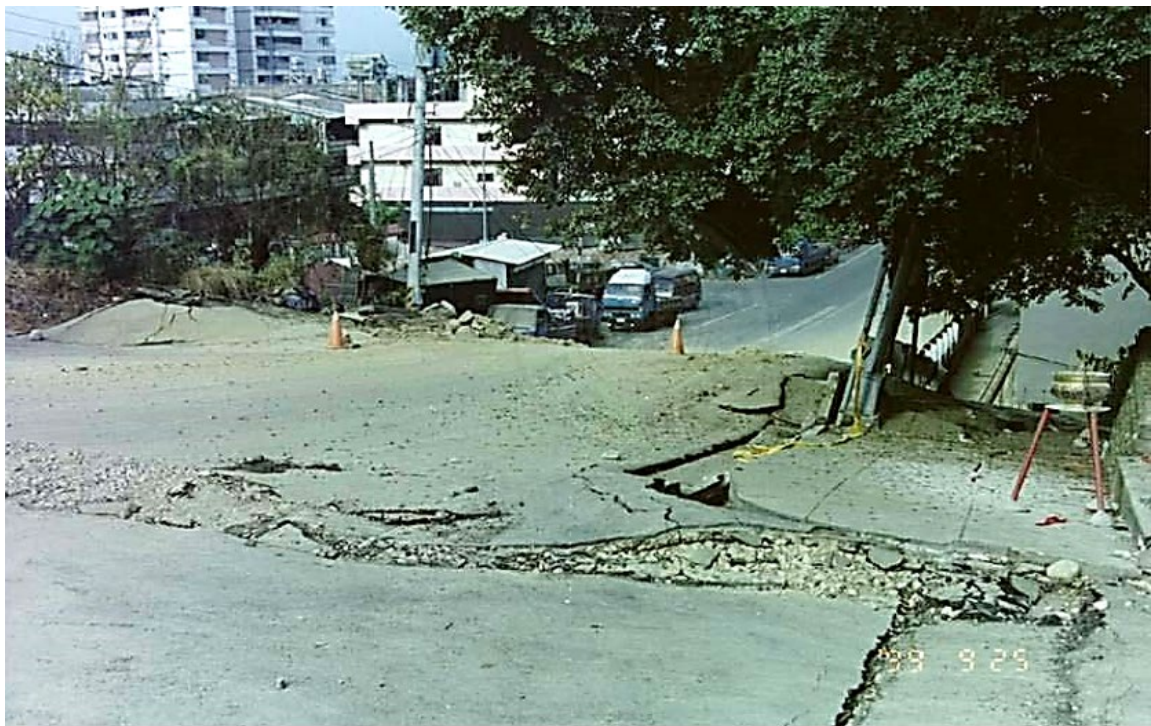


圖2 車籠埔斷層附近區域的地表變形



圖3 車籠埔斷層附近區域的地表裂隙

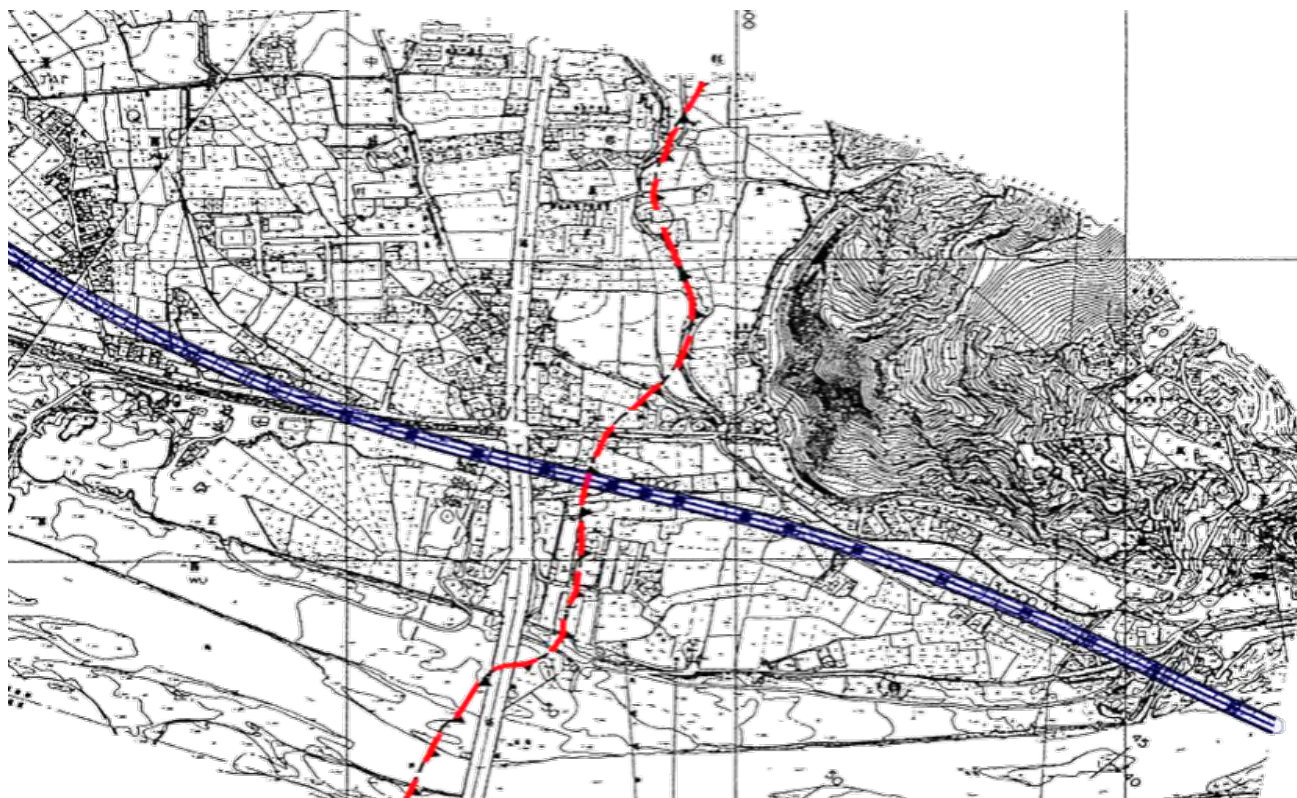


圖4 震後地表變形、張裂、錯動位置分布

(修改自國道六號南投段工程大地工程調查綜合評估報告，2009)

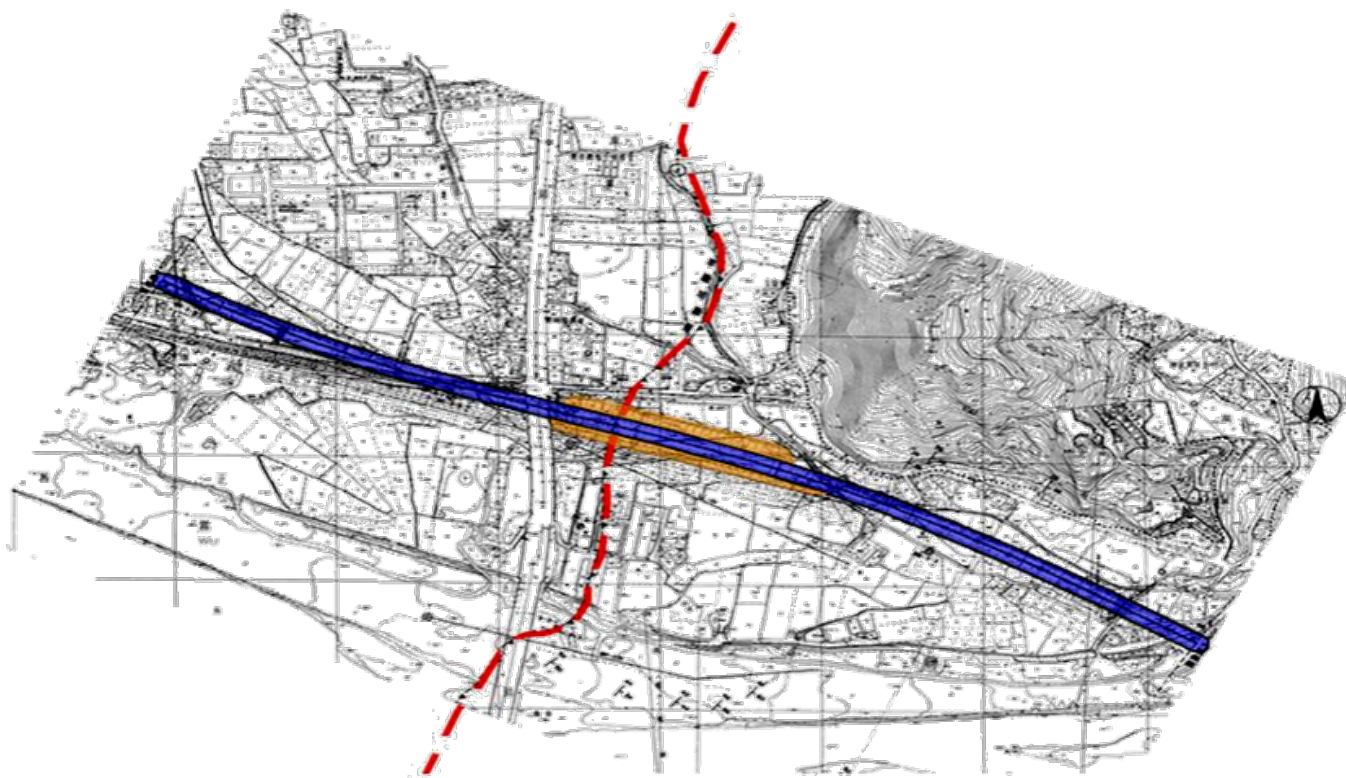


圖5 國道六號南投段通過車籠埔斷層路段結構變更設計
(修改自國道六號南投段工程大地工程調查綜合評估報告, 2009)



圖6 國道六號南投段通過車籠埔斷層路堤段
(修改自<https://hsg5877520.pixnet.net/blog/post/21184906>)

邊坡滑動

同一個工程建設，某路塹段邊坡開挖完成，進行邊坡保護工程時發生地質災變，大規模表層土石順著坡面向下滑動。這個邊坡地表崩積層及風化岩盤厚度可達10餘公尺，下伏地層為鉅厚塊狀灰黑色硬頁岩（圖7）。這個邊坡採相同形式的格梁/灌漿錨筋保護工設計施工（局部格梁地錨），包括開挖坡度、灌漿錨筋深度及灌漿錨筋間距，當邊坡開挖與護坡工程完成後，施作道路邊溝時切挖邊坡坡腳（圖8），大規模表層風化破碎岩層失去支撐順坡面滑落，此現象亦連動影響下部的風化岩層向下坍滑（圖9）。

地質災害發生後，地質師進一步評估開挖邊坡地質條件顯示，水長流層塊狀灰黑色硬頁岩岩體節理發育佳且具開口，表層岩體甚易風化破碎，且邊坡開挖移除大量上覆土岩極易在短時間內產生平行坡面之解壓節理，這些特性加總起來邊坡表層風化岩層順坡面方向坍滑之潛能甚高；加上坡頂至坡趾採V:H=1.0:1.2相同坡度開挖，造成解壓解理發育在相同深度，意即人為形成連續且大規模的類順向滑動面；另錨固表層土岩的自由型格梁灌漿錨筋長度也均相同僅3公尺，既然地質調查資料已顯示邊坡地表崩積層及風化岩盤厚度達10餘公尺，3公尺的灌漿錨筋長度明顯無法達成錨固效果外，反而將表層土岩連結成人為表層順向滑動單元；因此，未重視下伏地層水長流層鉅厚塊狀灰黑色硬頁岩易發育解壓節理的地質特性，加上相同開挖坡度設計，形成人為順向滑動面，這些條件偏向指示此邊坡破壞並非都歸屬於天然地質災害，實則有很大部分是沒有深入瞭解邊坡地質條件造成的人為地質災害。

後續依據對地質災害機制與地質條件的深入研析與瞭解，清除表層浮動土石後，將邊坡分割為為兩大台階形式，避免上部土岩移除後的解壓解理連貫形成類順向滑動面。其中，上層邊坡採V:H=1.0:1.5坡度開挖，灌漿錨筋改採5公尺/8公尺長度交錯排列；下層邊坡則採V:H=1.0:1.2坡度開挖，灌漿錨筋改採8公尺長度，將錨固深度加深，避免錨固深度仍在解壓解理嚴重發育深度內（圖10）。

僅憑粗淺的地質瞭解與經驗評估地質條件，輕忽看似簡單的土木工程項目，往往是造成人為地質災害的原因之一，這個案例來看，地質師必須能深入瞭解工程建設所在的地質特性，提供可能地質災害機制與潛能資料，土木工程師方能正確進行最適當的工程設計。

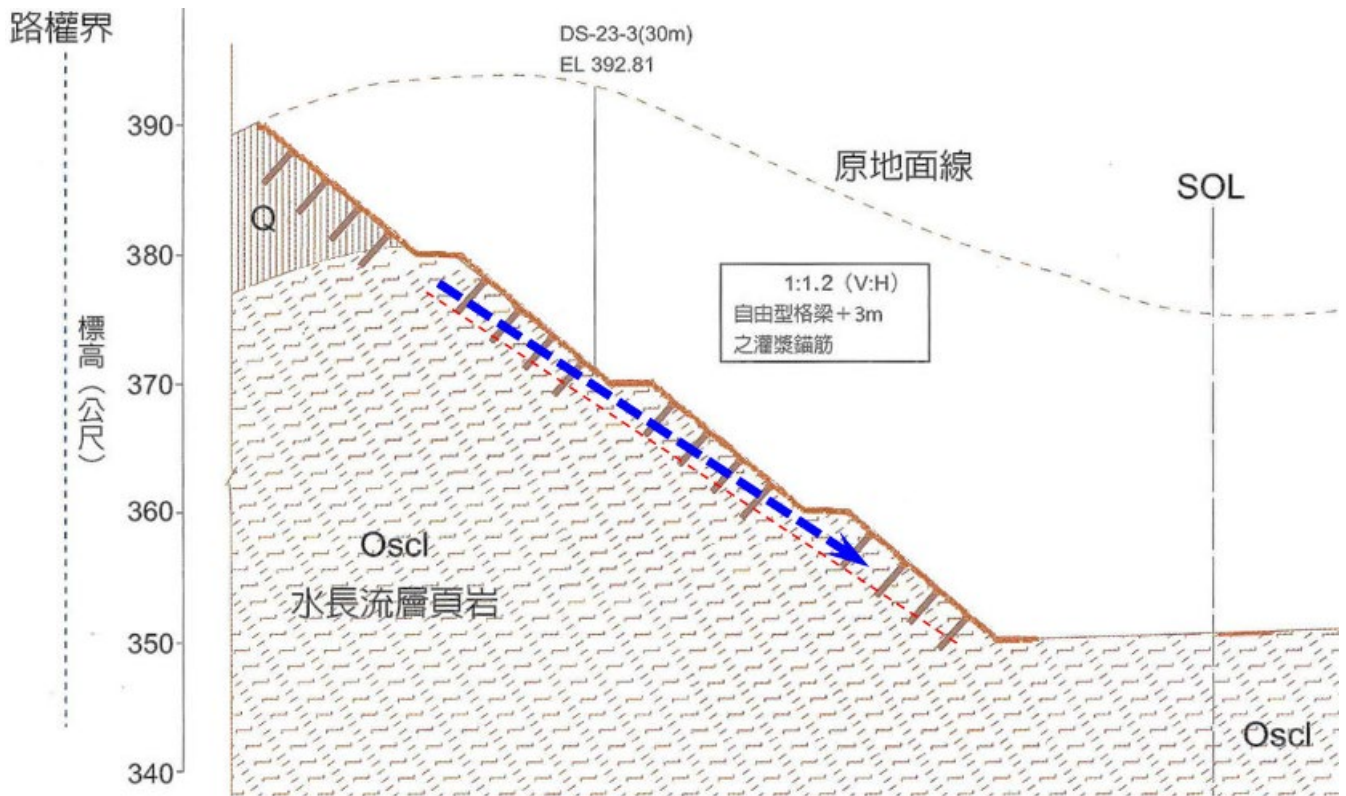


圖7 國道六號南投段路塹邊坡坍塌前保護工與地質剖面示意圖

(修改自國道6號興建專輯, 2010)



圖8 國道六號南投段路塹邊坡坡趾邊溝工程



圖9 國道六號南投段路塹邊坡坍塌

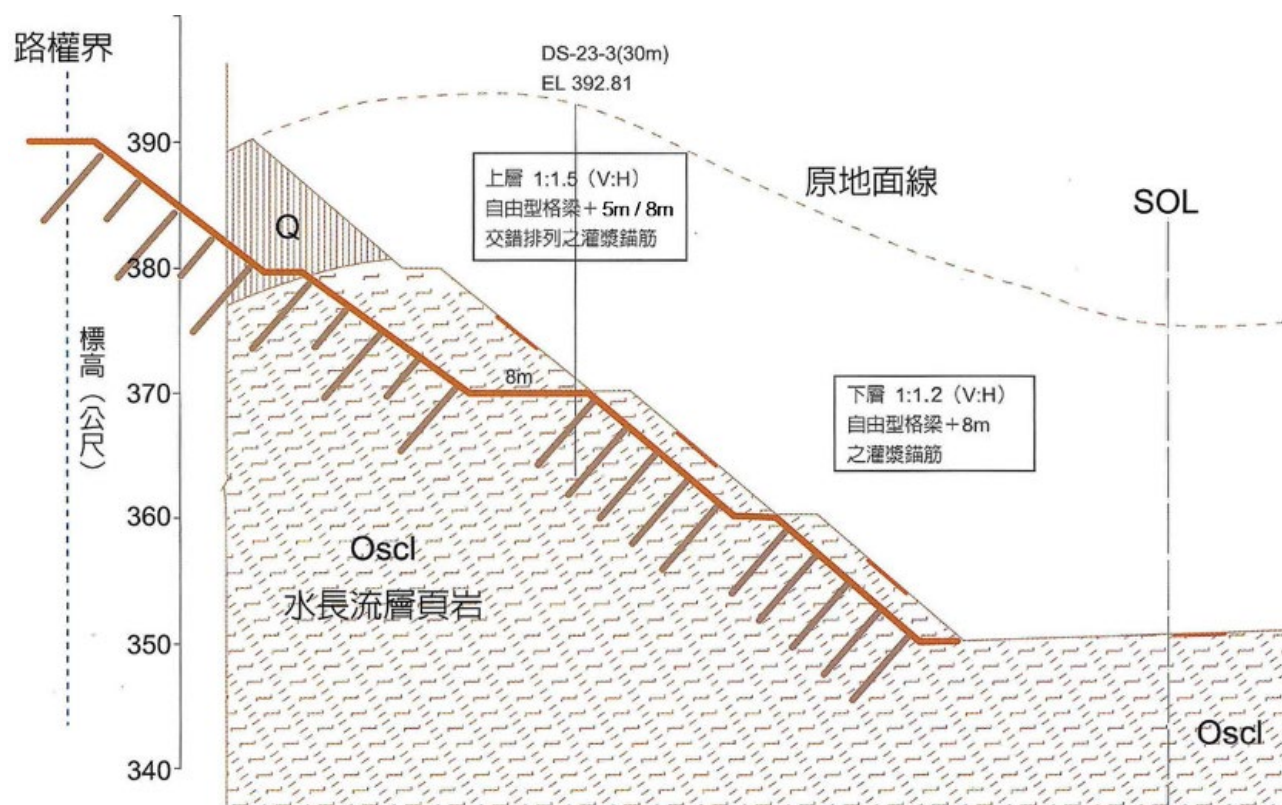


圖10 國道六號南投段路塹邊坡坍塌後保護工與地質剖面示意圖

(修改自國道6號興建專輯, 2010)



圖11 國道六號南投段路塹邊坡坍滑後邊坡保護工施工

隧道洞口橋台基礎

這條高速公路通過地形地質變化相當複雜的區域，曲流作用造成了陡峭的山脊（圖12），山脊趾部持續受河水侵蝕，邊坡除了坡度陡峭外，坡面岩體均破碎且不穩定（圖13），受限於坡度陡峭，若於邊坡設置橋梁橋台將有大規模的邊坡開挖，因此將橋台延伸進入隧道內，為了避免橋台荷重引發邊坡不穩定，故於隧道內施作基樁，將橋台荷重傳導至深部的堅實岩盤，當作橋台的基礎，然而基樁長度要如何決定呢？

地質師依據隧道下方的地質鑽探岩心破碎程度，決定基樁深度必須穿過表層破碎的岩體以及邊坡可能之滑動面（圖14）。

這是一個相當簡單卻極為重要的地質專業技術展現，因為破碎岩盤與堅實岩盤的接觸位置常常是邊坡破壞的滑動面，荷載橋台的基樁若未穿過破碎岩盤，不但無法提供橋台的支承力，反而增加了邊坡滑動的潛勢。



圖12 國道六號南投段橋梁與隧道銜接位置地形狀況



圖13 國道六號南投段隧道洞口邊坡破碎岩體

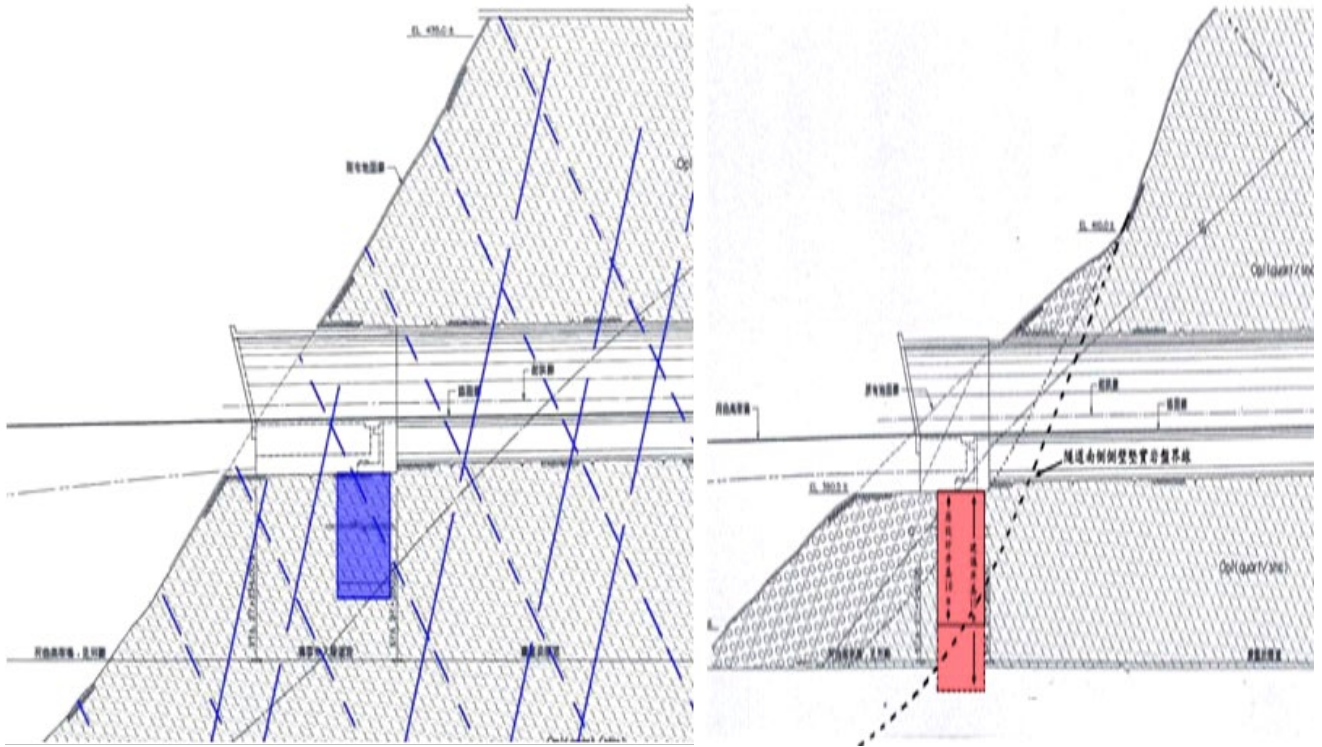


圖14 隧道洞口依據地質鑽探結果調整基樁深度

結語

地質是輔佐土木工程重要的專業項目之一，未善用地質調查成果或輕忽工程地質條件，均可能造成不可預期的地質災害；地質專業絕非獨善其身的科學研究與自我存在的工作內容，應是適切提供土木工程可用性與專業性的參考資料，地質學的不確定性與地質行為重現偏差性跟土木工程學精準定量性本就存在溝通的障礙[9]，地質師如何消除此障礙是成為土木工程建設的關鍵角色的重要課題，除了地質專業深入研究與瞭解外，也必須熟悉土木工程的需求，力求將定性化的資料轉化成定量的數據，這是跨越土木工程溝通障礙的重要作為，也是成為土木工程關鍵角色的重要一步。

礙於長摘要篇幅，地質學專業運用在土木工程的眾多案例與經驗，將在口頭報告中再多作說明。

參考文獻

1. 經濟部 (2010) , 「全國法規資料庫 - 地質法」 ,
<https://law.moj.gov.tw/LawClass/LawAll.aspx?pcode=J0020052> (2022年1月8日) 。
2. 林正洪 (2021) , 大自然年刊 , 143期 , 第4-8頁。
3. 交通部臺灣區國道新建工程局 (2010) , 「國道6號興建專輯-大地工程及隧道篇」 , 第14-15頁。
4. 王乾盈 (2013) , 「車籠埔斷層如何動」 , 國立中央大學應用地質研究所 ,
<http://gis.geo.ncu.edu.tw/921/faults/faultobs.htm> (2022年1月9日) 。
5. 陳文山 (2004) , 「921 集集地震斷層的特性」 , 2004年台灣活動斷層與地震災害研討會 , 國立成功大學。
6. 馬國鳳 (2002) , 「集集大地震破裂行為」 , 自然科學簡訊 , 第十四卷第一期。
7. <https://hsg5877520.pixnet.net> (2022年4月3日) 。
8. 李鐵峯 (2002) , 災害地質學 , 北京出版社。
9. 董家鈞 (2020) , 「知之為知之 , 不知為不知 , 是知也 : 淺談地質模型不確定性」 , 大地技師 , 20期 , 第73-82頁。
10. 交通部臺灣區國道新建工程局 (2009) , 「國道六號南投段工程大地工程調查綜合評估報告」。

MOLYBDENUM AND BORON ISOTOPIC EVIDENCE FOR CARBON-RECYCLING VIA CARBONATE DISSOLUTION IN SUBDUCTION ZONES

Yunying Zhang^{1,2}, Min Sun¹

¹ Department of Earth Sciences, The University of Hong Kong, Pokfulam Road, Hong Kong, China

² Key Laboratory of Ocean and Marginal Sea Geology, South China Sea Institute of Oceanology, Innovation Academy of South China Sea Ecology and Environmental Engineering, Chinese Academy of Sciences, Guangzhou 510301, China

Analytical technologies for non-traditional isotopes have been recently developed and non-traditional isotopes have been successfully used in study of geological, environmental and biological processes. In this study, Mo and B isotopes are analyzed and used to discuss carbon recycle in subduction zone.

Subduction zones are critical sites for carbon recycling between the earth surface and interior, which modulate the global carbon budget and influence Earth's climate (e.g., Kelemen and Manning, 2015).

In subduction zones, carbon can be injected into the deep mantle by subduction of carbonate-bearing rocks or be returned to the atmosphere via degassing of volcanoes (Kent and Muttoni, 2008). Decarbonation, a metamorphic reaction between carbonate and silicate minerals, has been envisaged to be the primary mechanism for carbon transfer from the subducted oceanic slab to mantle wedge and then to arc magmas (Kerrick and Connolly, 2001). However, thermodynamic modeling suggests that limited CO₂ can be released by such reactions because decarbonation takes place at much greater pressures and temperatures than those in typical subduction zones, which led to the conclusion that most carbon is possibly retained in the slab and brought to the deep mantle (Poli et al., 2009). In order to balance the carbon flux in subduction zones, carbon release through dissolution of carbonate minerals has been highlighted based on recent studies of fluid inclusions in high-pressure metamorphic rocks (e.g., Frezzotti et al., 2011). Despite considerable progress on carbonate dissolution (Manning et al., 2013), such as the discovery of dissolved carbonate species in diamond-bearing fluid inclusions from the Alps ultrahigh-pressure rocks (Frezzotti et al., 2011) and fluid-mediated carbonate removal accompanied by silicate precipitation (Ague and Nicolescu, 2014), the lack of direct evidence from arc lavas hampers our understanding of carbonate dissolution, which is critical for understanding the carbon recycling mechanism. Thus it remains unclear to what extent the subducted carbonates can be recycled back to the overriding plate.

As a moderately mobile element, molybdenum (Mo) can be efficiently mobilized by slab fluids and conveyed to sub-arc mantle wedges (König et al., 2016). It is further suggested that Mo isotopes can track the recycled supracrustal materials in the mantle source of arc magmas (Willbold and Elliott, 2017). For instance, the Lesser Antilles arc lavas have $\delta^{98}\text{Mo}$ values heavier than that of the depleted upper mantle ($\delta^{98}\text{Mo} = -0.20 \pm 0.06\text{‰}$; Freymuth et al., 2015), which have been ascribed to the incorporation of black shales with heavy Mo isotopic compositions into the mantle wedge (Freymuth et al., 2016). However, marine carbonates also give heavier $\delta^{98}\text{Mo}$ values ($1.43 \pm 0.97\text{‰}$, 2SD; Voegelin et al., 2009; Romaniello et al., 2016) relative to the depleted upper mantle (Fig. 1a), which are inherited from seawater that is enriched in heavy Mo isotopes. In this study, we distinguish source of black shales from carbonates by comparing their boron (B) isotopic compositions, as the former ($\delta^{11}\text{B} = -12.6 \pm 8.9\text{‰}$, 2SD; Romer et al., 2014) and latter ($\delta^{11}\text{B} = 22.5 \pm 4.4\text{‰}$, 2SD; Hemming and Hanson, 1992; Zhang et

al., 2017) have notably lighter and heavier $\delta^{11}\text{B}$ values, respectively, than that of the depleted upper mantle ($\delta^{11}\text{B} = -7.1 \pm 0.9\text{‰}$, 2SD; Marschall et al., 2017) (Fig. 1b). Thus, it is expected that if the mantle wedge was hydrated by carbonate-bearing fluids, arc volcanic rocks from such a source would have remarkable heavier Mo and B isotopic compositions than those from the normal mantle. In addition, B can be used as a powerful reference for the mobility of Mo and carbonate dissolution, since B is highly mobile in hydrous fluids.

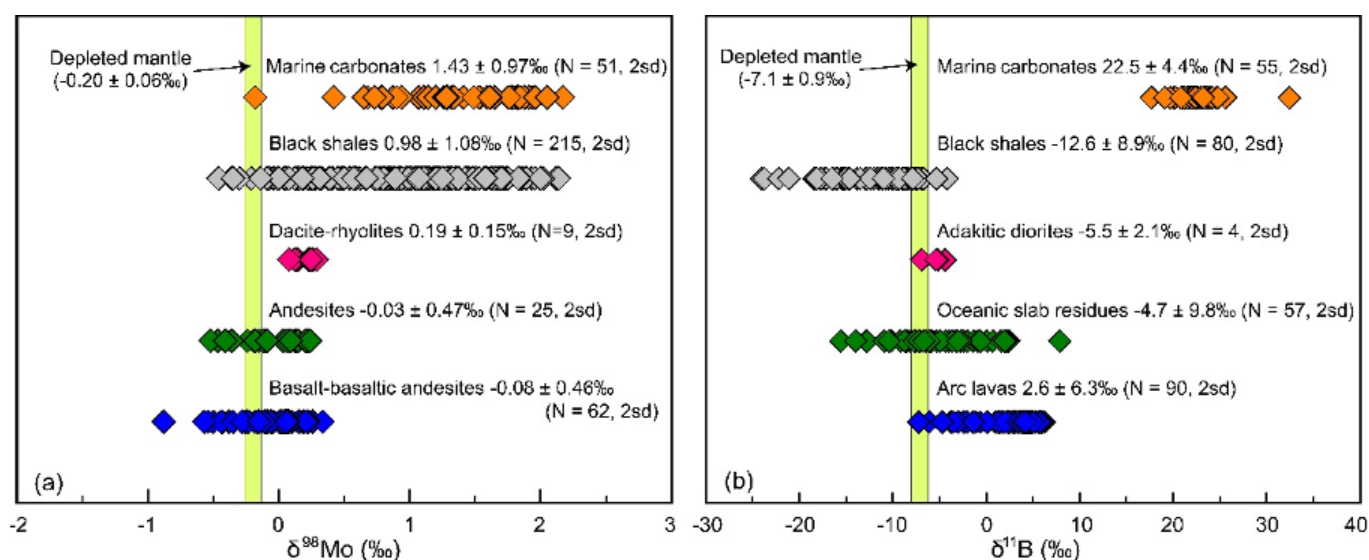


Fig. 1. (a) Compilation of $\delta^{98}\text{Mo}$ values for arc lavas, carbonates and black shales reported in the literature. (b) Compilation of $\delta^{11}\text{B}$ values for arc lavas, adakitic diorites, subducted slab residues, black shales and carbonates reported in the literature.

In order to explore the role of slab-derived fluids in the deep carbon cycle, we analyzed Mo and B isotopic compositions for the Silurian arc andesites (426 Ma) and adakitic andesites (422 Ma) from the Chinese North Tianshan, which represent partial melts of fluid-modified mantle wedge and dehydrated oceanic crust, respectively. The older arc andesites yielded $\delta^{98}\text{Mo}$ values (0.33–1.08‰) significantly higher than that (about -0.20‰) of the depleted mantle. Because their limited range of SiO_2 (53.8–55.3 wt.%) precludes differentiation as a cause for their variable $\delta^{98}\text{Mo}$ values and Mo isotopic fractionation solely by fluid mobilization is limited ($\leq 0.3\text{‰}$), the elevated $\delta^{98}\text{Mo}$ values is ascribed to the incorporation of crustal material with heavy Mo isotopes in the mantle wedge. Since marine carbonate is featured by both heavy Mo and B isotopes and our arc andesites also give heavy $\delta^{11}\text{B}$ (-1.63 to +4.00‰) values (Fig. 2a), we consider that marine carbonate was possibly involved as a component of the subducted slab, which modified Mo–B isotopic compositions of the mantle source. The positive correlations between Mo and B and between $\delta^{98}\text{Mo}$ and Ba/Rb (Fig. 2b–2c) suggest transport of subducted carbonates to the overlying mantle wedge via slab fluids, thus providing robust evidence for transfer of subducted carbon to the overriding plate by carbonate dissolution. Further insights into the involvement of marine carbonates and fluid metasomatism for the arc andesites is provided by the $\delta^{98}\text{Mo}$ –Ce/Mo systematics. Samples of the arc andesites and adakitic andesites show different trends in $\delta^{98}\text{Mo}$ –Ce/Mo diagram (Fig. 2d). A highly linear ($R^2 = 0.88$) and negative correlation between $\delta^{98}\text{Mo}$ and Ce/Mo is defined for the arc andesites, while a horizontal trend exists for the adakitic andesites. The high linearity between $\delta^{98}\text{Mo}$ and Ce/Mo for the arc andesites strongly suggests a binary mixing process. The high- $\delta^{98}\text{Mo}$ end-member probably represents carbonate. On the other hand, a downward extension of the $\delta^{98}\text{Mo}$ –Ce/Mo trend line for the arc andesites intersects with the average $\delta^{98}\text{Mo}$ line ($\delta^{98}\text{Mo} = -0.42\text{‰}$) for the adakitic andesites near the high-Ce/Mo end of the adakitic samples (Fig. 2d). Therefore, the low- $\delta^{98}\text{Mo}$ and high-Ce/Mo end-member for the arc andesites should be same oceanic crustal component that carries similar Mo isotopic signals for the adakitic andesites. Assuming an average $\delta^{98}\text{Mo}$ value of 1.43‰ for natural marine carbonate (Voegelin et al., 2009; Romaniello et al.,

2016), Ce/Mo ratio of the carbonate end-member can be determined by extrapolating the trend line for the arc andesites. The result suggests 41–78% contribution of Mo from the carbonate end-member, as shown in the mixing line of Figure 2d. In contrast, the younger adakitic andesites have light $\delta^{98}\text{Mo}$ (–0.48 to –0.27‰) and $\delta^{11}\text{B}$ (–9.43 to –2.05‰) values, implying an isotopically Mo- and B-light source without carbonate signature. Since heavy ^{98}Mo and ^{11}B were preferentially transported to the fluid phase during early slab dehydration, the remarkably light $\delta^{98}\text{Mo}$ and $\delta^{11}\text{B}$ values support a dehydrated oceanic crust as the magma source of the adakitic andesites. Based on the contrasting Mo–B isotopes for such two kinds of andesites, our study concludes that most carbonates can be dissolved and removed from the subducted slab to the overriding plate during oceanic subduction.

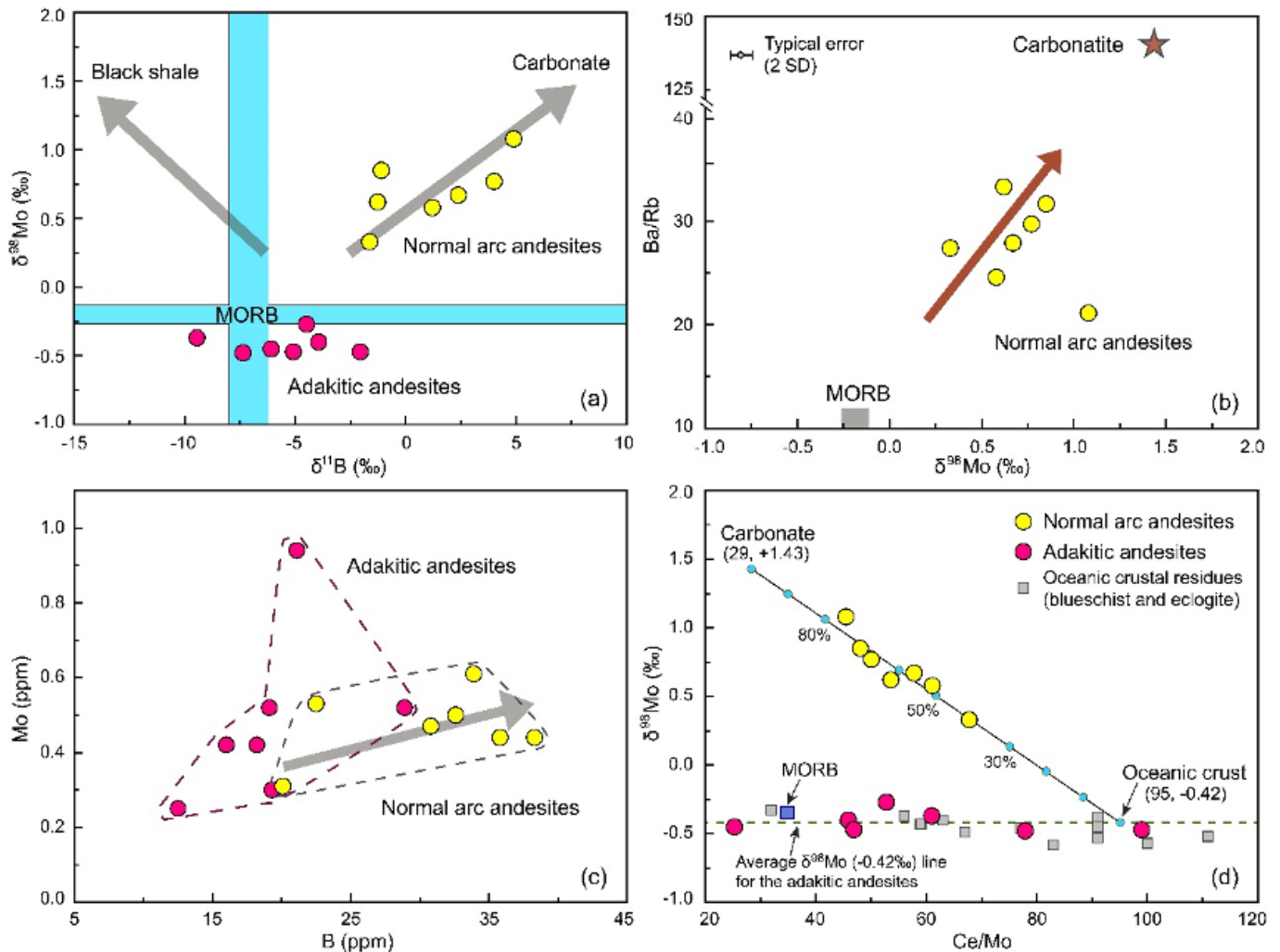


Fig. 2. (a) $\delta^{98}\text{Mo}$ versus $\delta^{11}\text{B}$, (b) Ba/Rb versus $\delta^{98}\text{Mo}$, and (c) Mo versus B diagrams. (d) The $\delta^{98}\text{Mo}$ versus Ce/Mo plot showing the Mo contributions from carbonate and subducted oceanic crust.

REFERENCES

- Ague J. J. and Nicolescu S. (2014) Carbon dioxide released from subduction zones by fluid-mediated reactions. *Nat. Geosci.* 7, 355–360.
- Freymuth H., Vils F., Willbold M., Taylor R. N. and Elliott T. (2015) Molybdenum mobility and isotopic fractionation during subduction at the Mariana arc. *Earth Planet. Sci. Lett.* 432, 176–186.
- Freymuth H., Elliott T., van Soest M. and Skora S. (2016) Tracing subducted black shales in the Lesser Antilles arc using molybdenum isotope ratios. *Geology* 44, 987–990.
- Frezzotti M. L., Selverstone J., Sharp Z. D. and Compagnoni R. (2011) Carbonate dissolution during subduction revealed by diamond-bearing rocks from the Alps. *Nature Geosci.* 4, 703–706.

- Hemming N. G. and Hanson G. N. (1992) Boron isotopic composition and concentration in modern marine carbonates. *Geochim. Cosmochim. Acta* 56, 537–543.
- Kelemen P. B. and Manning C. E. (2015) Reevaluating carbon fluxes in subduction zones, what goes down, mostly comes up. *Proc. Natl. Acad. Sci. USA* 112, E3997–E4006.
- Kent D. V. and Muttoni G. (2008) Equatorial convergence of India and early Cenozoic climate trends. *Proc. Natl. Acad. Sci. USA* 105, 16065–16070.
- Kerrick D. and Connolly J. (2001) Metamorphic devolatilization of subducted marine sediments and the transport of volatiles into the Earth's mantle. *Nature* 411, 293–296.
- König S., Wille M., Voegelin A. and Schoenberg R. (2016) Molybdenum isotope systematics in subduction zones. *Earth Planet. Sci. Lett.* 447, 95–102.
- Manning C. E., Shock E. L. and Sverjensky D. A. (2013) The chemistry of carbon in aqueous fluids at crustal and upper-mantle conditions: Experimental and theoretical constraints. *Rev. Mineral. Geochem.* 75, 109–148.
- Marschall H. R., Wanless V. D., Shimizu N., Strandmann P. A. E. P. V., Elliott T. and Monteleone B. D. (2017) The boron and lithium isotopic composition of mid-ocean ridge basalts and the mantle. *Geochim. Cosmochim. Acta* 207, 102–138.
- Poli S., Franzolin E., Fumagalli P. and Crottini A. (2009) The transport of carbon and hydrogen in subducted oceanic crust: An experimental study to 5 GPa. *Earth Planet. Sci. Lett.* 278, 350–360.
- Romaniello S. J., Herrmann A. D. and Anbar A. D. (2016) Syndepositional diagenetic control of molybdenum isotope variations in carbonate sediments from the Bahamas. *Chem. Geol.* 438, 84–90.
- Romer R. L., Meixner A. and Hahne K. (2014) Lithium and boron isotopic composition of sedimentary rocks — The role of source history and depositional environment: A 250 Ma record from the Cadomian orogeny to the Variscan orogeny. *Gondwana Res.* 26, 1093–1110.
- Voegelin A. R., Nägler T. F., Samankassou E. and Villa I. M. (2009) Molybdenum isotopic composition of modern and Carboniferous carbonates. *Chem. Geol.* 265, 488–498.
- Willbold M. and Elliott T. (2017) Molybdenum isotope variations in magmatic rocks. *Chem. Geol.* 449, 253–268.
- Zhang S., Henahan M. J., Hull P. M., Reid R. P., Hardisty D. S., Hood A. and Planavsky N. J. (2017) Investigating controls on boron isotope ratios in shallow marine carbonates. *Earth Planet. Sci. Lett.* 458, 380–393.

非洲納米比亞矽藻土的工程特性
Analysis of Engineering Properties for Diatomaceous Earth in Namibia, Africa

馬秋柱
MA Qiu-zhu

中交第四航務工程勘察設計院
CCCC-FHDI Engineering Co. Ltd., China

摘要：在實施納米比亞某專案的勘察過程中，遇到了一種特殊土——矽藻土。通過X射線衍射試驗和熱場發射電鏡掃描進一步確定了矽藻土的成分組成和微觀結構。針對矽藻土的特殊工程性質，現場採取土樣進行了大量細緻的室內土工試驗分析，並運用多種原位試驗手段，測試矽藻土的原位力學強度。測試結果表明矽藻土的含水量非常高、密度極低、孔隙比大，通過對比發現矽藻土的室內試驗剪切強度與通過原位試驗獲得的原位剪切強度較為一致；但其壓縮性卻顯著偏高，與土體的強度不匹配。

關鍵字：矽藻土；剪切強度；原位測試；高壓縮性

Abstract: One type of special soils called diatomaceous earth was encountered during the execution of site investigation in Namibia. The composition and microstructure of the diatomaceous earth were obtained by X-ray diffraction and thermal field emission scanning test. Detailed laboratory analysis tests and various in-situ tests were carried out to obtain the shear strength aiming at the special engineering properties. The results show that the water content of diatomaceous earth is very high, while the density is very low and the porosity is large. It is found that the shear strength of diatomaceous earth obtained by laboratory tests is consistent with that from the in-situ tests. However, compared with the shear strength, its compressibility is significantly higher which appears not matching with its shear strength.

Keywords : diatomaceous earth; shear strength; in-situ testing; high compression

國際上對矽藻土的認識始於19世紀，1870年矽藻土在美國密蘇里州西南部首次被發現。中國于1935年由楊鐘健在山東省濰坊市臨朐縣採集到上新世形成的灰白色矽藻土[1]，此後在我國雲南騰冲地區也發現了上新世時期形成的矽藻土[2]，但這些矽藻土形成年代久遠，逐漸失去了土的特性，已經成為岩狀矽藻土或稱“矽藻岩”。近些年來對矽藻土的研究也在逐漸增加，並引起更多人的關注，國內外的一些學者曾對矽藻土的工程特性做了一些研究，但大多都集中在矽藻土的工業應用領域。

矽藻土的工程特性相關研究是比較少見的，國際上關於矽藻土工程應用的案例極為罕見。目前國際上已有報導的案例只有墨西哥城和日本大阪關西機場專案[3-4]，國內尚未類似的工程案例。雖然近年來也有國內外學者在矽藻土力學特性方面有所涉獵[9]，但研究程度遠未達到工程應用的水準，因此研究矽藻土的工程特性有著重要的價值。

1.0 工程概況

納米比亞某專案擬在近岸海域填築人工島以形成陸地，並在其上建造碼頭泊位和集裝箱堆場以擴展現有港口的吞吐運輸能力。在該專案的勘察過程中發現，在工程區域內下覆有厚度超過20m的一類非常特殊的土體。這類“特殊土”呈黃綠色、顆粒分佈類似粉土，但其密度非常之小與泥漿接近，且含有硫化氫氣體。後經過研究，確定這種“特殊土”為矽藻土。區域內地質結構（圖1），表層為厚度約2m的鬆散沉積物，其下為厚度約15m的密實砂層，再往下為厚度約25m的矽藻土層，底層為密實砂和膠結砂礫層。

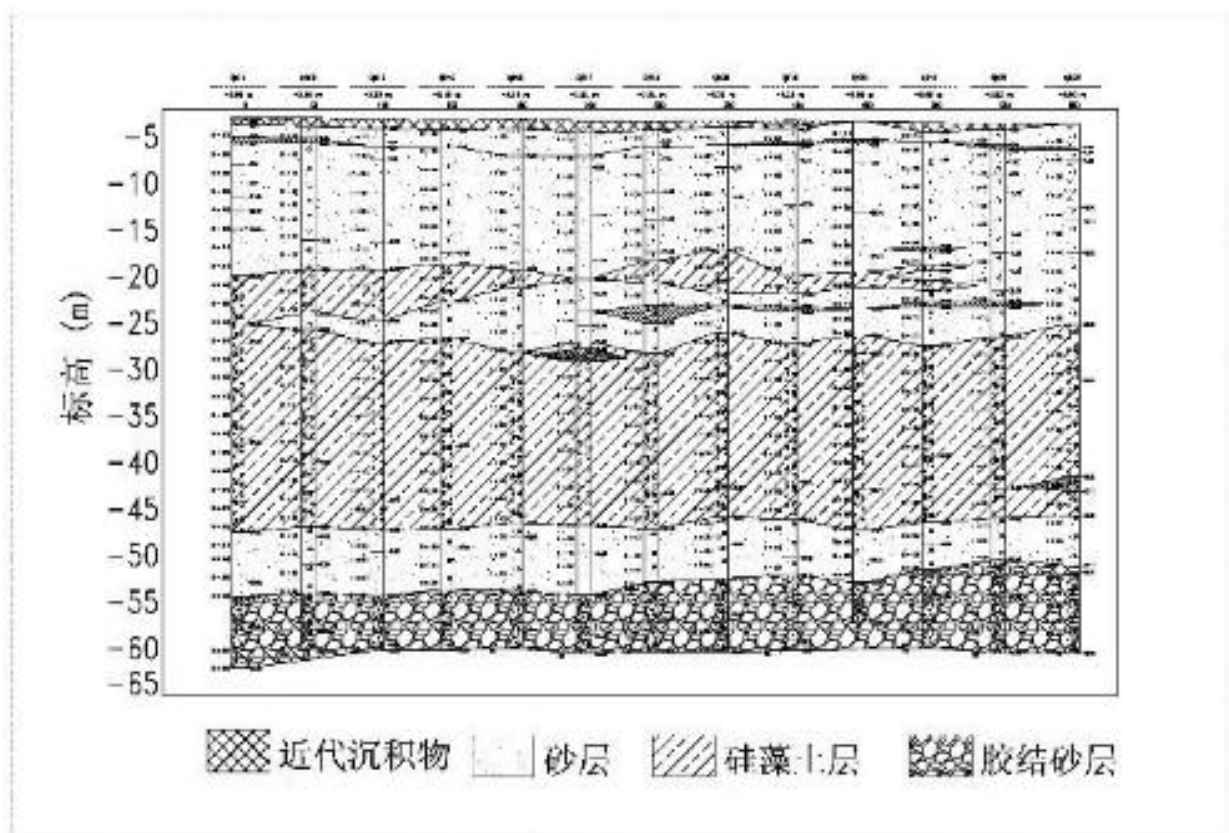


圖1 工程場區地基結構

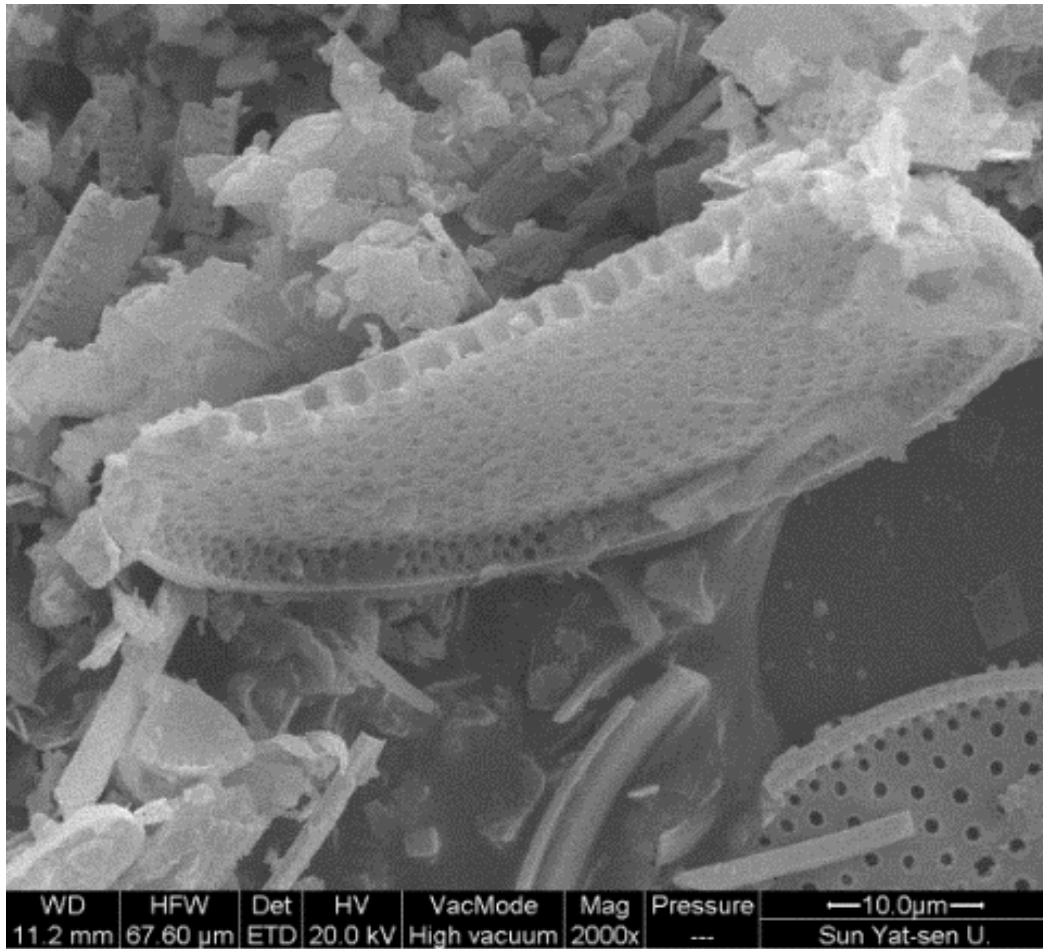


圖2 電鏡下的矽藻土微觀結構

2.0 矽藻土一般特徵

岩土材料複雜的物理力學性能是其微結構系統狀態和整體行為的集中體現[5]，因此瞭解工程中遇到的“特殊土”的微觀結構有助於分析和解釋其物理力學性能和土體工程行為的表現特徵。矽藻土的化學成分主要是無定形的 SiO_2 ，含有少量的 Al_2O_3 、 Fe_2O_3 、 CaO 、 MgO 等和有機質。

本次勘察對土層樣品開展了X射線衍射試驗和INCA能譜儀及熱場發射電鏡掃描。試驗結果表明該區“特殊土”為典型的矽藻土，通過電鏡試驗的圖片可以清晰觀察到矽藻殘骸。矽藻土微觀結構（圖2），矽藻呈現圓盤狀、針狀、羽狀等，另外還有矽藻骨骼破裂後的碎片，矽藻遺骸上佈滿直徑 $0.5\sim 1.0\mu\text{m}$ 的原生孔洞。

3.0 矽藻土物理指標測試

工程區域內矽藻土岩心（圖3），綠灰至灰綠色、夾雜淺灰褐色，似粉土狀，局部夾薄層至極薄層粉細砂、質輕、多孔。矽藻土位於海床面之下，其上部為強透水的砂層，土體處於完全飽和狀態。

根據土工試驗測試結果，含水率202%（164%~262%），天然（飽和）密度為1.19 g/cm³（1.13~1.28g/cm³），幹密度0.4 g/cm³（0.3~0.5 g/cm³），孔隙比4.5%（3.7%~5.6%），塑限57%（38%~87%）。顆粒分析試驗表明，絕大多數顆粒分佈在5~50μm，從顆粒分析角度而言，絕大多數為粉粒，顆粒分析曲線（圖4）。



圖3 矽藻土樣品

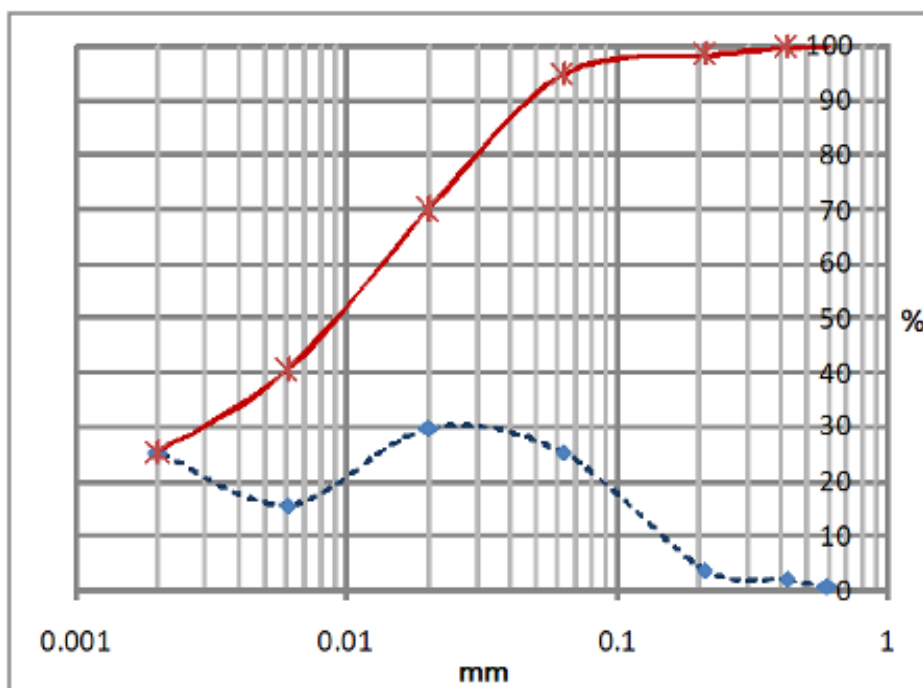


圖4 矽藻土顆分曲線

顆粒分析結果與Zeevaert (1957) 的分析結果基本一致[3]，只是小於 $2\mu\text{m}$ 的顆粒含量為31.8%，較“墨西哥土”的 40% 略低。

從土工試驗的物理指標和顆粒分析結果來看，本區土體屬於非常典型的矽藻土，物理指標與“墨西哥土”類似[4]，但指標分佈範圍較墨西哥土更為集中，這可能與本專案區域覆蓋範圍較小、地層更為均勻有關。

4.0 矽藻土力學試驗指標

國際上對矽藻土的工程特性研究極少，且所有遇到矽藻土的工程均出現了較大的沉降問題，如墨西哥、大阪關西機場等。對於矽藻土體剪切強度方面的應用，尚未見有關工程實踐的報導。因此在本次勘察中通過室內試驗和原位測試對矽藻土的強度和變形特徵進行了深入研究。

勘察中利用Shelby薄壁取土器採取原狀矽藻土試樣進行土工試驗。考慮到矽藻土上方覆蓋有約17m的覆蓋層，其中15m為密實砂層，因此土樣的卸荷效應會比較明顯，試驗過程中需要先進行一定的應力恢復才能更好類比土體原位剪切情況，因此室內試驗主要通過三軸固結不排水試驗來研究其剪切強度指標。試驗結果（表1），可以看出強度指標與墨西哥土的試驗結果十分接近。

土层	统计项目	三轴试验指标CU			
		C_{cu}	ϕ_{cu}	C'_{cu}	ϕ'_{cu}
		kPa	°	kPa	°
矽藻土	样本数量	24	24	25	25
	最大值	85.5	19.8	48.6	43.3
	最小值	24.3	11.4	10	34.5
	平均值	52.7	14.1	26.1	39
	变异系数	0.28	0.14	0.37	0.06

表1 矽藻土三軸剪切試驗指標

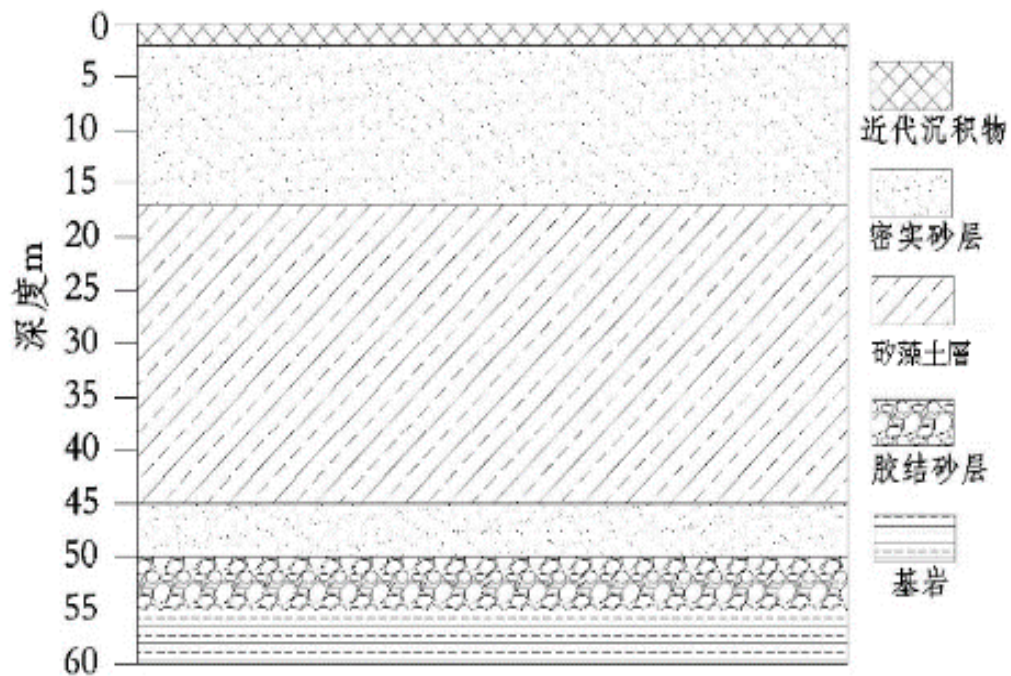


圖5 砂藻土地層分佈

4.1 砂藻土層的地質結構分析

根據區內地層的分佈結構和砂藻土的分佈特徵，簡化後的地質結構模型見圖5，上部2m為近代鬆散沉積層、2~17m為砂層、17~45m為砂藻土層，45m以下為密實砂層、膠結砂層和基岩。

而土層分佈特徵，估算砂藻土層中點的有效上覆壓力約為190kPa。通過區內41個樣本的固結試驗，測得的砂藻土層的平均前期固結壓力為218kPa（143~425kPa，變異系數0.25），因此砂藻土層的平均有效上覆壓力可按200kPa考慮。

4.2 室內三軸剪切試驗強度分析

選取砂藻土中點附近土樣獲得的壓密 - 不排水試驗（Consolidated Undrained）總強度剪切強度指標，繪製總應力與剪切強度的關係曲線（圖6）；在原位應力區間內（200kPa左右），砂藻土層的剪切強度在95~110kPa。根據室內三軸剪切強度試驗結果繪製的總強度包絡線（圖7），獲得總強度指標平均值 $C_{cu}=48\text{ kPa}$ ， $\phi_{cu}=15.8^\circ$ 。根據莫爾強度理論及上覆平均有效壓力，計算得在原位應力狀態下的平均強度為105kPa。

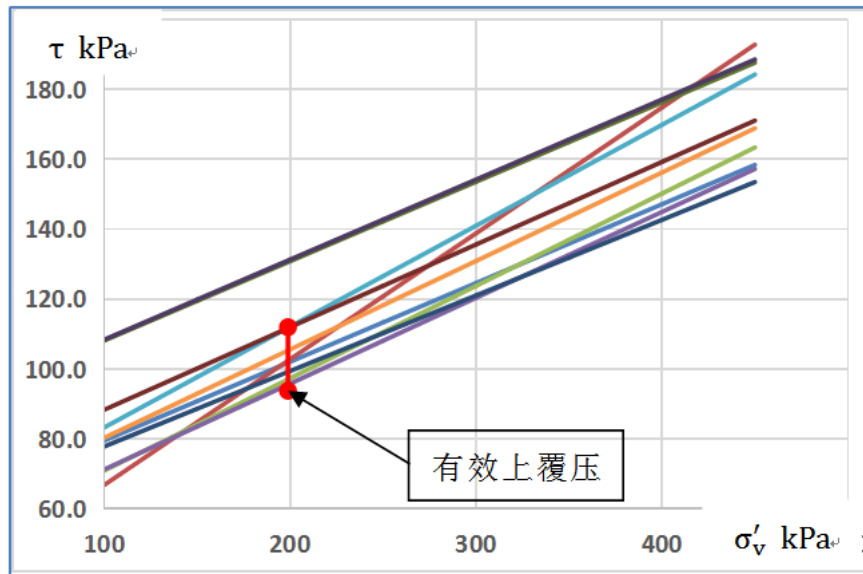


圖6 總應力與剪切強度關係曲線

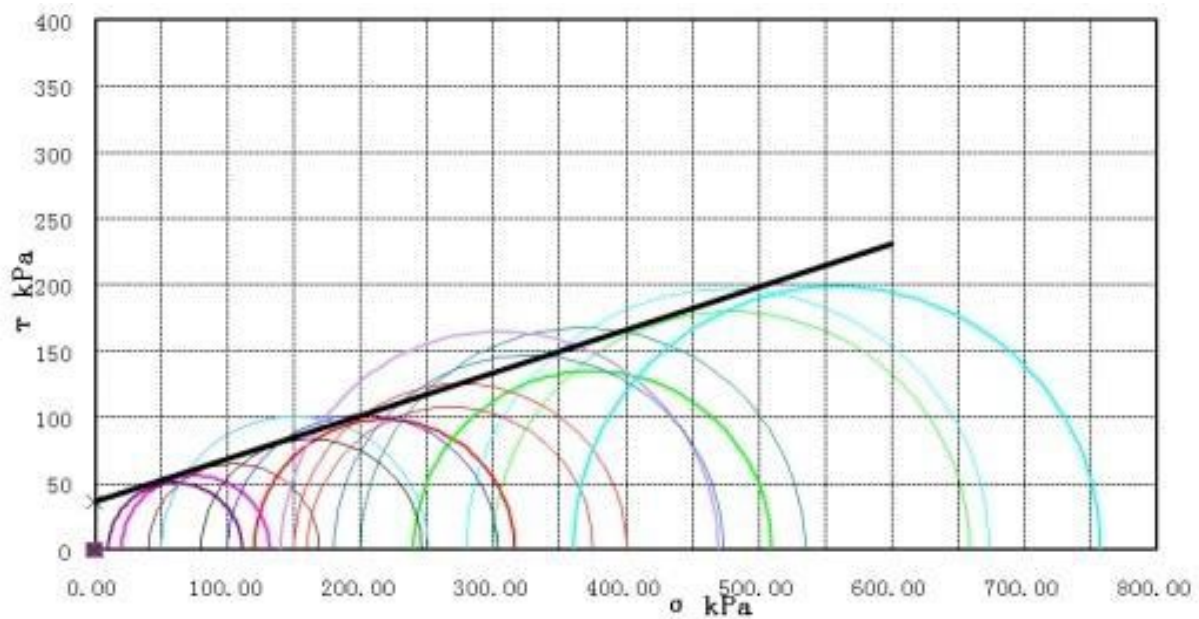


圖7 總強度包絡線

4.3 原位測試強度分析

現場選取RK09號鑽孔進行原位十字板並與標貫試驗（SPT）的試驗結果進行對比（圖8），剪切強度與標準貫入試驗擊數的擬合關係符合

$$Su=6N_{70} \quad \text{公式 (1)}$$

說明矽藻土原位剪切強度與標準貫入試驗的關係符合一般黏性土的經驗關係模型[6]。

矽藻土中的標貫擊數值 N_{70} 隨深度的分佈變化情況（圖9），土層中部標貫平均值為16擊；根據上述關係模型（ $S_u=6N_{70}$ ）計算得其剪切強度為96kPa，這一結果與CU試驗給出的矽藻土剪切強度非常一致，從而表明通過公式（1）採用標貫試驗獲得矽藻土剪切強度是可靠的。

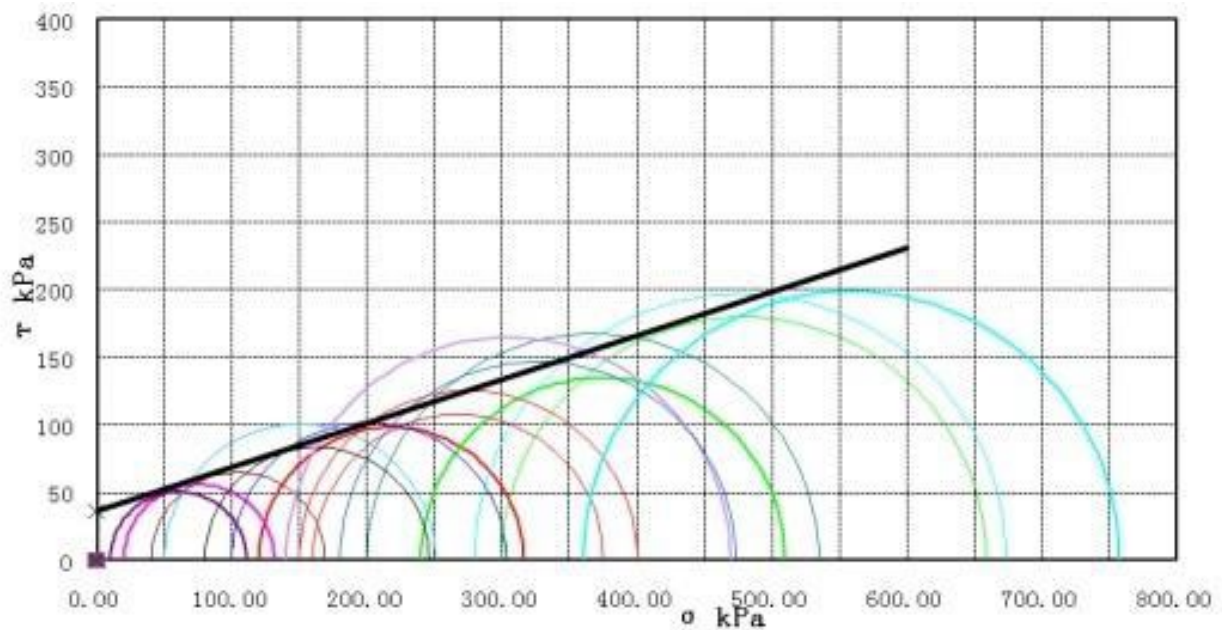


圖8 原位十字板與標貫試驗擬合關係

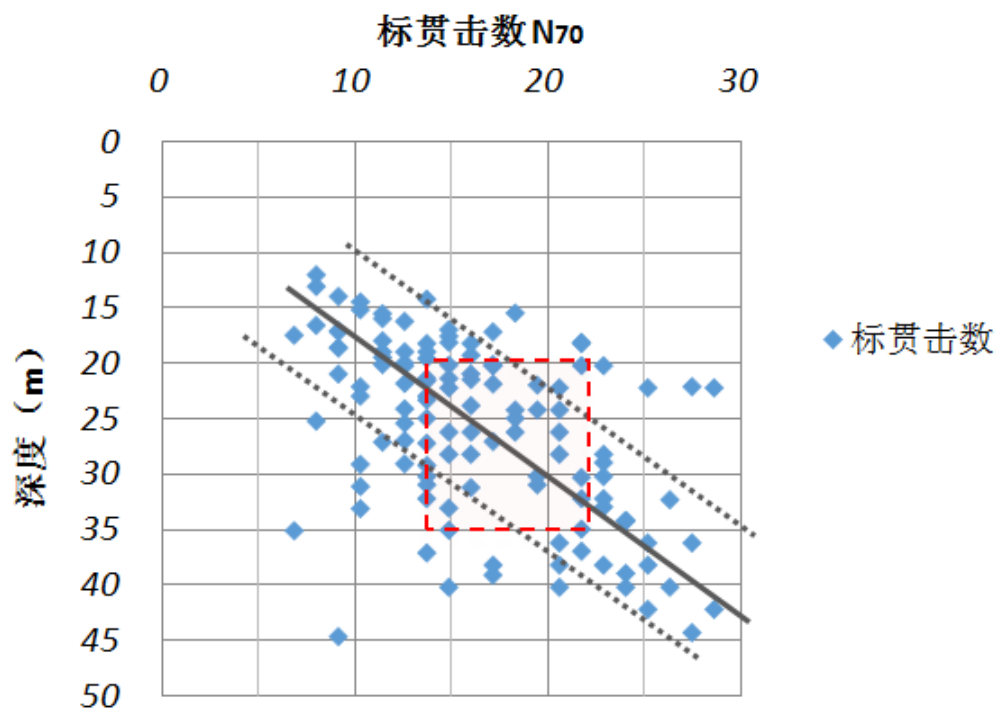


圖9 標貫擊數隨深度變化的分佈情況

5.0 矽藻土的變形特性分析

根據50幾個樣本的室內壓縮試驗，矽藻土層的壓縮指標統計情況（表2）矽藻土層的典型壓縮（含回彈和再壓縮）曲線（圖10）。根據室內試驗所得到的矽藻土層的平均壓縮模量，按各壓力計繪製壓力-壓縮模量變化情況（圖11）；由（圖11）可知，矽藻土層在原位應力作用下的壓縮模量在2.4MPa左右，屬高壓縮性土與其剪切強度指標嚴重不匹配。這種不匹配現象可能與矽藻的微觀結構有關，因為矽藻土顆粒多為非磨圓狀的粉土級顆粒組成（圖2），所以在現場試驗和室內試驗中均表現出良好的抗剪性能和較高的強度指標，而另一方面由於其孔隙比非常之高，從而又表現出很高的可壓縮性。

通過其微觀結構可知矽藻土為一種強結構性土，一旦施加的應力超過其前期固結應力，結構會發生劇烈變化，甚至可能導致矽藻土顆粒（原生矽藻外殼）的破裂，致使地面出現非常大的沉降[7-8]。

層號	土層	Item	壓縮模量（Es）			壓縮係數（Cv）			前期 固結 壓力 Pc	壓縮 指數 Cc	回彈 指數 Cs
			50 ~ 100 kPa	100 ~ 200 kPa	200 ~ 400 kPa	50 ~ 100 kPa	100 ~ 200 kPa	200 ~ 400 kPa			
			MPa			10 ⁻³ cm ² /s			kPa	--	--
5-1	矽藻土	統計個數	59	59	59	57	57	57	41	41	25
		最大值	4.072	4.596	4.893	9.270	7.430	6.080	425.7	2.740	0.289
		最小值	1.089	1.389	1.423	3.000	1.940	1.100	143.4	0.936	0.096
		平均值	1.894	2.401	2.781	5.973	4.934	3.788	218.0	1.791	0.174
		標準差	0.57	0.69	0.70	1.21	1.11	0.93	63.77	0.47	0.04
		變異係數	0.30	0.29	0.25	0.20	0.22	0.25	0.29	0.26	0.23

表2矽藻土層壓縮參數

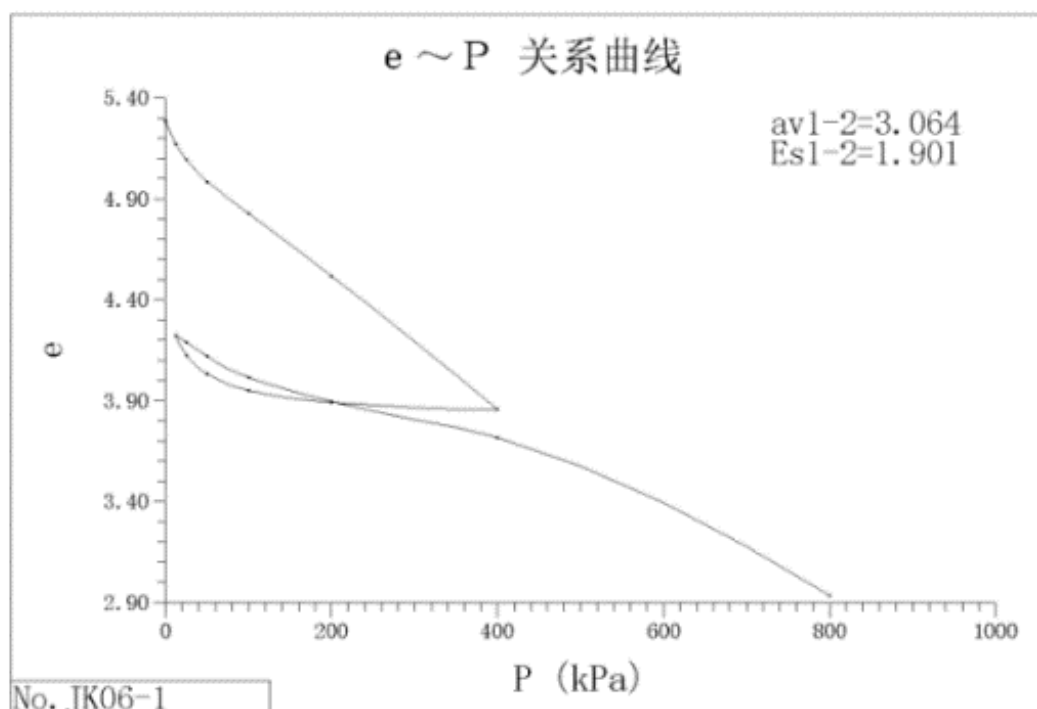


圖10 矽藻土典型壓縮曲線

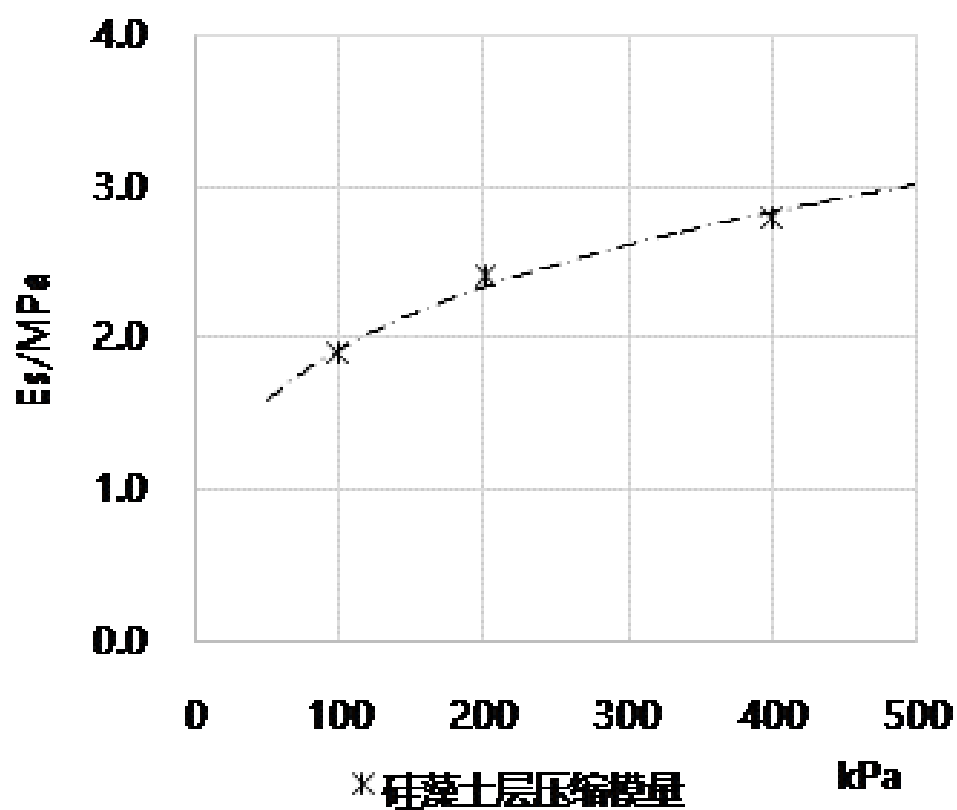


圖11 壓縮模量變化曲線

矽藻土強度指標與壓縮指標嚴重不匹配，可能導致矽藻土在長期剪應力作用下的剪切特性和流變特性具有很大的不確定性。從理論上講剪應變特性和壓縮應變都受控於土體孔隙比，因此可以推斷矽藻土的長期抗剪強度可能會遠小於其短期抗剪強度。

6.0 結論

- 1) 試驗表明工程區域遇到的“特殊土”為典型的矽藻土，其含水率和孔隙比極高而密度非常小，其密度甚至與泥漿密度相當；因此在後期工程灌注樁施工中經常出現大塊的矽藻土漂浮於灌注樁迴圈泥漿中，甚至堵塞泥漿溢流口。
- 2) 矽藻土中，通過原位標貫試驗和經驗公式計算所獲得土體強度與室內三軸試驗結果吻合度極高。根據標貫擊數及相關的經驗公式可以獲得較為可靠的矽藻土強度指標。
- 3) 由於矽藻土孔隙比非常之高，在室內試驗中表現出很高的可壓縮性。另外通過其微觀結構可知矽藻土為一種強結構性土，一旦施加的應力超過其前期固結應力，土體結構會發生劇烈變化，可導致嚴重的地面沉降問題。
- 4) 矽藻土強度指標與壓縮指標嚴重不匹配，可能導致矽藻土在長期剪應力作用下的剪切特性和流變特性具有很大的不確定性。

參考文獻：

- [1] 楊鐘健. 中國中新統蠟螈化石的首次發現. 古生物學報, 1965(3): 455-457, 460-462.
- [2] 陳庸勳, 貝豐, 宋振亞, 等. 雲南騰冲盆地矽藻土中有機質的初步研究. 礦物岩石, 1986(4): 260-269.
- [3] Mesrig, Rokhsar A, Bohor B F. Composition and Compressibility of Typical Samples of Mexico City Clay. Geotechnique, 1975, 11(12):527-554.
- [4] Diaz-Rodríguez J, Abraham. Diatomaceous Soils: Monotonic Behavior. International Symposium on Deformation Characteristics of Geomaterials. Seoul, Korea, 2011.
- [5] 張華傑, 孫秋, 胡昕, 洪寶寧. 岩土微結構試驗研究綜述. 土工基礎, 2008(4): 49-52.
- [6] Joseph E Bowles. Foundation analysis and Design. 5th edition. Peoria, Illinois: The McGraw-Hill Companies, Inc., 1996.

- [7] Robert W. Day. Engineering Properties of Diatomaceous Fill. Journal of Geotechnical Engineering, 1995, 121(12): 908-910.
- [8] Locat J, Tanaka H. A new class of soils: fossiliferous soils. Proceedings of the Fifteenth International Conference on Soil Mechanics and Geotechnical Engineering, Istanbul, Turkey. Volumes 1-3, 2001:2295-2300.
- [9] 洪振舜,立石義孝,鄧永鋒. 天然矽藻土的應力水準與孔隙空間分佈的關係. 岩土力學, 2004(7): 1023-1026.

A SIMPLE TECTONIC MAP AS A LEARNING AID TO THE COMPLEX GEOLOGY OF CHINA

Tseng Hing Tin, Kingston

Retired Doctor, Geology Enthusiast

From his own experience in learning the complex geology of China, the author finds that a simple and reliable tectonic map is a very effective learning tool. It enables meaningful comparison of geology with the major tectonic influence on China. One very simple tectonic map of China has been published in a paper by Chinese and American scholars (Ref. 1). Upon further research, the author found that the map was largely based on another map by YF Zheng, WJ Xiao and Guochun Zhao (Ref. 2). However, these maps were drawn in a diagrammatic format and may not match easily with local geologies. The author has reworked the map so that the tectonic details are cartographically corrected based on national maps and research references (Ref. 1-6). The result is a tectonic map that can be used together with a general geological map of China (Fig. A, Ref. 7)

Here, I shall briefly outline the five tectonic tiers in this revised simplified tectonic map of China (Fig. A):

Tier 1. The Central Asian Orogenic Belt; or Altaids.

Tier 2. Ancient Continental Nuclei: North China Craton and Tarim Craton.

Tier 3. The Central China Orogen and the related Tethyan Domain.

Tier 4. South China Block, Tibetan Block and the related Tethyan Domain.

Tier 5. Cenozoic Foldbelt of Taiwan.

Finally, I use two examples to illustrate how one can appreciate the geology of China using this Simplified Tectonic Map.

Example 1. With the map one can easily correlate the Archean rock formations in North China (see the pink colored area labeled 1 in Fig. B) with the North China Craton outlined in Fig. A.

Example 2. The extensive NE to SW aligned granitic formations in SE China (in Fig. B) are readily correlated with the Cathaysia Foldbelt in South China in Fig. A.

CONCLUSION

A simplified tectonic map is helpful in learning the complex geology of China. Based on published data, the author has edited a simplified tectonic map of China, such that the map's tectonic details are correlated to geolocations. This should improve the map's usefulness as a learning tool for beginners to the geology of China.

從中國地塊構造簡圖去認識中國地質

曾慶田
退休醫生 地質愛好者

從過去幾年的學習經驗，筆者發覺使用一張簡單的中國地塊構造圖對學習中國地質屬事半功倍。在眾多的地塊構造圖中，筆者選擇了一張頗受認可，又相當簡單的地塊構造圖為基礎。此圖把今天的中國劃分為五大構造層區。筆者的參考圖出自2018年中美學者的方案（參考1）。查其出處，這圖主要參考了鄭永飛，肖文交，趙國春於2013年刊於 Gondwana Research 的中國地質板塊構造圖（參考2）。筆者以這圖為基礎，再根據重點參考資料（參考1-6）把原圖中圖像化的表述修改為按實際位置的構造圖（圖A; 參考7）。

以下簡述此圖中的中國地塊五大層區：

- (第1層) 中亞造山帶. 又稱阿爾泰型造山帶
- (第2層) 古大陸核. 包括: 華北克拉通和塔里木克拉通
- (第3層) 中國中央造山帶與特提斯地域
- (第4層) 華南板塊、西藏地塊與相關之特提斯地域
- (第5層) 台灣新生代褶皺帶

在下面我用兩個簡例來說明如何使用這地圖去學習中國的地質。

例一: 在華北有多處太古宇的岩層（見圖B），在圖A我們可見其位置屬於華北克拉通範圍之內。

例二: 在中國之東南方有東北至西南排列的花崗岩層（見圖B），在圖A我們可見其位置屬於華夏褶皺帶範圍之內。

結論

簡單的地塊構造圖可以幫助初學者加深了解中國的地質。筆者根據重點參考資料有關地塊構造的確實位置而整理了一份地塊構造簡圖，以期增進初學者對中國地質之理解及興趣。

REFERENCES

1. Robert J. Stern, 李世民 Shi-Min Li, G. Randy Keller. Continental crust of China: A brief guide for the perplexed. *Earth-Science Reviews*. 179, 4/18, 72-94
2. YF Zheng, WJ Xiao, 趙國春 Guochun Zhao. Introduction to tectonics of China. *Gondwana Research* 23, 2013, 1189-1206
- 3 Pirajno F. The Geology and Tectonic Settings of China's Mineral Deposits. Springer Science. 2013
4. 中國地質圖集. 地質出版社.北京. 2002
5. Tianfeng Wan. The Tectonics of China. Data, Maps and Evolution. Higher Education Press. Beijing. 2010
6. Minngguo Zhai (Editor). Precambrian Geology of China. Springer 2015. Precambrian Geology of China
7. 曾慶田 中國地塊解讀.與地質愛好者一起探索. Tseng Hing Tin. Reading China's Rock Formations. Discovering with geology enthusiasts. 7/21. Hong Kong

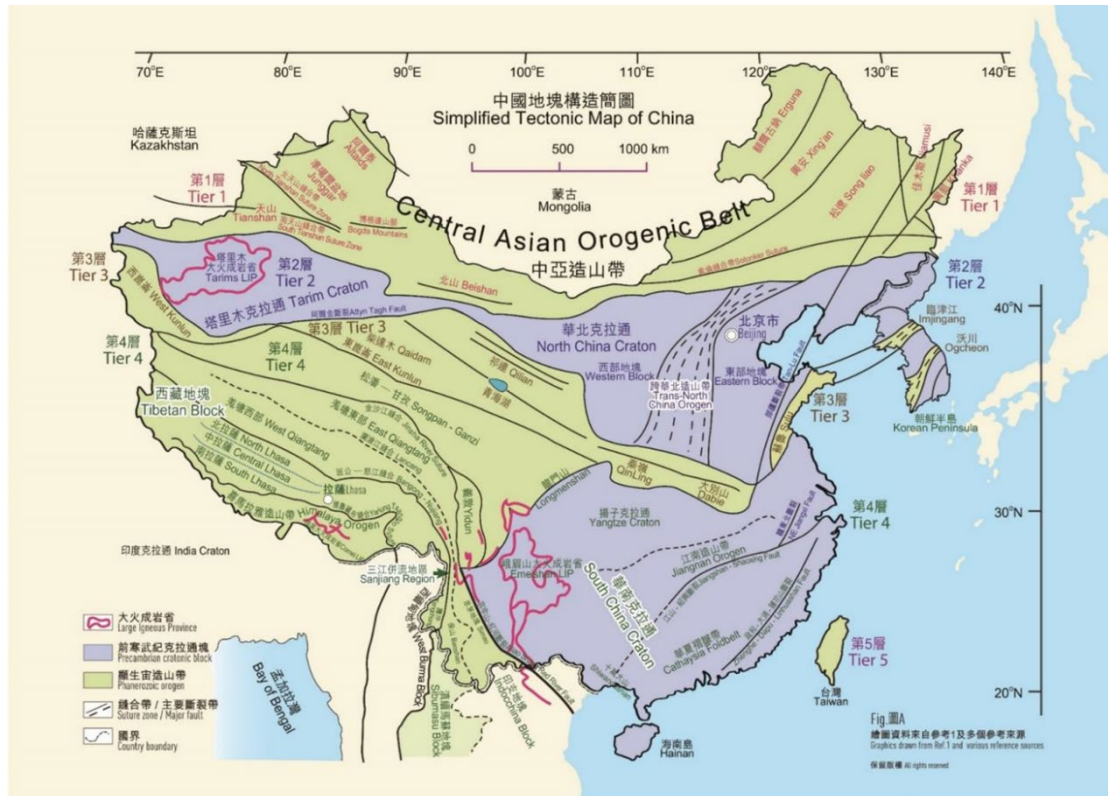


Fig. A – Simplified Tectonic Map of China
圖 A – 中國地塊構造簡圖

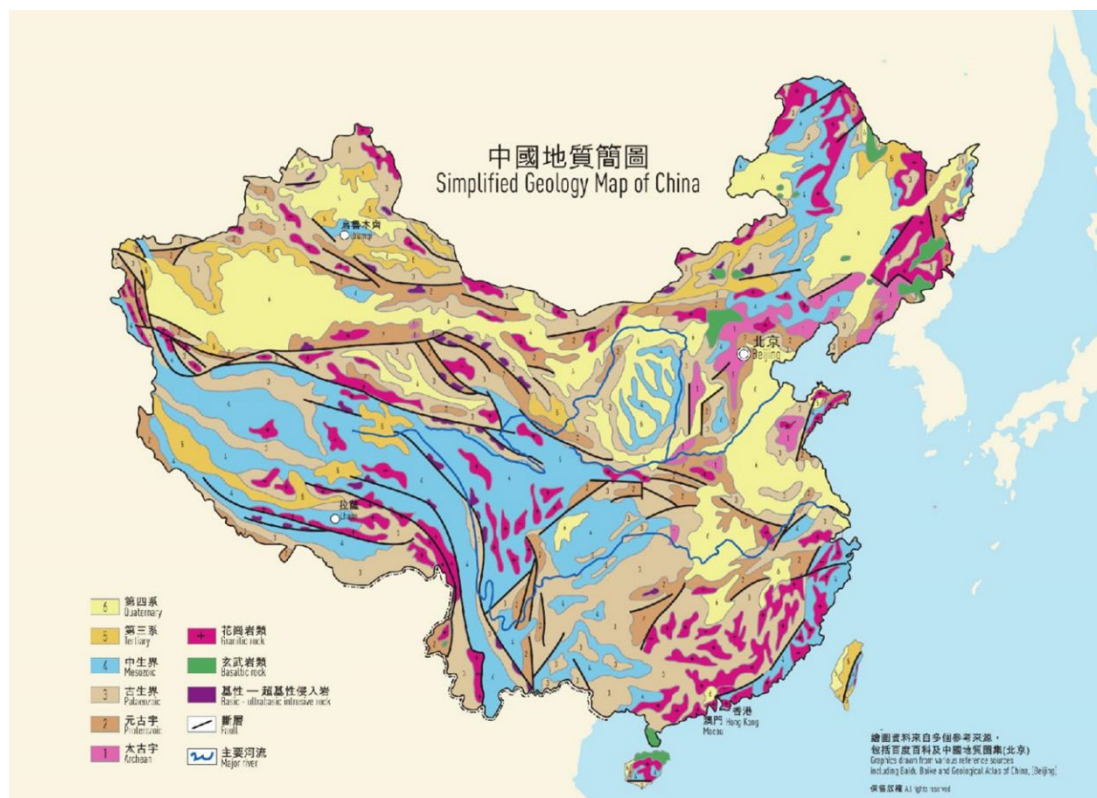


Fig. B – Simplified Geological Map of China
圖 B – 中國地質簡圖

從雙極排列直流電阻法探究地下地質構造模式

*顏一勤¹、葛岳淵²、李彪³、黃能偉⁴

¹顏一勤應用地質技師事務所/國立中央大學應用地質研究所(ichin.yen@g.ncu.edu.tw)

²岳科應用地質技師事務所

³聯合大地工程顧問股份有限公司

⁴中興工程顧問股份有限公司

關鍵字: 地電阻剖面法、地下地質構造模式

一、前言

地下地質的探查工作，主要在於建立地下地質剖面，藉以了解地下之地質構造模式。[W使1] 常見的地下地質探查方法，則為地質鑽探工作。然而，地質鑽探在地質剖面扮演著點與線的角色，其往往受限於規畫初期的經費限制，常無法進行深度大於100公尺的地質鑽探岩心取樣工作，或者面對複雜的地下地質構造時，又欠缺二維空間分布的關鍵性證據。[W使2] 因此，如何在點與線所構成的剖面模型中，填補資料點間的空缺。本文就作者先前的工作案例，提出以地電阻剖面法來填補地質鑽探所建立的地質剖面中的缺陷，以精進地下地質構造模型的完整性與確定性。

本文分別以三義斷層調查工作的兩個剖面，來說明地質鑽探深度不足時，以及調查場址的地下地質構造複雜，鑽探孔數不足時，利用地電阻剖面法的探查結果，彌補資料空缺的部分，提升地下地質剖面資料精度，確認三義斷層的位置及斷層模式。

二、調查方法

本文之地電阻影像剖面探查採用雙極排列法(Pole-pole array)進行施測，為四極法之架構，它是將電流極的一支與電位極的一支分別置於遠離探測剖面位置並插入地表固定不移動，且彼此也相距甚遠。在探測剖面上置一支電流極與一支電位極。施測時在探測剖面線上以等間距排列多支電極供作自動換極測量。

雙極排列的優點較其他排列方式有最好的水平收斂及最深的探測深度，其理論探測深度最大為測線長度之0.867倍，相較於其他主要排列理論探測深度為測線長度之0.173-0.361倍深；雙極排列受測線周圍之干擾影響範圍較其他排列小。雖雙極排列解析度較其他排列低，在電極間距不大於10公尺及足夠之電極數量(足夠資料密度)下已可解析數百公尺內之地下地質構造電性形貌。若需提高淺部地層解析度，可於一定長度之測線內增加電極數目(縮小電極間距)以提高資料密度。

三、討論

3.1 場址一

本場址於調查期間，原規劃的地質鑽探為100公尺深及50公尺深，經地質鑽探完工後，雖於100公尺深的地質井中鑽獲岩盤岩層，但因其岩盤深度超過50公尺，故對比於50公尺深的地質井後，並無法確定斷層的位置及於地下之分布型態。為了解深度超過50公尺以下之地下地質特徵，本文採用雙極排列直流電阻法，獲取地下約400公尺深之地電阻剖面，配合原規劃之鑽探成果，建立地下地質剖面，釐清斷層的分布位置與深度(顏，2014)。

2.2 場址二

本場址於第一階段調查後，已建立初步的地下地質剖面(李等人，2016)。隨後，由於地質鑽探資料的增加(中興工程，2017)，地下地質剖面與斷層的模式亦獲得新的見解(Ho et al.,2020)，但也存在著未有地質鑽探資料處，地質模式解釋的差異。為釐清在相同的地質鑽探資料下，具有不同的地質解釋模式，本文採用雙極排列之直流電阻法，獲取地下約300公尺深之地電阻剖面，並配合原規劃之鑽探成果，重新檢視地下地質剖面，釐清此剖面位置上的斷層模式。

四、結論

屬於高侵蝕速率與高堆積速率區域的臺灣，地下地質的探查工作，受限於第四紀沉積物過厚，造成許多工程地質調查的地質鑽探探查深度過淺，以至於無法了解位於地下較深處岩盤的地質構造型態。本文提出之雙極排列之直流電阻法，相較於其他排列方式的直流電阻法，其探測優點在於能獲得較深(大於100公尺)的地質資訊。

以本文所舉的兩個實際案例，顯示雙極排列之直流電阻法，能滿足針對地下探勘資料的不足處，提供更完整的地質資料，以精進地下地質構造模型的完整性與確定性。

參考文獻

1. 李友恒、田正智、李民政、吳富洵、吳東錦、鄒瑞卿、黃能偉(2016)，「活動斷層調查與位移危害度分析案例介紹」，*土木水利*，第43卷，第2期，第11-16頁。
2. Ho, G. R., Chang, P. Y., Lee, J. C., Lewis, J. C., Chen, P. T. and Hsu, H. R. (2020). "Surface traces and related deformation structures of the southern Sanyi Fault, Taiwan, as deduced from field mapping, electrical-resistivity tomography, and shallow drilling." *Engineering Geology*, 273(11), DOI: 10.1016/j.enggeo.2020.105690.
3. 中興工程顧問有限公司(2017)，「國道四號台中環線豐原潭子段工程設計暨配合工作」，交通部臺灣區國道新建工程局報告。
4. 顏一勤(2014)，「103年度活動斷層補充地質調查案」，經濟部中央地質調查所報告。

ACTIVE VOLCANOES AROUND THE TAIPEI METROPOLIS: HAZARD IDENTIFICATION AND RISK ASSESSMENT

Su-Chin Chang¹ and Jui-Pin Wang²

1. Department of Earth Sciences, The University of Hong Kong

2. Department of Civil Engineering, National Central University

The Northern Taiwan Volcanic Zone is an active volcanic feature influencing both onshore and offshore areas of north Taiwan (Wang et al. 2004). This zone broadly consists of the Tatun Volcano Group, the Keelung Volcano Group, Tsaolingshan, and several offshore volcanic islets along the eastern Eurasian continental margin (Figure 1). Following decades of efforts to reconcile conflicting evidence, geological consensus holds that the eruptions of the Tatun Volcano Group consist largely of calc-alkaline andesite generated either by the opening of the Okinawa Trough (Teng, 1996) or post-collisional extension in North Taiwan (Wang et al., 1999; Wang et al. 2004). Despite extensive geochemical and geophysical investigation, controversy remains as to whether the Tatun Volcano Group is still active (Song et al., 2000; Konstantinou et al., 2007; Lee et al., 2008; Konstantinou et al., 2009; Belousov et al., 2010; Kagiya et al., 2010; Wen et al., 2012). Before the late 1990s, the Tatun Volcano Group was considered an extinct or dormant feature based on the absence of historical evidence for eruptions. Geochronologic data, including K/Ar (Juang and Bellon, 1984; Juang and Chen, 1989; Tsao, 1994), fission track (Wang and Chen, 1990) and $^{40}\text{Ar}/^{39}\text{Ar}$ whole rock (Lee, 1996) analyses of different Tatun Volcano Group features all indicate an onset of volcanism at around 2.8-2.5 Ma and ending at 0.3 Ma. Sporadic younger volcanic events ceased by 0.2 Ma according to this dataset. The dating techniques used in establishing the dataset however are imprecise by modern-day standards and are no longer considered appropriate for dating young volcanic samples.

Recent studies indicate that the magma reservoir beneath the Tatun Volcano Group is active and thus highlights the risk of future eruptions (Yang et al., 1999; Kim et al., 2005; Lee et al., 2005; Lin et al., 2005; Konstantinou et al., 2007, 2009; Lee et al., 2008; Lin and Pu, 2016). For example, the $\text{CO}_2/\text{H}_2\text{O}$ ratio of 0.027 obtained from Tatun Volcano Group magma is close to that measured from active volcanoes in Japan. Researchers have used this and other data to interpret a continuous supply of volatiles to the magma from a source deeper than the magma chamber (Ohba et al., 2010). Helium isotopic results from Tatun Volcano Group fumaroles have further shown that 60% of helium release derives from mantle sources indicating active degassing (Lee et al., 2008).

In the first part of this study, we use high-precision $^{40}\text{Ar}/^{39}\text{Ar}$ geochronology to establish the eruption history of the Northern Taiwan Volcanic Zone. Our preliminary study for one sample collected from Chihshingshan yields an age of 86 ± 4 ka (2 sigma errors) (Figure 2). This surprisingly young age for the Tatun Volcano Group suggests that the previous age estimation and eruption history were wrong. With further study on at least 10 more volcanic samples collected from the Keelung Volcano Group, Tsaolingshan, and offshore volcanic islets, our results will provide a robust age framework for interpreting recent volcanic activity throughout Northern Taiwan Volcanic Zone. Critically, the study will also identify potential active volcanoes near Taipei.

In the second part of this study, we aim to identify and quantify volcanic hazards. With a population of 7 million people, the Taipei metropolitan area is one of the most densely populated areas in the world. Systematic investigation of the Northern Taiwan Volcanic Zone began in the early 2000s, following the construction of two nuclear power plants near the foot of the Tatun Volcano Group (Figure 3). Recently

scientists, media sources, and the general public have raised concerns that volcanic activity may impact these nuclear power plants and cause a catastrophic disaster. Seismic analysis by Lin (2016, 2019) interpreted a large, active magma reservoir beneath the crust of northern Taiwan. An offshore volcanic eruption could also produce tsunamis that would impact surrounding areas including nuclear power plants near Taipei. Our study can help inform risk models for nuclear facilities and nearby urban areas.

This work will foster collaboration between geologists, planners, and engineers. Together, geologist (Chang) and geotechnical engineer (Wang) will seek to constrain understanding of natural hazards and minimize risk for one of the most populous cities in Asia.

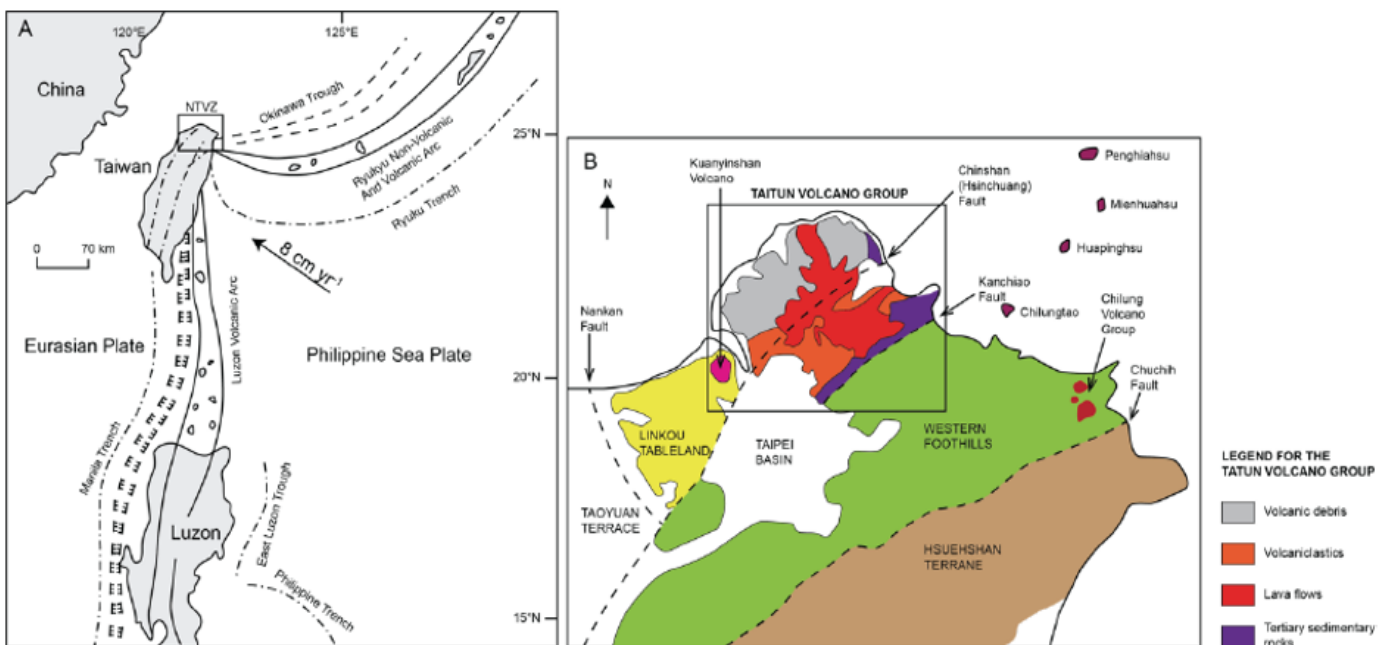


Figure 1: (A) A map showing the convergent tectonic setting of Taiwan; (B) Taipei, one of the most populous cities in the world, is located in the Northern Taiwan Volcanic Zone.

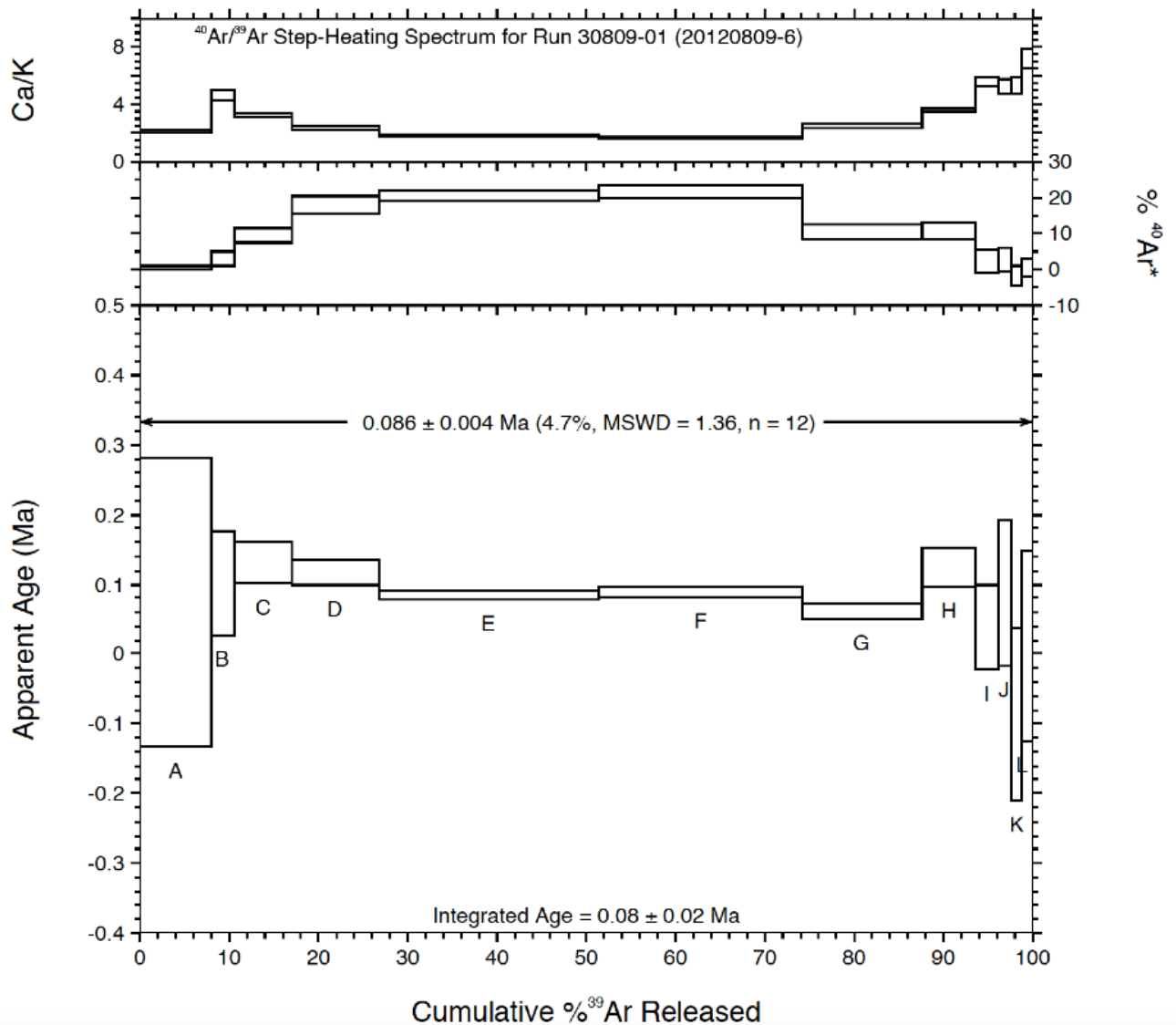


Figure 2: Our preliminary study for one sample collected from Chihsingshan yields an age of 86 ± 4 ka. This study, for the first time, provided a precise age for the lava flow in the Tatun Volcano Group. Our result refutes the widely accepted age model for the Tatun Volcano Group and suggested that the eruption history should be re-appraised.

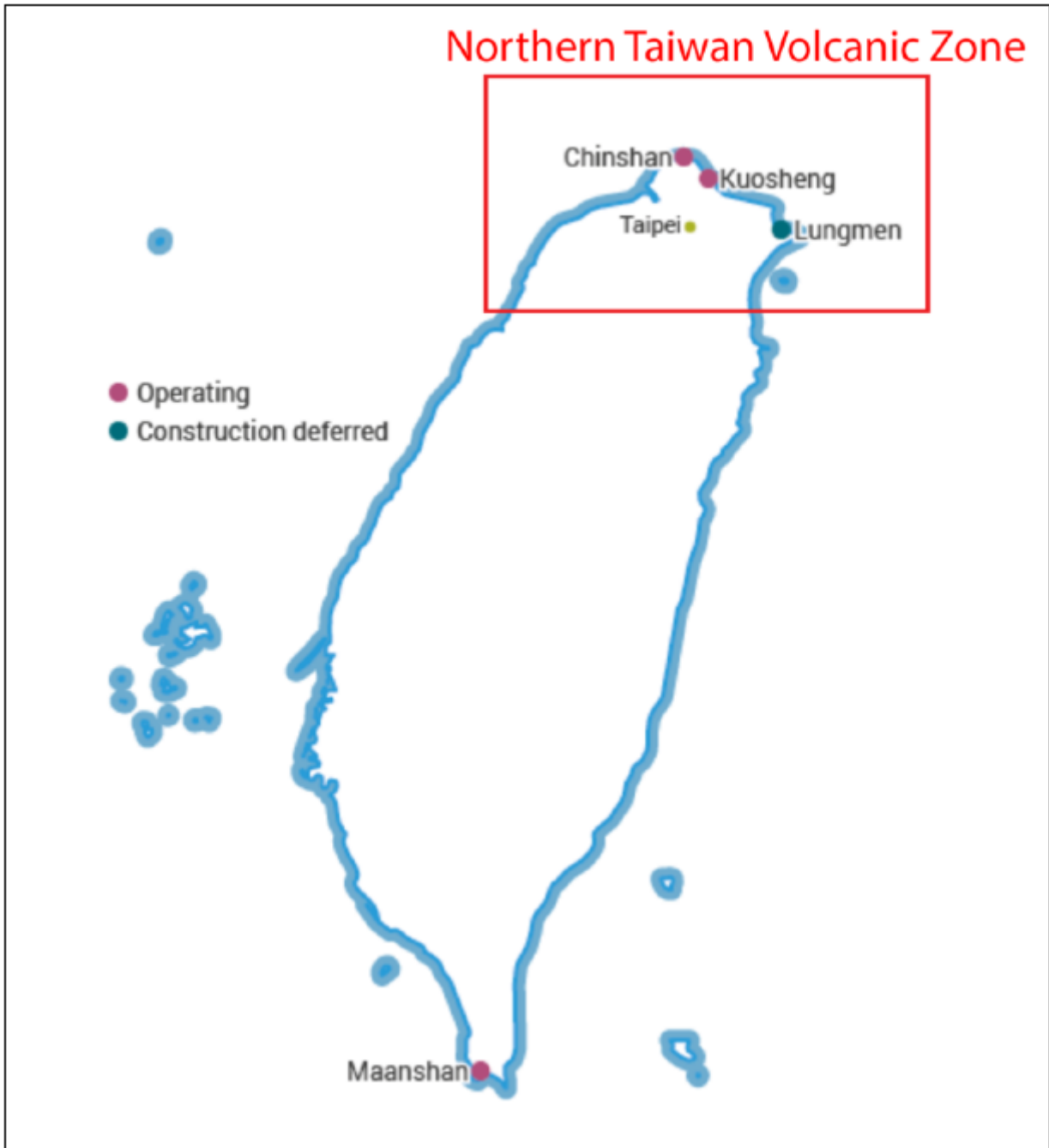


Figure 3: Taiwan has three operating nuclear power plants. Two of them are located in the Northern Taiwan Volcanic Zone (modified from World Nuclear Association).

Detailed Exploration QA/QC Plan for Andranovato Gibbsite Bauxite, Madagascar

Zhang Jianguo

Mada Mineral Holdings Limited

ABSTRACT

The Andranovato gibbsite bauxite ($\text{Al}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$) in Madagascar is a weathered residual deposit, which proto-ore rock is quartz syenite. Pitting and shallow drilling are used for detailed exploration to control the ore body. The overburden with an average thickness of 1m is favorable for open-pit mining. The bauxite has good washability, processability and meltability. A detailed exploration plan for Andranovato bauxite has been developed according to Chinese standard (DZ/T 0202-2002) and Canadian standard (NI 43-101). The QA/QC plan is working well. The relative discrepancy of the independent resource estimates based on these two standards is 8.4%, which indicates that the resource estimates are robust and reliable. The results of the detailed exploration of Andranovato project show that the entire Ankaizina gibbsite bauxite mineralization zone has huge resource potential, is concentrated in an area of 6000km², which is conducive to the future development of the local aluminum processing industry chain.

Keyword: Andranovato, Ankaizina, Bauxite, QA/QC Plan, Tsaratanana, Detailed Exploration

1. INTRODUCTION

The Andranovato gibbsite bauxite ($\text{Al}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$) project is located in Antsohihy area, Madagascar. The deposit is part of the Ankaizina bauxite mineralized belt^[1] and confined to the western section of the Tsaratanana laterite plateau at 1100-2200 meters above sea level.

The climate is sub-tropical. On the Tsaratanana laterite plateau, leaching conditions of lateritization are very intense and widespread because of the hot, wet climate and good drainage^[2]. This strong lateritization forms the Ankaizina gibbsite-bauxite mineralization. The Andranovato gibbsite bauxite is located in Betsimisaraka Suture Zone^[3], with the host quartz syenite belonging to the Proterozoic Maevarano suite granitoids, which is the main proto-ore rock.

The bauxite exploration for Andranovato were conducted over two phases. In the 1st phase, prior to the 1980s, the main work was basic geologic investigation^[4]. The 2nd phase, from 2008 to present, the main work has focused on the research of bauxite resources verification and processability (washability/smeltability). The detailed exploration within 248.75km² was completed from 2014 to 2016. Since 2017, a small-scale industrial beneficiation experiment / trial mining has been carried out, and the feasibility study report was prepared.

The distribution and occurrence of the deposit are controlled by topography. Mineralization is usually concentrated above hillsides, and mineralization at the bottom of valleys and streams is lost due to erosion. The weakly weathered granitoids are exposed on the slopes and in the valleys as barren non-ore blank windows in the laterite layer. There are also iron-rich laterite crusts near the local surface.

The typical bauxite profile in the Andranovato deposit consists of about 1-m-thick overburden, 3~8m of bauxite, and approximately 2m of transition layer mixed with clay. The deposit is of stratiform shape, dipping gently between 0~10°. The bauxite has a light-red color and is predominantly earthy with some sandy texture. Honeycomb bauxite is exposed in the west. There is a few waste layer within the mineralization horizon.

2. EXPLORATION EXPERIMENTS

2.1 The Thin Section Petrography and Mineral Processing

Questions are often raised about the mineralogical analysis of the target mineral^[5], which is also a key factor in the cost of alumina production. According to JORC 2012 clause 49^[6], the industrial mineral resources or reserves must be reported in terms of mineral specifications, and taken particular account of certain key characteristics or qualities. In accordance with the Chinese Exploration Code^[7], the thin section petrography of sample, mineral processing test for washability and smeltability of ore must were carried out before the detailed exploration design.

A total 447 kg were channel-sampled (100cm×10cm×10cm) from 6 evenly distributed pits. The samples were blended into a composite test sample in equal proportion. The compositions of samples were analyzed using X-ray diffraction and X-ray fluorescence, and the results are listed in the Table 1 and Table 2.

Table 1 Mineral compositions

Mineral	Gibbsite	Kaolinite	Alumogoethite	Hematite	Llmenite	Total
Components(%)	34.3	23.5	8.0	3.1	2.0	97.4

Table 2 Chemical components of test samples

Sample name	Al ₂ O ₃	SiO ₂	Fe ₂ O ₃	TiO ₂	LOI	A/S
Component(%)	32.33	38.04	9.55	1.89	16.48	0.85

The gibbsite can be smelted by the Bayer method, and the cost is low, which is the economic value of this bauxite mine. There are two types of silica: one is inert silica, such as quartz, and the other is reactive silica, such as kaolin.

The petrographic analysis^[8] of thin sections shows that the gibbsite, kaolinite and quartz in the sample have a high degree of dissociation, and the embedded particle size is relatively coarse. Desliming and desilication test were carried out on the samples by the combined beneficiation process of washing and reverse flotation. The quality of the concentrate ore: the available-alumina (AA₂O₃) grade is 48.56%, the available aluminum-silicon ratio (AA/S) is 12.65; the AA₂O₃ recovery rate is 58.87 %^[9].

2.2 The Pitting/Drilling Spacing

The pitting/drilling fieldwork was conducted in three phases: The 1st phase, the drilling and pitting program was carried out on 400×400 m spacing. The 2nd phase, the program consisted mainly of infill drilling and pitting on 200×200 m spacing over 85% of the project area. The 3rd phase, an infill drilling program at a grid of 140×140 m was implemented in the 20.17km² test area.

In the 3rd phase infill drilling area, two rectangular areas of total 18.42 km² were selected to carry out the comparison test of the drilling spacing. For the three drilling spacing grids on the main ore body, the resources estimation, ore body thickness, average Al₂O₃ grade, AAl₂O₃ average grade, A/S, number of non-ore blank windows and their coefficient of variation (CV) were compared in the Table 3. The results show that the CV for the two spacing grids of 200×200m and 140×140m are extremely small; However, the various parameter values of 400×400m spacing grids, their CV is relatively large. Therefore, the 200×200m spacing grid is used as the drilling spacing grid to control the ore body.

Table 3 Parameters and CV comparison of three spacing grids 400×400m, 200×200m, 100×100m

Spacing (m)	Drilling number	Thickness (m)		Al ₂ O ₃ (%)		A/S		AAl ₂ O ₃ (%)		Blank	Res (MT)
		avg	CV%	avg	CV%	avg	CV%	avg	CV%		
400×400	113	5.40	29.3	31.49	8.4	0.85	28.9	17.83	39.2	1	13.68
200×200	450	5.25	28.7	31.67	7.4	0.86	26.7	19.43	30.4	5	12.53
140×140	876	5.30	28.2	31.48	6.9	0.85	26.4	18.75	34.6	6	13.42

3. QA/QC PLAN DURING DETAILED EXPLORATION

3.1 Bulk Density Data

A total of 85 bulk samples were collected from 22 pits which distributed evenly over the area. The average grade of these samples is basically the same as the average grade of the whole area. Channel method was applied to take those samples with channel size of 50cm×30cm×100cm from pit walls. The weight of samples ranges from 219.5kg to 326.5kg. These samples are air-dried and dried at low temperature (≤105°C) in the on-site laboratory, and weighed to constant weight for several times.

The distribution of the results is generally in a normal distribution, Kurtosis=2.71474^[10], Figure 1. 80% of the samples have dry density of 1.30~1.70g/cm³. These samples reflect an average density value of 1.62g/cm³ on a wet basis with an average moisture content of 8 %, and 1.49g/cm³ on a dry basis.

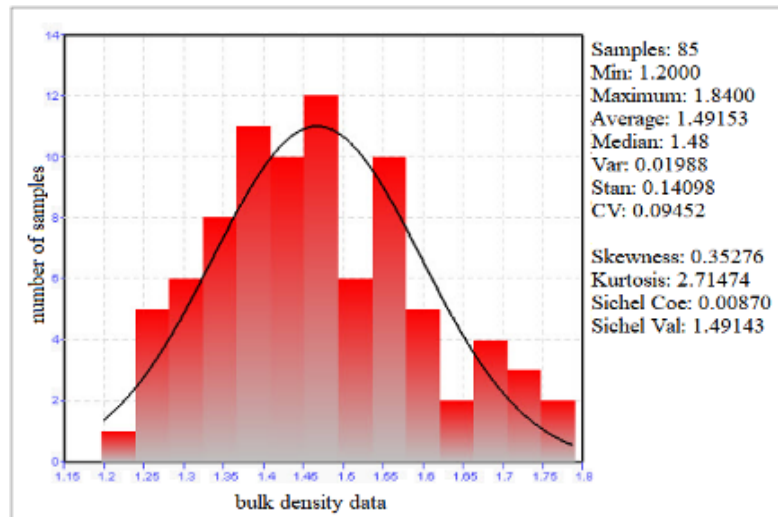


Figure 1 Bulk density data distribution frequency histogram (red histogram), the distribution of the results is generally in a normal distribution (black line).

3.2 Sample Preparation

A sample preparation laboratory is located on site. The sample preparation followed the procedures detailed below in Figure 2. Finally, 50g of fine (-74 microns) samples were packed and sent to the test centre for basic analysis while 500g of fine samples were securely stored as pulp duplicates.

3.3 Samples Analysis and Statistics

The basic exploration samples were subjected to analysis by X-ray fluorescence, Bayer methods. The standard samples, blank samples and external inspection samples are used to detect systematic errors in the analysis. To detect the accidental error of the test, pulp duplicates and the internal inspection samples were used in the analysis. Field replicates and coarse duplicates were used to detect accidental errors in the process of sample preparation and assay analysis.

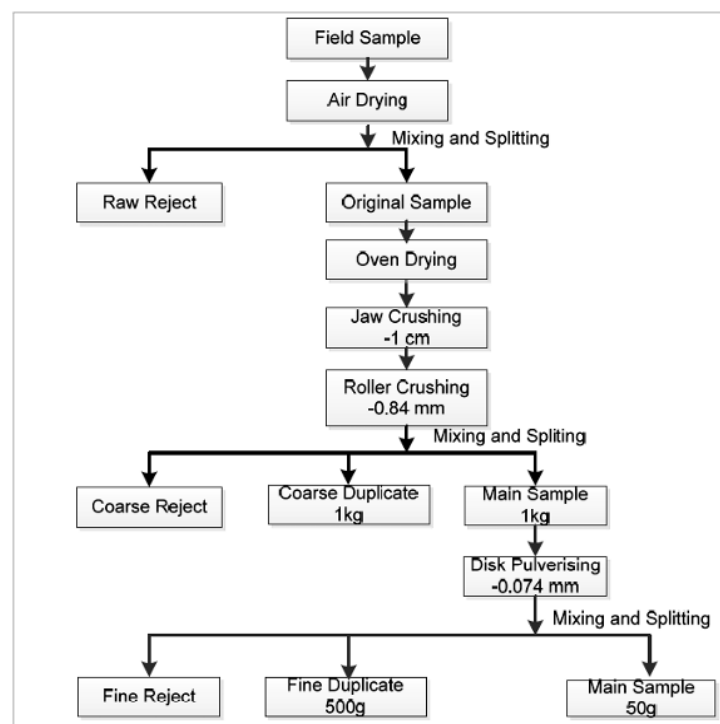


Figure 2 Sample preparation flow chart

All standard samples (“CRM”) were purchased from the Institute of Geophysical and Geochemical Exploration in China. Blank samples were taken from pure limestone, believed to be barren rock in terms of targeted components, located 30 km northeast of the deposit.

We inserted total 5099 quality control samples into the QA/QC process during the analysis, including 468 CRMs, 471 field replicates, 471 coarse crushes, 471 pulp duplicates and 468 blanks, 1970 Internal inspection-samples, 780 external inspection samples. Each type of quality control samples were split into batches and checked in parallel.

Most of the field replicates, coarse replicates, internal check, external check display relatively good correlation with the field samples, with deviations from the field samples of less than 10%. Most of the CRMs and blanks returned results within an expected and reasonable range, indicating no material bias in sample analysis. See the Figure 3.

For the internal inspection, the QR exceeds 95%. For the external inspection, the QR exceeds 90%, see the Table 4. These QRs show that the chemical assays should be accurately repeatable.

Table 4 Statistical results of internal and external samples

Item		Al ₂ O ₃	SiO ₂	Fe ₂ O ₃	TiO ₂	Loss	AAI ₂ O ₃	RSiO ₂
Internal Inspection	Total	1970	1970	1970	1970	1970	1970	1970
	Qualified	1886	1890	1895	1924	1897	1932	1908
	QR (%)	95.74	95.94	96.19	97.66	96.29	98.07	96.85
External Inspection	Total	980	980	980	980	980	980	980
	Qualified	965	949	955	963	956	951	929
	QR (%)	98.47	96.84	97.45	98.27	97.55	97.04	94.8

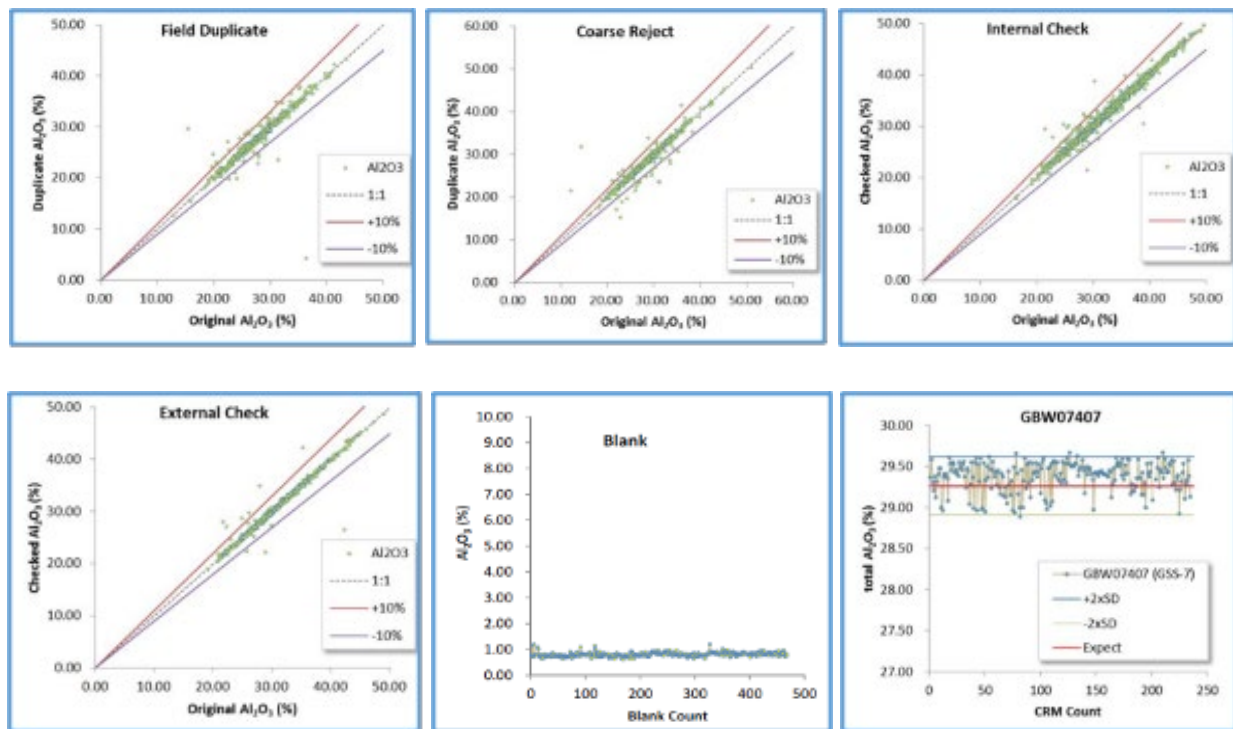


Figure 3 Scatter charts comparing QA/QC results for Al_2O_3 for field replicates, coarse crushes, internal check, external check, CRMs and blanks. They display relatively good correlation.

3.4 Evaluation of the Total QA/QC Plan for the Detailed Exploration

We use the comparison of ore resources estimated respectively by Canada NI 43-101 and China GB/T17766-1999 to evaluate the QA/QC plan and operation effect. The total resources for (Mea+Ind+Inf) is 1001Mt by Canada NI 43-101^[11]. The total resources for (331+332+333) is 1085Mt by China GB/T 17766-1999^[12], see the Table 5. The estimated resource difference based on the two standards is 8.4%, showing that the total QA/QC plan is reasonable and effective. The estimated amount of resources is robust and reliable.

It is worth noting that the NI 43-101 standard for reporting mineral resources and reserves is different from the Chinese reporting system. Broadly, Chinese categories 331, 332, and 333 correspond to NI 43-101 Measured, Indicated, and Inferred resources, respectively. Because the Chinese 334 resources requires no engineering control, it can't be reported under the NI 43-101 code. In additional, under NI 43-101, only Measured and Indicated Mineral resources can be converted to Mineral Reserves for future mine design.

Table 5 The relative difference of the total resources is 8.4% between the two different standards

Canada NI 43-101 Standard (V2014) (Mt)				China GB/T 17766-1999(Mt)			
Category	Resources	Al ₂ O ₃ (%)	SiO ₂ (%)	Category	Resources	Al ₂ O ₃ (%)	SiO ₂ (%)
Measured	207	31.4	39.1	331	213	32.03	37.78
Indicated	415	30.1	40.4	332	410	31.38	37.37
Inferred	379	30.2	42.5	333	462	30.55	40.97
Total	1001	30.4	40.92	Total	1085	31.16	38.99

4. CONCLUSION

Andranovato gibbsite bauxite is a weathered residual deposit, which proto-ore rock is quartz syenite. Therefore, pitting and shallow drilling can be used for detailed exploration to control the ore body. The beneficiation and metallurgical tests confirmed that the bauxite has good washability and meltability.

The detailed exploration plan and QA/QC plan for the Andranovato bauxite deposit were formulated in accordance with Chinese standard (DZ/T 0202-2002) and Canadian standard (NI 43-101). The QA/QC programme has worked well. The independent estimated resource difference based on these two standards is 8.4%, which indicates that the resource estimates are robust and reliable.

The detailed exploration result of the Andranovato bauxite project shows that the Ankaizina gibbsite bauxite mineralization zone has great resource potential. There are several extra-large bauxite deposits in the 6,000km² oval-shaped mineralization zone, which is beneficial to the future development of the local aluminum processing industry chain.

5. ACKNOWLEDGMENT

We highly express our gratitude to the Mada Mineral Holdings Ltd, the SRK Consulting (China) Ltd, the 3rd Brigade of HNBNGMR. Their works contributed greatly to the success of this project.

REFERENCE

- [1] A. Emberger. 1957: Etude geologique et prospection miniere de L'Ankaizina et sa bordure sud. Service de la geologie in Madagascar.
- [2] Abzalov M. Z., Bower, J. 2014: Geology of bauxite deposits and their resources estimation practices. Applied Earth Science 123 (2): 118-134.
- [3] Tucker R.D., Roig J.Y., Delor C. 2011: Neoproterozoic extension in the greater dharwar craton: A reevaluation of the Betsimisaraka suture in Madagascar. Can. J. Earth Sci. 48(2): 389-417. Doi:10.1139/E10-034.
- [4] Service de la geologie in Madagascar. 2003: Les bauxites de Madagascar.
- [5] Andrew Scoggings. 2015: Graphite Where size matters. Australia's paydirt. 2015(3): 78-79.
- [6] JORC. 2012: The Australasian code for reporting of exploration results, mineral resources and ore reserves.
- [7] NSTCGM in China. 2002: Specifications for bauxite, smelter-grade magnesite exploration (DZ/T0202-2002).
- [8] B. Theophile, A. Panda, M. Denyse. 2021: Bauxite Mineral Exploration Study of Mainpat Plateau Deposits in Surguja District, Chhattisgarh, India, IJERT, Vol 10: 649-653.
- [9] Zhengzhou Nonferrous Metal Research Institute. 2015: Washing and Processing Test Report on Madagascar Bauxite Deposit.
- [10] Zhiqiang L., Jianming W., et al. 2008: The Statistical Meaning of Kurtosis and Its New Application to Identification of Persons Based on Seismic Signals. Sensors Vol 8: 5106–5119.
- [11] SRK Consulting (China) Ltd. 2016: Technical Report on the Mineral resources Estimate of the Andranovato Bauxite Project, Madagascar, Africa.
- [12] The 3-rd Brigade of HNBNGMR. 2016: Bauxite exploration report in Andranovato area, Sofia province, Madagascar.

Mobilization of Rare Earth Elements along Hillslope during Sub-tropical Weathering: Insight from Hong Kong

Martin Yan Hei Li¹, Hon Chim Chiu²

1. Department of Earth Sciences, The University of Hong Kong

2. Department of Geography and Resource Management, Chinese University of Hong Kong

Weathering is one of the most important processes affecting the Earth's surface and is the dominant factor controlling the chemistry of oceans, rivers and other reservoirs in the environment. Rare earth elements (REE), commonly applied as tracers in various geological processes, are mobilized, distributed and fractionated during weathering. Such processes form part of the REE cycle in the environment, and enable REE to be a powerful tool to snapshot the weathering process. This study utilized well-exposed weathering profiles along the hillslopes at the Mt. Butler quarry in Hong Kong (Fig. 1) to investigate the behavior of REE in the sub-tropical weathering of granitic bedrock.

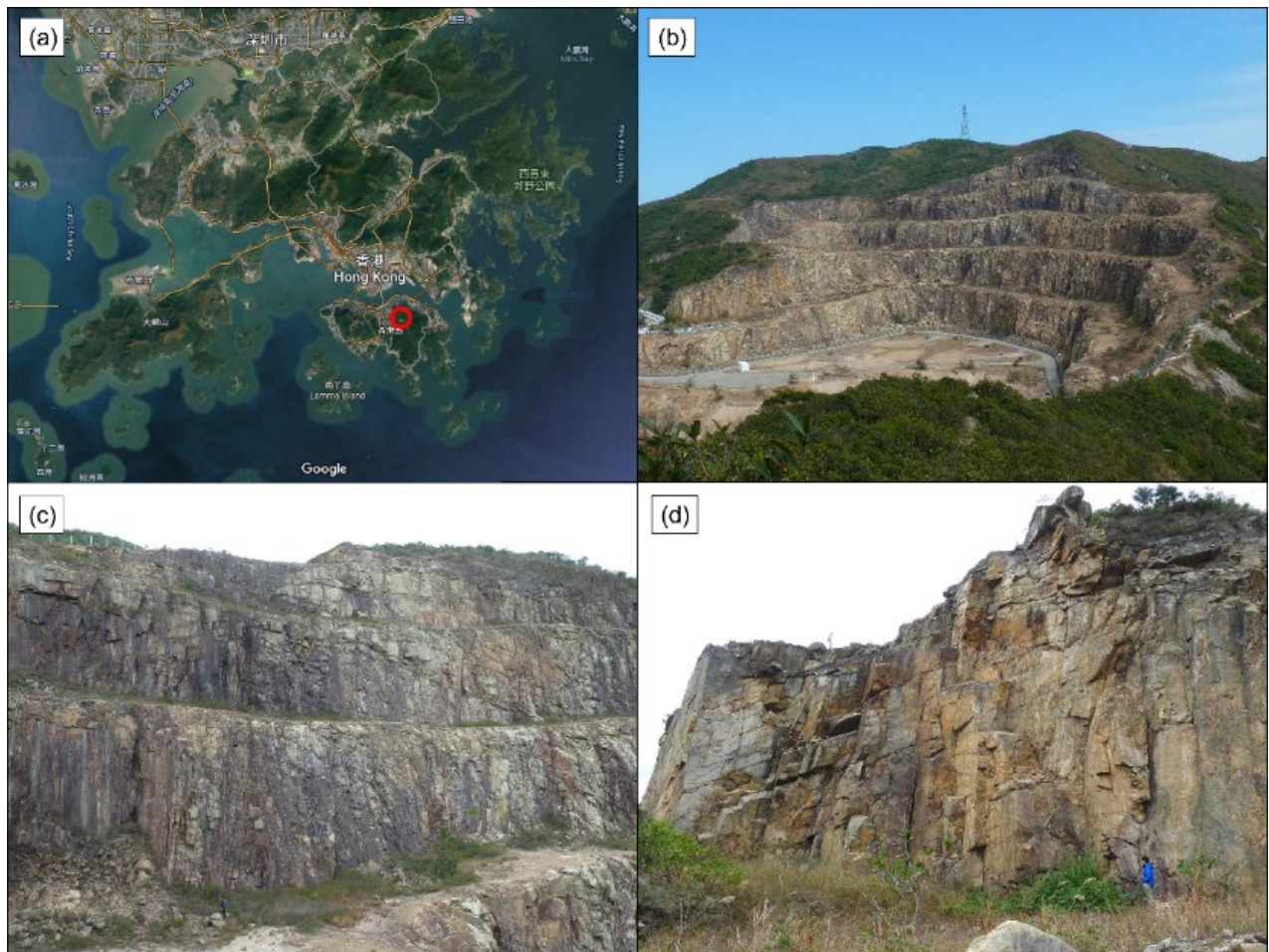


Figure 1. (a) Location of Mt. Butler quarry. (b)-(d) Overview of the site.

In the study site, the weathering crust develops from massive, fine-to medium grained granite with K-feldspar, plagioclase, quartz, and sub-ordinate biotite as the major rock-forming minerals. With

progressive weathering, plagioclase is altered to halloysite, and further to kaolinite and gibbsite; whereas biotite is weathered to chlorite and vermiculite, and further to kaolinite. The weathering crust is well developed with clear zonation comprising a layer of pedolith underlain by the saprolite and saprock (Fig. 2). Two profiles, one located near ridge and the other one at the mid-slope, have been selected for further comprehensive investigation. Thickness of the weathering crust increases towards downslope, for instance, the pedolith layer increases from ~1 m near the ridge (ridge profile) to ~2.5 m at a mid-slope profile located at ~30 m lower in elevation (mid-slope profile).

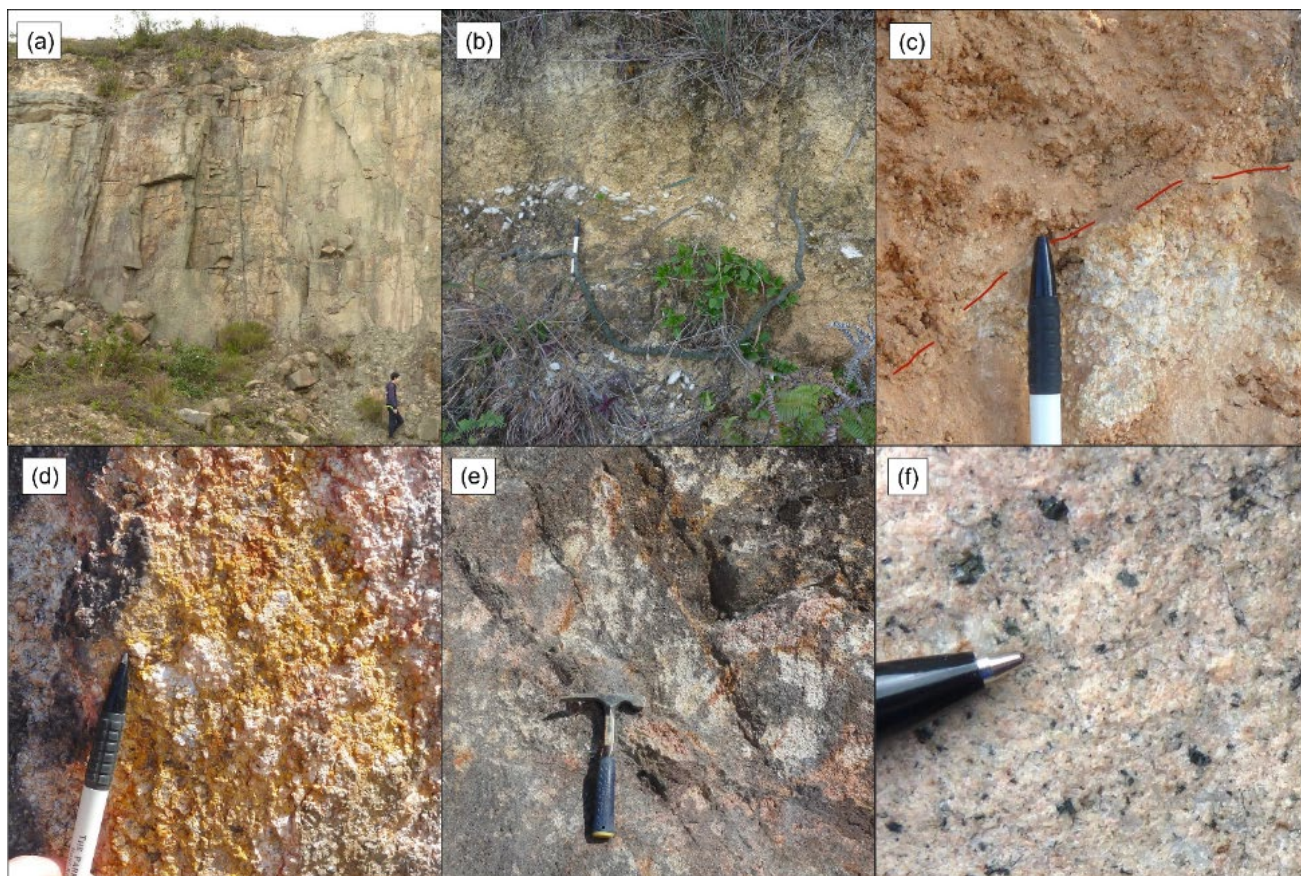


Figure 2. (a) A typical weathering profile of the site. (b) Appearance of the humic layer and pedolith. (c) Appearance of the pedolith-saprolite interface. (d) Mottle brownish and pinkish saprolite. (e) Relict joints in saprolite. (f) Fresh bedrock of fine-grained granite.

Both profile show depletion of REE, except Cerium (Ce), relative to the parent granite, however, the mid-slope profile shows slightly higher REE concentration than the ridge profile (Fig. 3). Cerium is strongly enriched in the mid-slope profile but depleted or only slightly enriched in the ridge profile (Fig. 4). At the ridge profile, REE concentration gradually increases from the topsoil towards the pedolith-saprolite interface, then decreases beyond this depth before gradually increasing again towards the base of the profile. Whereas at the mid-slope profile, REE concentration fluctuates in the pedolith and abruptly increases at the pedolith-saprolite interface (Fig. 3). The variation in vertical REE pattern indicate vertical leaching and erosion of regolith, promoting removal of REE from the profile. The relatively lower Chemical Index of Alteration (CIA) value of pedolith at the ridge also indicates intense erosion and exposure of less weathered regolith on surface. At the mid-slope, deposition of soil particles translocated from upslope is indicated by higher kaolinite content and CIA value of the pedolith. Influx of REE is likely contributed by translocation of (REE-sorbed)-kaolinite and throughflow in regolith. Strong positive Ce anomaly throughout the entire mid-slope profile, but not in the ridge profile (Fig. 4),

is also consistent with the translocating soil profile, including Fe oxyhydroxides which commonly oxidize and host Ce in regolith, from the ridge towards downslope.

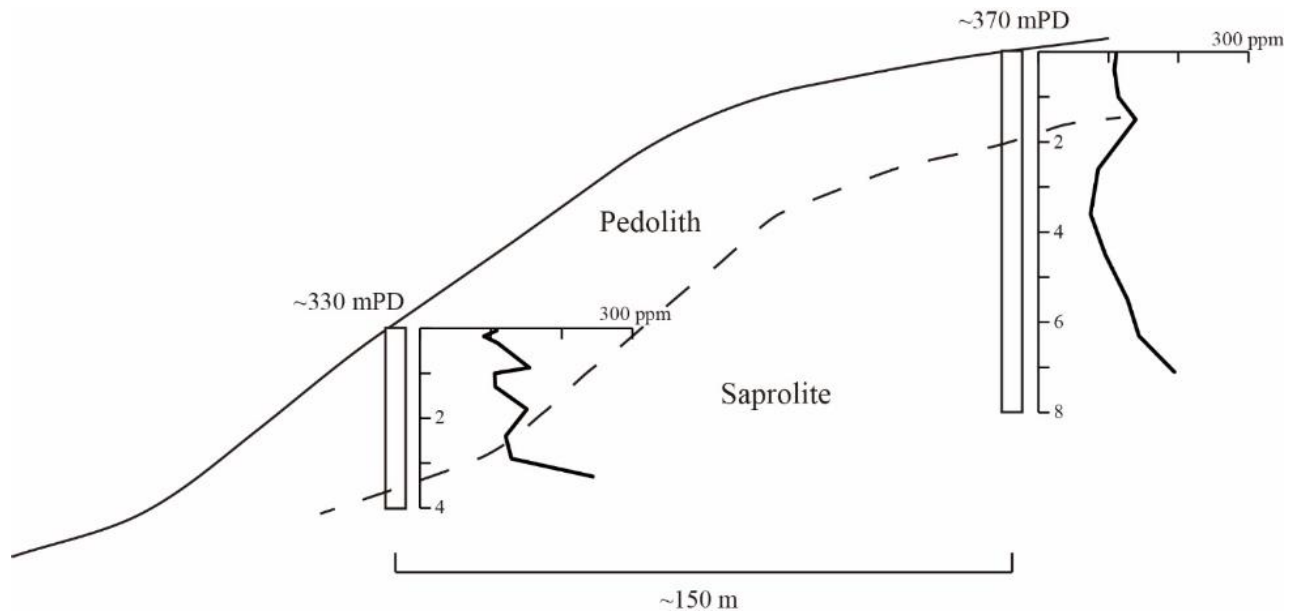


Figure 3. Schematic profile of the hillslope and the vertical patterns of REE of the two studied profiles. Note that the schematic diagram is not to scale.

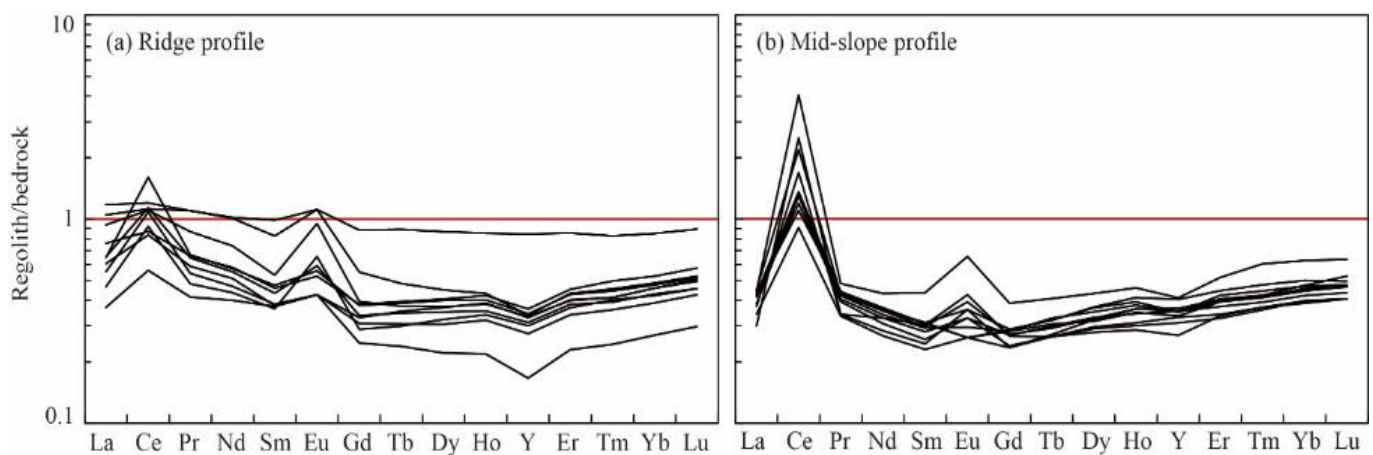


Figure 4. REE patterns of regolith from the two studied profiles.

To conclude, intense denudation at ridges could efficiently liberate REE from the bedrock. The released REE would then be fixed on kaolinite through sorption and hosted by Fe oxyhydroxides, especially for Ce, through oxidation. Translocation of these particles, together with solute transport of dissolved REE in groundwater, transport REE towards downslope, causing REE enrichment.

References

- Anderson, S. P., Von Blanckenburg, F., & White, A. F. (2007). Physical and chemical controls on the critical zone. *Elements*, 3(5), 315–319. <https://doi.org/10.2113/gselements.3.5.315>
- Berger, A., Janots, E., Gnos, E., Frei, R., & Bernier, F. (2014). Rare earth element mineralogy and geochemistry in a laterite profile from Madagascar. *Applied Geochemistry*, 41, 218–228. <https://doi.org/10.1016/j.apgeochem.2013.12.013>

- Braun, J. J., Pagel, M., Herbillon, A., & Rosin, C. (1993). Mobilization and redistribution of REEs and thorium in a syenitic lateritic profile: A mass balance study. *Geochimica et Cosmochimica Acta*, 57(18), 4419–4434. [https://doi.org/10.1016/0016-7037\(93\)90492-F](https://doi.org/10.1016/0016-7037(93)90492-F)
- Braun, J. J., Riotte, J., Battacharya, S., Violette, A., Oliva, P., Prunier, J., Maréchal, J. C., Ruiz, L., Audry, S., & Subramanian, S. (2018). REY-Th-U Dynamics in the critical zone: Combined influence of reactive bedrock accessory minerals, authigenic phases, and hydrological sorting (Mule Hole Watershed, South India). *Geochemistry, Geophysics, Geosystems*, 19(5), 1611–1635. <https://doi.org/10.1029/2018GC007453>
- Duzgoren-Aydin, N., & Aydin, A. (2006). Chemical and mineralogical heterogeneities of weathered igneous profiles: implications for landslide investigations. *Natural Hazards and Earth System Sciences*, 6, 315–322. <http://www.nat-hazards-earth-syst-sci.net/6/315/2006/>
- Duzgoren-Aydin, N., & Aydin, A. (2009). Distribution of rare earth elements and oxyhydroxide phases within a weathered felsic igneous profile in Hong Kong. *Journal of Asian Earth Sciences*, 34, 1–9. <https://doi.org/10.1016/j.jseaes.2008.03.010>
- Duzgoren-Aydin, N. S., Aydin, A., & Malpas, J. (2002) Distribution of clay minerals along a weathered pyroclastic rock profile, Hong Kong. *Catena*, 50, 17–41. [https://doi.org/10.1016/S0341-8162\(02\)00066-8](https://doi.org/10.1016/S0341-8162(02)00066-8)
- Ichimura, K., Sanematsu, K., Kon, Y., Takagi, T., & Murakami, T. (2020). REE redistributions during granite weathering: Implications for Ce anomaly as a proxy for paleoredox states. *American Mineralogist*, 105(6), 848–859. <https://doi.org/10.2138/am-2020-7148>
- Laveuf, C., & Cornu, S. (2009). A review on the potentiality of rare earth elements to trace pedogenetic processes. *Geoderma*, 154(1–2), 1–12. <https://doi.org/10.1016/j.geoderma.2009.10.002>
- Li, M. Y. H., Zhou, M.-F., & Williams-Jones, A. E. (2020). Controls on the dynamics of rare earth elements during subtropical hillslope processes and formation of regolith-hosted deposits. *Economic Geology*, 115(5), 1097–1118. <https://doi.org/10.5382/econgeo.4727>
- Malpas, J., Duzgoren-Aydin, N., & Aydin, A. (2001). Behaviour of chemical elements during weathering of pyroclastic rocks, Hong Kong. *Environmental International*, 26, 359–368. [https://doi.org/10.1016/S0160-4120\(01\)00013-7](https://doi.org/10.1016/S0160-4120(01)00013-7)
- Wen, B.-P., Duzgoren-Aydin, N., & Aydin, A. (2004). Geochemical characteristics of the slip zones of a landslide in granitic saprolite, Hong Kong: implications for their development and microenvironments. *Environmental Geology*, 47, 140–154. <https://doi.org/10.1007/s00254-004-1145-6>
- Yusoff, Z. M., Ngwenya, B. T., & Parsons, I. (2013). Mobility and fractionation of REEs during deep weathering of geochemically contrasting granites in a tropical setting, Malaysia. *Chemical Geology*, 349–350, 71–86. <https://doi.org/10.1016/j.chemgeo.2013.04.016>

Acknowledgement

We are thankful to Mr. Leo Ng for providing field photos and figures from his dissertation project.

The Characteristics of Cretaceous and Paleogene Fault Basins in Hong Kong

K W Lai

The Hong Kong Geological Map of 1:20,000 was published in 2000 by Hong Kong Geological Survey. Over the past 22 years. Plenty of site investigation works have been done such as geophysical investigation including marine magnetic and seismic anomaly survey and gravitational method, also geological exploration with more than 300 marine boreholes in the offshore area, as well as 230 fossils have been found to recognize their strata and geological age. Three new fault basins are discovered surround Hong Kong including Tai Pang Wan, Hau Hoi Wan and Po Toi-Dangan Fault Basins.

Tai Pang Wan Fault Basin (大鵬灣斷陷盆地) (Figure 1). It is situated in Tai Pang Wan 大鵬灣 (Mirs Bay) with 25km long and 12km wide which are controlled by both northeast and northwest trending faults. The rock types in the fault basin are divided into two formations: the late Cretaceous Chek Chau Formation and Paleogene Ping Chau Formation.

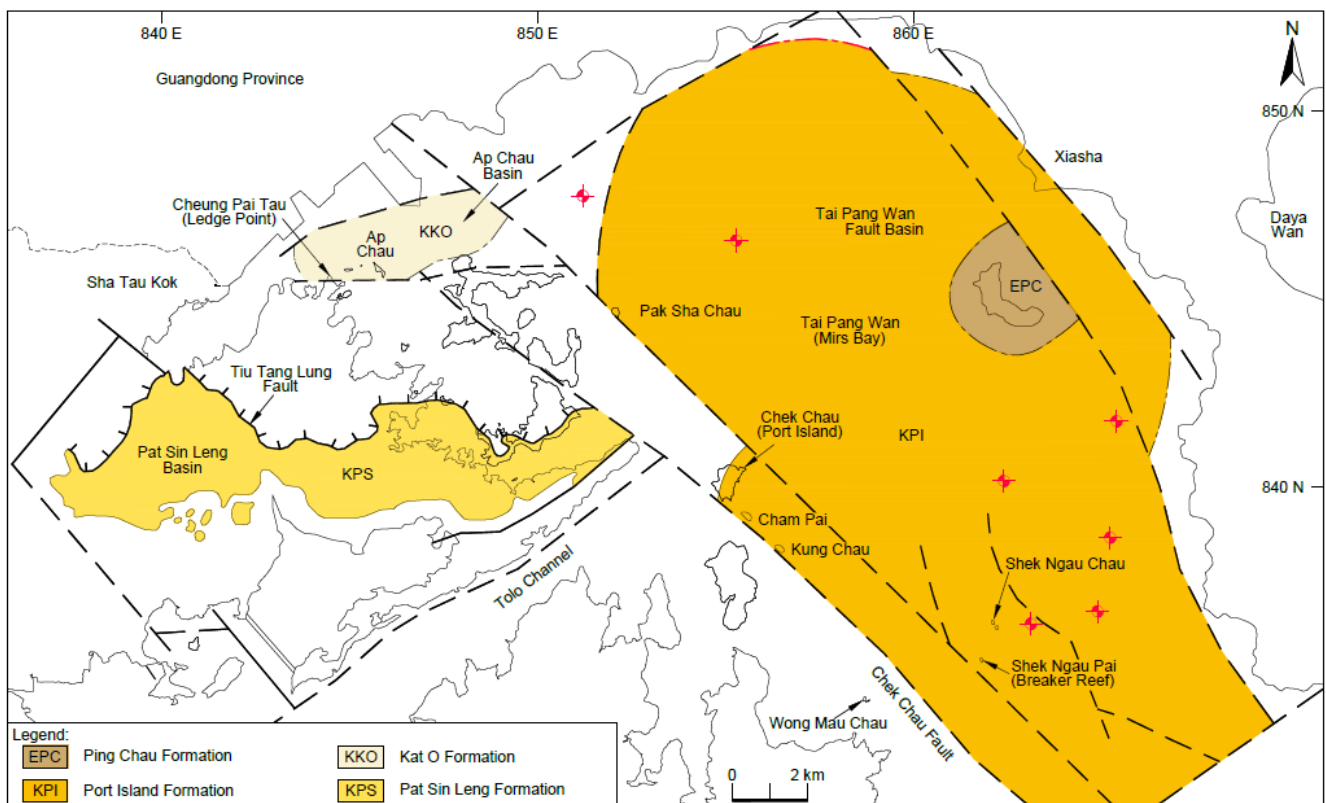


Figure 1 Tai Pang Wan Fault Fault Basin

The Chek Chau Formation comprises very thickly to thickly bedded reddish brown to purple red sandstone and siltstone with some conglomerate. The stratum is unconformably overlain on the volcanic rock of early Cretaceous Long Harbor Formation at Chek Chau. In recent years, the dinosaur eggs of late Cretaceous have been found at Ping Shan in the eastern area of Shenzhen. Meanwhile Lee C M (1985) found the fossil *Charophyte* algae (genue *Atopochara*) at Chek Chau. The fossil also belongs to late Cretaceous. The fossil evidence indicates the geological age of the formation is late Cretaceous.

Their rock outcrops expose in scattered area on the southwest side of the fault basin. It forms small islands and reefs along the Chek Chau Fault from Pak Sha Chau (白沙洲) (Round Island) in the north to Chek Chau (赤洲) (Port Island), Cham Pai (杉排), Kung Chau (弓洲) and Shek Ngau Pai (石牛排) in the south. On the other hand, the thickly bedded reddish brown conglomerates expose at Xiasha (下沙) of Shenzhen on the northeast side of the Fault Basin. The same rock also occurs at Shek Ngau Chau (石牛洲) in the centre of southeast side of the basin. Recently thirty-five marine boreholes confirmed that the Chek Chau Formation underlie much of the Fault Basin.

The Ping Chau Formation occurs at Ping Chau Island with 2000m long and 700m wide in the northeast side of Tai Pang Wan. The magnetic anomaly map shows the formation under the seabed having 6000m long and 3000m wide. It comprises thinly bedded dark grey calcareous zeolite- and aegirine-bearing siltstone with a 0.6m to 1.2m thick chert. Most bedding of the formation are varying from 20 to 60 mm thick with a gently northeastward dipping. The thickness is estimated 200m thick. The geologists of Nanjing Institute of Geology and Palaeontology, Academia Sinica have helped Hong Kong to collect and identify fossils. These included specimens of some 200 fossil plants and 39 fossil insects. Numerous fossils are found in the strata of Ping Chau. Among fossil plants and sporopollens, the angiosperms are dominant. The fossil insects: cf. *Liutaiprosbole* sp. and *Coleoptera* sp., the macroplants: *Cercis* sp. and *Ocotea sinensis* and the sporopollens: *Quercordites microhenrici*, *Engelhardtoidites punctatus* and *Ulmoideipites granulatus* indicate that the geological age of Ping Chau Formation is Paleogene. Based on all evidence, those strata in Tai Pang Wan Fault Basin are formed from late Cretaceous to Paleogene.

Hau Hoi Wan Fault Basin (后海湾断陷盆地) (Figure 2). The fault basin is controlled by two northeast trending faults with 20km long and 4km wide existing in Hau Hoi Wan (Deep Bay). According to the site investigation data from more than 200 marine boreholes in the fault basin, it is found that much of the seabed are covered by granite. The sedimentary rocks cropping out in the basin comprise thickly bedded reddish brown conglomerate, coarse grain-sandstone and siltstone. They only exposed in scattered area at Lau Fau Shan (流浮山) in the southeast coast and at Baishizhou (白石洲) in the northeast coast of the basin. The same rocks are also buried under the seabed between Shekou (蛇口) and Pak Nai (白泥), which found by Boreholes M167--M170. The site investigation report suggests that the age of the sedimentary rock in the basin is Lok Ma Chau Formation belonging to Carboniferous age. These are violated the fact. The isotope dating age of granite done by Hong Kong Geological Survey is 236.3 ± 0.8 Ma before present. It is belonged to Triassic age. the granite is covered by a completely weathering zone ranging from several m up to 10m. These reflect the granite has subjected to a long period of weathering and erosion. The contact relationship between the granite and Lok Ma Chau Formation is not the magma intruding into the overlain rock. Based on the lithology, the formation may be correlated to the same outcrop at Baishizhou (白石洲) in the same fault basin which is indicated the late Cretaceous age. Those strata in Shenzhen are named Tai Long Shan Formation (大壆山組) which is equal to Chek Chau Formation in Hong Kong.

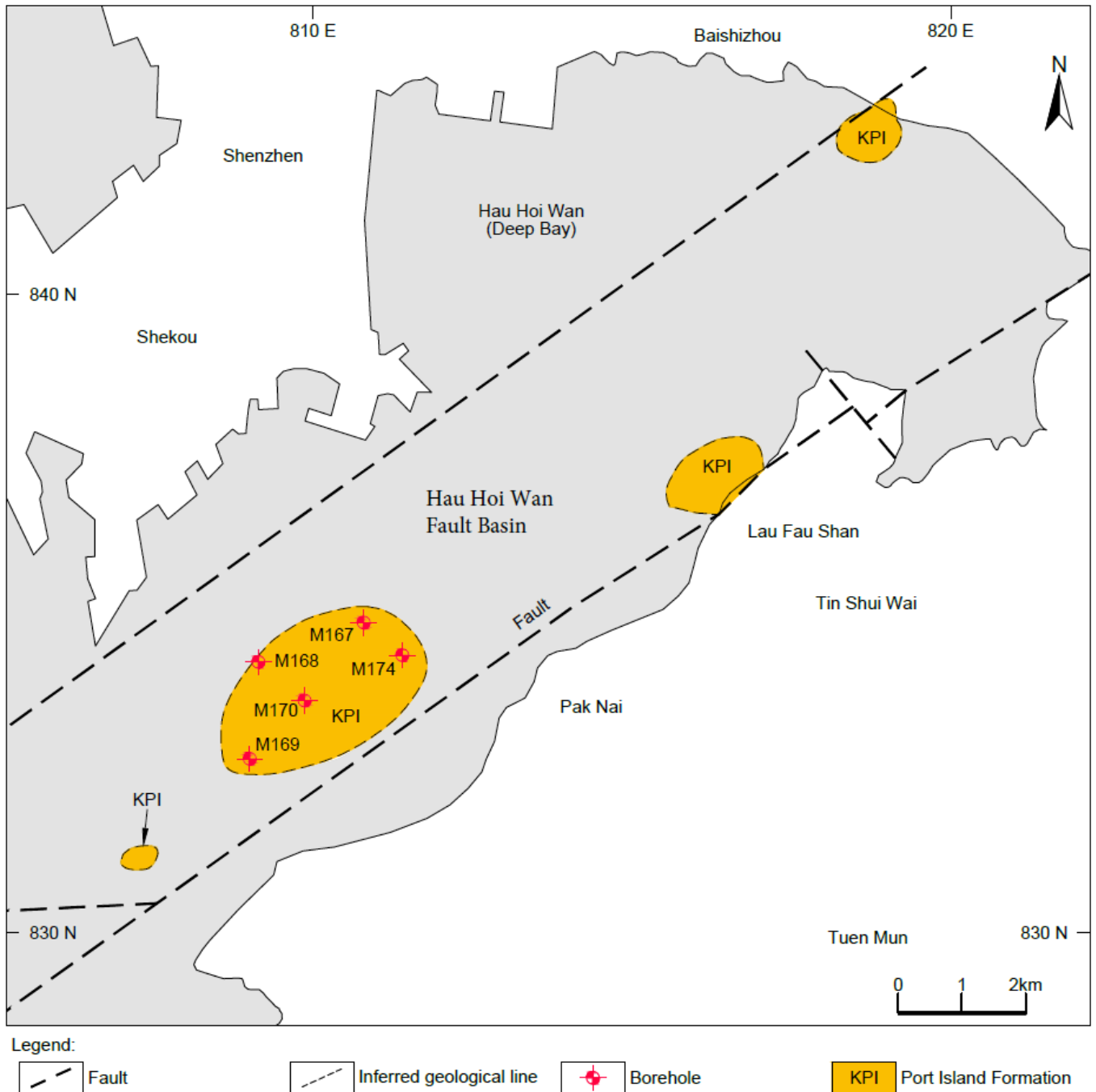


Figure 2 Hau Hoi Wan Fault Basin

Po Toi--Dangan Fault Basin (蒲台--擔桿列島斷陷盆地) (Figure 3). There are two ENE trending strike-slip faults bounded a pull-apart basin (拉分盆地). The distance from the basin to Po Toi is 4km, to Dangan Islands is 5km. The fault basin is 25km long and up to 5km wide and is overlain by a cover of over 170m of Quaternary sediments. The Tertiary strata recovered from boreholes within the basin mainly comprise grey to dark grey, thinly bedded calcareous siltstone and mudstone which are characterized by thinly laminated detrital and chemical cycle deposits. The fossil sporopollens and ostracods indicate that the strata may be possibly correlated to Ping Chau Formation of early Tertiary age. The Tertiary sequence is over 300m thick.

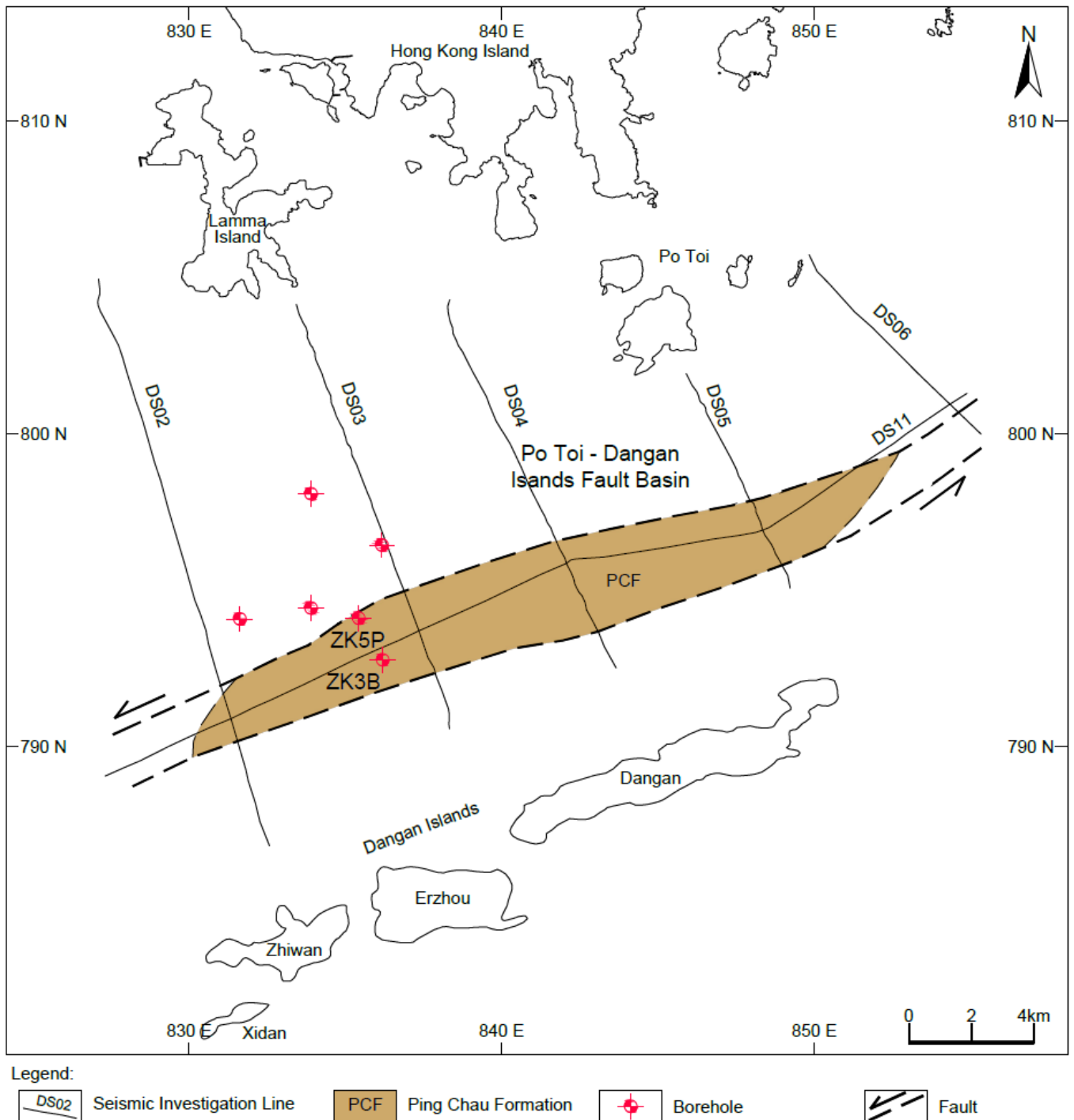


Figure 3 Po Toi - Dangan Islands Fault Basin

References

- Lai, K. W. (1986) A review of the late Cretaceous-Palaeogene fault basins around Hong Kong. *Proceedings of the seminar on the Marine Geology of Hong Kong and the Pearl River Mouth*, Hong Kong. 39-45.
- Lai, K.W. (1991) The stratigraphy of Ping Chau Formation, Hong Kong. *Geological Society of Hong Kong Newsletter*, 9(2), 2-23
- Lai, K.W. (1997) Early Tertiary depositional basins of Hong Kong, *Proceeding of the 30th International Geological Congress*. International Sciences Publishers. Netherlands, 8,107-120.

The Geological Society of Hong Kong - 40th Anniversary

- Lee C.M., Chen J.H. & He G.X. (1998). *The Palaeontology and Stratigraphy of Hong Kong*. 242p. (in Chinese) Science Press. Beijing.
- Lai, K.W. and James J.W.C. (2000) The Dangan Basin-- a fault-bounded Tertiary off southern Hong Kong. *Hong Kong Geologist*, 1-11.
- Sewell, R.J., Campbell, S.D.G., Fletcher, C.J.N., Lai, K.W. and Kirk, P.A. (2000) *The Pre-Quaternary Geology of Hong Kong*. Hong Kong Geological Survey, Civil Engineering Department, Hong Kong Government SAR. 181p

25 August 2022

參觀展覽：香港科學館地球科學廳及專題展覽【八大·尋龍記】

Hong Kong Science Museum Tour:

Earth Science Gallery and “The Big Eight – Dinosaur Revelation” Special Exhibition



資料來源：康樂及文化事務署

Information Source: Leisure and Cultural Services Department

27 August 2022

野外考察：鳳凰笏、虎王洲及吉澳（馬料水碼頭集合）
Field Workshop: Fung Wong Wat, Fu Wong Chau and Kat O
(Gather at Ma Liu Shui Ferry Pier)

Led by Prof. LS Chan, Ms Trudy Kwong, Mr Edison Tse and Ms. Jasmine Song

The field workshop is scheduled for 27 August 2022 (Saturday). A group of 30 participants gathers at Ma Liu Shui Ferry Pier at 9:00am to embark on an adventurous yet pleasant boat trip to three main locations, namely Fung Wong Wat, Fu Wong Chau and Kat O.

At Fung Wong Wat, subvertical beds of quartz conglomerate of Devonian Bluff Head Formation outcrop along the coast. The quartz-pebble conglomerate form a spectacular landscape jutting out of the water. Onshore, thick sandstone strata from fine-to coarse-grained dips steeply and show cross-stratification. Detailed observations of the cross-bedding provide clues to better understand the structure hidden in the tilted strata.

At Fu Wong Chau, a kidney-shaped isolated island in Double Haven, the group takes speedboat to reach the island and inspects the hydrothermal breccia outcrops. The breccia is intensely altered by the upwelling and intrusion of silica-rich hydrothermal fluids, resulting in chalcedonic veins, chaotic and mosaic breccias and a variety of hydrothermal textures and structures. Such hydrothermal phenomenon appears to be widespread and can be traced in different locations in Double Haven.

At Kat O, aka Crooked Island, the group will visit bedded breccia of Cretaceous Kat O Formation. The formation is distinguished from other formations by its abundant calcareous sediment, which is inferred to be the filling of a small fault-bounded depositional basin. The presence of reddish terrigenous sediments signifies an arid environment probably existed into the Cretaceous.



Subvertical Quartz Conglomerate Beds Cross



Bedding on Sandstone at Fung Wong Wat



Hydrothermal Breccia at Fu Wong Chau



Bedded Breccia at Kat O

3 September 2022

參觀寶珊排水隧道-山泥傾瀉科技展學館

Visit to Po Shan Drainage Tunnel –

Landslide Sci -Tech Chamber

資料來源：寶珊排水隧道-山泥傾瀉科技展學館
Fact Sheet : Po Shan Drainage Tunnel - Landslide Sci-Tech Chamber
(05/2022)

寶珊排水隧道—長遠防治工程項目資料

Po Shan Drainage Tunnel—Landslip Prevention and Mitigation Works Details

項目資料 Project Information

項目名稱 Project Title	半山區寶珊地段防治山泥傾瀉工程 Landslip Preventive Works at Po Shan, Mid-levels
工程部門 Works Department	土木工程拓展署 Civil Engineering and Development Department
工程範圍 Project Scope	為長期提升寶珊地段山坡穩定以防止各類山泥傾瀉的發生 To improve the long term stability of the Po Shan area against various types of landslides
工程裨益 Engineering Merits	- 為居住於寶珊地段的居民減少受山泥傾瀉影響的風險 Reducing the landslide risk for residents living in Po Shan Area - 全自動化水位監察及調控大大減少所需保養費用 Automatic groundwater monitoring and control minimize maintenance cost - 與香港天文台合作作裝置高精度地震儀以探測世界各地地震並協助發出海嘯警告 Installation of a broadband seismograph station in collaboration with the Hong Kong Observatory for monitoring earthquakes worldwide and assisting issuance of tsunami warning for the local and international communities
工程費用 Project Cost	約一億六千五百萬港元 Around HK\$165million
完成日期 Completion Date	2009年12月 December 2009

工程項目概要 Summary of Construction Works

排水隧道 Drainage Tunnels	用鑽挖機建造 Constructed by Tunnel Boring Machine
高位隧道 High Tunnel	直徑 Diameter - 3.5米 (m) 長度 Length - 305米 (m)
低位隧道 Low Tunnel	直徑 Diameter - 3.5米 (m) 長度 Length - 208米 (m)
排水斜管 Sub-vertical Drains	172條, 24-100米長 (172 nos., 24-100m long)
柔性防護網 Flexible Barriers	120米長, 5米高, 防護能級 高達 3000千焦耳 120m long, 5m high with 3000kJ energy category
隧道入口斜坡泥釘工程 Soil Nailing Works at Tunnel Portal	285條, 15-29.5米長 285 nos., 15-29.5m long
鄰近天然山坡泥釘工程 Soil Nailing Works at Nearby Natural Slopes	685條, 20米長 685 nos., 20m long

詳細資料 Works Details



高位隧道
High Tunnel

低位隧道
Low Tunnel

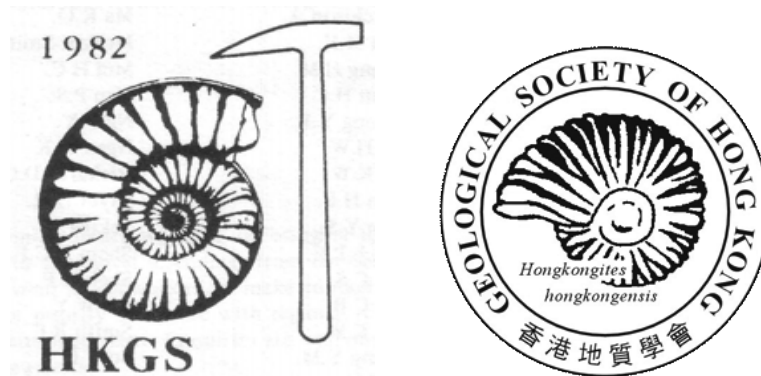
資料來源：土木工程拓展署

Information Source: Civil Engineering and Development Department

History of the Geological Society of Hong Kong

The Geological Society of Hong Kong (GSHK), a non-profit making organization, was officially registered under the Societies Ordinance on the 26th July 1982 formed by a group of geologists work-based in Hong Kong, with an aim to pursue its prime objective as stated in the Constitution, namely “the Advancement of Geological Sciences, Particularly in Hong Kong and Nearby Areas”. It also provides a platform for both professional geologists and amateurs to meet and promote knowledge exchange, enhance interests of its members as well as the general public on geological studies and findings.

The original logo of the Geological Society of Hong Kong had described the Geological Society with a geological hammer and the iconic 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 more 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 formation of the Geological Society of Hong Kong was first considered back in early 1980. Following a few ‘Social’ meetings between Maurice Atherton (Senior Lecturer, Hong Kong Polytechnic then Hong Kong Polytechnic University), Peter Randall (Engineering Geologist in Ove Arup, then Chief Investment Officer), Dr. David Workman (Professor in Department of Geography, University of Hong Kong), Andrew Leach and Dr. Alistair Burnet (Chief Geotechnical Engineer (Geologist)/Geotechnical Engineering Office), 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 field.

The Geological Society of Hong Kong - 40th Anniversary

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 (then Hong Kong Polytechnic University), a talk by Brian Ruxton (Department of Geography, University of Hong Kong) and field trips throughout Hong Kong.

The ‘ad hoc’ Committee, comprising Messrs Alister Burnett & Steve Hencher (Geologists in the Geotechnical Engineering Office), Andrew Leach, Peter Randall, Dr. David Workman, John Sekura and Morris Atherton (Hong Kong Polytechnic), met at the beginning of 1981. On 27th January 1981, the Committee set up a program of events for 1981 (lectures, films and field excursions); establish a 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. 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 Society of Hong Kong and its Constitution was officially granted registration on 26th January 1982.

In order to refresh our memories, the first “Chairman’s Message” related to the 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 Appendix 1.

Since its establishment, the Geological Society of Hong Kong has been holding geological conferences and seminars regularly, and organizing local and overseas geological field trips as well as lectures. At present, the GSHK maintains approximately 250 members, including professional geologists from the public and private sectors, academia, as well as teachers, students and amateurs.

The Society revitalized the Teachers Group in 1985/86, conducting workshops in earth science teaching in support of the reform of new school curriculum. IA Nature Explorers subgroup for young members was established in 2002, which 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 aspects. Besides knowledge acquisition and attitude formation, we also encourage our members to behave environment-friendly to protect our environment and to adopt a sustainable lifestyle.” The Marine Studies Group was also first formed in 1984/85 led by

The Geological Society of Hong Kong - 40th Anniversary

experienced geologists specialized in marine geology. All the above formed as part of GSHK's endeavours to reach out to the general public.



GSHK has established the Profession Branch (GSHK-PB) in 2006 to oversee the benefits and professional status of its members. The logo of GSHK-PB symbolizes the complexity of Hong Kong geology which includes onshore and offshore stratigraphy, major rocks and simplified geological structures. GSHK-PB has close relationship with the Geological Societies in China, Taiwan and the nearby regions. GSHK-PB has been organizing, supporting, and working with the Geological Society of London, Hong Kong Regional Group (GSL HKRG), Association of Geotechnical and Geoenvironmental Specialists (HK) (AGS(HK)), The Hong Kong Institution of Engineers (Geotechnical Division), Institute of Materials, Minerals and Mining (HK Branch), Institute of Quarrying (HK Branch) and The Geotechnical Engineering Office, Civil Engineering and Development Department, such as providing professional opinions and comments on the draft version of GEO Publication No. 1/2007, Engineering Geological Practice in Hong Kong.

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.

Before 10 November 2010, the GSHK had been registered as an unincorporated society under the Societies Ordinance. The General Committee at the time had decided to re-register the GSHK as a limited company, addressing members' concerns of holding unlimited liabilities.

GSHK-PB has been the Hong Kong Regional group in the International Association of Engineering Geology and Environment (IAEG) since 2018. GSHK-PB members attended the IAEG Councils meeting in the USA (2018) and Korea (2019), and the subsequent annual IAEG Council meetings on Zoom platform. GSHK-PB also co-organised the 13th Asian Regional Conference of IAEG held in Singapore in 2021. Dr. Louis Wong, one of our members, is currently the Editor-in-Chief of the Bulletin of Engineering Geology and the Environment (2021 impact factor = 4.130), the official journal of the IAEG.

GSHK co-organised the Cross Strait Three Places Engineering Geology Conferences with the Taiwan Central University, The State Key Laboratory of Geohazard Prevention and Geoenvironment Protection (SKLGP), The Chengdu University of Technology in 2018 (hosted in Taiwan) and in 2019 (hosted in Hong Kong).

The Geological Society of Hong Kong - 40th Anniversary

GSHK has worked closely with the Geological Society of Guangdong Province (GSGD), for example, their professional geologists led GSHK members to a field trip in Danxia Shan Geopark in May 2019, and held an online talk on the Geologic relicts and geoparks in Guangdong in 2020.

Moreover, GSHK-PB took the lead and gathered other professional geotechnical engineers, and assisted HKU School of Professional and Continuing Education (HKU SPACE) to set up the Higher Diploma course in Geotechnical Engineering in 2016.

GSHK has continued to reach out students from high schools and universities through talks on career of geologist and geotechnical engineer.

The Society's Committee

Over the years, GSHK has many enthusiastic members who has taken part in running the Society's matters with relentless effort at their free time. We should give them a big applause. In Appendix 2, we have compiled a summary of the Chairmen/Chairlady and Secretaries of the Society since its establishment for reference.

Publications

GSHK owns 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 40 years has been archived in the website of the Geological Society of Hong Kong (<http://geolsoc.org.hk/>). The publications focus on topics of geology of Hong Kong at different localities such as the Quaternary stratigraphy for Hong Kong, dolomitic limestone in Tolo Harbour, tectonic framework of Hong Kong and vicinity and its relationship to regional seismicity, etc. Members are able to retrieve these publications for reference from the website of the Society. In addition, tertiary education institute had often approached GSHK to use our published papers for their lectures and research, e.g. Open University of Hong Kong (now Hong Kong Metropolitan University).

The publications of GSHK have 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 reports of field trip written by our members in the form of articles which are recorded in the Society's website.

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 prospect 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 purposes. 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

Chairmen / Chairlady of the Geological Society of Hong Kong

Year	Chairmen / Chairlady
1982-1987	Dr A. D. Burnett
1987-1988	Dr D. R. Workman
1988-1989	Mr K. W. Lee
1989-1991	Mr M. J. Atherton
1991-1997	Dr R. Shaw
1997-1998	Mr C. M. Lee
1998-2000	Prof. R. B. Owen
2000-2004	Prof. L. S. Chan
2004-2006	Mr K. W. Lai
2006-2014	Dr Margie Q. F. Chen
2014-2020	Mr K. F. Leung
2020-Now	Mr Paul C. T. Cheung

Appendix 2 (Cont')

Secretaries of the Geological Society of Hong Kong

Year	Secretaries
1982-1987	Dr D. R. Workman
1987-1990	Mr R. L. Langford
1990-1992	Dr R. J. Neller
1992-1997	Prof. R. B. Owen
1997-1998	Mr William C. H. Chow
1998-2000	Dr R. J. Neller
2000-2007	Mr William C. H. Chow
2007-2012	Mr Patrick C. S. Ho
2012-2014	Mr Felix Lee
2014-2018	Ms Tracy Leung
2018-Now	Ms Sandie Ho

The Geological Society of Hong Kong - 40th Anniversary

2017-2018



2017-2018



2017-2018



The Geological Society of Hong Kong - 40th Anniversary

2017-2018



2017-2018



2018-2019



2018-2019



2018-2019



2019-2020



2019-2020



2020-2021



2020-2021





緬懷地層古生物學家李作明先生

剛剛從微信群裡知道，香港地層古生物學家李作明先生因病醫治無效，不幸於2019年10月22日與世長辭。我內心不由地悲痛起來！

李先生1934年出生於印尼，1952年畢業於雅加達巴達維亞中學（巴中）。高中畢業後，回到中國，考取了北京地質學院（現在的中國地質大學），走科學建國道路。在1956年成為該校首批大學畢業生之一。大學畢業後，分配到中蘇合作的南嶺區域地質測量隊工作，主要任務是調查南嶺花崗岩分佈，鎢、錫、鉬、稀土和鈾礦礦產分佈。這打下了我國鎢鈾礦生產的基礎，也培育了不少專業人才。四年後，因蘇聯專家撤走，這個測量隊解散，又進入廣東省地質局。他努力工作，富有成績，曾出席地質部的地質工作先進生產者代表會議，受到表揚獎勵。

1973年，他來香港定居，在香港理工大學做地質實驗工作，從事地層古生物化石研究。他在1979年發現了泥盆紀的魚化石（盾皮魚，下圖），把香港最古老的沉積地層推早了1億多年，從原來的二疊紀推早到了大約4億年前的泥盆紀年代。這個發現引起了香港社會轟動和地質界熱烈討論。後來，李先生把這塊魚化石贈送給了中國地質博物館永久保存。他在1997年和1998年分別出版了“香港古生物和地層”上下兩冊專著。他是一位重要的香港地層古生物專家。



李先生在香港理工大學建立了香港最豐富的岩石標本和最系統的地層標本。很多標本都是他親自在野外獲取的、用背包背回到實驗室的。李先生也把他在中蘇合作隊學會的打好和修理岩石標本基本功，傳授給了很多同行和晚輩。現在，我們還可以從香港理工大學的地質實驗室的標本中領會到這些基本功。

我與李先生認識開始于1997年。當時，我參加了香港地質學會的一些地質考察活動，跟李先生學習香港地質。最為重要的是，多年來，李先生一直在幫助香港大學土木工程系帶本科生的野外地質實習培育工作。在2009年，我開始在香港大學負責講授工程地質課，就與李先生交流多了一些。特別地，我參加了他帶隊指導的2009年2月28日在香港大埔附近的馬屎洲野外地質實習課。

李先生是一位愛國歸僑，一位踏實勤奮的地質學家。從1952年踏上祖國大地開始，就跟隨共和國一起成長，經歷了種種風雨。最為重要的是，李先生為香港的地質歷史譜寫了生動的新篇章。

在歡慶我們偉大新中國70華誕之際，李先生走完了人生的最後道路。李先生一生都是勤勤懇懇、生動感人，是我們地質學校友的楷模！李先生一路走好，您永遠活在我們心中！

岳中琦

2019年11月12日21:22寫成于香港大學602辦公室



1988年南京地質古生物研究所專家抵港
考察新疆古地磁研究任務。地政站。
合影於中文大學大學車站前



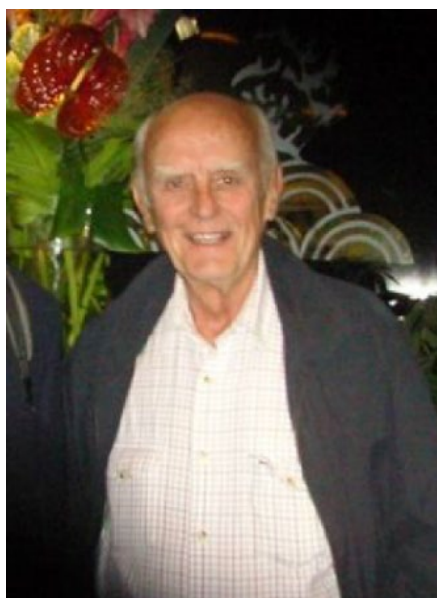
2000年代 2005年
考察新疆·阿勒泰地區 喀納斯冰川湖(喀納斯湖)北端
後面背景雪山最高處為友誼峰(中蘇交界)

The Geological Society of Hong Kong - 40th Anniversary



The Geological Society of Hong Kong - 40th Anniversary





Obituary

Dr David Workman (1935 – 2017)

The Society notes with great sadness the recent passing of Dr David Workman, former Lecturer and Senior Lecturer in Geology at The University of Hong Kong.

After graduation in the UK, David was briefly employed at the University of Leeds, before joining the then Overseas Geological Survey (OGS) of the British Ministry of Overseas Development as a Senior Scientific Officer from 1963 to 1968. During this period he carried out geological mapping and mineral exploration in Lesotho, Thailand and Laos, followed by a two-year secondment as an adviser to a United Nations Development Programme Committee for Co-ordination of Investigations of the Lower Mekong Basin, based in Bangkok.

David was then promoted to Principal Scientific Officer in the Overseas Division of the Institute of Geological Sciences (IGS, successor to the OGS) and spent two more years on mineral exploration projects in Turkey and Korea, before rejoining the UNDP Committee for the Lower Mekong as a Programme Officer from 1972-1976. This was followed by further mineral surveys in Korea, and planning investigations for dam and irrigation projects in Thailand, during a brief period working for a US engineering consultancy based in Denver. In 1977 David took up broader responsibility for regional mineral resources development, as an Economics Affairs Officer attached to the UN Economic and Social Commission for Asia and the Pacific, also based in Bangkok.

David joined HKU in late 1979 and was Lecturer (1979-1981) and then Senior Lecturer in Geology for a total of 18 years, up to his retirement in late 1997. He first joined the Department of Geography and Geology (later the Department of Geography), but switched to the new Earth Sciences Unit in 1993, to begin undergraduate teaching for the new BSc in Earth Sciences, along with Professor Wyss Yim, and remained there as Senior Lecturer when the Department of Earth Sciences was formally established in 1995.

DES alumni from those early years will recall David's warm and friendly teaching style, his wide-ranging knowledge of the geology of Hong Kong and the region, and lectures fully illustrated by many of his fine field photographs. He was widely respected for the quality of his teaching and academic writing, and also as a dedicated and inspiring supervisor.

David was one of the founder and an active supporter of the GSHK throughout his time in Hong Kong, helping to organise and lead field trips and seminars, and as Secretary to the committee from 1982 to 1987 and as Chairman from 1987 to 1988. David was very keen to follow the news of Hong Kong and he was involved in heritage protection works in Hong Kong 2 years ago.

David's authoritative knowledge of regional geology led to him authoring or co-authoring four key contributions (on the geology of Cambodia, Laos, Thailand and Vietnam) in the Encyclopedia of European and Asian Regional Geology (eds. Moores & Fairbridge, 1998). He also co-authored a 100-page summary of the geology of Hong Kong published in the Bulletin of the Association of Engineering Geologists in 1989. These were among some 40 other publications up to the late 1990s, mainly on the geology, mineral resources and tectonics of South East Asia.

After leaving HKU, David retired to Bath in Western England with his family and remained active for many years, leading geological walking tours through the city based on the variety of building and paving stones used in Bath's historical architecture.

Paul Cheung

p.s. The above message was written by Dr. Dick Martin with information provided by Prof. L S CHAN and Kennex of Earth Sciences Department in the University of Hong Kong

鳴謝

Acknowledgement



土木工程拓展署

Civil Engineering and Development Department



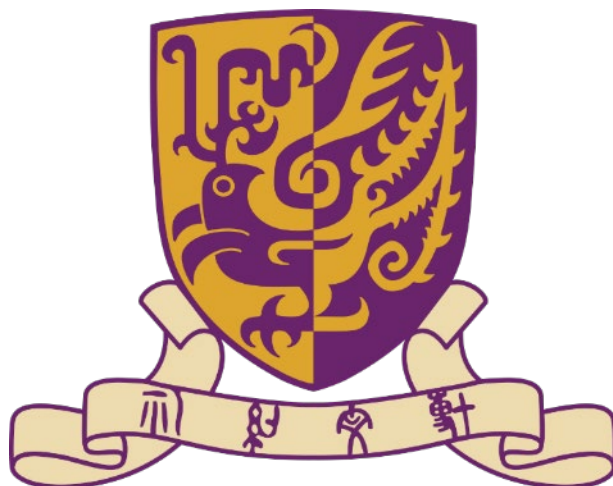
康樂及文化事務署

Leisure and Cultural Services Department

協辦機構
Supporting Organisations



香港大學 地球科學系
Department of Earth Sciences,
The University of Hong Kong



香港中文大學 地球與環境科學課程
Earth System Science Programme,
The Chinese University of Hong Kong

贊助商(白金級)
Sponsor (Platinum)



亞洲寶石學院及鑑定所有限公司
Asian Gemmological Institute and Laboratory Limited

贊助商(黃金級)
Sponsor (Gold)



香港建造商會
Hong Kong Construction Association

Site Investigation Contractors Committee

贊助商(黃金級)
Sponsor (Gold)

陳龍生 教授
Prof. Chan Lung Sang

石頭塵地質顧問有限公司
Chan & Co Geoconsulting Limited

贊助商(黃金級)
Sponsor (Gold)

AECOM

艾奕康有限公司
AECOM Asia Company Limited

贊助商(黃金級)
Sponsor (Gold)



歐美大地儀器設備中國有限公司
Earth Products China Limited

贊助商(黃金級)
Sponsor (Gold)



金門建築有限公司
Gammon Construction Limited

贊助商(黃金級)
Sponsor (Gold)



中國地質工程集團有限公司
China Geo-Engineering Corporation

贊助商(黃金級)
Sponsor (Gold)



SAS Asia Bar Systems Pte. Limited

贊助商(黃金級)
Sponsor (Gold)



興澳工程顧問有限公司
Sinomac Engineering Consultants Limited

贊助商(黃金級)
Sponsor (Gold)



佳為工程勘察測繪有限公司
Engineering Survey and Geophysics Limited

贊助商(銀級)
Sponsor (Silver)



黃志明建築工程師有限公司
CM Wong & Associated Limited



萬利仕(亞洲)顧問有限公司
Mannings (Asia) Consultants Ltd

贊助商(銀級)
Sponsor (Silver)

JACOBS®

嘉科工程顧問有限公司
Jacobs China Limited

**aurecon**

澳昱冠(香港)有限公司
Aurecon Hong Kong Limited

贊助商(銀級)
Sponsor (Silver)



法國地基建築有限公司
Bachy Soletanche Group Limited



永豐建築工程(香港)有限公司
Winfield Engineering (Hong Kong) Limited

贊助商(銀級)
Sponsor (Silver)



輝固土力工程有限公司
Fugro Geotechnical Services Limited



德晟工程有限公司
Dethon Engineering Limited

晚宴贊助
Sponsor for Dinner

ARUP

奧雅納工程顧問有限公司
Ove Arup & Partners Hong Kong Limited



華益土力有限公司
Lam Geotechnics Limited



歐美大地

EARTH PRODUCTS CHINA LIMITED

The Ultimate Testing Instruments Provider



**Koden Ultrasonic Drilling Monitor
for 100m and 150m**



**Structural Health
Monitoring System**



Ménard Pressuremeter



3D-Radar (GPR)



Asphalt Density Gauge



Corrosion Detector

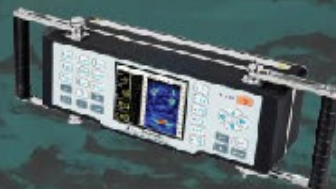
原位測試	環境監測
壓樁檢測	紅外線檢
工程物探	地下管線勘探
地基勘探	工業無損檢測
無損檢測	橋樑結構監測
應變電測	岩土及結構監測
道路測試	建材及結構測試



**Retroflectometer for
Signs and Road Markings**



Infrared Camera



Ultrasonic Tomograph



**Shaft Area
Profile Evaluator**

T (852) 2392 8698

W en.epccn.com

F (852) 2395 5655

E info@epc.com.hk

**A 12/F Asia Trade Centre, 79 Lei Muk Rd.,
Kwai Chung, N.T., H.K.**



YOUR NUMBER ONE PARTNER FOR AMBITIOUS PROJECTS

Products made by "Stahlwerk Annahütte"

Established in 2012, SAS Asia Bar Systems Pte Ltd supplies fully-thread steel bars from Stahlwerk Annahütte in Germany to the Asia Pacific region. Our thread bar systems come in different grades and diameters, suitable for various applications such as formwork ties, geotechnical, post-tensioning, as well as LNG cryogenic uses. SAS thread bar systems have been successfully used on several signification projects in Asia.

Do let us know on how we can support your project needs.



STEEL

essential for

LIFE



SAS Asia Bar Systems Pte. Ltd.
1100 Lower Delta Road • EPL Building • #03-05A • Singapore 169206
Phone +65-6276 4880 • Fax +65-6270 4842 • info@sas-asia.sg • www.sas-asia.sg



Delivering a better world

At AECOM, we envision a world where **infrastructure creates opportunity for everyone.**

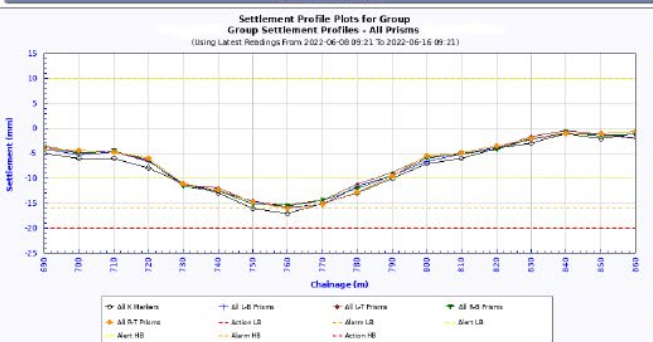
Our geologists and geoscience professionals deliver a wide variety of geological services on geotechnical and civil engineering projects, including ground modelling, slope stability, rock engineering, geohazards and hydrogeology. Supported by our industry-leading technical expertise, we provide tailored sustainable solutions to shape our collective future.

No.1 ranking by Fortune magazine as World's Most Admired Company in its industry

Congratulations to the Hong Kong Geological Society on its 40th Anniversary

The construction industry is a vital component of Hong Kong's healthy economy and the Geologists and Engineers working in Gammon are proud to have contributed to the success of our city and its society. We have helped investigate, design and build much of the transportation network including Chek Lap Kok airport and the West Kowloon Express Rail terminus. We have constructed dams and water schemes that supply Hong Kong with water and have built skyscrapers that are icons of our modern city.

Geologists and Geotechnical Engineers have played a significant role in the transformation of Hong Kong, building a city of the future where we can all live in comfort, safety and pride.



We look forward to continuing our support for the Hong Kong Geological Society over the next 40 years, taking with us core values underpinned by quality, integrity, safety, social responsibility and the goal of adding value to all our endeavors.



中国地质工程集团有限公司
CHINA GEO-ENGINEERING CORPORATION

我們的主要業務包括：
Our Business includes:

基礎工程

Foundation Works

斜坡及擋土牆長遠防治山泥傾瀉工程

Construction of Landslip Preventive
and Mitigation Works to Slopes and
Retaining Walls

道路及渠務工程

Roads and Drainage

水務工程

Waterworks

地盤平整工程

Site Formation



香港灣仔港灣道30號新鴻基中心24樓2421-25室
Rm. 2421-25, 24/F., Sun Hung Kai Centre, 30 Harbour Road, Wanchai, Hong Kong
TEL : (852) 2511 9001 FAX : (852) 2580 0697



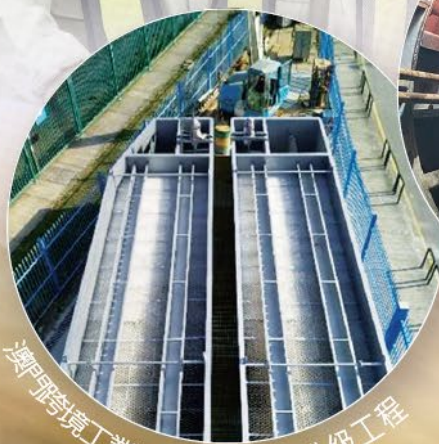
ISO 9001:2015
Certificate No.: CC 1776



ISO 14001:2015
Certificate No.: CC 3287



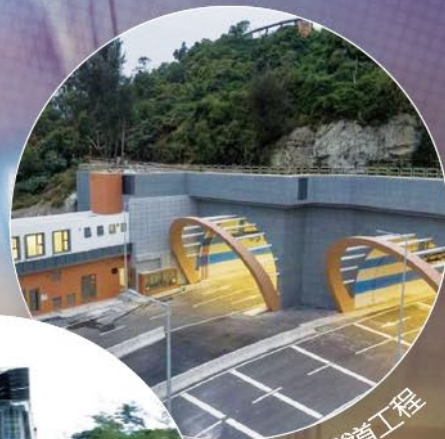
ISO 45001:2018
Certificate No.: CC 6799



澳門跨境工業區污水處理站升級工程



完善新口岸污水截流管潛盾隧道可行性研究及基本設計



路環九澳隧道工程



氹仔湖畔花園至龍環葡韻步行徑工程

SINOMAC

■ 興澳公司為臺灣中興工程顧問股份有限公司於2008年在澳門註冊之子公司
主要業務項目為>工程設計、工程諮詢、環境影響評估、GIS地理資訊系統開發與維護
及地球物理調查，綜合性領域之業務範圍包括電力工程、工業建設、環境工程
水利工程、岩土工程、機電工程、社區開發、交通工程、建築景觀工程等全方位專業服務





Congratulations to The Geological Society of Hong Kong on 40th Anniversary

With Compliment

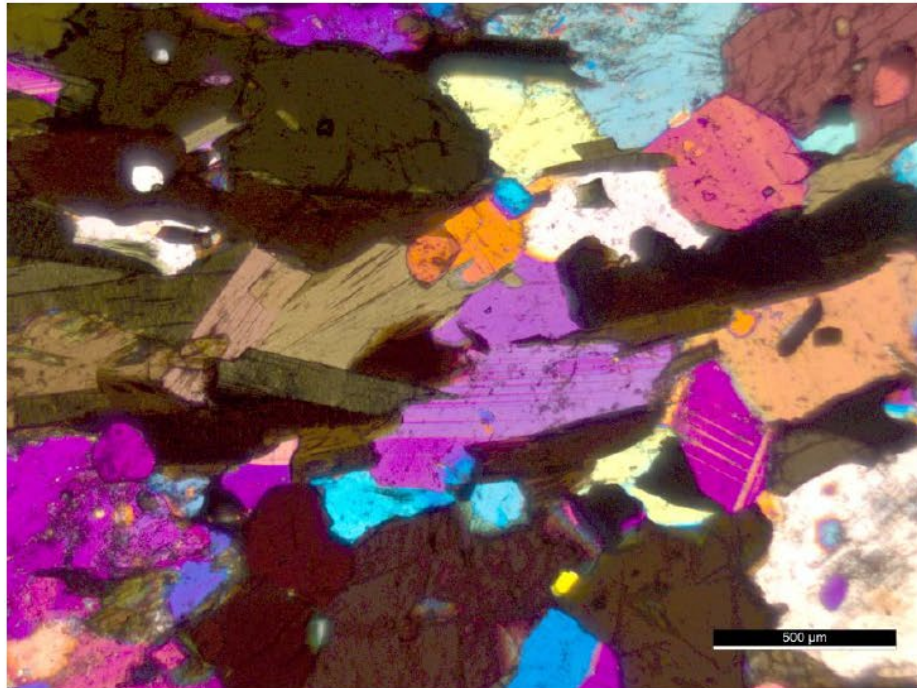
Engineering Survey and Geophysics Limited

佳為工程勘察測繪有限公司

致意

Contact: Dr. Wilson Yeh

Email: WilsonYeh@esg-hk.com



Your Assistant in Geology

We make geological knowledge accessible!

Assessment of cladding stones

Testing services on geology of stones according to ASTM standards
On-site assessment of stone blocks for facade
Slip-resistance testing

Geological mapping and investigation

Field mapping and petrographic study
Geochemical analyses

Knowledge products in geology & geophysics

Provision of expertise on local geology
Consulting service on engineering geophysical methods
Training workshops on geology and geophysics

www.geoconsultingco.com; chan.geoconsulting@gmail.com



C M WONG & ASSOCIATES LTD
黃志明建築工程師有限公司

11/F Universal Trade Centre
3-5A Arbuthnot Road, Hong Kong
Tel: (852)2522-1068
Fax: (852)2526-3111
www.cmwal.com
cmwal@cmwal.com

C M Wong & Associates Ltd is a Hong Kong based consulting engineer in providing a full range of professional services including feasibility studies, planning, design and supervision in relation to building and infrastructure projects. Our clients include various Hong Kong Government departments, institutions and major developers.

We adopt a flexible approach to suit clients' needs. We are also renowned for providing innovative engineering solutions for challenging projects especially for those with difficult ground conditions.



**Sustainable Slope
Excellence Award 2020
Champion**
11NW-A/C597 Reservoir Dam
of Kowloon Eyewash Reservoir



**Sustainable Slope
Excellence Award 2020
Special Merit**
11SW-A/C1113
Hornsey Road near Chater Hall



ISO 9001:2015
Certificate No.: CC 801



ISO 14001:2015
Certificate No.: CC 5409



ISO 45001:2018
Certificate No.: CC 7933

*Congratulations to Geological Society of Hong Kong
40th Anniversary*

**INSPIRATION
WITH EXCELLENCE**

Mannings (Asia) Consultants Limited

Wholly owned subsidiary of Boltek Holdings Limited (HKEX Stock Code 8601)
5/F, Winning Commercial Bldg., 46-48 Hillwood Rd., Tsim Sha Tsui, Kln., Hong Kong
Tel : (+852) 3168 2028 Fax : (+852) 3168 2022



**MANNINGS
Consultants**

建基香港 五十年

*Celebrating
50 Years
in Hong Kong*



BACHY SOLETANCHE
法國地基建築公司

Unit 1503-06 · 15/F Wing On Kowloon Centre
345 Nathan Road · Kowloon · Hong Kong
Tel +852 2369 2869 | Fax +852 2722 0227

永豐
建築工程
(香港)
有限公司

we are artisans . . .

*Winfield Engineering (Hong Kong)
Limited*

Contact us: info@winfield.hk



Jacobs

Challenging today.
Reinventing tomorrow.

We deliver impactful global solutions to create a more connected, sustainable world — from intelligence to infrastructure, cyber security to space exploration. Our 55,000 employees across 40 countries work every day, challenging the expectations of today to reinvent the way we'll all live tomorrow.

Jacobs applies wide ranging professional management capabilities to projects in over 30 countries and has a wealth of experience in infrastructure development, including design and engineering consultancy for geotechnical works.

Find out more at jacobs.com

in @ t f v



FUGRO

UNLOCKING **INSIGHTS** FROM **GEO-DATA**
FOR A **SAFE** AND **LIVEABLE** WORLD



Since the early 1970s, Fugro has been the first international geotechnical specialist to establish consultancy & contracting services in Hong Kong. Through integrated data acquisition, analysis and advice, Fugro supports our clients in mitigating risks during design, construction and operations in civil, structural and geotechnical engineering projects. Our expertise in asset integrity assessment and management embraces digitalization and delivers innovative solutions in support of the energy transition, sustainable infrastructure and climate change adaptation.



中交第四航務工程勘察設計院有限公司
CCCC-FHDI ENGINEERING CO., LTD.

德晟工程有限公司為
中交四航院全資子公司



德晟工程有限公司
DETHON ENGINEERING LIMITED



業務範圍：

- ✓ 陸地/海洋地質勘探、工程監測、現場原位測試；
- ✓ 地球物理勘測、大地測量、海洋測量、專項岩土施工。



公司地址：香港干諾道西 188 號香港商業中心 2313-2315 室
電話 TEL：3913 1360 傳真 FAX：2603 5587

新界辦公室：屯門龍鼓灘沙埔崗 257 號
郵箱 E-mail：maqiuz@fhdigz.com

Reimagine engineering for a better future

As a leading engineering, design and advisory company that knows Asia well, we bring vital geotechnical experience, technical capability and design expertise to create clever, innovative solutions to solve for Hong Kong's most complex challenges.

At Aurecon, we imagine a better tomorrow, bring ideas to life and design solutions engineered for life.

aurecon
*Bringing ideas
to life*





香港建造商會
Hong Kong Construction Association

Site Investigation Committee

- *Dedicate to promote best standard practice for site investigation works in Hong Kong*
- *Provide updates / sharing on technical, regulatory, contractual requirements, and administrative issues for all stakeholders*
- *Serve as a bridge between academia and industry and establish scholarship*



亞洲寶石學院及鑑定所有限公司

Asian Gemmological Institute and Laboratory Limited

40th
周年
Anniversary

香港成立歷史最悠久的專業
高科技寶石鑑定所

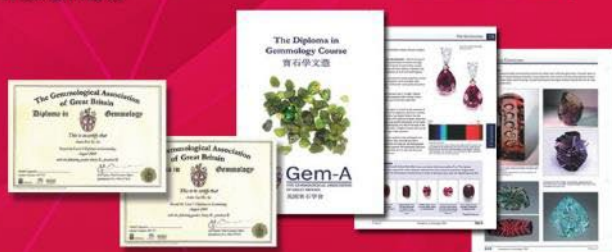
AGIL, OLDEST PROFESSIONAL GEM TESTING
LABORATORY ESTABLISHED IN HONG KONG SINCE 1983

Advanced (high-tech) Gem Testing
高端科技寶石鑑定

Gemmology Education
專業寶石學課程 (面授+線上智能教學)

International Gemmological Conference
國際寶石學研討會

Laboratory Research
寶石學鑑定研究



國際認可

英國寶石學會認可教學中心
Gem - A (FGA/DGA) Accredited Teaching Centre
- 1992 Tully Medal Award
- 1992 Anderson Bank Prize
- 1997 Bruton Medal Award
- 2009 The Mok Diamond Practical Prize
- 2014 The Deeks Diamond Prize
- 2021 Anderson Bank Prize



香港第一家 (認可翡翠實驗室)

香港特別行政區政府香港認可處認可翡翠鑑定所
The First Fei Cui (Jadeite Jade) Testing Laboratory
in Hong Kong Accredited to ISO / IEC 17025 by
HKAS of HKSAR Government



亞洲寶石學院網址
AGIL Website

香港九龍尖沙咀加拿芬道18號恒生尖沙咀大廈7樓707-708
707-708, 7/F., Hang Seng Tsimshatsui Building,
No. 18 Carnarvon Road, Tsimshatsui, Kowloon, Hong Kong
電話 Tel : (852) 2723 0429 傳真 Fax : (852) 2367 5201
電郵 Email : agil@agil.com.hk 網站 Website : www.agil.com.hk



微信公眾號
WeChat Account