Dating of Debris Fan Complexes from Lantau Island, Hong Kong

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GEO Report No. 322

R.J. Sewell

Geotechnical Engineering Office
Civil Engineering and Development Department
The Government of the Hong Kong
Special Administrative Region

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Preface

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H.N. Wong
Head, Geotechnical Engineering Office
October 2016

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Foreword

This report presents the findings of a detailed stratigraphic and age-dating study of five large debris fan complexes along the coastal foothills of western Lantau Island, with particular reference to the potential relationship between past periods of climate change and landslide activity.

K.C. Ng
Chief Geotechnical Engineer/Planning

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Abstract

Five debris fan complexes bordering the coastal foothills of western Lantau Island, Hong Kong, have been the subject of a detailed stratigraphic and dating study to explore the potential relationship between past periods of climate change and landslide activity. The debris fan complexes generally comprise an upper sequence of dominantly loose, gravelly colluvium and alluvium overlying a lower sequence of dominantly cohesive, bouldery colluvium. Luminescence (OSL) ages from the debris fan complexes, supported by a few radiocarbon ages (14C) on duplicate samples, suggest six main periods of accumulation: 800 – 1,350 yr BP, 3,320 – 3,560 yr BP, 4,230 – 4,370 yr BP, 5,000 – 8,000 yr BP, 11,000 – 14,500 yr BP, and 20,000 – 28,000 yr BP. The younger periods (< 10,000 yr BP) appear to be dominated by relatively thin (0.5 – 1.5 m) colluvial units deposited by mainly 'watery' debris flow and debris flood events, whereas the older periods are dominated by thicker (1.0 – 3.5 m) colluvial units deposited by 'drier' debris flow events. We hypothesise that immediately prior to the Last Glacial Maximum (LGM, i.e. 21,000 yr BP), the climate was cool and dry. Upland areas were probably devoid of vegetation, providing favorable conditions for sediment production in source areas. These debris-laden source areas are likely to have been mobilized *en masse* during periodic rainstorm activity, rapidly channelised over relatively short drainage courses, and then deposited as thick, sediment-rich, debris flow deposits along the coastal foothills. During post-LGM, the climate was warmer and more humid. Pluvial conditions predominated; forests occupied the upland source areas, leading to possibly reduced sediment yields, more frequent flash floods and deposition dominated by 'watery' debris flows or debris floods. Compared with recent studies on the weathering and erosion history of the Pearl River Delta, our landslide age data suggest a potential link between increased landslide activity and intensification of the Asian Monsoon during the Early to Mid. Holocene.

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1 Introduction

Understanding the landscape response to climate change has become a high priority area of research following confirmation of unequivocal warming of the global climate system (IPCC, 2007 & 2013). Recent projections for East Asia, including Southeast China, suggest rises in sea-level of between 0.48 and 1.0 m by the year 2100 coupled with intensification of the East Asia Monsoon. Current Probable Maximum Precipitation (PMP) analysis (e.g. Lin, 2009) suggests the likelihood of increased frequency of extreme weather events, including typhoons, and unprecedented extreme rainfall events. With 44% of the world's population living within 150 km of the coast (UN Atlas, 2010), global sea level rise is likely to have huge economic and societal impacts. In mountainous coastal regions, there is also the additional threat of increased landslide activity.

With a population of over 7 million people concentrated within a relatively small hilly coastal area (1,104 km^2), Hong Kong is especially vulnerable to extreme weather events and forecast sea level rise. Landslides and flooding are the most readily identifiable natural hazards but little is known about how the hilly terrain in general will respond to increased precipitation and rising sea-level, what the characteristics of landslides will be under these new conditions, and what if any, is the relationship between landslide activity and climate change.

Debris fan complexes along mountain range fronts are known to be sensitive indicators of changes in hydrological conditions and hence may serve as a proxy for climate change (Thomas, 2004; Crozier, 2010). Previous research in high altitude arid areas has revealed that changes in landslide activity can be linked with changes in climate (Bookhagen et al, 2005; Dortch et al, 2009; Borgatti & Soldati, 2010; Reynard et al, 2012). However, it is uncertain to what effect such a link can be extended to include low altitude, subtropical climates. In order to explore these issues, this study focuses on five large debris fan complexes along the coastal foothills of western Lantau Island (Figure 1.1) to examine how the Hong Kong landscape has responded to past periods of climate change, the timing of these changes, and the characteristics of the landslide deposits.

2 Previous Work

In 2004, the Geotechnical Engineering Office of the Civil Engineering and Development Department (GEO/CEDD) sought to build a high precision numerical landslide age dataset to develop a quantitative framework for improvements to design events adopted in natural terrain landslide hazard mitigation works. The first step was to conduct a pilot study to test which methods of dating natural terrain landslides would be most suitable for Hong Kong (Sewell & Campbell, 2005). The study proved that radiocarbon dating, luminescence dating, and surface exposure dating (cosmogenic nuclide dating) could be applied reliably and effectively, despite the seemingly unfavourable circumstances of low altitude and low latitude (Sewell et al, 2006). Subsequently, a broader dating study was carried out to examine the potential relationship between neotectonic activity and natural terrain landslides. Although no unequivocal link could be established between neotectonic activity and natural terrain landslides, nevertheless by 2012, 24 landslide sites across Hong Kong had been successfully dated. These comprised over 72 cosmogenic nuclide (CN) isotope (^{10}Be, ^{26}Al) ages, 142 optically stimulated luminescence (OSL) ages, and 32 radiocarbon (14C) ages (Sewell &

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Tang, 2015). The selected sites targeted relict landslide features, mostly deep-seated scarps and large debris lobes, but also some clusters of boulders from rockfalls.

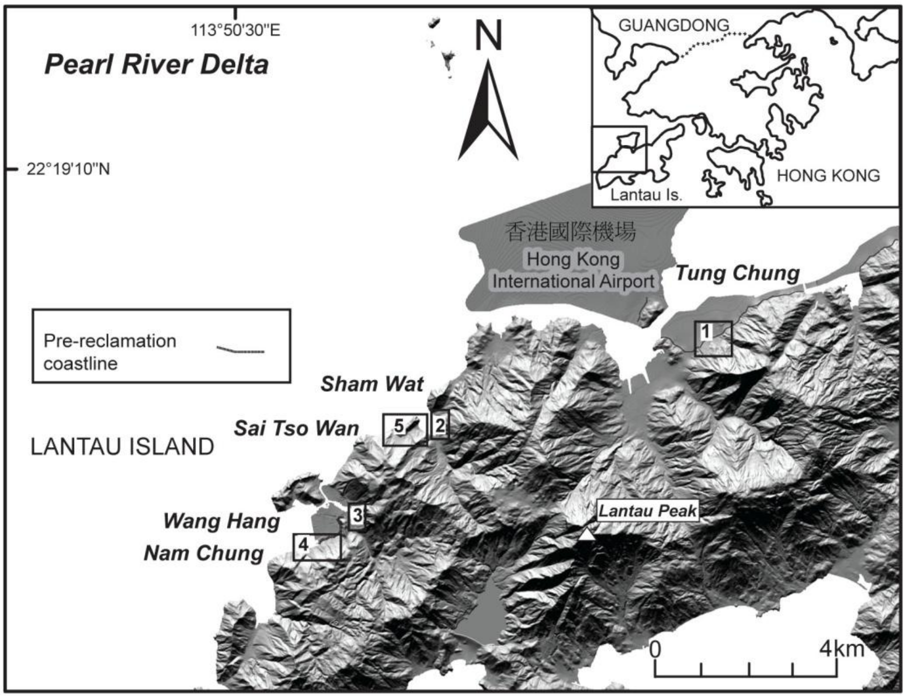

Figure 1.1 Location Map of Dated Fan Complexes (1 to 5) on Western Lantau Island

Direct observation of a channelised debris flow during a severe rainstorm in June 2008 on western Lantau Island, in which debris from a shallow open hillside failure was channelised and rapidly deposited on a coastal debris fan, confirmed that the debris fan complexes of western Lantau Island were probably built up by repeated mass flow activities (AECOM, 2012). This prompted the initiation of a comprehensive study of these debris fans with a view to:

(a) acquiring numerical age data on debris deposits to enhance understanding of how the Hong Kong landscape has responded to past periods of climate change,

(b) integrating the new age data from these debris deposits with a previous dating study on deep-seated landslides,

(c) forecasting possible future behaviour of Hong Kong natural terrain landslides with respect to IPCC climate change models, and

(d) developing a quantitative framework for improvements to design events adopted in natural terrain landslide hazard mitigation works (GEO, 2008).

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3 Geological Setting

Western Lantau Island, Hong Kong, is underlain mainly by Upper Jurassic silicic ash-flow tuffs and volcaniclastic rocks (Langford et al, 1995; Sewell et al, 2000; Campbell et al, 2007). The highest point is Lantau Peak (934 m) which lies on a central divide separating drainage basins from the north and south (Figure 1.1). A narrow (600 m) strip of low-land along the northern coast is underlain by Jurassic sedimentary rocks intruded by granites, and mainly in fault contact with the volcanic rocks.

The foothills along the northern coast are bordered by numerous debris fans that are thought to have been active since the Late Pleistocene (Langford et al, 1995). These debris fans emanate from relatively short stream courses that drain the steep volcanic terrain. The apexes of typical debris fans initiate at elevations between approximately 50 - 80 m and broaden rapidly with decreasing gradient toward the coastline.

4 Site Selection, Ground Investigation, Sampling and Dating Methods

4.1 Site Selection

Each of the five debris fan complexes on western Lantau, namely Tung Chung, Sham Wat, Sai Tso Wan, Nam Chung and Wang Hang (Figure 1.1) comprises a group of debris fans, some of which overlap, that initiate in the lower mid-slope from prominent drainage lines and terminate close to or at the existing shoreline. Aerial photograph interpretation (API) was carried out to characterise the morphology of the complexes and to identify suitable locations for ground investigation works. For the Tung Chung, Nam Chung, Sham Wat and Wang Hang study sites, comprehensive Natural Terrain Hazard Assessment (NTHA), including field mapping, was additionally carried out by independent consultants (OAP, 2005; AFJV, 2011, 2012 & 2014). Ground investigation works for the Tung Chung, Wang Hang, and Sai Tso Wan fan complexes were supplemented by those from previous natural terrain hazard investigations (Sewell & Campbell, 2005). A total of 25 trial pits (max. 3 m deep), two trial trenches (max. 3 m deep) and ten boreholes were used to examine the stratigraphy of the fan complexes and to obtain suitable materials for dating. Owing to the presence of thick debris deposits, the Wang Hang study site (Figure 1.1) was the subject of extensive ground investigation and dating analysis.

4.2 Ground Investigation

The locations of trial pits, trial trenches and boreholes were selected with a view to determining the chronologies of multiple debris deposit events, or in relation to hazard mitigation works. Ground investigation was carried out by certified drilling contractors and logged according to standard Hong Kong practice (GCO, 1987 & 1988). Triple-tube core barrels with foam flush drilling practices were used to achieve maximum core recovery in boreholes. The contractors logs were then checked and refined by the different consultants based on site inspection or desk study review of photographs, thus preserving the independence and integrity of the observations. Finalised contractor logs for all ground investigation works are given in Appendix A.

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4.3 Sampling

Sampling was based on careful examination of borehole cores and trial pits, and the suitability of material for dating analysis. Where possible, all major stratigraphic horizons in boreholes and trial pits were sampled for luminescence dating. Duplicate samples for radiocarbon analysis were taken when relict organic material was encountered.

The criteria used for identifying separate colluvial units included (i) colour of soil and clast materials, (ii) grain size, sorting, and rounding of clasts, (iii) degree of weathering of larger clasts, and (iv) compactness and consistency of the materials (c.f. Franks, 1999) (Figure 4.1). Comparison with previous studies on description of debris flow and debris flood deposits from trial pits (e.g. Mulvey, 1993), overseas studies (e.g. Coussot & Meunier, 1996; Giraud, 2005), and local studies on recent debris flows from North Lantau (e.g. Franks, 1999), were used as a basis for interpreting the type of deposit in trial pits and boreholes. In general, debris flow deposits were distinguished when the material was matrix-supported, with solids by weight equaling 70 to 90 percent of the deposit, and with larger clasts supported by finer grained material (Costa, 1984). By contrast, debris flood deposits were distinguished when the materials were dominantly clast-supported, generally showed better sorting, and contained 40 to 70 percent boulders, cobbles, and sand. It is noted that some authors (e.g. Wieczorek et al, 1983 & 1989; Sohn et al, 1999) have used the term "debris flood" interchangeably with "hyperconcentrated flow".

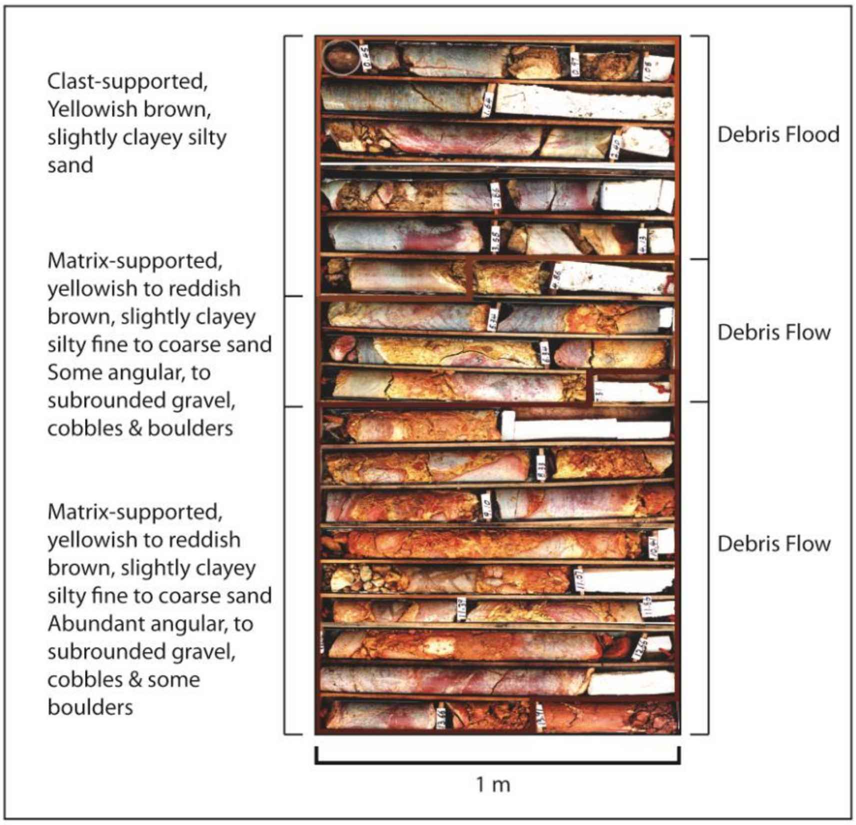

Figure 4.1 Example from BH-1, Wang Hang, Showing Criteria Used for Distinguishing Debris Flood from Debris Flow Deposits in a Borehole

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Samples from trial pits were collected using 500 x 100 mm steel tubes (U100) driven horizontally into the sidewalls, and in one case vertically into the floor, of the excavations. Location details of the analysed samples are given in Table 4.1. A summary of interpreted ground investigation logs for the boreholes and trial pits is given in Appendix B.

4.4 Dating Methods

Dating analysis was carried out by contracted dating laboratories through an open tendering process. Optically Stimulated Luminescence (OSL) dating was mostly carried out by the Luminescence Dating Laboratory, School of Geography, Environment and Earth Sciences, Victoria University of Wellington (VUW), New Zealand, while 10 samples were also analysed by the Radiation Dosimetry Laboratory, Oklahoma State University (OSU), Stillwater, USA. AMS radiocarbon (C14) dating was carried out by the Radiocarbon Dating Laboratory, University of Waikato, Hamilton, New Zealand. Although the Purdue Rare Isotope Measurement (PRIME) Laboratory, Purdue University, West Lafayette, USA, was contracted to carry out cosmogenic nuclide isotope measurements, no suitable samples were identified in this study for the purpose of dating landslide debris.

For samples analysed at VUW, the luminescence ages have been determined using the silt fraction (4 - 11 µm). Samples were measured using either the Multiple Aliquot Additive Method (MAAD) or the Single Aliquot Regenerative Method (SAR). The palaeodose, i.e. the radiation dose accumulated in the sample after the last light exposure (assumed at deposition), was determined either by: measuring the blue or broadband luminescence output from the feldspar fraction during infrared (IR) optical stimulation. The dose rate was estimated on the basis of a low level gamma spectrometry measurement. For samples analysed at OSU, the luminescence ages were determined on the silt fraction (4 - 11 µm) using the SAR method by measuring the blue luminescence under IR stimulation.

Except for depths of sampling, no other location details or descriptions of the materials were provided to the laboratories. Thus, the independence of the analytical tests was preserved ensuring quality control, particularly where duplicate samples were dated using both techniques. Luminescence and radiocarbon age data are reported in Table 4.2, and the description and interpretation of the analysed samples are given in Table 4.3. Full details of the luminescence and radiocarbon dating reports are given in Appendix C.

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Table 4.1 Location Details of the Analysed Samples

Sample No.	Latitude	Longitude	Altitude^	Sampled Depth (m)	Sample Type
Tung Chung					
HK13220	22.17340687	113.5715378	13.6	0.8	U-100 Sample, horizontal
HK13222	22.16550267	113.5631076	39.9	0.5	U-100 Sample, horizontal
HK13221	22.17306841	113.5712798	24.8	1.5	U-100 Sample, horizontal
HK12433	22.17286322	113.5710077	28.6	1.7	U-100 Sample, horizontal
HK12445	22.16532064	113.5631324	47.3	1.7	U-100 Sample, horizontal
HK13218	22.17109072	113.5641984	43.5	3.1	Mazier Sample, vertical
HK13217	22.17299335	113.5710738	22.8	3.9	Mazier Sample, vertical
HK13219	22.17109072	113.5641984	43.5	5.8	Mazier Sample, vertical
Sham Wat					
HK13349	22.16107945	113.5318029	17.4	1.5	U-100 Sample, horizontal
HK13353	22.16255639	113.5323622	41.0	0.8	U-100 Sample, horizontal
HK13352	22.16232903	113.5324814	60.0	0.7	U-100 Sample, horizontal
HK13351	22.16205197	113.5320663	47.2	0.7	U-100 Sample, horizontal
HK13347	22.16053025	113.5319297	17.0	0.8	U-100 Sample, horizontal
Sai Tso Wan					
HK12479	22.16102438	113.5243101	19.0	0.1	U-100 Sample, horizontal
HK12477	22.16102438	113.5243101	19.0	0.6	U-100 Sample, horizontal
HK12480	22.16060225	113.5245834	56.3	1.0	U-100 Sample, horizontal
HK12474	22.16090708	113.5241706	27.5	0.8	U-100 Sample, horizontal
HK12490	22.16117387	113.5242818	10.1	2.6	Mazier Sample, vertical
HK12483	22.16015326	113.5243958	97.2	0.3	U-100 Sample, horizontal
HK12489*	22.16106049	113.530294	16.0	0.8	U-100 Sample, horizontal
HK12485	22.16009499	113.5245286	103.6	0.8	U-100 Sample, horizontal
HK12487	22.16103377	113.5258958	21.0	0.8	U-100 Sample, horizontal
Nam Chung					
HK13359	22.14517136	113.5158565	24.5	1.2	U-100 Sample, horizontal
HK13358	22.14389893	113.5135091	34.1	1.5	U-100 Sample, horizontal
HK13360	22.1445378	113.5143667	30.8	0.9	U-100 Sample, horizontal
HK13361	22.14416207	113.5134072	13.4	0.8	U-100 Sample, horizontal
HK13362	22.14416207	113.5134072	13.4	1.8	U-100 Sample, horizontal
Wang Hang					
HK12455	22.15167418	113.5213318	25.4	0.8	U-100 Sample, horizontal
HK12458	22.15122576	113.5214446	40.0	1.1	U-100 Sample, horizontal
HK13459	22.15021121	113.5213211	15.8	1.3	U-100 Sample, horizontal
HK13462	22.15052962	113.5212191	11.2	2.2	U-100 Sample, horizontal
HK12461	22.1504909	113.5213763	27.8	1.0	U-100 Sample, horizontal
HK12463	22.15160899	113.5212412	17.0	2.5	Mazier Sample, vertical
HK13460	22.15021121	113.5213211	15.8	3.3	U-100 Sample, vertical
HK13461	22.15052962	113.5212191	11.2	0.7	U-100 Sample, horizontal
HK13560	22.15171984	113.5214086	31.6	6.7	U-100 Sample, horizontal
HK12466	22.15113395	113.5210327	2.8	4.0	Mazier Sample, vertical
HK12468	22.15059762	113.5210757	5.2	6.3	Mazier Sample, vertical
HK13557	22.15043226	113.5213101	18.2	3.8	U-100 Sample, horizontal
HK13553	22.15049067	113.5212541	16.3	8.8	U-100 Sample, horizontal
HK13554	22.15052319	113.5212575	15.6	6.5	U-100 Sample, horizontal
HK13561	22.15174232	113.5212618	23.4	8.4	U-100 Sample, horizontal
HK13556	22.15043226	113.5213101	18.2	8.3	U-100 Sample, horizontal
HK13555	22.15052319	113.5212575	15.6	8.5	U-100 Sample, horizontal
HK13558	22.15043226	113.5213101	18.2	5.5	U-100 Sample, horizontal
HK13559	22.15043226	113.5213101	18.2	6.9	U-100 Sample, horizontal

Note: ^ All elevations measured in metres above Hong Kong Principal Datum (PD) which is 1.23 m below Mean Sea Level (SMO, 1995).

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Table 4.2 Measured *a*-value and Equivalent Dose, Dose Rate and Luminescence Age for Analysed Samples

Sample No.	Lab. Code[a]	*a*-value	D_e (Gy)	d*D*/d*t* (Gy ka^{-1})	OSL Age (ka)	Field Code
Tung Chung						
HK13220	WLL794	0.072 ± 0.012	29.3 ± 2.4	8.39 ± 0.58	3.49 ± 0.37 (MA)	TP2
HK13222	WLL799	0.06 ± 0.03*	15.3 ± 0.6	4.64 ± 0.60	3.3 ± 0.44 (SAR)	TPB
HK13221	WLL795	0.06 ± 0.03*	78.9 ± 4.8	7.50 ± 1.01	10.5 ± 1.6 (SAR)	TP3
HK12433	WLL258	0.056 ± 0.010	111.5 ± 12.2	8.28 ± 0.63	13.5 ± 1.8 (MA)	TP1
HK12445	WLL242	0.087 ± 0.018	158.2 ± 17.7	8.77 ± 0.75	18.0 ± 2.4 (MA)	TP5
HK13218	WLL797	0.06 ± 0.03*	215.6 ± 17.3	8.42 ± 0.95	25.6 ± 3.5 (SAR)	DH13
HK13217	WLL796	0.06 ± 0.03*	199.1 ± 11.6	6.60 ± 0.98	30.2 ± 4.8 (SAR)	DH5
HK13219	WLL798	0.06 ± 0.03*	462.8 ± 137.0	6.86 ± 0.90	67.5 ± 21.8[#] (SAR)	DH13
Sham Wat						
HK13349			25.7 ± 1.1	8.19 ± 0.29	3.14 ± 0.17 (SAR)	SW-TP5
HK13353			20.15 ± 0.83	5.94 ± 0.20	3.39 ± 0.18 (SAR)	SW-TP15
HK13352			13.81 ± 0.56	4.03 ± 0.13	3.43 ± 0.18 (SAR)	SW-TP14
HK13351			18.11 ± 0.74	3.67 ± 0.12	4.93 ± 0.26 (SAR)	SW-TP10
HK13347			51.6 ± 2.1	9.23 ± 0.34	5.59 ± 0.30 (SAR)	SW-TP1
Sai Tso Wan						
HK12479	WLL254		2.29 ± 0.05	6.41 ± 0.45	0.36 ± 0.03 (SAR)	TP6
HK12477	WLL248	0.046 ± 0.011	7.05 ± 0.13	5.27 ± 0.61	1.34 ± 0.11 (MA)	TP6
HK12480	WLL257		11.8 ± 0.9	4.44 ± 0.37	2.66 ± 0.30 (SAR)	TP7~
HK12474	WLL274	0.051 ± 0.005	54.9 ± 3.7	6.92 ± 0.47	7.93 ± 0.68 (MA)	TP5
HK12490	WLL267	0.049 ± 0.006	79.0 ± 8.2	7.60 ± 0.53	10.5 ± 1.2 (MA)	BH4~
HK12483	WLL275		60.8 ± 2.2	5.29 ± 0.37	11.5 ± 0.9 (SAR)	TP8
HK12489	WLL255	0.074 ± 0.020	77.7 ± 11.0	6.61 ± 0.58	11.8 ± 2 (MA)	TP11
HK12485	WLL243	0.054 ± 0.013	82.2 ± 8.2	5.73 ± 0.44	14.4 ± 1.7 (MA)	TP9
HK12487	WLL244	0.056 ± 0.014	73.4 ± 7.9	4.97 ± 0.37	14.8 ± 1.8 (MA)	TP10
Nam Chung						
HK13359			9.05 ± 0.37	7.52 ± 0.28	1.02 ± 0.07 (SAR)	NC-TP26
HK13358			24.04 ± 0.58	10.48 ± 0.39	1.34 ± 0.07 (SAR)	NC-TP19
HK13360			27.8 ± 1.2	12.09 ± 0.52	2.3 ± 0.14 (SAR)	NC-TP32
HK13361			38.8 ± 1.7	9.11 ± 0.39	4.26 ± 0.26 (SAR)	NC-TP34
HK13362			58.8 ± 2.5	8.43 ± 0.33	6.97 ± 0.4 (SAR)	NC-TP34
Wang Hang						
HK12455	WLL260	0.099 ± 0.022	10.4 ± 1.6	12.66 ± 1.15	0.82 ± 0.15 (MA)	TP1
HK12458	WLL271	0.095 ± 0.028	11.1 ± 1.2	9.99 ± 1.00	1.11 ± 0.16 (MA)	TP2[~]
HK13459	WLL949	0.07 ± 0.03	9.96 ± 2.74	7.93 ± 0.89	1.3 ± 0.4 (MA)	WH6-TT1
HK13462	WLL952	0.07 ± 0.03	25.81 ± 3.71	8.50 ± 1.01	3.0 ± 0.6 (MA)	WH5-TT1[~]
HK12461	WLL273	0.082 ± 0.014	45.2 ± 2.5	10.61 ± 0.72	4.26 ± 0.37 (MA)	TP3[~]
HK12463	WLL249	0.077 ± 0.015	54.3 ± 7.8	12.4 ± 1.4	4.38 ± 0.53 (MA)	BH1
HK13460	WLL950	0.07 ± 0.01	43.11 ± 5.48	7.63 ± 0.30	5.6 ± 0.8 (MA)	WH6-TT1
HK13461	WLL951	0.06 ± 0.01	126.49 ± 19.46	9.46 ± 0.49	13.4 ± 2.2 (MA)	WH5-TT1
HK13560	WLL984	0.06 ± 0.01	180.40 ± 22.55	9.50 ± 0.48	19.0 ± 2.6 (MA)	WH2-DH10
HK12466	WLL245	0.075 ± 0.025	196.3 ± 23.7	9.69 ± 0.97	20.3 ± 3.2 (MA)	BH2
HK12468	WLL272	0.050 ± 0.004	237.8 ± 19.0	11.56 ± 0.96	20.6 ± 2.1 (MA)	BH3
HK13557	WLL981	0.05 ± 0.03*	164.92 ± 29.42	7.04 ± 0.89	23.4 ± 5.1 (SAR)	WH6-DH2
HK13553	WLL977	0.05 ± 0.03*	248.00 ± 37.77	9.68 ± 1.16	25.6 ± 5.0 (SAR)	WH5-DH3
HK13554	WLL978	0.05 ± 0.03*	227.32 ± 25.72	8.40 ±1.08	27.1 ± 4.6 (SAR)	WH5-DH2
HK13561	WLL985	0.05 ± 0.03*	312.19 ± 50.70	9.52 ± 1.27	32.8 ± 6.9 (SAR)	WH2-DH12
HK13556	WLL980	0.05 ± 0.03*	328.15 ± 53.53	9.29 ± 1.20	35.3 ± 7.4 (SAR)	WH6-DH2
HK13555	WLL979	0.05 ± 0.03*	329.54 ± 71.17	8.41 ± 1.10	39.2 ± 9.9 (SAR)	WH5-DH2
HK13558	WLL982	0.05 ± 0.03*	355.70 ± 50.07	7.47 ± 0.92	47.6 ± 8.9[ˆ] (SAR)	WH6-DH2
HK13559	WLL983	0.05 ± 0.03*	458.51 ± 66.60	8.74 ± 1.12	52.5 ± 10.2[ˆ] (SAR)	WH6-DH2

Notes:
- * *a*-value estimated, as alpha-irradiated subsample was saturated. MA = Multi-Aliquot; SAR = Single Aliquot Regenerative.
- [#] Sample showed clear signs of bleaching. Therefore OSL age should be interpreted as a maximum.
- [ˆ] Sample measured under blue stimulation as no broadband luminescence was detected under IR stimulation.
- [a] Samples with codes WLL measured at Luminescence Dating Laboratory, VUW, Wellington, NZ (Analysts: U. Rieser, N.S. Wang), all other samples measured at Radiation Dosimetry Laboratory, OSU, Stillwater, USA (Analyst: R. DeWitt).
- [~] Radiocarbon ages on duplicate samples: 1122 ± 43 a BP (HK12458), 3110 ± 30 a BP (HK13462), 11758 ± a BP (HK12461), 10658 ± 116 a BP (HK12490), 2416 ± 45 a BP (HK12480) (Analyst: A. Hogg).

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Table 4.3 Description and Interpretation of the Analysed Samples (Sheet 1 of 2)

Sample No.	Sample Description	Field Code	Thickness (m)	Type of Deposit
Tung Chung				
HK13220	Clast-supported, subangular, fine to coarse gravel, cobbles, and boulders with some greyish brown sandy silt	TP2	0.9	Debris flood
HK13222	Clast-supported, angular coarse gravel, cobbles and boulders with some light greyish brown and light yellowish brown, silty fine to medium sand	TPB	1	Debris flood
HK13221	Matrix-supported, light brown sandy silt with come subangular coarse gravel and cobbles	TP3	1.3	Debris flow
HK12433	Matrix-supported, yellowish brown silty fine to medium sand with abundant cobbles	TP1	1.7	Debris flow
HK12445	Matrix-supported, dark brown, silty fine to medium sand with some subangular and subrounded fine to coarse gravel, cobbles and boulders	TP5	1.3	Debris flow
HK13218	Matrix-supported, reddish brown sandy silt with some subangular fine to coarse gravel and cobbles	DH13	4.6	Debris flow
HK13217	Matrix-supported, reddish orange, silty fine to medium sand with occasional angular gravel	DH5	3.2	Debris flow
HK13219	Matrix-supported, light grey silty sand with abundant cobbles	DH13	2.2	Debris flow
Sham Wat				
HK13349	Clast-supported, angular gravel and cobbles with some brown, slightly silty fine to coarse sand	SW-TP5	2	Debris flood
HK13353	Clast-supported, angular gravel and cobbles with some light brown silty fine to coarse sand	SW-TP15	0.7	Debris flood
HK13352	Clast-supported, angular gravel and cobbles with some light brown, silty fine to coarse sand	SW-TP14	1	Debris flood
HK13351	Clast-supported, angular gravel and cobbles with some light brown, silty fine to coarse sand	SW-TP10	0.7	Debris flood
HK13347	Clast-supported, angular cobbles and boulders with some brown to light reddish brown, angular gravelly sandy clayey silt	SW-TP1	0.9	Debris flood
Sai Tso Wan				
HK12479	Weakly bedded, dark greyish brown, slightly clayey sandy silt with much rootlets and some angular to subangular fine to coarse gravel	TP6	0.5	Alluvium
HK12477	Greyish brown to yellowish brown, slightly clayey, silty fine to coarse sand with much rootlets	TP6	0.2	Alluvium
HK12480	Clast-supported angular to subangular fine to coarse gravel, cobbles and boulders, with some greyish brown very clayey silty sand	TP7	1.2	Debris flood
HK12474	Clast-supported, yellowish brown to reddish brown, angular to subangular fine to coarse gravel, cobbles and boulders with some slightly clayey sandy silt	TP5	1.2	Debris flood
HK12490	Matrix-supported, yellowish brown to reddish brown slightly clayey sandy silt with abundant angular to subangular fine to coarse gravel and some cobbles	BH4	3	Debris flow
HK12483	Matrix-supported, yellowish brown slightly clayey sandy silt with abundant angular to subangular fine to coarse gravel and cobbles, and occasional boulders	TP8	0.9	Debris flow
HK12489*	Clast-supported, angular to subangular fine to coarse gravel, cobbles and boulders, with some reddish brown to yellowish brown, clayey silty sand	TP11	1.7	Debris flood
HK12485	Matrix-supported, yellowish brown to reddish brown, slightly clayey sandy silt with abundant angular to subangular fine to coarse gravel, cobbles, and boulders	TP9	1.3	Debris flow
HK12487	Matrix-supported, reddish brown to brownish grey, slightly clayey sandy silt with abundant angular to subangular fine to coarse gravel, cobbles and some boulders	TP10	2.8	Debris flow

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Table 4.3 Description and Interpretation of the Analysed Samples (Sheet 2 of 2)

Sample No.	Sample Description	Field Code	Thickness (m)	Type of Deposit
Nam Chung				
HK13359	Matrix-supported, reddish brown, slightly sandy silt with abundant angular to subangular gravel, cobbles and boulders	NC-TP26	1.1	Debris flow
HK13358	Poorly compacted, angular to subangular gravel, cobbles and boulders with some dark brown sandy silt	NC-TP19	1.3	Debris flood
HK13360	Matrix-supported, orangish brown to brow slightly sandy silt with occasional angular to subangular fine to coarse gravel, cobbles and boulders	NC-TP32	1.1	Debris flow
HK13361	Poorly compacted, angular to subangular coarse gravel, cobbles and boulders, with some reddish brown, slightly sandy silt	NC-TP34	1.8	Debris flood
HK13362	Poorly compacted, angular to subangular coarse gravel, cobbles and boulders, with some reddish brown, slightly sandy silt	NC-TP34	1.8	Debris flood
Wang Hang				
HK12455	Clast-supported, greyish brown to reddish brown, angular to subangular fine to coarse gravel, cobbles and boulders	TP1	1.1	Debris flood
HK12458	Greyish brown, organic-rich, slightly clayey sandy silt with angular to subangular fine to coarse gravel	TP2~	0.3	Buried soil
HK13459	Poorly compacted, matrix- to clast-supported, brownish grey to dark grey, slightly sandy gravelly silt with abundant angular to subangular coarse gravel	WH6-TT1	0.8	Debris flood
HK13462	Clast-supported, reddish brown, slightly silty fine to coarse sand with abundant angular to subangular coarse gravel, cobbles, and some boulders	WH5-TT1~	1.1	Debris flood
HK12461	Matrix-supported, yellowish brown, slightly clayey sandy silt with abundant angular to subangular fine to coarse gravel, cobbles and some boulders	TP3~	1.8	Debris flow
HK12463	Clast-supported, subangular to subrounded boulders and coarse gravel with occasional yellowish brown, slightly clayey silty sand	BH1	4	Debris flood
HK13460	Matrix-supported, orangish brown, slightly clayey sandy silt with abundant subangular gravel, cobbles, and occasional boulders	WH6-TT1	1.1	Debris flow
HK13461	Matrix-supported, light orangish yellow sandy silt with fine to coarse gravel and occasional subangular to subrounded cobbles and boulders	WH5-TT1	1.1	Debris flood
HK13560	Matrix-supported, yellowish brown, slightly clayey sandy silt with abundant subangular gravel, cobbles, and occasional boulders	WH2-DH10	2.6	Debris flow
HK12466	Matrix-supported, yellowish brown to reddish brown, slightly clayey sandy silt with occasional angular to subangular coarse gravel	BH2	0.9	Debris flow
HK12468	Matrix-supported, brownish grey slightly clayey, silty fine to coarse sand and some angular medium to coarse gravel and cobbles	BH3	1.5	Debris flow
HK13557	Matrix-supported, reddish brown to brownish clayey sandy silt with abundant coarse gravel, sub-angular cobbles and occasional boulders	WH6-DH2	3.2	Debris flow
HK13553	Matrix-supported, orangish brown silty clay with coarse sand, and abundant subangular gravel, cobbles and occasional boulders	WH5-DH3	3.5	Debris flow
HK13554	Matrix-supported, yellowish brown, slightly clayey silty sand with abundant subangular to subrounded medium to coarse gravel	WH5-DH2	2.2	Debris flow
HK13561	Clast-supported, subangular to subrounded boulders with occasional well-sorted yellowish brown to reddish brown, slightly clayey sand silt	WH2-DH12	4.2	Debris flood
HK13556	Matrix-supported, reddish brown to brownish grey, slightly fine to coarse sand with some angular to subrounded gravel and occasional cobbles	WH6-DH2	2.4	Debris flow
HK13555	Matrix-supported, yellowish brown to reddish brown slightly clayey sandy silt with some subangular to subrounded medium to coarse gravel	WH5-DH2	1.8	Debris flow
HK13558	Matrix-supported, reddish brown to dark grey, slightly clayey silty sand with some subangular to subrounded boulders and cobbles	WH6-DH2	2.6	Debris flow
HK13559	Matrix-supported, reddish brown to dark brown, slightly clayey silty sand with abundant subangular to subrounded medium to coarse gravel with some cobbles and occasional boulders	WH6-DH2	1.8	Debris flow

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5 Site Description and Sampling Strategy

5.1 Tung Chung

Five debris fans were studied on the northwest-facing slopes overlooking Tung Chung town (Figure 5.1). The apexes of the debris fans are generally located within drainage channels at mid-slope elevations between 80 – 100 m and extend downslope to coincide with the old coastline that existed prior to reclamation works. The morphology of the debris fans as revealed by aerial photograph interpretation (OAP, 2005), suggests they comprise colluvial materials of different ages, some of which have been reworked by more recent processes. The toes of older debris lobes have also been truncated by coastal erosion (OAP, 2005). Debris Fans 1, 2, 4 and 5 comprise multiple lobes and were selected for dating investigation.

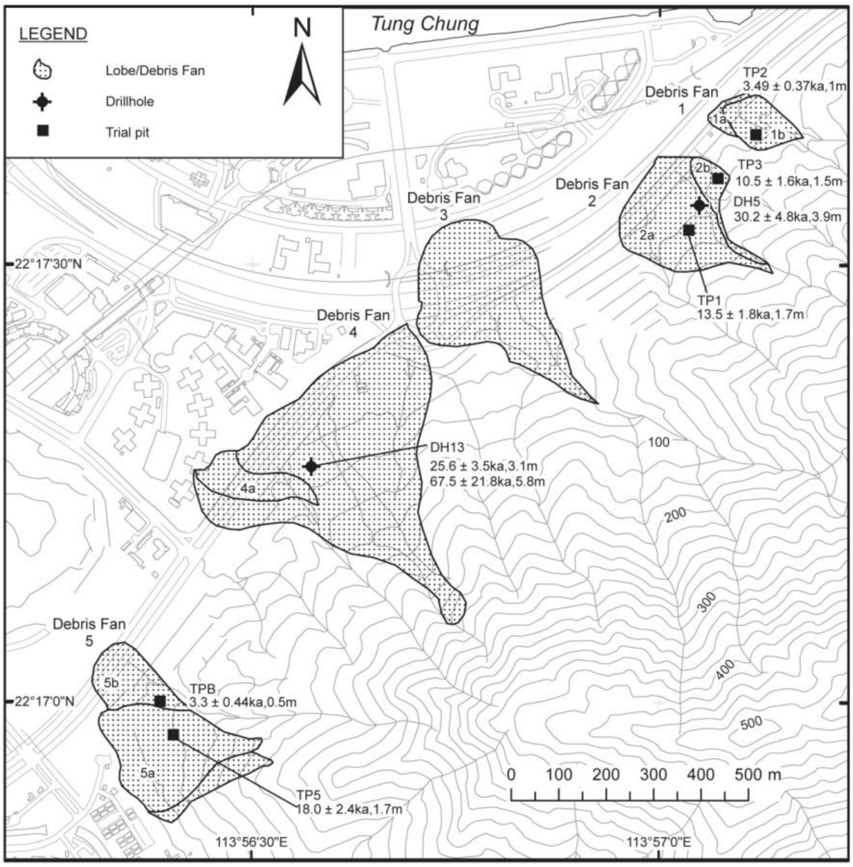

Figure 5.1 Coalescing Debris Fan Deposits at Tung Chung

Trial pit TP2, at an elevation of 13.6 m, was excavated in Debris Fan 1b, which is thought to be the younger of two large lobes forming Debris Fan 1. Sample HK13220 came from colluvial materials at 1 m deep comprising greyish brown sandy silt with abundant subangular, fine to coarse gravel, cobbles, and boulders.

Debris Fan 2 comprised two lobes, both of which were sampled for dating. Trial pit TP1 and borehole DH5 were located in the larger and older Debris Fan 2b at elevations of

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28.6 and 22.8 m, respectively. Sample HK12433 came from a depth of 2.2 m from TP1 and consisted of yellowish brown silty fine to medium sand with abundant cobbles. Sample HK13217 in DH5 came from a depth of 3.9 m and comprised reddish orange, silty fine to medium sand with occasional angular gravel. One sample (HK13221) came from a depth of 1.8 m in trial pit TP3 located in Debris Fan 2a. The colluvial materials comprised light brown sandy silt with some subangular coarse gravel and cobbles.

Debris Fan 4 comprised two lobes, including the largest lobe (4b) recorded at the Tung Chung site. Two samples (HK13218 & HK13219) were obtained from one borehole (DH13) located in the older and larger debris fan 4b at an elevation of 43.5 m. HK13218 came from a depth of 3.1 m and comprised reddish brown sandy silt with some subangular fine to coarse gravel and cobbles, whereas HK13219 came from a depth of 5.8 m and was composed of light grey silty sand with abundant cobbles.

Two lobes were identified forming Debris Fan 5 at the southernmost part of the Tung Chung site. One trial pit (TP5) was located in the older lobe (5a) at an elevation of 47.3 m, whereas trial pit TPB was located in lobe 5b at an elevation of 39.9 m. Sample HK12445 came from a depth of 1.7 m in trial pit TP5 and comprised dark brown, silty fine to medium sand with some subangular and subrounded fine to coarse gravel, cobbles and boulders. Sample HK13222 came from a depth of 0.8 m in trial pit TPB and consisted of light greyish brown and light yellowish brown, silty fine to medium sand with some angular coarse gravel, cobbles and boulders.

5.2 Sham Wat

Four debris fans on the west-facing slopes overlooking Sham Wat village (Figure 5.2) were previously studied by AFJV (2011) as part of a landslide hazard study. The debris fans include a large composite fan complex (Debris Fan 1) and three smaller debris fans. The three largest debris fans (Debris Fans 1, 2 and 4) were selected for dating investigation. The debris fans typically comprise low gradient (5 – 20°) heterogeneous accumulations of poorly sorted, clast-supported materials. The deposits are notably coarse, with abundant gravel, cobbles and boulders, and an intervening sandy matrix. These are interpreted as dominantly debris flood deposits. The apexes of the fans are located at elevations of 40 – 50 m and extend downslope toward the present coastline. As no single large scarps could be identified in the source areas, the fans are thought to have built up from numerous mass flow events over a prolonged period of time (AFJV, 2011).

Debris Fan 1 is divided into two main lobes: Fan 1a, and the larger, composite Fan 1b. Three trial pits provided samples for dating. Sample HK13353 came from trial pit TP15 located at an elevation of 41 m near the apex of Debris Fan 1a. The colluvial materials comprised clast-supported, angular gravel and cobbles, with a light brown silty fine to coarse sand matrix. Samples HK13352 and HK13351 were obtained from trial pits TP14 and TP10, and at elevations of 60 m and 47.2 m, respectively, near the apexes of Debris Fan 1b. They came from depths of 0.8 m and 0.7 m, respectively, and comprised light brown, silty fine to coarse sand from intervening matrix within a clast-supported angular gravel and cobble-dominated colluvium.

Debris Fan 2 is largely restricted to the toe of relatively steep hillside overlooking the

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Sham Wat village and terminates at the present-day coastline. One sample (HK13349) came from a depth of 1.5 m in trial pit TP5 located near the apex of the fan at an elevation of 17.4 m. The colluvial materials comprised clast-supported, angular gravel and cobbles with an intervening brown, slightly silty fine to coarse sand matrix.

Debris Fan 4 is located slightly to the south and inland from Debris Fan 3 (Figure 5.2). The toe of the fan probably coincided with an old coastline during high-stands of sea level. Sample HK13347 was obtained from a depth of 0.8 m in trial pit TP1 situated at an elevation of 17 m. The materials comprised brown to light reddish brown, angular gravelly sandy clayey silt set within clast-supported angular cobbles and boulders.

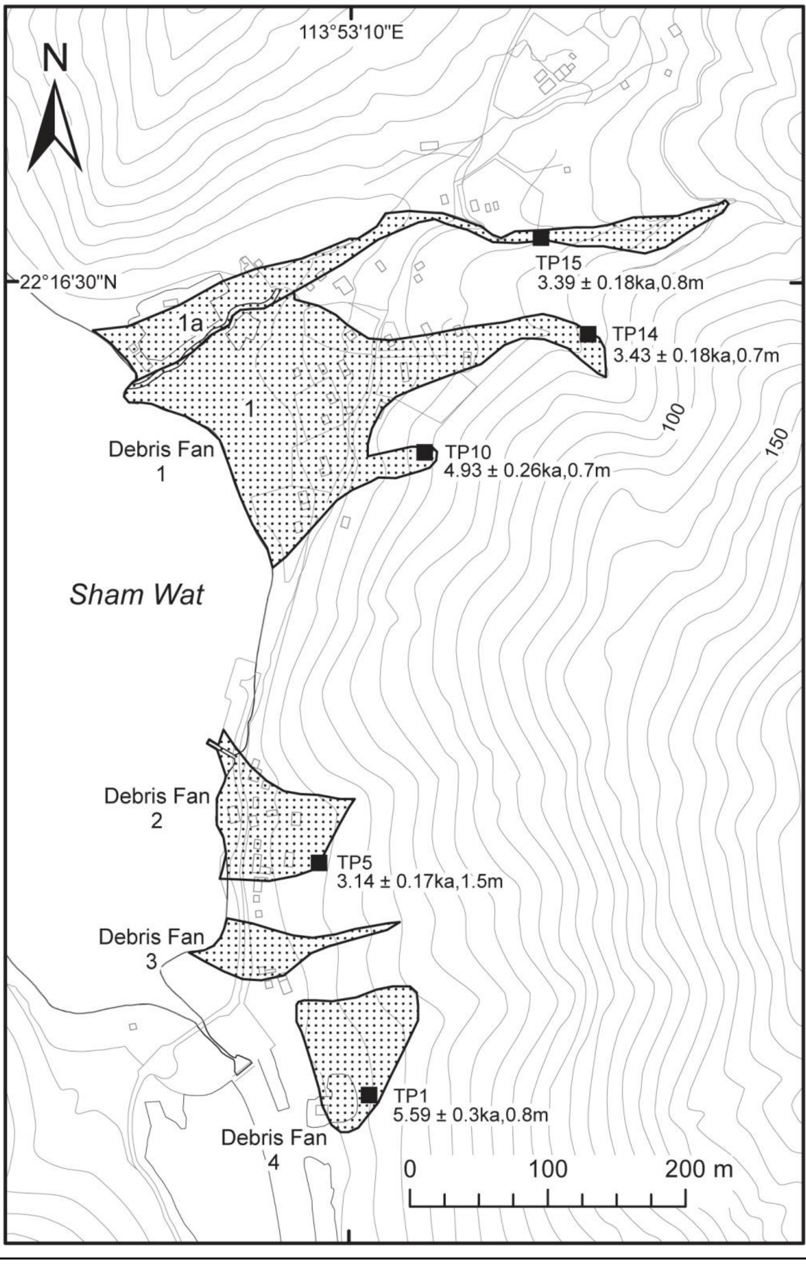

Figure 5.2 Coalescing Debris Fan Deposits at Sham Wat

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5.3 Sai Tso Wan

Five large debris fans were mapped at the Sai Tso Wan site (Figure 5.3). Two fans (Debris Fans 2 and 3) are located well away from the present coastline and therefore were excluded from dating investigation. The debris fans mostly originate from single well-defined drainage lines and amalgamate downslope into a complex series of overlapping colluvial lobes.

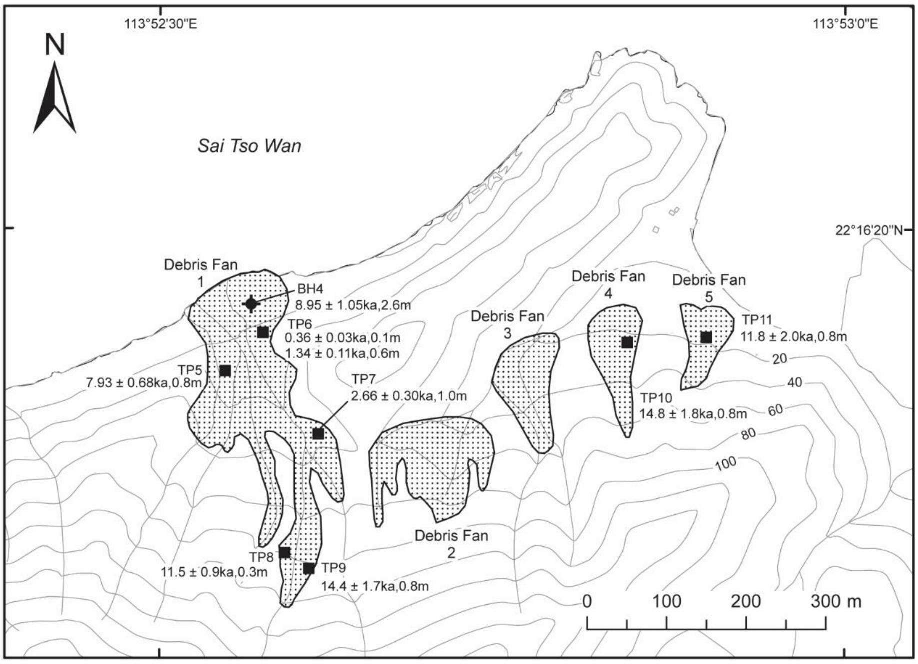

Figure 5.3 Coalescing Debris Fan Deposits at Sai Tso Wan

Debris Fan 1 comprises multiple lobes extending from an elevation of approximately 120 m to the coastline. Five trial pits and one borehole were used to obtain suitable materials for dating. Two trial pits (TP8 & TP9) were excavated at elevations of 97.2 m and 103.6 m, respectively, close to the apex of the largest lobe and yielded two samples (HK12483 & HK12485) for dating. HK12483 from a depth of 0.3 m comprised yellowish brown slightly clayey sandy silt with abundant angular to subangular fine to coarse gravel and cobbles, and occasional boulders, whereas HK12485 from a depth of 0.8 m was composed of yellowish brown to reddish brown, slightly clayey sandy silt with abundant angular to subangular fine to coarse gravel, cobbles, and boulders. One sample (HK12480) was obtained from a trial pit (TP7) located at a mid-elevation (56.3 m) of the fan complex. This sample, from a depth of 1.0 m, consisted of yellowish brown to greyish brown slightly clayey sandy silt with occasional angular to subangular fine to medium gravel. Two trial pits (TP5 & TP6) were excavated in the lower, thickest part of the fan complex at elevations of 27.5 m and 19 m, respectively, and yielded three samples for dating (HK12474, HK12477 & HK12479). HK12474 from a depth of 0.8 m in TP5 comprised yellowish brown slightly clayey sandy silt with occasional angular to subangular fine to coarse gravel with some cobbles and boulders. HK12477 from a depth of 0.6 m in TP6 was composed of greyish

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brown, slightly clayey, silty sandy angular to subangular fine to coarse gravel with some cobbles and boulders, while HK12479 from a depth of 0.1 m comprised yellowish brown, slightly clayey silty fine to coarse sand with some angular to subangular fine to medium gravel. Borehole BH4, located closest to the coastline and an elevation of 10.1 m provided an estimate of the thickness of the debris deposit as well as one sample (HK12490) for dating. HK12490 from a depth of 2.6 m comprised yellowish brown to reddish brown, slightly clayey sandy silt with abundant angular to subangular fine to coarse gravel and some cobbles.

Debris Fan 4 comprises an isolated debris lobe extending from an elevation of approximately 60 m to 10 m and probably terminated at an old coastline. Trial pit TP10 at an elevation of 21.0 m provided one sample (HK12487) for dating. This sample came from a depth of 0.8 m and comprised reddish brown to brownish grey, slightly clayey sandy silt with abundant angular to subangular fine to coarse gravel, cobbles and some boulders.

The smallest debris fan at the site is Debris Fan 5 which comprises a single lobe extending from approximately 60 m elevation to the present coastline. One trial pit (TP11) at an elevation of 16 m yielded one sample (HK12489) for dating. This sample came from a depth of 0.8 m and comprised reddish brown to yellowish brown, clayey silty sandy angular to subangular fine to coarse gravel with abundant cobbles and some boulders.

5.4 Nam Chung

Three debris fan complexes on the west-facing slopes overlooking the village of Nam Chung (Figure 5.4) were sampled based on a detailed study by AFJV (2012). The largest fan complex (Debris Fan 3) comprises four overlapping fans whereas Debris Fans 1 and 2 comprise individual fans. The fans were developed by recurrent mass wasting processes at the mouths of prominent drainage lines.

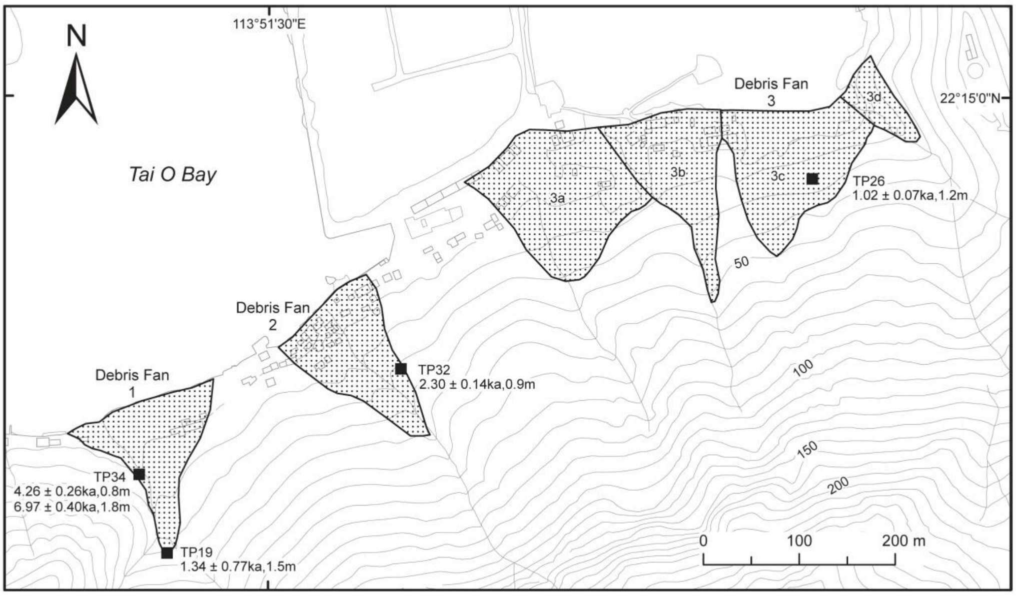

Figure 5.4 Coalescing Debris Fan Deposits at Nam Chung

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The debris fans are generally composed of a mixture of recent and relict colluvium. Relict colluvium forms the bulk of the fan deposits and consists mostly of reddish brown, matrix-supported gravelly silt/clay with cobbles and boulders. The relict colluvium has been incised by active drainage channels, which in places have been infilled with recent colluvium comprising firm to stiff, greyish brown, matrix-supported gravelly silt/clay with boulders and cobbles.

One sample (HK13359) was obtained from trial pit TP26 in Debris Fan 3c at an elevation of 24.5 m. The sample came from a depth of 1.2 m and was composed of reddish brown, slightly sandy silt with abundant angular to subangular gravel, cobbles and boulders. Another sample (HK13360) was obtained from trial pit TP32 in Debris Fan 2 at an elevation of 30.8 m. This sample from a depth of 0.9 m comprised orangish brown to brown slightly sandy silt with occasional angular to subangular fine to coarse gravel, cobbles and boulders.

Two trial pits were sampled in Debris Fan 1. Trial pit TP34 at an elevation of 13.4 m showed two distinct layers of debris, and therefore, two samples (HK13361 and HK13362) were obtained for dating. HK13361 from a depth of 0.8 m was composed of reddish brown, slightly sandy silt with some angular to subangular coarse gravel, cobbles and boulders. HK13362 from a depth of 2.1 m comprised reddish brown, slightly sandy silt with some angular to subangular coarse gravel, cobbles and boulders. Trial pit TP19 located close to the apex of the debris fan at an elevation of 34.1 m was also sampled for dating (HK13358). This sample from a depth of 1.5 m comprised dark brown sandy silt with abundant angular to subangular gravel cobbles and boulders.

5.5 Wang Hang

Four debris fan complexes overlooking the village of Wang Hang (Figure 5.5) were the subject of detailed study and ground investigation. The results from an earlier pilot dating study (Sewell & Campbell, 2005) were combined with a detailed Natural Terrain Hazard investigation (AFJV, 2014) to yield the most comprehensively studied fan complex to date. In total, nineteen samples for dating were obtained from eight boreholes, three trial pits and two trial trenches (Figures 5.6 & 5.7).

5.5.1 Debris Fan 1

Debris Fan 1 comprises two large overlapping fans that collectively make up the largest of the fan complexes studied at Wang Hang. The southern larger fan was investigated using three boreholes (BH1, WH2-DH10 and WH2-DH12) and one trial pit (TP1). Mapping of the southern fan distinguished five surface lobes (AFJV, 2014). Borehole WH2-DH10 was located nearest to the apex of the southern lobe at an elevation of 31.6 m in notably clast-supported coarse sediments (Lobe 4; AFJV, 2014). One sample for dating (HK13560) was recovered from a depth of 6.7 m. The sampled material is composed of matrix-supported yellowish brown, slightly clayey sandy silt with abundant subangular gravel, cobbles, and occasional boulders. Borehole WH2-DH12 was located at an elevation of 23.4 m downslope and to the west of WH2-DH10, also in clast-supported coarse superficial materials (Lobe 4; AFJV, 2014). HK13561 came from a depth of 8.4 m and the sampled material is composed of matrix-supported, yellowish brown to reddish brown, slightly clayey sand silt with occasional

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fine to medium gravel, cobbles and boulders. Borehole BH1 was located at an elevation of 17 m also within clast-supported coarse superficial material (Lobe 3; AFJV, 2014). One sample for dating (HK12463) from a depth of 2.5 m was composed of clast-supported, yellowish brown, slightly clayey silty sand surrounded by subangular fine to coarse gravel (Appendix A). Trial pit TP1 was located at an elevation of 25.4 m between BH1 and WH2-DH10, and also within clast-supported coarse superficial material (Lobe 3; AFJV, 2014). HK12455 was sampled from a depth of 0.8 m within sediment composed of clast-supported, greyish brown to reddish brown, angular to subangular fine to coarse gravel, cobbles and boulders.

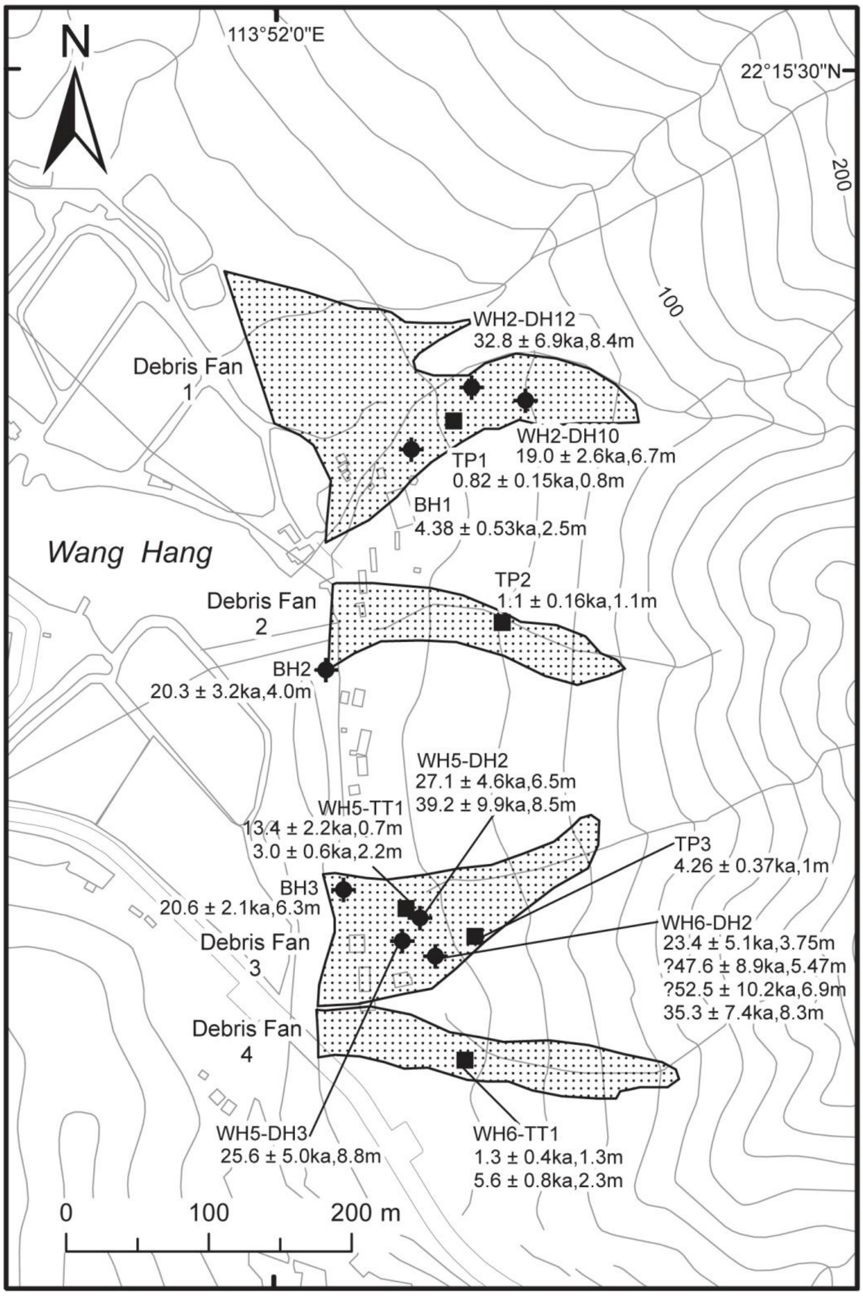

Figure 5.5 Coalescing Debris Fan Deposits at Wang Hang

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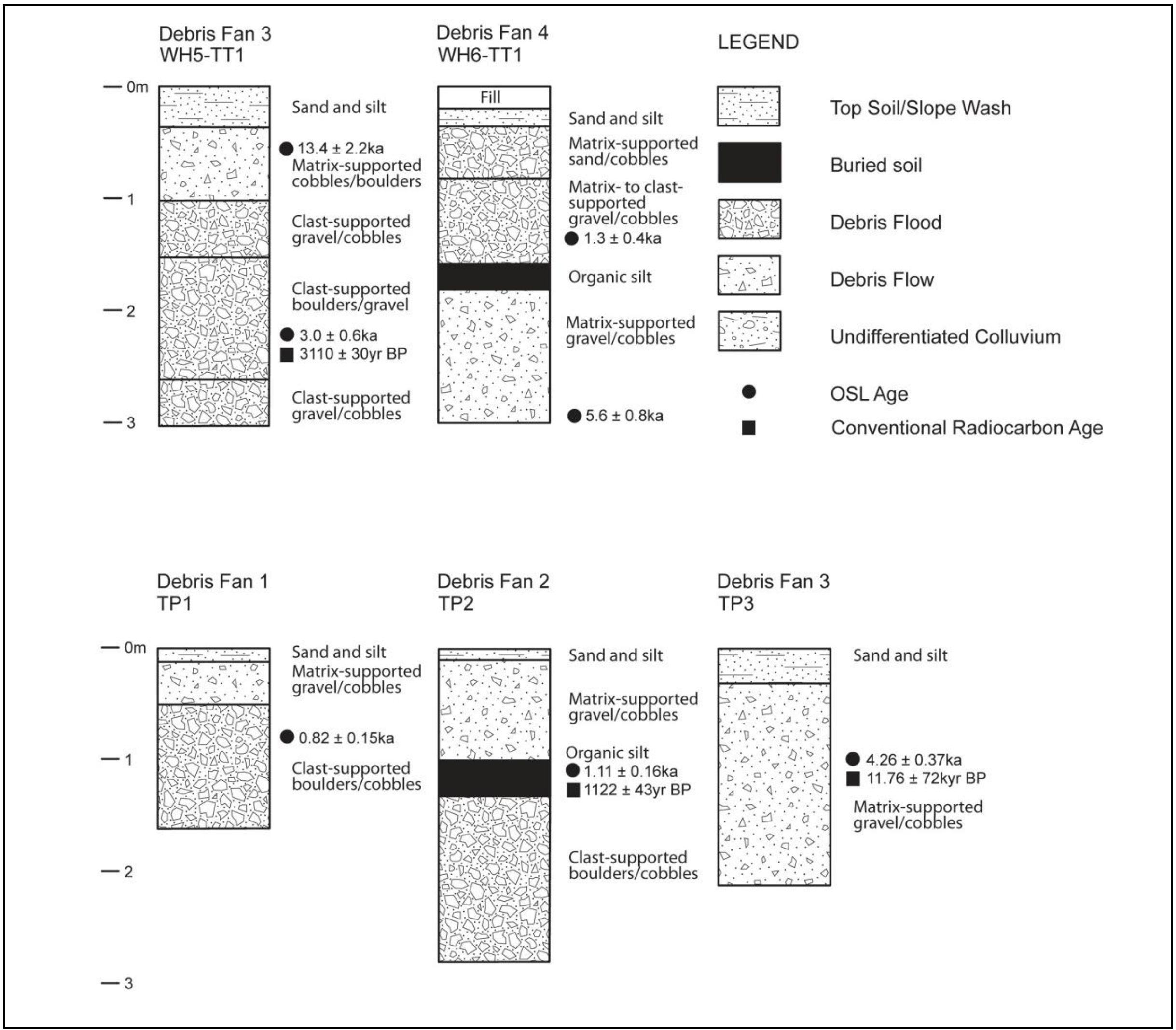

Figure 5.6 Simplified Logs from Wang Hang Trial Pits Showing Locations of Dated Samples

5.5.2 Debris Fan 2

Debris Fan 2 comprises three relatively narrow debris lobes with the shortest reach of the fan complexes studied at Wang Hang (AFJV, 2014). One trial pit (TP2) was located at an elevation of 40 m close to the mid-point of the lobe in boulder-dominated debris (Lobe 3; AFJV, 2014), whereas a borehole (BH2) was located at the toe of Lobe 1 (AFJV, 2014) to intercept possible intercalation of marine deposits. Two samples (HK12458 & HK12466) were obtained for dating from TP2 and BH2, respectively. HK12458 came from an organic rich layer at a depth of 1.1 m and the material comprised greyish brown, to yellowish brown, slightly clayey sandy silt. HK12466 came from a depth of 4 m and comprised matrix-supported, yellowish brown to reddish brown, slightly clayey sandy silt with occasional angular to subangular coarse gravel. However, excavation of TP3, which was located on a trail leading to an ancestral burial ground, revealed evidence of possible anthropogenic disturbance.

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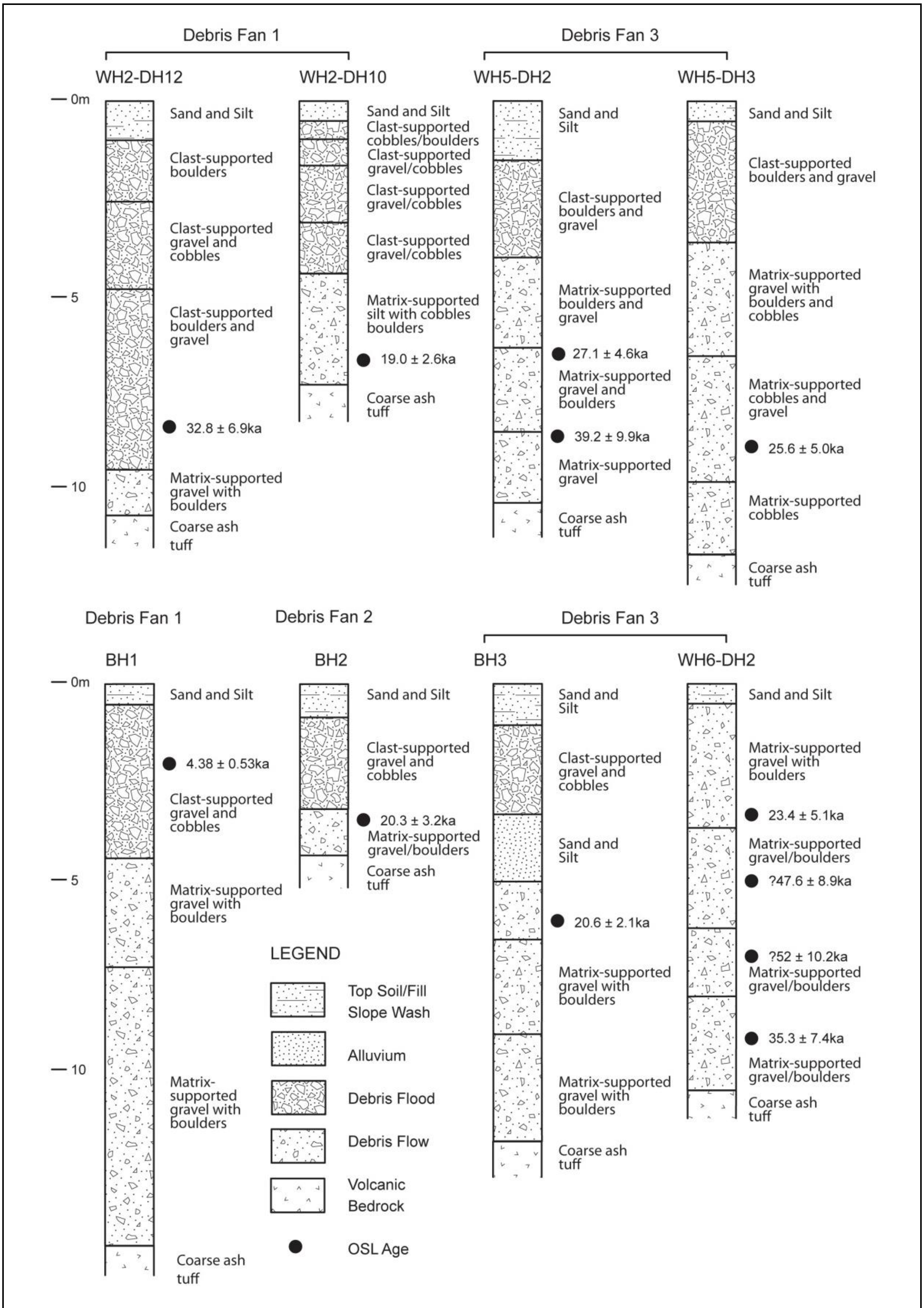

Figure 5.7 Simplified Logs from Wang Hang Boreholes Showing Locations of Dated Samples

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5.5.3 Debris Fan 3

Five lobes were mapped in Debris Fan 3 (AFJV, 2014) which was the thickest fan complex studied at Wang Hang. Four boreholes (WH6-DH2, WH5-DH2, WH5-DH3 & BH3), one trial pit (TP3) and one trial trench (WH5-TT1) in Debris Fan 3 yielded eleven samples for dating.

Four samples came from WH6-DH2 located at an elevation of 18.2 m within a distinctive lobe dominated by boulders (Lobe 1; AFJV, 2014), where one sample came from trial pit TP3 located near the apex of this lobe at an elevation of 27.8 m. Samples HK13557, HK13558, HK13559 and HK13556 were recovered from WH6-DH2 at depths of 3.8 m, 5.5 m, 6.9 m, & 8.3 m, respectively. HK13557 was composed of matrix-supported, reddish brown to brownish clayey sandy silt with abundant coarse gravel, sub-angular cobbles and occasional boulders. HK13558 consisted of matrix-supported reddish brown to dark grey, slightly clayey silty sand with some subangular to subrounded boulders and cobbles. HK13559 consisted of matrix-supported, reddish brown subangular to coarse gravel and HK13556 comprised matrix-supported, reddish brown subangular to subrounded medium gravel. Sample HK12461 from a depth of 0.9 m in TP3 consisted of yellowish brown, slightly clayey sandy silt with abundant angular to subangular fine to coarse gravel, cobbles and some boulders.

Borehole WH5-DH2 was located at an elevation of 15.6 m within very coarse bouldery debris (Lobe 5; AFJV, 2014) whereas borehole BH3 was located at the toe of the same lobe at an elevation of 5.2 m (Figure 7.1). Two samples (HK13554 & HK13555) were recovered from WH5-DH2 at depths of 6.5 m and 8.5 m, respectively. HK13554 comprised matrix-supported, yellowish brown, slightly clayey silty sand with abundant subangular to subrounded medium to coarse gravel. HK13555 consisted of matrix-supported, yellowish brown to reddish brown slightly clayey sandy silt with some subangular to subrounded medium to coarse gravel. One sample (HK12468) was recovered from BH3 at a depth of 6.3 m. This sample comprised brownish grey slightly clayey, silty fine to coarse sand and some angular medium to coarse gravel and cobbles. Trial trench WH5-TT1 was located at an elevation of 11.2 m approximately 15 m to the west of WH5-DH2 adjacent to the present day stream channel (AFJV, 2014). Two samples (HK13461 and HK13462) were recovered from depths of 0.7 m and 2.2 m. HK13461 came from matrix-supported, yellowish brown slightly clayey sandy silt with abundant subrounded gravels and cobbles. HK13462 came from clast-supported, reddish brown, slightly silty fine to coarse sand with abundant angular to subangular coarse gravel, cobbles, and some boulders.

WH5-DH3 was located at an elevation of 16.3 m within a lobate boulder mound (Lobe 3; AFJV, 2014). One sample (HK13553) was recovered from WH5-DH3 at a depth of 8.8 m. The material comprised matrix-supported, orangish brown silty clay with coarse sand, and abundant subangular gravel, cobbles and occasional boulders.

5.5.4 Debris Fan 4

Three main overlapping lobes were distinguished at the Debris Fan 4 which comprises the southernmost fan complex at Wang Hang (Figure 5.6; AFJV, 2014). Two samples (HK13459 & HK13460) were obtained from a trial trench (WH6-TT1) in Lobe 3 (AFJV,

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2014), which was located at an elevation of 15.8 m. HK13459 was recovered from a depth of 1.3 m within material composed of matrix-supported, brownish grey to dark grey, slightly sandy gravelly silt with abundant angular to subangular coarse gravel. HK13460, from the floor of the trial pit, comprised yellowish brown, gravelly silt, with abundant subangular to coarse gravel and some angular boulders.

6 Dating Results and Interpretation

Thickness estimates for dated colluvial units were based on examination of trial pit and borehole logs. In boreholes, these were generally well-constrained since the borehole usually terminated in bedrock. For trial pits, minimum estimates of thickness were given where the trial pit had reached termination depth of 3 m in a sample unit. However, where the trial pit terminated at a shallower level, due to an obstacle such as a major boulder layer, this was assumed to represent a basal contact with an underlying colluvial unit, thereby enabling a reliable thickness to be estimated.

6.1 Tung Chung

Age data for the Tung Chung site are summarized in Table 4.2. The youngest materials from depths of < 1 m in trial pits TP2 and TPB returned OSL ages between 3.26 – 3.52 ka, with a weighted average of 3.39 ± 0.13 ka. These comprised greyish brown silt and sand embedded within predominantly clast-supported boulder-dominated colluvium which prevented excavation beyond about 1 m (Appendix A). Colluvial materials in Debris Fan 2 at depths between 1.8 and 2.2 m returned ages between 10.7 and 14.5 ka, whereas a sample from Debris Fan 5 at 1.7 m returned a considerably older age of 18.0 ± 2.4 ka. All these materials were described as being orangish brown, yellowish brown and reddish brown silt or sand, and predominantly matrix-supported with some boulders (see Appendix A). The oldest materials came from depths between 3.1 and 5.8 m in boreholes from Debris Fans 2 and 4. Typically, the ages range between 25.6 and 30.2 ka, with an anomalously old age of 67.5 ka. Laboratory records show that the sample with the oldest age (HK13219) showed clear signs of bleaching, so this sample is now excluded from further discussion. The oldest samples in Debris Fans 2 and 4 were described as reddish brown or reddish orange silt or sand with occasional boulders or gravel suggesting that these deposits were predominantly matrix-supported.

Applying the chi-square goodness of fit statistical test after Barrows et al (2002), age data from debris fans at Tung Chung record three periods of mass movement activity (3.26 – 3.52 ka, 9.9 – 14.1 ka and 24.7 – 31.1 ka) with an outlier at 18.0 ± 2.4 ka.

6.2 Sham Wat

The youngest age of colluvium (3.14 ± 0.17 ka) came from trial pit TP5 at a depth of 1.5 m. This material comprised mostly silty fine to coarse sand with angular gravel and cobbles and probably represents a debris flow deposit. Slightly older ages of colluvium were yielded by materials at relatively shallower depths (< 0.8 m) in trial pits TP14 and TP15 which returned OSL ages of 3.39 ± 0.18 ka and 3.43 ± 0.18 ka, respectively. These materials

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were described as brown to light brown silty fine to coarse sand and occur as interstitial matrix within gravel and cobble-dominated debris (Appendix A) suggestive of debris flood deposition. Somewhat older deposits of colluvium occur at similar depths (0.7 – 0.8 m) in trial pits TP1 and TP10, which yielded ages of 5.59 ± 0.3 ka and 4.93 ± 0.26 ka, respectively. The materials comprised mostly loose, brown silty fine to coarse sand with angular gravel and cobbles. Nearby boreholes at the same depths encountered angular cobble and boulder fragments which collectively suggest either debris flow or debris flood deposition.

Most of the OSL ages obtained from shallow colluvium at the Sham Wat site suggest events < 5,500 years old. A chi-square test on the youngest three samples suggest they record a single event with average age of 3.32 ± 0.16 ka ($\chi^2/\upsilon = 0.82$). The two samples from TP1 and TP10 may record separate earlier events.

6.3 Sai Tso Wan

Single events based on API were considered to have formed the debris lobes of Debris Fans 4 and 5 (Sewell & Campbell, 2005). Colluvium from 0.8 m depth within debris of these fans (TP10 and TP11) yielded OSL ages of 14.8 ± 1.8 ka and 11.8 ± 2.0 ka, respectively, with an average age of 13.3 ± 2.1 ka. The reddish brown to brownish grey colour of the sand and silt matrix together with abundant highly decomposed coarse gravel, cobbles and boulders suggest a relatively ancient, weathered, debris flow deposit.

OSL ages of 11.5 ± 0.9 ka and 14.4 ± 1.7 ka were returned from trial pits TP8 and TP9 respectively near the apex of the main lobe of Debris Fan 1. Matrix material from TP8 came from a very shallow depth (0.3 m) and its yellowish brown colour combined with abundant moderately decomposed gravel, cobbles and boulders is suggestive of a relatively unoxidised debris flow deposit. By contrast, the slightly deeper (0.8 m) sample from TP9 combined with a yellowish brown to reddish brown colour within highly decomposed boulder-dominated debris is suggestive of an ancient oxidised debris flow deposit.

Samples from TP6 near the toe of Debris Fan 1 comprised mostly shallow alluvium. Finegrain OSL ages of 2.82 ± 0.62 ka and 1.34 ± 0.11 ka were obtained on alluvial samples from depths of 0.1 and 0.6 m, respectively. However, an SAR-OSL age on the same material from 0.1 m yielded a value of 0.36 ± 0.03 ka, which is in marked contrast to the finegrain OSL age. Moreover, fragments of charcoal within the alluvium collected from depths between 0.2 and 0.6 m in TP6 have yielded radiocarbon ages ranging from 170 ± 46 ^{14}C yr BP (300 – 60 CalBP) to 703 ± 47 ^{14}C yr BP (730 – 620 CalBP). Together, the SAR-OSL age interpretation and radiocarbon determinations suggest that the shallow (0.1 – 0.6 m) alluvium in TP6 is probably less than 700 years old. Besides, the SAR-OSL age is more applicable in this case as the alluvial material could have been incompletely bleached (Sewell & Campbell, 2005).

Colluvium from 1.0 m depth in TP7 within Debris Fan 1 yielded a finegrain OSL age of 3.57 ± 0.32 ka and a radiocarbon age of 2,416 ± 45 ^{14}C yr BP (2,550 – 2,340 CalBP). Since an SAR-OSL age on the same material yielded a value of 2.66 ± 0.30 ka comparable with the calibrated radiocarbon age (2,550 – 2,340 CalBP), this is the best estimate of the age of the colluvium (Sewell & Campbell, 2005).

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An OSL age of 7.93 ± 0.68 ka was obtained from TP5 at a depth of 0.8 m. This age is unlike any other nearby. Either a separate event occurred c.8.0 ka for which no other record has so far been observed, or the sample has been incompletely bleached. It is noteworthy that the sample in TP5 came from 0.8 m deep, well within the depth range of incompletely bleached alluvial samples in nearby TP6.

Colluvium from 2.6 m deep in BH4 at the toe of Debris Fan 1, yielded an OSL age of 10.5 ± 1.2 ka, and a radiocarbon age of 10,658 ± 116 ^{14}C yr BP (13,000 – 12,300 CalBP). These ages are generally consistent with the ages of colluvium from trial pits TP8 and TP9 near the apex of the debris fan, and with the ages of debris in Debris Fans 4 and 5 (see above).

Overall, the luminescence and radiocarbon age data for debris lobes suggest that debris flow events at Sai Tso Wan occurred mainly between approximately 15,000 and 8,000 years ago. Smaller mass movement events may have occurred between approximately 3,000 and 1,000 years ago. However, alluvium that has accumulated near the toe of Debris Fan 1 is probably < 700 years old, although the ages obtained from TP6 are close to the lower limit of analytical precision for luminescence dating.

6.4 Nam Chung

The youngest OSL age of colluvium (1.02 ± 0.07 ka) came from Debris Fan 3c in trial pit TP26 at a depth of 1.2 m. It was noted in the trial pit log that the number of boulders increased downward and the excavation was terminated at 1.5 m depth owing to the density of large boulders (Appendix A). This suggests that the deposit is dominantly clast supported. The reddish brown matrix suggests the matrix material is partly oxidized, but owing to the young age, it is more likely that matrix was derived from previously oxidized material rather than due to in-situ weathering.

A slightly older OSL age (1.34 ± 0.07 ka) came from Debris Fan 1 in trial pit TP19 at a depth of 1.5 m. The dated material comprised mainly dark brown sandy silt forming a matrix within a boulder-dominated deposit. The excavation was terminated at 2.2 m owing to the density of coarse materials. Overall, the description suggests that the colluvium consists of a dominantly clast-supported debris deposit.

Colluvium at a depth of 0.8 m from trial pit TP32 in Debris Fan 2 returned an OSL age of 2.30 ± 0.14 ka. The orangish brown colour of the analysed material suggests a relatively unoxidised deposit which is in agreement with the relatively young age of the matrix. The existence of occasional coarse gravel, cobbles and boulders suggests that the deposit is dominantly matrix-supported. The excavation was terminated at depth of 1.4 m after encountering a layering of densely-pack boulders comprising moderately to highly weathered clasts. This suggests an older debris deposit underlies the sampled unit.

A relatively shallow (0.8 m) sample colluvium in the fan deposit of NC2 (TP34) returned a OSL age of 4.26 ± 0.26 ka, whereas a deeper (1.8 m) sample of colluvium from the same trial pit yielded an OSL age of 6.97 ± 0.40 ka. The ages are consistent with increasing depth, and therefore, two colluvial units appear to be present. Both samples exhibit a reddish brown slightly sandy matrix suggestive of slight oxidation. Although some coarse gravel, cobbles, and boulders are present, the samples appear to be from dominantly

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matrix-supported colluvial units.

Overall, a chi-square test (χ^2/υ = 6.11) on the two youngest ages suggests a single debris flood event occurred at about 1,200 years ago. Separate debris flow events appear to have occurred at 2.3 and 4.26, and c.7 ka.

6.5 Wang Hang

Shallow (0.8 m) colluvium from TP1 in Debris Fan 1 returned a finegrain OSL age of 0.821 ± 0.147 ka. The sampled material came from interstitial yellowish brown clayey silty sand within a particularly clast-supported, boulder-dominated deposit which prevented excavation beyond about 1.65 m (Appendix A). Similar clast-supported boulder, cobble and gravel-dominated deposits were described from depths of up to 6.9 m in boreholes BH1, WH-DH12 and WH2-DH10 from the same debris fan (Figure 5.7). The only date from this material came from BH1 where an OSL age of 4.38 ± 0.53 ka was obtained from a depth of 2.5 m. The clast-supported yellowish brown character of the dated interstitial clayey silty sand suggests that it is probably a weakly oxidized deposit. Distinctly older OSL ages were obtained at deeper levels in matrix-supported debris from Debris Fan 1. An age of 19.0 ± 2.6 ka was obtained from a depth of 6.7 m in borehole WH2-DH10, whereas an age of 32.8 ± 6.9 ka was returned from WH2-DH12 at a depth of 8.4 m. Coincident with the significantly older ages in matrix-supported debris, was a distinctive reddening of the colluvial material signifying an overall more oxidized and weathered character of the deposit compared to shallower material.

Charcoal from a buried soil horizon within Debris Fan 2 (TP2 at a depth of 1.1 m) yielded two radiocarbon ages of 1,195 ± 44 ^{14}C yr BP (1,260 – 970 CalBP) and 1,122 ± 43 ^{14}C yr BP (1,170 – 930 CalBP) (Figure 5.6). The enclosing colluvium of the soil horizon yielded a finegrain OSL age of 1.11 ± 0.16 ka. Overlying material was dominantly matrix-supported suggesting that it was the product of a mass flow event around 1,100 years ago. Colluvium beneath the organic rich layer comprised dominantly clast-supported material. Colluvium at the toe of Debris Fan 2, at a depth of 4.0 m in BH2, yielded an OSL age of 20.3 ± 3.2 ka (Figure 5.7). It is notable that this material, which is matrix-supported, is moderately to strongly oxidized as shown by its reddish colour (Appendix A).

Colluvium in Debris Fan 3, from a depth of 1.0 m in TP3, yielded a finegrain OSL age of 4.26 ± 0.37 ka, whereas a radiocarbon determination on charcoal from the same horizon, returned a value of 11,758 ± 72 ^{14}C yr BP (14,150 – 13,350 CalBP). The distinctly older radiocarbon age suggests some possible disturbance of the deposit, possibly due to anthropogenic activity (see Section 5.5.2). Two OSL ages were obtained from depths of 0.7 m and 2.2 m in trial trench WH5-TT1. The shallower sample, which has been interpreted as a debris flow deposit (AFJV, 2014), yielded an age of 13.4 ± 2.2 ka and this is consistent with its relatively weathered, reddish brown appearance. By contrast, the deeper sample, which has been interpreted as a debris flood deposit, returned an age of 3.0 ± 0.6 ka. Charcoal fragments from this same sample yielded a radiocarbon age of 3,110 ± 30 ^{14}C yr BP (3,380 – 3,260 CalBP) which is within error of the OSL age. There is no evidence from laboratory records to suggest that the shallower sample has been incompletely bleached. Therefore, a possible explanation for the apparent age discrepancy is that an older debris flow deposit has been undercut by a younger debris flood deposit related to more recent stream

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incision (AFJV, 2014). Colluvium, from 6.3 m deep in borehole BH3 at the toe of Debris Fan 3, returned an OSL age of 20.6 ± 2.1 ka. This material also is matrix-supported, but appears to be relatively unweathered judging by its brownish colour.

Boreholes WH5-DH2, WH5-DH3 and WH6-DH2 in Debris Fan 3 revealed distinctly older ages of colluvium at deeper levels in predominantly matrix-supported material (Figure 5.7). OSL ages of 27.1 ± 4.6 ka and 39.2 ± 9.9 ka were obtained at depths of 6.5 m and 8.5 m, respectively, in borehole WH5-DH2. The ages coincide with separate units identified from the boreholes, indicating an ancient succession of stacked debris deposits. These deposits were notably moderately to strongly weathered as indicated by their yellowish brown to reddish brown colour (Table 4.3). A similar OSL age of 25.6 ± 5.0 ka was obtained from borehole WH5-DH3 at a depth of 8.8 m, and is within error of the age at 6.5 m in borehole WH5-DH2. Likewise, the material is moderately to strongly weathered as shown by the colour and is matrix-supported (Table 4.3). Four OSL ages (23.4 ± 5.1 ka, 47.6 ± 8.9 ka, 52.0 ± 10.2 ka and 35.3 ± 7.4 ka) were obtained from borehole WH6-DH2 at depths of 3.75 m, 5.47 m, 6.9 m and 8.3 m, respectively. The OSL ages obtained at 3.75 m and 5.47 m are the oldest so far reported in this study and appear to overlie younger material at 8.3 m. There are three possible explanations:

(a) the two older ages are possibly due to incomplete bleaching so that the sediment grains carried some inherited luminescence signal. However, there is no indication from laboratory records of incomplete bleaching.

(b) The younger age at 8.3 m could have resulted from transport of sediment grains to deeper levels by way of soil pipes and/or bioturbation. However, no soil pipes or evidence of biological disturbance was noted in borehole logs.

(c) Laboratory records reveal that the two oldest samples lacked broadband luminescence and had to be measured under blue stimulation (Table 4.2). Since these are the only samples in the study that were not measured under IR stimulation, the ages need to be treated with caution.

A final observation from the borehole descriptions (AFJV, 2014; Appendix A) is that material from 5.47 m and 6.9 m is not significantly more reddened due to oxidation than the younger deposits as might be expected from ancient weathered materials. Therefore, for reliability and compatibility with the remaining dataset, these anomalously old OSL ages are excluded from further consideration.

A composite cross-section of Debris Fan 3 (Figure 6.1) based on the available ground investigation records reveals a stacked succession of ancient debris flow units. The oldest deposits appear to be at least 37,000 years old.

Samples recovered from depths of 1.3 m and 2.3 m in trial trench WH6-TT1 in Debris Fan 4 returned OSL ages of 1.3 ± 0.4 ka and 5.6 ± 0.8 ka, respectively. The shallower unit, which is matrix- to clast-supported, is brownish grey to dark grey, suggesting it is relatively unweathered. This unit has been interpreted as a debris flood deposit (AFJV, 2014) and

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overlies an organic silt layer (Appendix A) which thought to represent a buried soil horizon (AFJV, 2014). Attempts to date the organic layer using radiocarbon methods proved unsuccessful. The deeper unit has been interpreted to be a debris flow deposit based on its matrix-supported character (AFJV, 2014). Its yellowish to orangish brown colour suggests that it is more weathered than the overlying unit and this is consistent with its older OSL age.

Overall, a normalized chi-square test on the three youngest units (χ^2/υ = 0.18) suggests that a debris flood event occurred around 1,070 years ago. Other debris flood and debris flow events may have occurred at around 3.0 ka, 4.3 ka and 13 ka (Table 4.2). A normalized chi-square test on the youngest group of Pleistocene debris flow deposits (χ^2/υ = 0.96) suggest they are part of a single population with a mean age of 22.7 ± 3.2 ka. A separate debris flood event may have occurred around 33 ka, whereas a chi-square test on the two older debris flow deposits (χ^2/υ = 0.11) suggests they likely record a single event at around 37.3 ± 2.8 ka.

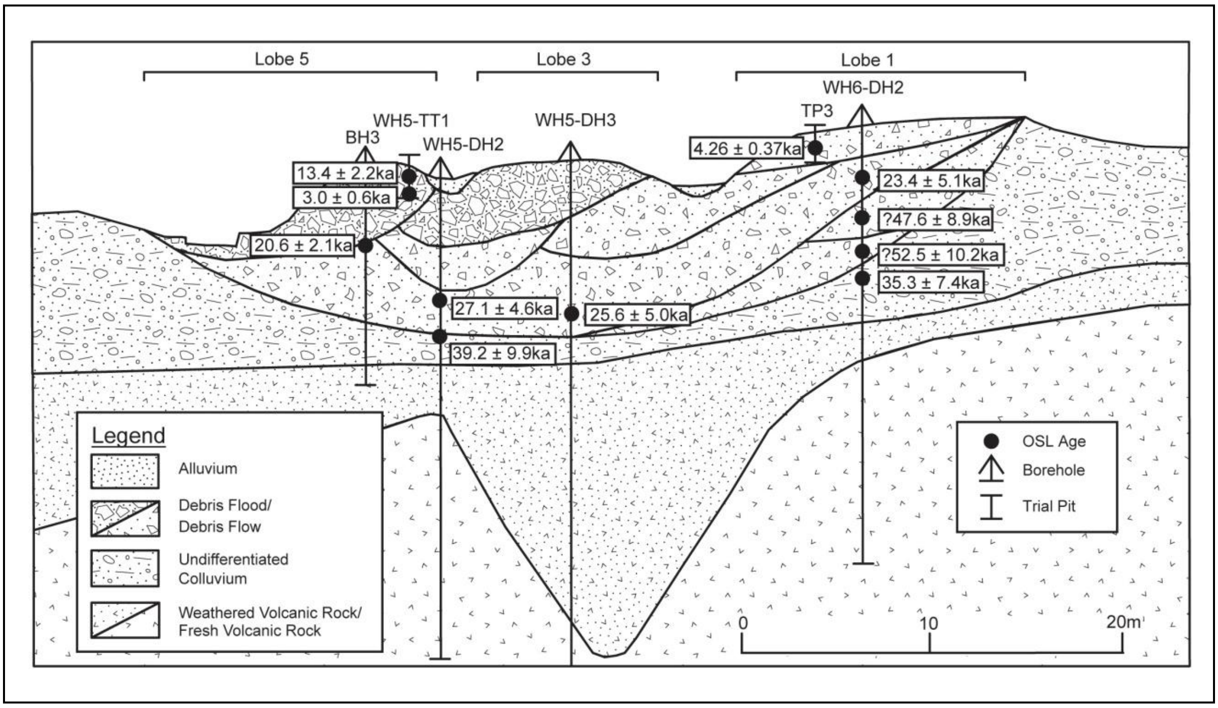

Figure 6.1 Composite Cross-section of Debris Fan 3 at Wang Hang (Modified after AFJV, 2014)

7 Discussion

7.1 Characteristics of Hong Kong Debris Flows

It has generally been perceived (e.g. Wong, 2009) that Hong Kong debris flows possess a higher sediment concentration (i.e. relatively 'dry') compared with debris flows that occur on sizeable debris flow catchments elsewhere because they are predominantly initiated by landslides at source, catchment size is generally small and drainage lines are relatively short. Thus, Hong Kong's debris flows contain sediment-water mixtures with a higher strength, and are therefore less mobile than those which have a higher water content (i.e. low sediment

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concentration). However, this perception has recently been challenged following a severe rainstorm that affected Lantau Island in June 2008. Over 670 mm of rain fell within 48 hours, including a one-hour period when more than 100 mm was recorded (Lam et al, 2012). As a result, over 2,400 natural terrain landslides were generated in Lantau Island alone, some of which intercepted drainage lines and were channelised into debris flows with unusually long runouts. Of particular note was that significant debris entrainment was observed in these channelised debris flows (Wong, 2009; AECOM, 2012). Comparison with previous natural terrain failures suggested that the landslide debris generated by the June 2008 event was more mobile and the debris entrainment ratio within channelised debris flows was up to 10 or higher (Lo & Lam, 2013). Selected studies of long runout channelised debris flows (e.g. AECOM, 2012), including one which was observed directly, revealed that the debris was mixed with a high water content, resulting in higher mobility. This 'watery' debris was considered to have been produced under a particular set of circumstances, including:

(i) debris flows along a major drainage line with a long flow path,

(ii) debris occurring during heavy rain, and

(iii) debris flows along a drainage line fed by multiple tributaries (Wong, 2009; Lo & Lam, 2013).

Comparison of these 'watery' debris flow deposits (Figure 7.1) with ancient debris flood deposits described in this study indicate they share some common characteristics. For example, the ancient debris flood deposits are described as dominantly clast-supported, loose, gravelly colluvium and alluvium, with crude sorting. Wong (2009) describes the 'watery debris' flow deposits associated with long runout channelised debris flows on Lantau Island as typically loose, unconsolidated, and showing considerable sorting. The geometry of these 'watery debris' flow deposits also appear to have characteristics not dissimilar to ancient debris flood deposits described from Lantau Island (e.g. thin, relatively wide, sheet-like deposits of poorly sorted debris). Debris floods differ from debris flows in that they are very rapid, surging flows of water which source debris from within the drainage channel, rather than from landslides which have intercepted the channel (Hungr et al, 2001). The resulting deposits may show evidence of traction current deposition (e.g. sorting), and are generally fines-depleted compared with debris flow deposits. However, given the similar characteristics of the deposits, the ancient debris flood deposits described in this study may, in fact, be equivalent to 'watery' debris flow deposits described by Wong (2009). Thus, it is postulated that during the Early to Middle Holocene, dominance of relatively thin, debris flood deposits recorded in the Lantau debris fan complexes may point to a period of more frequent high intensity rainstorms that generated 'watery' debris flows with long runouts and high debris entrainment ratios.

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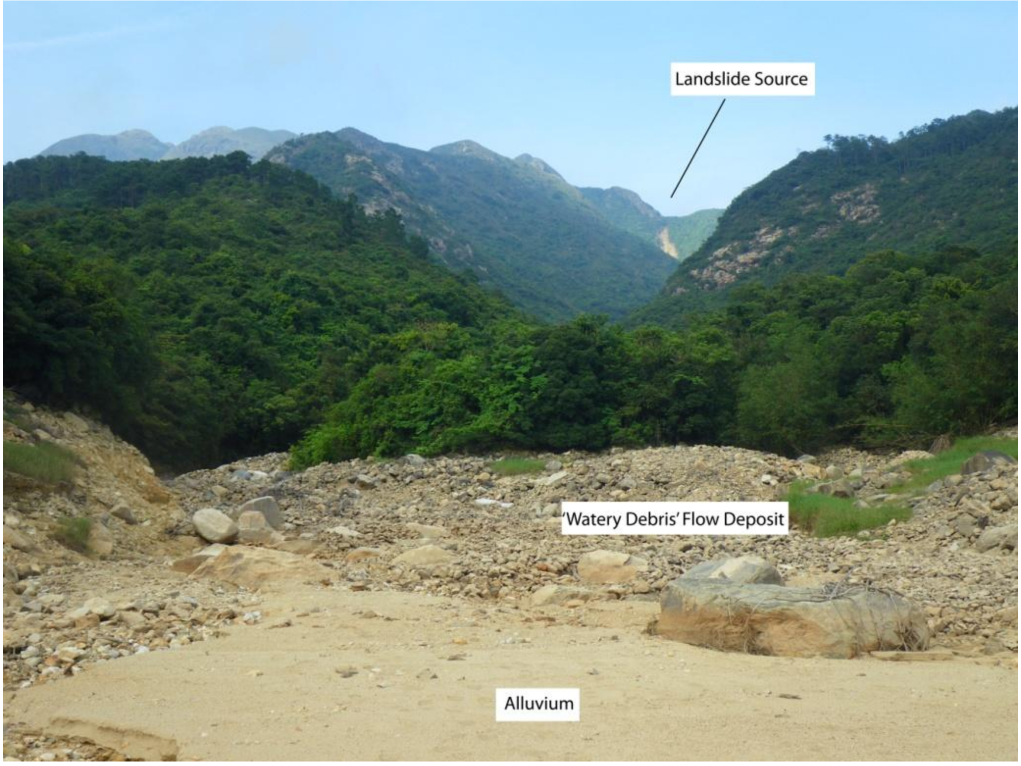

Figure 7.1 'Watery' Debris Flow Deposit Generated by Long Run-out Debris Flow on 7 June 2008 (Note the Moderately sorted, Clast-supported, Coarse gravel to Bouldery Character. Landslide Source over 1.4 km in Distance. Location: Shek Pik No. 4, Lantau Island (Photo Taken on 27.5.2010))

7.2 Past Periods of Landslide and/or Debris Flow Activity

A statistical analysis of the forty OSL ages obtained from debris lobes from the five fan complexes was carried out to determine whether clustering of ages could possibly represent past periods of increased landslide and/or debris flood activity. This analysis was then compared with the results of an earlier dating study on relict large landslides across Hong Kong.

Using the chi-square test of goodness of fit, the age data from debris fan complexes fall into six age populations. The oldest group of ages examined includes dominantly debris flow deposits that range been about 20,000 and 40,000 years old (excluding the two samples that were measured under blue luminescence). The three oldest ages (32.8 ± 6.9 ka, 35.3 ± 7.4 ka and 39.2 ± 9.9 ka) in this group do not form a single population. However, the remaining ages cluster within a single population with mean age of 24.0 ± 3.9 ka ($\chi^2/\upsilon = 1.43$, 95% probability of fit). Thus, the results suggest that between about 20,000 and 28,000 years ago, the fan complexes were building vigorously mainly by large scale debris flow activity. This period approximately corresponds to the Last Glacial Maximum (LGM) sea-level low-stand (26.5 to 19 ka) (Clark et al, 2009). Pollen data from deep sea sediments from the continental slope of the southern South China Sea (Sun et al, 2000 & 2003), and from coastal areas of Southeast China (Yu et al, 2000), suggest a cooler dryer climate for

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South China during the last glacial period sea-level low-stand.

The next cluster of ages recorded by the debris lobes occurs between about 11,000 years and 14,500 years ago. The OSL ages from eight debris deposits form a single population (χ^2/υ = 1.22) with a mean age of 12.6 ± 1.7 ka. One outlier dated at 18,000 years does not appear to belong to any existing population. The climatic period between 11,000 and 14,500 years ago saw major fluctuations in warming and cooling. Speleothem data for South China (Wang et al, 2001) indicate intensification of the East Asia Monsoon from 15,000 to 8,500 years ago. However, accelerated global warming from 15,000 years to 12,500 years ago, was interrupted by a sudden period of cooling (Younger Dryas) over the next 1,400 years. It seems that during this period debris lobes forming the fan complexes along Western Lantau Island were dominated by debris flow deposition. This could be attributed to the availability of large amounts of weathered materials in the source areas of major catchments. The previous glacial maximum period is likely to have witnessed a cool dry climate with accelerated sediment production in the source areas, but without concomitant removal by precipitation. During the immediate post-glacial warming period, this sediment appears to have been mobilized in the form of large-volume debris flows.

A third cluster of ages is found between about 5,000 and 5,800 years ago. Three ages form a single population (χ^2/υ = 1.75) with mean age of 5.37 ± 0.4 ka. In contrast to the earlier mass movement activity, the fan deposits appear to result from a mixture of debris flow and debris flood activity. The period between about 8,000 and 6,000 years is known to have been one of gradual warming followed by gradual cooling until about 3,000 years ago (Wang et al, 2005). Speleothem data from the Dongge Cave in Southern Guangdong Province (Dykoski et al, 2005) along with weathering proxies from Holocene sediments of the Pearl River Estuary (Hu et al, 2013) reveal a strong Asian monsoon and strong chemical weathering from 9.5 to 6.0 ka followed by gradual weakening of the Asian monsoon (Zong et al, 2009; Yu et al, 2011) and weaker chemical weathering until about 2.5 ka. During the Early to Mid. Holocene therefore, the climatic conditions are likely to have been warm and humid. Chemical weathering in the upland source areas is probably coupled with increased vegetation cover as indicated by pollen studies (Sun et al, 2003). Such conditions, combined with high summer rainfall (Dykoski et al, 2005), would have favoured the mobilization of 'watery' debris flows and/or debris floods which are the dominant debris deposit of this period.

Three further pulses of debris deposition appear to have occurred between about 4,370 and 4,230 years ago (Mean age: 4.3 ± 0.07 ka, n = 3, χ^2/υ = 0.03), 3,560 and 3,320 years ago (Average age: 3.40 ± 0.08 ka, n = 4, χ^2/υ = 0.05), with the youngest group of debris deposits yielding a single population with mean age of 1.19 ± 0.15 ka, but with somewhat lower probability than previous clusters (χ^2/υ = 2.15). Four debris deposit ages are recorded between 2,300 and 3,100 years ago but the ages do not form a single population suggesting that these were the product of isolated single mass flow events.

Comparing the age of the deposits with thickness (Figure 7.2), the two older periods activity (11,000 – 14,500 yrs BP, 20,000 – 28,000 yrs BP) are generally dominated by thick (1.0 – 3.5 m) colluvial units deposited mainly by debris flow events, whereas the younger periods (< 10,000 yrs BP) are dominated by thinner (0.5 – 1.5 m) colluvial units represented by debris flood events or 'watery' debris flow events.

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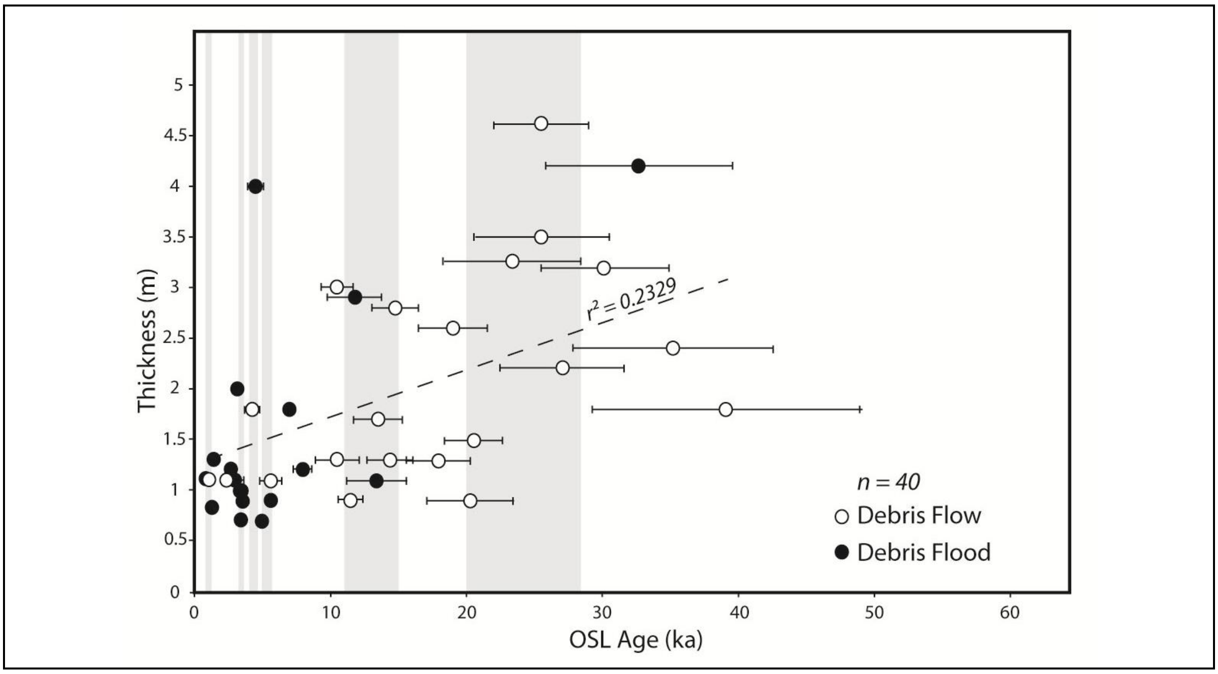

Figure 7.2 Age-thickness Relationships of Debris Deposits at West Lantau

Considering the age data for deep-seated landslides and rockfalls over different parts of Hong Kong (Sewell & Campbell, 2005; Sewell et al, 2006; Sewell & Tang, 2015; Figure 7.3), there is a general trend toward smaller volume, more frequent landslide activity during the post-LGM period, compared with less frequent, large volume landslide activity extending back to the limit of relict landslide recognition at about 50,000 yr BP (Sewell & Campbell, 2005; Sewell et al, 2006).

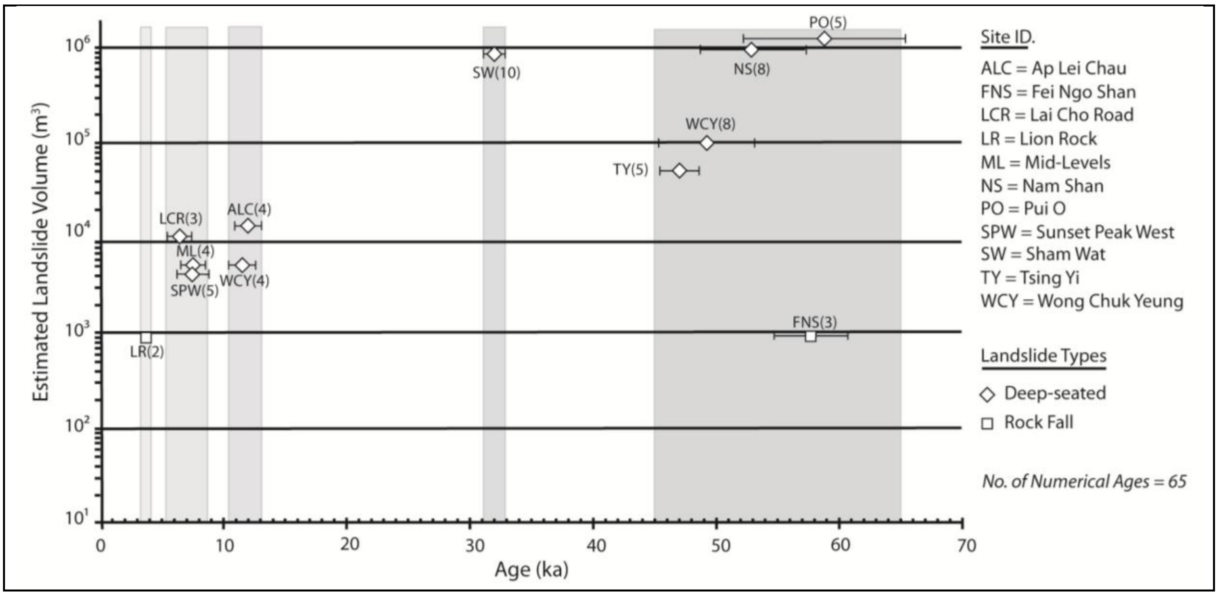

Figure 7.3 Landslide Age/Volume Relationships (Data from Sewell & Campbell, 2005; Sewell et al, 2006; Sewell & Tang, 2015)

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7.3 Hong Kong Landscape Response to Climate Change

This study has revealed that debris fan complexes along the coastal foothills of Western Lantau Island, Hong Kong, preserve a record of the landscape response to past periods of climate change. This response has been in the form of increased frequency of ‘watery’ debris flows triggered by landslide activity during periods of intensified summer rainfall in the Early to Mid. Holocene. Evidence of increased deep-seated landslide activity during the immediate post-LGM period and Early Holocene (Sewell et al, 2006) coincides with known rapid rises in sea-level (Zong, 2004; Smith et al, 2011) and may reflect the landscape response to rising base-level and increasing pore-pressures. Hu et al (2013) have shown that offshore sediments deposited in the immediate vicinity of Hong Kong in the Early to Mid. Holocene reflect stronger chemical weathering coincident with more humid, warmer weather conditions during intensification of the Asian Monsoon. Thus, it can be forecast that with the onset of global warming landslide activity is likely to increase as a result of stronger chemical weathering and increased rainfall. More frequent, high-intensity hydroclimatic events are likely to produce more common long run out ‘watery’ channelised debris flows. Rising sea-level is also likely to increase pore pressures in the natural terrain which may lead to increased frequency of deep-seated landslides and rockfalls as observed during past periods of climate change. Therefore, changes in mitigation strategies will need to be made concurrently with changes in climate in order to manage the risk from natural terrain landslide hazards.

8 Conclusions

Age data from debris fan complexes from the coastal foothills of Lantau Island reveal at least six periods of significant landslide activity. Some of these periods can be directly linked with known climatic changes. It appears that general warming of the climate corresponds with increasing frequency of debris flood activity, whereas, cool dry periods were characterised mainly by debris flow activity. The potential for future adjustment of the landscape in response to global warming cannot be ruled out. The anticipated increase in frequency of extreme weather events in Hong Kong as a result of global warming may increase the likelihood of natural terrain landslide failures producing higher mobility, ‘watery’ debris flow hazards.

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Appendix A

Finalised Contractor’s Logs for Ground Investigation Stations
(in CD ROM)

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Appendix B

Summary of Interpreted Ground Investigation Logging Records

Table B1 Interpreted ground investigation logging records for stations at the Tung Chung site

Borehole/ Trial Pit	Thickness (m)	Depths (m)	Sample Description	Type of Deposit
Debris Fan 1				
TP2	0.1	0 - 0.1	Dark grey, sandy sillt with much rootlets	Top soil
	0.9	0.1 - 1.0*	Clast-supported, subangular, fine to coarse gravel, cobbles, and boulders with some grayish brown sandy silt	Debris flood
Debris Fan 2				
TP3	0.3	0 - 0.3	Greyish brown, sandy silt with some rootlets	Top soil
	1.3	0.3 - 1.6*	Matrix-supported, light brown sandy silt with come subangular coarse gravel and cobbles	Debris flow
TP1	0.3	0 - 0.3	Dark grey, clayey sandy silt with some rootlets	Top soil
	1.7	0.3 - 2.0*	Matrix-supported, yellowish brown silty fine to medium sand with abundant cobbles	Debris flow
DH5	0.7	0 - 0.7	Brown to grey, silty fine to medium sand, with some gravel and cobbles	Slope wash
	1.2	0.7 - 1.9	Clast-supported, dark grey, cobbles and boulders	Debris flood
	1	1.9 - 2.9	Matrix-supported, brown, silty sand with abundant gravels and cobbles	Debris flow
	3.2	2.9 - 6.1*	Matrix-supported, reddish orange, silty fine to medium sand with occasional angular gravel	Debris flow
Debris Fan 4				
DH13	0.5	0 - 0.5	Greyish brown, silty fine to medium sand with occasional rootlets	Top soil
	0.5	0.5 - 1	Light yellowish brown, silty fine to medium sand	Alluvium
	4.6	1.0 - 5.6*	Matrix-supported, reddish brown sandy silt with some subangular fine to coarse gravel and cobbles	Debris flow
	2.2	5.6 - 6.4*	Matrix-supported, light grey silty sand with abundant cobbles	Debris flow
Debris Fan 5				
TPB	1	0 - 1*	Clast-supported, angular coarse gravel, cobbles and boulders with some light greyish brown and light yellowish brown, silty fine to medium sand	Debris flood
TP5	0.2	0 - 0.2	Dark greyish brown, sandy silt with many rootlets	Top soil
	1.3	0.2 - 1.5*	Matrix-supported, dark brown, silty fine to medium sand with some subangular and subrounded fine to coarse gravel, cobbles and boulders	Debris flow
	1.2	1.5 - 2.7	Matrix-supported, yellowish brown to light pinkish brown, slightly clayey sandy silt with much angular to subangular fine to coarse gravel, cobbles and boulders	Debris flow

*Dated unit (see Table 4.2 for details)

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Table B2 Interpreted ground investigation logging records for stations at the Sham Wat site

Borehole/ Trial Pit	Thickness (m)	Depths (m)	Sample Description	Type of Deposit
Debris Fan 1				
SW-TP15	0.4	0 - 0.4	Brown, angular fine gravelly silt to coarse sand with occasional gravel, cobbles and rootlets	Top soil
	0.7	0.4 - 1.1*	Clast-supported, angular gravel and cobbles with some light brown silty fine to coarse sand	Debris flood
SW-TP14	0.3	0 - 0.3	Brown angular fine gravelly silty fine to coarse sand with occasional gravel, cobbles and rootlets	Top soil
	1	0.3 - 1.3*	Clast-supported, angular gravel and cobbles with some light brown, silty fine to coarse sand	Debris flood
SW-TP10	0.4	0 - 0.4	Brown angular fine gravelly silty fine to coarse sand with occasional gravel, cobbles and rootlets	Top soil
	0.7	0.4 - 1.1*	Clast-supported, angular gravel and cobbles with some light brown, silty fine to coarse sand	Debris flood
Debris Fan 2				
SW-TP5	0.3	0 - 0.3	Brown angular fine gravelly silty fine to coarse sand with occasional gravel, cobbles and rootlets	Top soil
	2	0.3 - 2.3*	Clast-supported, angular gravel and cobbles with some brown, slightly silty fine to coarse sand	Debris flood
Debris Fan 4				
SW-TP1	0.4	0 - 0.4	Brown angular fine gravelly silty fine to coarse sand with occasional gravel, cobbles and rootlets	Top soil
	0.9	0.4 - 1.3*	Clast-supported, angular cobbles and boulders with some brown to light reddish brown, angular gravelly sandy clayey silt	Debris flood

*Dated unit (see Table 4.2 for details)

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Table B3 Interpreted ground investigation logging records for stations at the Sai Tso Wan site

Borehole/ Trial Pit	Thickness (m)	Depths (m)	Sample Description	Type of Deposit
Debris Fan 1				
BH4	0.35	0 - 0.35	Greyish brown to yellowish brown, slightly clayey sandy silt with occasional rootlets	Top soil
	1.65	0.35 - 2.0	Clast-supported, angular cobbles with occasional coarse gravel and boulders and some brownish grey to yellowish brown, slighlty clayey sandy silt	Debris flood
	3	2.0 - 5.0*	Matrix-supported, yellowish brown to reddish brown slightly clayey sandy silt with abundant angular to subangular fine to coarse gravel and some cobbles	Debris flow
	3.2	5.0 - 8.2	Matrix-supported, reddish brown to yellowish brown, slightly clayey sandy silt with abundant angular to subangular fine to coarse gravel, some cobbles, and occasional boulders	Debris flow
	1.9	8.2 - 10.1	Matrix-supported, reddish brown, slightly clayey sandy silt with some angular to subangular, coarse gravel and occasional cobbles	Debris flow
TP5	0.2	0 - 0.2	Dark greyish brown slightly clayey sandy silt with much rootlets and some angular to subangular fine to coarse gravel and occasional boulders	Top soil
	0.4	0.2 - 0.6	Matrix-supported, yellowish brown slightly clayey sandy silt with some rootlets and occasional angular to subangular fine to coarse gravel	Debris flow
	1.2	0.6 - 1.8*	Clast-supported, yellowish brown to reddish brown, angular to subangular fine to coarse gravel, cobbles and boulders with some slightly clayey sandy silt	Debris flood
TP6	0.2	0 - 0.2*	Greyish brown to yellowish brown, slightly clayey, silty fine to coarse sand with much rootlets	Alluvium
	0.5	0.2 - 0.7*	Dark greyish brown, slightly clayey sandy silt with much rootlets and some angular to subangular fine to coarse gravel	Alluvium
	0.3	0.7 - 1	Matrix-supported, greyish brown, slightly clayey silty fine to coarse sand with some angular to subangular fine to medium gravel, cobbles and boulders	Debris flow
	0.4	1 - 1.4	Matrix-supported, yellowish brown to reddish brown, slightly clayey, silty sandy angular to subangular coarse gravel, with occasional boulders and cobbles	Debris flow
TP7	0.1	0.3 - 0.4	Dark greyish brown, slightly clayey sandy silt with much rootlets	Top soil
	0.4	0.4 - 0.8	Matrix-supported, yellowish brown slightly clayey sandy silt with occasional angular to subangular fine to medium gravel	Debris flow
	1.2	0.8 - 2*	Clast-supported angular to subangular fine to coarse gravel, cobbles and boulders, with some greyish brown very clayey silty sand	Debris flood
TP8	0.2	0 - 0.2	Dark greyish brown, slightly clayey sandy silt with much rootlets	Top soil
	0.9	0.2 - 1.1*	Matrix-supported, yellowish brown slightly clayey sandy silt with abundant angular to subangular fine to coarse gravel and cobbles, and occasional boulders	Debris flow

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Borehole/ Trial Pit	Thickness (m)	Depths (m)	Sample Description	Type of Deposit
	0.8	1.1 - 1.9	Clast-supported, angular to subangular fine to coarse gravel, cobbles and boulders with some yellowish brown slightly clayey sandy silt	Debris flood
TP9	0.5	0 - 0.5	Dark greyish brown, slightly clayey sandy silt with much rootlets	Top soil
	1.3	0.5 - 1.8*	Matrix-supported, yellowish brown to reddish brown, slightly clayey sandy silt with abundant angular to subangular fine to coarse gravel, cobbles, and boulders	Debris flow
Debris Fan 4				
TP10	0.2	0 - 0.2	Greyish brown, sandy silt with some rootlets	Top soil
	2.8	0.2 - 3*	Matrix-supported, reddish brown to brownish grey, slightly clayey sandy silt with abundant angular to subangular fine to coarse gravel, cobbles and some boulders	Debris flow
TP11	0.3	0 - 0.3	Dark greyish brown, slightly clayey sandy silt with much rootlets	Top soil
	2.9	0.3 - 3.2*	Clast-supported, angular to subangular fine to coarse gravel, cobbles and boulders, with some reddish brown to yellowish brown, clayey silty sand	Debris flood

*Dated unit (see Table 4.2 for details)

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Table B4 Interpreted ground investigation logging records for stations at the Nam Chung site

Borehole/ Trial Pit	Thickness (m)	Depths (m)	Sample Description	Type of Deposit
Debris Fan 1				
NC-TP34	0.3	0 - 0.3	Dark brown slightly sandy silt with some angular to subangular fine to coarse gravel and rootlets	Top soil
	1.8	0.3 - 2.1*	Poorly compacted, angular to subangular coarse gravel, cobbles and boulders, with some reddish brown, slightly sandy silt	Debris flood
NC-TP19	0.6	0 - 0.6	Dark brown, slightly sandy silt with some angular to subangular medium to coarse gravel and occasional cobbles	Top soil
	1.3	0.6 - 1.90*	Poorly compacted, angular to subangular gravel, cobbles and boulders with some dark brown sandy silt	Debris flood
	0.3	1.9 - 2.2	Matrix-supported, dark brown slightly sandy silt with many angular to subgular gravel, cobbles and boulders	Debris flow
Debris Fan 2				
NC-TP32	0.1	0.2 - 0.3	Greyish brown and brown sandy silt with occasional angular to subangular fine to coarse gravel and cobbles, and rootlets	Top soil
	1.1	0.3 - 1.4*	Matrix-supported, orangish brown to brow slightly sandy silt with occasional angular to subangular fine to coarse gravel, cobbles and boulders	Debris flow
Debris Fan 3				
NC-TP26	0.1	0.3 - 0.4	Dark brown slightly sandy silt with much angular to subangular gravel, cobble, and boulders	Top soil
	1.1	0.4 - 1.5*	Matrix-supported, reddish brown, slightly sandy silt with abundant angular to subangular gravel, cobbles and boulders	Debris flow

*Dated unit (see Table 4.2 for details)

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Table B5 Interpreted ground investigation logging records for stations at the Wang Hang site

Borehole/ Trial Pit	Thickness (m)	Depths (m)	Sample Description	Type of Deposit
Debris Fan 1				
WH2-DH10	0.5	0 - 0.5	Brown, slightly clayey sandy silt with occasional angular to subangular coarse gravel	Top soil
	0.8	0.5 - 1.3	Clast-supported, brownish grey to brown, angular to subangular cobbles and some boulders	Debris flood
	0.7	1.3 - 2.0	Clast-supported brownish grey to brown, subangular gravel with occasional cobbles	Debris flood
	1.1	2.0 - 3.1	Clast-supported, brownish grey to yellowish brown, angular to subangular gravel with some cobbles and occasional boulders	Debris flood
	1.6	3.1 - 4.7	Clast-supported, yellowish brown to greyish brown, angular to subangular gravel with some cobbles and boulders	Debris flood
	2.6	4.7 - 7.3*	Matrix-supported, yellowish brown, slightly clayey sandy silt with abundant subangular gravel, cobbles, and occasional boulders	Debris flow
WH2-DH12	1	0 - 1	Pale grey, slightly sandy clayey silt with some angular to subangular fine to medium gravel	Top soil
	1.6	1.0 - 2.6	Pale grey, subangular boulders	Debris flood
	2.2	2.6 - 4.8	Clast-supported, yellowish brown, subangular to subrounded, medium to coarse gravel with occasional boulders	Debris flood
	4.2	4.8 - 9.0*	Clast-supported, subangular to subrounded boulders with occasional well-sorted yellowish brown to reddish brown, slightly clayey sand silt	Debris flood
	1.7	9.0 - 10.7	Subangular boulders with yellowish brown clayey sandy silt at base	Debris flow
BH1	0.5	0 - 0.5	Greyish brown, sandy silt with occasional rootlets and some angular to subangular fine to coarse gravel	Top soil
	4.0	0.5 - 4.5*	Clast-supported, subangular to subrounded boulders and coarse gravel with occasional yellowish brown, slightly clayey silty sand	Debris flood
	2.8	4.5 - 7.3	Matrix-supported, yellowish brown to reddish brown, slightly clayey silty fine to coarse sand with some angular to subangular gravel, cobbles and boulders	Debris flow
	6.7	7.3 - 14.0	Matrix-supported, yellowish brown to reddish brown, slightly clayey, silty fine to coarse sand with abundant angular to subangular gravel, cobbles and some boulders	Debris flow
TP1	0.1	0 - 0.1	Dark greyish brown, slightly clayey sandy silt with much rootlets	Top soil
	0.4	0.1 - 0.5	Matrix-supported, greyish brown slightly clayey sandy silt with abundant angular to subangular fine to coarse gravel and occasional cobbles and boulders	Debris flow
	1.1 (min.)	0.5 - 1.6*	Clast-supported, grayish brown to reddish brown, angular to subangular fine to coarse gravel, cobbles and boulders	Debris flood
Debris Fan 2				
BH2	1.9	0 - 1.9	Greyish brown coarse sand to slightly sandy silt with abundant gravels and occasional shells	Fill
	1.6	1.9 - 3.5	Clast-supported, light grey to yellowish brown and reddish brown, angular to subangular medium to coarse gravel and	Debris flood

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Borehole/ Trial Pit	Thickness (m)	Depths (m)	Sample Description	Type of Deposit
			some cobbles and boulders	
	0.9	3.5 - 4.4*	Matrix-supported, yellowish brown to reddish brown, slightly clayey sandy silt with occasional angular to subangular coarse gravel	Debris flow
TP2	0.1	0 - 0.1	Dark greyish brown, sandy silt with much rootlets and some angular to subangular cobbles	Top soil
	0.9	0.1 - 1.0	Matrix-supported, yellowish brown, slightly clayey sandy silt with some angular to subangular fine to coarse gravel, coobles and boulders	Debris flow
	0.3	1.0 - 1.3*	Greyish brown, organic-rich, slightly clayey sandy silt with angular to subangular fine to coarse gravel	Buried soil
	1.5 (min.)	1.3 - 2.8	Clast-supported, angular to subangular fine to coarse gravel, cobbles and some boulders with yellowish brown, slightly clayey sandy silt	Debris flood
Debris Fan 3				
WH6-DH2	0.5	0 - 0.5	Dark brown slightly sandy silt with some subangular medium to coarse gravel	Top soil
	3.25	0.5 - 3.75*	Matrix-supported, reddish brown to brownish clayey sandy silt with abundant coarse gravel, sub-angular cobbles and occasional boulders	Debris flow
	2.55	3.75 - 6.3*	Matrix-supported, reddish brown to dark grey, slightly clayey silty sand with some subangular to subrounded boulders and cobbles	Debris flow
	1.8	6.3 - 8.1*	Matrix-supported, reddish brown to dark brown, slightly clayey silty sand with abundant subangular to subrounded medium to coarse gravel with some cobbles and occasional boulders	Debris flow
	2.4	8.1 - 10.5*	Matrix-supported, reddish brown to brownish grey, slightly fine to coarse sand with some angular to subrounded gravel and occasional cobbles	Debris flow
WH5-DH2	1.5	0 - 1.5	Brown, slightly clayey silt with some medium to coarse gravel	Top soil
	2.8	1.5 - 4.3	Clast-supported, reddish grey to bluish grey angular to subangular boulders with occasional yellowish brown clayey sandy silt	Debris flood
	2	4.3 - 6.3	Matrix-supported, yellowish brown to greyish brown, slightly clayey sandy silt with abundant subangular boulders and some gravel and cobbles	Debris flow
	2.2	6.3 - 8.5*	Matrix-supported, yellowish brown, slightly clayey silty sand with abundant subangular to subrounded medium to coarse gravel	Debris flow
	1.8	8.5 - 10.3*	Matrix-supported, yellowish brown to reddish brown slightly clayey sandy silt with some subangular to subrounded medium to coarse gravel	Debris flow
WH5-DH3	0.5	0 - 0.5	Pale brown, slightly clayey silt with some subangular medium gravel	Top soil
	3.1	0.5 - 3.6	Clast-supported, pinkish grey to brownish grey, cobbles and boulders with some reddish brown sandy clayey silt	Debris flood
	2.7	3.6 - 6.3	Matrix-supported, orangish reddish brown, subangular to subrounded coarse gravel with some cobbles and boulders, and slightly silty fine to coarse sand	Debris flow

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Borehole/ Trial Pit	Thickness (m)	Depths (m)	Sample Description	Type of Deposit
	3.5	6.3 - 9.8*	Matrix-supported, orangish brown silty clay with coarse sand, and abundant subangular gravel, cobbles and occasional boulders	Debris flow
	1.8	9.8 - 11.6	Reddish brown slightly clayey silty sand with some angular to subangular gravel and cobbles	Debris flow
BH3	2.1	0 - 2.1	Dark yellowish brown to pinkish brown, silty fine to coarse sand with occasional rootlets and much angular to subangular fine to coarse gravel	Fill
	1.2	2.1 - 3.3	Clast-supported, yellowish brown, slightly clayey, siltly sandy angular to subangular fine to coarse gravel, with some cobbles and boulders, and yellowish brown silty fine to coarse sand	Debris flood
	1.8	3.3 - 5.1	Brownish grey to greyish brown, slightly clayey, siltly fine to coarse sand with abundant medium to coarse gravel and occasional organic material	Alluvium
	1.5	5.1 - 6.6*	Matrix-supported, brownish grey slightly clayey, silty fine to coarse sand and some angular medium to coarse gravel and cobbles	Debris flow
	2.4	6.6 - 9.0	Matrix-supported, reddish brown, slightly clayey, silty sandy angular to subangular fine to coarse gravel with some cobbles and yellowish brown slightly clayey, silty fine to coarse sand	Debris flow
	2.8	9.0 - 11.8	Matrix-supported, yellowish brown to brownish grey and reddish brown, slightly clayey, silty sandy angular to subangular fine to coarse gravel with occasional cobbles and boulders	Debris flow
WH5-TT1	0.35	0 - 0.35	Light yellowish brown slightly clayey sandy silt with some subangular gravel and cobbles	Top soil
	0.55	0.35 - 0.9*	Matrix-supported, light orangish yellow sandy silt with fine to coarse gravel and occasional subangular to subrounded cobbles and boulders	Debris flow
	0.6	0.9 - 1.5	Matrix-supported, yellowish brown slightly clayey sandy silt with abundant subrounded gravels and cobbles	Debris flood
	1.1	1.5 - 2.6*	Clast-supported, reddish brown, slightly silty fine to coarse sand with abundant angular to subangular coarse gravel, cobbles, and some boulders	Debris flood
	0.4 (min.)	2.6 - 3.0	Clast-supported, orangish red to reddish brown subangular to subrounded gravel with occasional reddish brown silty fine to coarse sand	Debris flood
TP3	0.3	0 - 0.3	Dark greyish brown, slightly clayey sandy silt and abundant angular to subangular fine to coarse gravel and cobbles	Top soil
	1.8 (min.)	0.3 - 2.1*	Matrix-supported, yellowish brown, slightly clayey sandy silt with abundant angular to subangular fine to coarse gravel, cobbles and some boulders	Debris flow
Debris Fan 4				
WH6-TT1	0.12	0.26 - 0.38	Medium brown, silty sand with some gravel and cobbles	Top soil
	0.4	0.38 - 0.78	Matrix-supported, greyish brown silty sand with abundant subangular to subrounded gravel, cobbles and boulders, with evidence of grading and weak imbrication	Debris flood
	0.82	0.78 - 1.6*	Poorly compacted, matrix- to clast-supported, brownish grey to dark grey, slightly sandy gravelly silt with abundant angular to subangular coarse gravel	Debris flood
	0.3	1.6 - 1.9	Blackish grey to brown, sandy organic silt	Buried soil

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Borehole/ Trial Pit	Thickness (m)	Depths (m)	Sample Description	Type of Deposit
	1.1 (min.)	1.9 - 3.0*	Matrix-supported, orangish brown, slightly clayey sandy silt with abundant subangular gravel, cobbles, and occasional boulders	Debris flow

*Dated unit (see Table 4.2 for details)

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Appendix C

Luminescence and Radiocarbon Dating Reports
(in CD ROM)

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GEO PUBLICATIONS AND ORDERING INFORMATION
土力工程處刊物及訂購資料

A selected list of major GEO publications is given in the next page. An up-to-date full list of GEO publications can be found at the CEDD Website http://www.cedd.gov.hk on the Internet under "Publications". Abstracts for the documents can also be found at the same website. Technical Guidance Notes are published on the CEDD Website from time to time to provide updates to GEO publications prior to their next revision.

部份土力工程處的主要刊物目錄刊載於下頁。而詳盡及最新的土力工程處刊物目錄，則登載於土木工程拓展署的互聯網網頁http://www.cedd.gov.hk 的"刊物"版面之內。刊物的摘要及更新刊物內容的工程技術指引，亦可在這個網址找到。

Copies of GEO publications (except geological maps and other publications which are free of charge) can be purchased either by:

Writing to
Publications Sales Unit,
Information Services Department,
Room 626, 6th Floor,
North Point Government Offices,
333 Java Road, North Point, Hong Kong.

or

- Calling the Publications Sales Section of Information Services Department (ISD) at (852) 2537 1910
- Visiting the online Government Bookstore at http:// www.bookstore.gov.hk
- Downloading the order form from the ISD website at http://www.isd.gov.hk and submitting the order online or by fax to (852) 2523 7195
- Placing order with ISD by e-mail at puborder@isd.gov.hk

讀者可採用以下方法購買土力工程處刊物(地質圖及免費刊物除外):

書面訂購
香港北角渣華道333號
北角政府合署6樓626室
政府新聞處
刊物銷售組

或

- 致電政府新聞處刊物銷售小組訂購 (電話：(852) 2537 1910)
- 進入網上「政府書店」選購，網址爲 http://www.bookstore.gov.hk
- 透過政府新聞處的網站 (http://www.isd.gov.hk) 於網上遞交訂購表格，或將表格傳真至刊物銷售小組 (傳真：(852) 2523 7195)
- 以電郵方式訂購 (電郵地址：puborder@isd.gov.hk)

1:100 000, 1:20 000 and 1:5 000 geological maps can be purchased from:

Map Publications Centre/HK,
Survey & Mapping Office, Lands Department,
23th Floor, North Point Government Offices,
333 Java Road, North Point, Hong Kong.
Tel: (852) 2231 3187
Fax: (852) 2116 0774

讀者可於下列地點購買1:100 000、1:20 000及1:5 000地質圖：

香港北角渣華道333號
北角政府合署23樓
地政總署測繪處
電話: (852) 2231 3187
傳真: (852) 2116 0774

Requests for copies of Geological Survey Sheet Reports and other publications which are free of charge should be directed to:

For Geological Survey Sheet Reports which are free of charge:
Chief Geotechnical Engineer/Planning,
(Attn: Hong Kong Geological Survey Section)
Geotechnical Engineering Office,
Civil Engineering and Development Department,
Civil Engineering and Development Building,
101 Princess Margaret Road,
Homantin, Kowloon, Hong Kong.
Tel: (852) 2762 5380
Fax: (852) 2714 0247
E-mail: jsewell@cedd.gov.hk

For other publications which are free of charge:
Chief Geotechnical Engineer/Standards and Testing,
Geotechnical Engineering Office,
Civil Engineering and Development Department,
Civil Engineering and Development Building,
101 Princess Margaret Road,
Homantin, Kowloon, Hong Kong.
Tel: (852) 2762 5346
Fax: (852) 2714 0275
E-mail: florenceko@cedd.gov.hk

如欲索取地質調查報告及其他免費刊物，請致函：

免費地質調查報告:
香港九龍何文田公主道101號
土木工程拓展署大樓
土木工程拓展署
土力工程處
規劃部總土力工程師
(請交:香港地質調查組)
電話: (852) 2762 5380
傳真: (852) 2714 0247
電子郵件: jsewell@cedd.gov.hk

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標準及測試部總土力工程師
電話: (852) 2762 5346
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電子郵件: florenceko@cedd.gov.hk

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MAJOR GEOTECHNICAL ENGINEERING OFFICE PUBLICATIONS
土力工程處之主要刊物

GEOTECHNICAL MANUALS

Geotechnical Manual for Slopes, 2nd Edition (1984), 302 p. (English Version), (Reprinted, 2011).

斜坡岩土工程手冊(1998)，308頁(1984年英文版的中文譯本)。

Highway Slope Manual (2000), 114 p.

GEOGUIDES

Geoguide 1	Guide to Retaining Wall Design, 2nd Edition (1993), 258 p. (Reprinted, 2007).
Geoguide 2	Guide to Site Investigation (1987), 359 p. (Reprinted, 2000).
Geoguide 3	Guide to Rock and Soil Descriptions (1988), 186 p. (Reprinted, 2000).
Geoguide 4	Guide to Cavern Engineering (1992), 148 p. (Reprinted, 1998).
Geoguide 5	Guide to Slope Maintenance, 3rd Edition (2003), 132 p. (English Version).
岩土指南第五冊	斜坡維修指南，第三版(2003)，120頁(中文版)。
Geoguide 6	Guide to Reinforced Fill Structure and Slope Design (2002), 236 p.
Geoguide 7	Guide to Soil Nail Design and Construction (2008), 97 p.

GEOSPECS

Geospec 1	Model Specification for Prestressed Ground Anchors, 2nd Edition (1989), 164 p. (Reprinted, 1997).
Geospec 3	Model Specification for Soil Testing (2001), 340 p.

GEO PUBLICATIONS

GCO Publication No. 1/90	Review of Design Methods for Excavations (1990), 187 p. (Reprinted, 2002).
GEO Publication No. 1/93	Review of Granular and Geotextile Filters (1993), 141 p.
GEO Publication No. 1/2006	Foundation Design and Construction (2006), 376 p.
GEO Publication No. 1/2007	Engineering Geological Practice in Hong Kong (2007), 278 p.
GEO Publication No. 1/2009	Prescriptive Measures for Man-Made Slopes and Retaining Walls (2009), 76 p.
GEO Publication No. 1/2011	Technical Guidelines on Landscape Treatment for Slopes (2011), 217 p.

GEOLOGICAL PUBLICATIONS

The Quaternary Geology of Hong Kong, by J.A. Fyfe, R. Shaw, S.D.G. Campbell, K.W. Lai & P.A. Kirk (2000), 210 p. plus 6 maps.

The Pre-Quaternary Geology of Hong Kong, by R.J. Sewell, S.D.G. Campbell, C.J.N. Fletcher, K.W. Lai & P.A. Kirk (2000), 181 p. plus 4 maps.

TECHNICAL GUIDANCE NOTES

TGN 1	Technical Guidance Documents

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