The Potential Evidence for Neotectonic Fault Movement and Correlation with Natural Terrain Landslides in Hong Kong

GEO Report No. 307

R.J. Sewell & D.L.K. Tang

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

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Prepared by:

Geotechnical Engineering Office,
Civil Engineering and Development Department,
Civil Engineering and Development Building,
101 Princess Margaret Road,
Homantin, Kowloon,
Hong Kong.

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Preface

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H.N. Wong
Head, Geotechnical Engineering Office
January 2015

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Foreword

This report synthesises the findings of an investigation of possible evidence for neotectonic fault activity and the potential correlation with natural terrain landslides in Hong Kong. It is based on separate reports from four study areas including (1) Ho Lek Pui, (2) Wong Chuk Yeung, (3) Tung Chung East, and (4) Nam Shan and Pui O. The results of these studies are evaluated in the context of other evidence for neotectonic fault activity, and integrated with earlier landslide dating and fault studies to provide a preliminary assessment of the palaeoseismicity of Hong Kong.

The original studies were carried out by Ms D. L. K. Tang, Mr J. C. F. Wong and Mr C. W. Lee under the supervision of Dr R. J. Sewell and Professor Y. Z. Ding. This report was written by Dr R. J. Sewell and Ms D. L. K. Tang.

K.C. Ng
Chief Geotechnical Engineer/Planning Division

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1 Introduction

1.1 Background

'Neotectonic activity' refers to tectonic activity that has occurred during the final stages of the Earth's history, generally taken to mean the Quaternary Period, i.e. in the last 2.6 million years (Gibbard et al, 2009). Neotectonic activity could result in ground vibration, surface rupture, ground displacement and changes in hydrogeological conditions, thereby leading to natural terrain landslides. While signs of possible neotectonic fault movement have been reported and are being investigated in the nearby region in Mainland China (Ding, 2004 and references therein), not much is known about the neotectonic activity in Hong Kong (herein the Special Administrative Region).

Aerial photograph interpretation (API), carried out during the updating of the 1:20,000-scale Geological Map Sheet No. 7 (Sewell et al, 2007), revealed the existence of a large relict natural terrain landslide in close proximity to a NW-trending fault showing evidence for possible neotectonic movement in the Ho Lek Pui area (Tang et al, 2009). This challenged the view long held by the local geological/geotechnical community that there is no direct evidence of fault displacements in either the offshore or onshore Quaternary superficial deposits in Hong Kong (Whitaker et al, 1992; Sewell et al, 2000). Furthermore, it stimulated the need to reassess the evidence for possible neotectonic activity on major faults in Hong Kong, and potential correlation with natural terrain landslides.

As a result, a study was initiated to examine the potential evidence for neotectonic movement and correlation with natural terrain landslides in Hong Kong (hereafter "the project"). The project was carried out between April 2006 and the end of 2009. Professor Y.Z. Ding, ex-Director of Guangdong Seismological Bureau, was engaged as Expert Consultant for the project to provide specialist knowledge of the regional neotectonic activity and tectonic framework, as necessary.

1.2 Objectives and Scope of the Project

The project was concerned with the investigation of possible active faults in the Hong Kong landscape, and natural terrain landslides which might have been earthquake induced. For the purposes of the project, the term 'active fault' is defined as a fault showing unequivocal evidence for neotectonic activity in the geologically recent past (i.e. < 100,000 years). The objectives of the project were:

(a) to identify, review and examine the evidence for possible neotectonic activity on major faults in Hong Kong,

(b) to investigate possible correlation between neotectonic activity and natural terrain landslides in Hong Kong, and

(c) to review the age, volume and distribution of large landslides in Hong Kong for potential evidence of a seismic shaking history.

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Four study areas in the New Territories and Lantau Island were selected to investigate for potential evidence of neotectonic fault movement and correlation with natural terrain landslides (Figure 1.1). Their key features are as follows:

(a) Ho Lek Pui, New Territories - NW-trending fault showing evidence for possible neotectonic fault movement,

(b) Wong Chuk Yeung, New Territories - large relict landslide, possibly triggered by fault movement at Ho Lek Pui,

(c) Tung Chung East, Lantau Island - five large relict debris lobes overlooking Yu Tung Road and North Lantau Expressway, in close proximity to the Shek Pik Fault, and

(d) Nam Shan and Pui O, Lantau Island - two giant relict landslides, in close proximity to the Yam O Fault.

1.3 Scope and Contents of the Report

The results from the four study areas have been reported separately (Tang et al, 2009 & 2010; Wong & Ding, 2010; Wong et al, 2010). This report integrates these findings and attempts to evaluate possible seismic relationships with sizable natural terrain landslides in Hong Kong by comparing their geomorphological characteristics, volume, age, and spatial distribution. This report also reviews and discusses other possible evidence for recent fault activity in Hong Kong, and presents a preliminary assessment of the palaeoseimicity[1] of Hong Kong.

2 Methodology

2.1 Identification of Possible Neotectonic Fault Movement

Detailed geomorphological studies and analysis of superficial deposits provide valuable information for identifying and evaluating possible neotectonic fault movement. Suspected active fault traces are commonly identified in the landscape using API and other remote sensing techniques. These features are then investigated in the field for evidence of recent movement, such as displacement of superficial deposits, formation of rock scarps, stream offsets, shear zones, etc. Abrupt changes in the thickness of superficial deposits across a suspected fault trace, or the presence of shear zones through superficial deposits can provide both indirect and direct evidence, respectively, of recent fault movement. Accurate assessment of superficial deposit thicknesses normally requires drillhole investigation down to bedrock. Detailed stratigraphic sections of superficial deposits can also be obtained from excavation of trial pits. Where possible, trenching across suspected fault traces can yield valuable information on the characteristics of fault movement and suspected deformation of superficial deposits. Even where there is no visible displacement of superficial deposits, dating of the deposits can place constraints on the timing of last fault movement. For example, where a superficial deposit mantles a suspected fault trace with no observed changes in thickness, the age of the basal superficial units can provide a minimum age for last fault movement.

[1] Palaeoseismicity is the study of geological evidence for past earthquakes.

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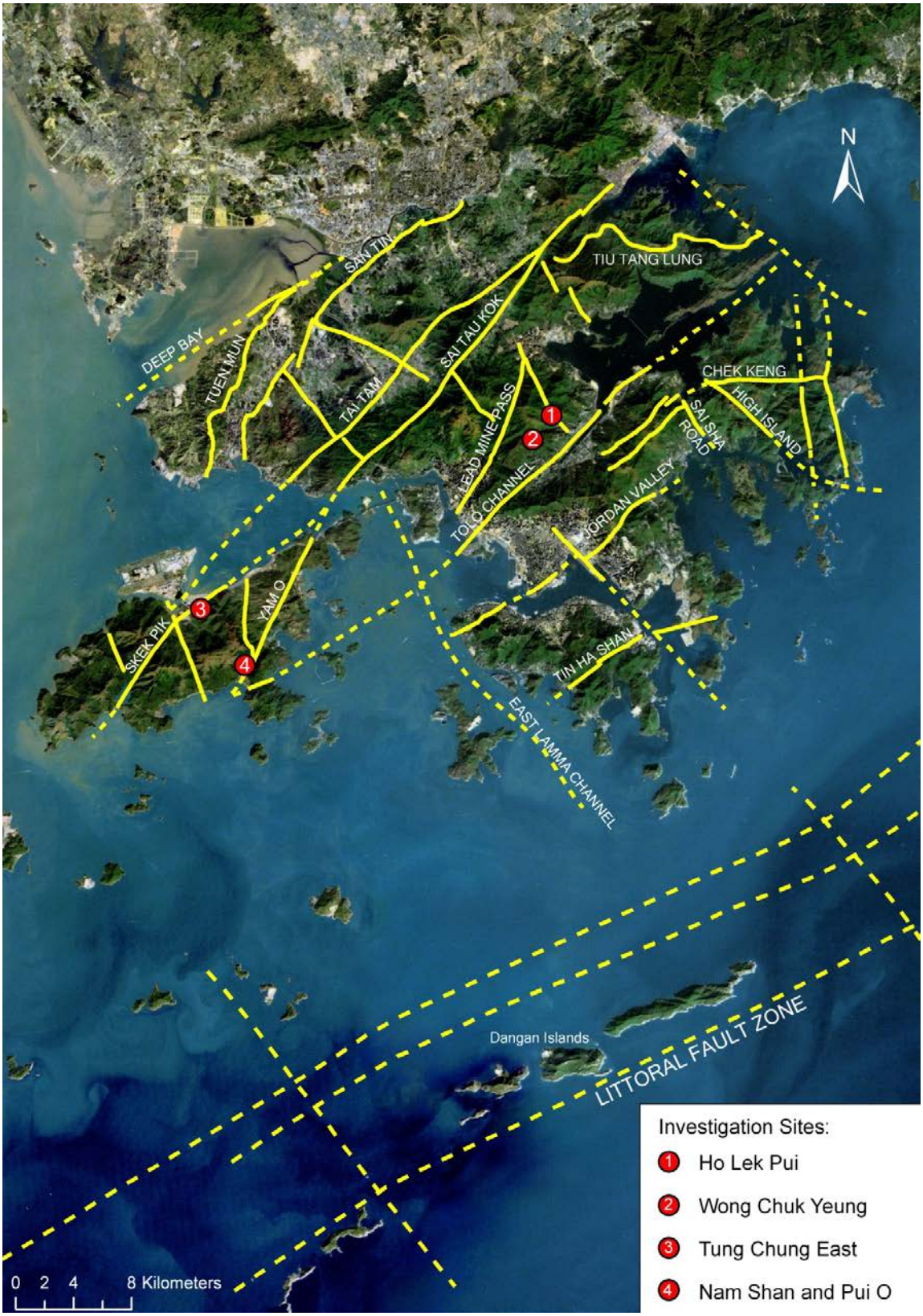

Figure 1.1 Location Plan of Investigation Sites and Major Faults in Hong Kong and the Nearby Offshore Area

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2.2 Palaeoseismic Landslide Analysis

In the absence of geomorphological evidence for recent surface rupture on major faults, palaeoseismic landslide analysis can be used as an alternative method for identifying potential evidence of neotectonic fault movement (Keefer, 1984). This entails examining the landscape for possible earthquake-induced landslides in order to characterise the seismic shaking history of a region.

In a comprehensive review of the state of knowledge of palaeoseismic landslide analysis, Jibson (2009) emphasised that the approach involves three steps:

(a) identification of a landslide feature,

(b) dating the landslide, and

(c) showing that the landslide feature was triggered by an earthquake event.

The final step is recognised as being the most difficult, as there are no specific landslide types or features that are known to be uniquely related to earthquakes. Moreover, it is generally considered that a set of criteria need to be satisfied before any attempt can be made at correlating relict natural terrain landslides with earthquakes active in the geological past.

Crozier (1992) listed six criteria that could be used to support a seismic origin for landslides, including:

(a) a known history of earthquake-induced landslides within a region,

(b) liquefaction associated with landslides,

(c) large landslide size,

(d) landslide occurrence that cannot easily be explained solely by geomorphological or geological conditions,

(e) geotechnical parameters which indicate that an earthquake would be required to induce slope failure, and

(f) the association of landslides within a fault zone or seismically active region.

Based on modern observations of earthquake-induced landslides, Nikonov (1988) used the spatial and temporal clustering of relict large landslides within an active seismic zone to infer a palaeoseismic origin. In particular, very large, deep-seated landslides were interpreted as having been triggered by earthquakes with Modified Mercalli (MM) intensity values of between VII and IX. This interpretation concurs with the general view of Crozier (1992), who argued that although landslide size alone is not indicative of a particular

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triggering mechanism, it may be an important indicator of an earthquake trigger when clusters of large landslides are produced simultaneously. However, it must be emphasised that the seismic origin of such relict large landside clusters remains tentative and ultimately cannot be proven.

2.3 Landslide Dating Techniques

Sewell & Campbell (2005) demonstrated that direct dating of natural terrain landslides in Hong Kong is feasible using optically stimulated luminescence (OSL), radiocarbon (^{14}C) and surface exposure dating techniques (cosmogenic ^{10}Be and ^{26}Al). These dating techniques were employed in the project to help constrain the minimum age of fault movement (e.g. Ho Lek Pui site), and to provide numerical ages of relict large landslide features that are located in close proximity to major faults (e.g. Wong Chuk Yeung, Tung Chung East, and Nam Shan and Pui O sites). Descriptions of the three landslide dating techniques are summarised in the following sections.

2.3.1 Optically Stimulated Luminescence (OSL) Dating

Luminescence dating techniques rely on the capacity of mineral grains such as quartz and feldspar to trap electrons in their crystal lattices. The electrons are derived from natural ionizing radiation in the surrounding material due to the decay of mostly ^{238}U, ^{232}Th and ^{40}K and their daughter products (Forman et al, 2000). When the electrons are subsequently heated (TL, Thermoluminescence - see Section 2.4.2) or stimulated by light (OSL) in a laboratory, the energy released in the form of light can be measured. The OSL technique relies on the sediment grains being completely 'bleached' at the time of deposition to remove all trace of a previous luminescence signal (i.e. the electron traps in the crystal lattice have been completely emptied). Since the OSL dating technique is based on the time elapsed since buried sediment grains were last exposed to sunlight, the measured OSL signal should therefore record a maximum age (i.e. the age of the sediment could not be any older than the age of last exposure to sunlight).

The fine-grain method of measurement, after Aitken & Xie (1992) and a protocol as described by Lang & Wagner (1997), is generally adopted where samples consist mainly of silt. However, where 'partial' or 'incomplete' bleaching is suspected, the '5% Leading Edge' SAR method (Olley et al, 1998) is generally applied as the lowest values of the dose distribution curve can be taken as the best estimate of the true dose since the sample was bleached. OSL techniques have been successfully applied to dating sediments between 1,000 and 1,000,000 years old. This age range extends well beyond the maximum limit of radiocarbon dating so is ideal for dating Pleistocene as well as most Holocene sediments, providing the sand grains have been fully bleached on exposure to sunlight.

2.3.2 Radiocarbon (^{14}C) Dating

Radiocarbon dating is commonly used to date organic materials. The method is based on the assumption that the isotope ratio of carbon cells of living things is identical to that in the air because of the balance between photosynthesis and respiration. Atoms of the radioisotope

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^{14}C mix with other carbon isotopes in the atmosphere and hydrosphere making up a steady state concentration. The carbon is then incorporated into plant and animal tissue and the ^{14}C subsequently decays to ^{14}N. The ^{14}C isotope has a half-life of 5,730 years. Owing to the relatively short half-life of ^{14}C, radiocarbon dating is only effective in dating material younger than 50,000 years (Reimer et al, 2009). Radiocarbon dating on organic materials contained in landslide deposits or buried organic-rich soil strata generally provides maximum ages for the landslide event (Sewell & Campbell, 2005).

2.3.3 Surface Exposure (Cosmogenic Isotope) Dating

Cosmogenic nuclides are produced by the interaction of cosmic rays with minerals on the surface of the Earth. Surface exposure dating depends on the build up of these cosmogenic nuclides that has occurred in a rock surface since it was last exposed to cosmic radiation (Zreda & Philips, 2000). The most commonly measured cosmogenic nuclides are ^{10}Be, ^{26}Al, and ^{36}Cl. Since cosmic ray particles may penetrate up to 3 m into an exposed rock surface, the true age of last exposure can only be determined if the exposed rock surface had no previously accumulated (inherited) cosmogenic signal (i.e. the exposed rock surface must originally have been deeper than 3 m below ground surface), and that the rock surface has been stable since it was exposed.

With regard to cosmogenic dating of relict natural terrain landslides, it is important to ensure that samples are collected from scarps that are deeper than 3 m from the original ground surface. Boulders from the associated debris also need to be carefully selected to avoid, as far as possible, any possible cosmogenic inheritance effects.

Ideally the minimum scarp and boulder surface exposure ages for a relict natural terrain landslide should correspond to the time at which the landslide detached from its source area. However, in practice, several environmental factors can contribute to an underestimate of the true age. For example, younger apparent ages may be generated from:

(a) an eroded source area,

(b) a disturbed source area, or

(c) boulders in the associated debris which have subsequently been exhumed.

Conversely, overestimates of the true age of relict natural terrain landslides may be generated by:

(a) a source area which is less than 3 m deep, or

(b) boulders in the associated debris which have been derived from a source less than 3 m deep.

The maximum surface exposure age is the maximum age of the rock surface that is permitted by the analytical data. Usually, the maximum surface age at relict natural terrain landslide sites is considered to be the age of the original ground surface.

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2.4 Dating Techniques for Fault Materials

Two dating techniques on fault materials, namely the argon-argon (^{40}Ar-^{39}Ar) and thermoluminescence (TL) methods, have been used previously in Hong Kong (e.g. Ding & Lai, 1997; Campbell & Sewell, 2007) to provide direct constraints on age of fault movement. A review of these methods and their limitations are given below.

2.4.1 Argon-Argon (^{40}Ar-^{39}Ar) Dating

The ^{40}Ar-^{39}Ar dating method is based on the same radioisotope decay system as that used in the potassium-argon (K-Ar) method of dating, whereby natural, spontaneous radioactive decay of the potassium isotope ^{40}K, occurs at a known rate to produce the argon isotope ^{40}Ar (Renne, 2000). The fundamental difference between the ^{40}Ar-^{39}Ar and K-Ar methods (Noller et al, 2000) is that the ^{40}Ar-^{39}Ar method allows all the information needed to calculate a sample's age to be determined from the argon isotopic composition of irradiated samples. In the simplest case, this requires measuring only the relative atomic abundances of ^{40}Ar, ^{39}Ar and ^{36}Ar by mass spectrometry; ^{36}Ar is used, as in K-Ar dating to provide information about non-radiogenic ^{40}Ar, most commonly in making air correction. The measurement of K indirectly via ^{39}Ar is more precise and has better abundance sensitivity (Noller et al, 2000) than most of the commonly used techniques for measuring K in K-Ar dating, and avoids error due to potential homogeneity of K, and thus avoids the need to measure absolute amounts of Ar. The advantages of the ^{40}Ar-^{39}Ar dating method generally outweigh those of the K-Ar method, although the latter is cheaper and faster, and is not subject to recoil of ^{39}Ar atoms produced by the ^{39}K-^{39}Ar reaction (redistribution and/or loss of ^{39}Ar within/from small samples potentially introducing artificial age complexities to age spectra without necessarily affecting the total gas age).

The ability to calculate an age using only Ar isotope data permits the analysis of extremely small samples, including individual crystal phases (e.g. mica, feldspar, pyrite, chlorite), by incremental heating or total fusion. This enables potentially complex histories of formation and deformation (e.g. faulting) to be dated separately within the same samples. The method has been applied to dating of Hong Kong fault gouges using a twofold approach:

(a) indirectly constraining the age of faulting by dating hydrothermal mineralization in the faulted rocks (e.g. pyrite), and

(b) directly constraining the age by identifying extremely small heating events in the silicate minerals (Campbell & Sewell, 2007).

2.4.2 Thermoluminescence (TL) Dating

As with OSL dating (see Section 2.3.1), the TL dating technique relies on the capacity of mineral grains such as quartz and feldspar to trap electrons derived from natural background radiation in their crystal lattices. TL dating of fault gouge is based on the principle that when quartz and feldspar grains are subjected to frictional heating, the electron traps are emptied, i.e.

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the luminescence signal of materials constituting the fault gouge is 'zeroed', thereby resetting the 'clock' (Banjaree et al, 1999). However, owing to uncertainties over the different effects of confining pressure, temperature, and strain rates on the luminescence signal (Ji & Gao, 1988; Ji et al, 1994), the application of the TL technique to dating of fault gouge has not been widely adopted internationally and is largely confined to studies from Mainland China and India (e.g. Ji & Gao, 1988; Ji et al, 1994; Singhvi et al, 1994; Ding & Lai, 1997; Banjaree et al, 1999).

3 Summary of Findings of the Study Areas

3.1 Ho Lek Pui, Sha Tin

Detailed geomorphological assessment, field mapping and ground investigation was carried out to investigate the NW-trending fault and the two associated prominent scarps at the Ho Lek Pui site (Tang et al, 2009, Figure 3.1). The ground investigation comprised five drillholes, four trial pits and one trial trench that was intended to intersect, and thereby expose, the inferred fault trace. The findings of the ground investigation and field observations revealed no evidence for displacement of the superficial deposits by the NW-trending fault (Tang et al, 2009). OSL and ^{14}C dating of superficial deposits was therefore employed as an indirect method to constrain the age of last fault movement.

Tang et al (2009) concluded that the two prominent sub-parallel scarps at the Ho Lek Pui site, identified from the aerial photographs, probably formed as a result of surface rupture during the last movement of the NW-trending fault. Movement on the fault was probably of a dip-slip nature, forming prominent bedrock scarps that were subsequently draped by superficial deposits. The OSL ages of superficial deposits overlying the weathered rock surfaces (c. 14 to 124 ka) place a constraint on the timing of the last fault movement, which is best interpreted as late Pleistocene.

3.2 Wong Chuk Yeung, Sha Tin

Two groups of landslide features were studied at the Wong Chuk Yeung site, including a large colluvial lobe in the western part, and an assemblage of rock scarps and associated bouldery colluvium in the eastern part (Figure 3.2). These landslide features were considered to be potentially related to neotectonic movement on the NW-trending fault studied at Ho Lek Pui (see Section 3.1 above). The study at Wong Chuk Yeung involved a detailed geomorphological assessment, ground investigation comprising three drillholes and four trial pits, as well as OSL dating of colluvial materials, and surface exposure dating of rock scarps and very large boulders (Wong & Ding, 2010).

Based on the findings of a comprehensive geomorphological assessment, ground investigation and OSL dating of the colluvial deposits, Wong & Ding (2010) concluded that the colluvial lobe (with an estimated volume of 1 Mm^3) in the western part of the site could have formed in a single event dated at approximately 49.2 ± 3.9 ka. By contrast, surface exposure dating of prominent rock scarps and very large boulders in the eastern part of the site suggested that they formed from multiple landslide events, dated at 11.4 ± 1.1 ka, 28.5 ± 4.7 ka, 79.2 ± 5.3 ka and 115.9 ± 7.6 ka.

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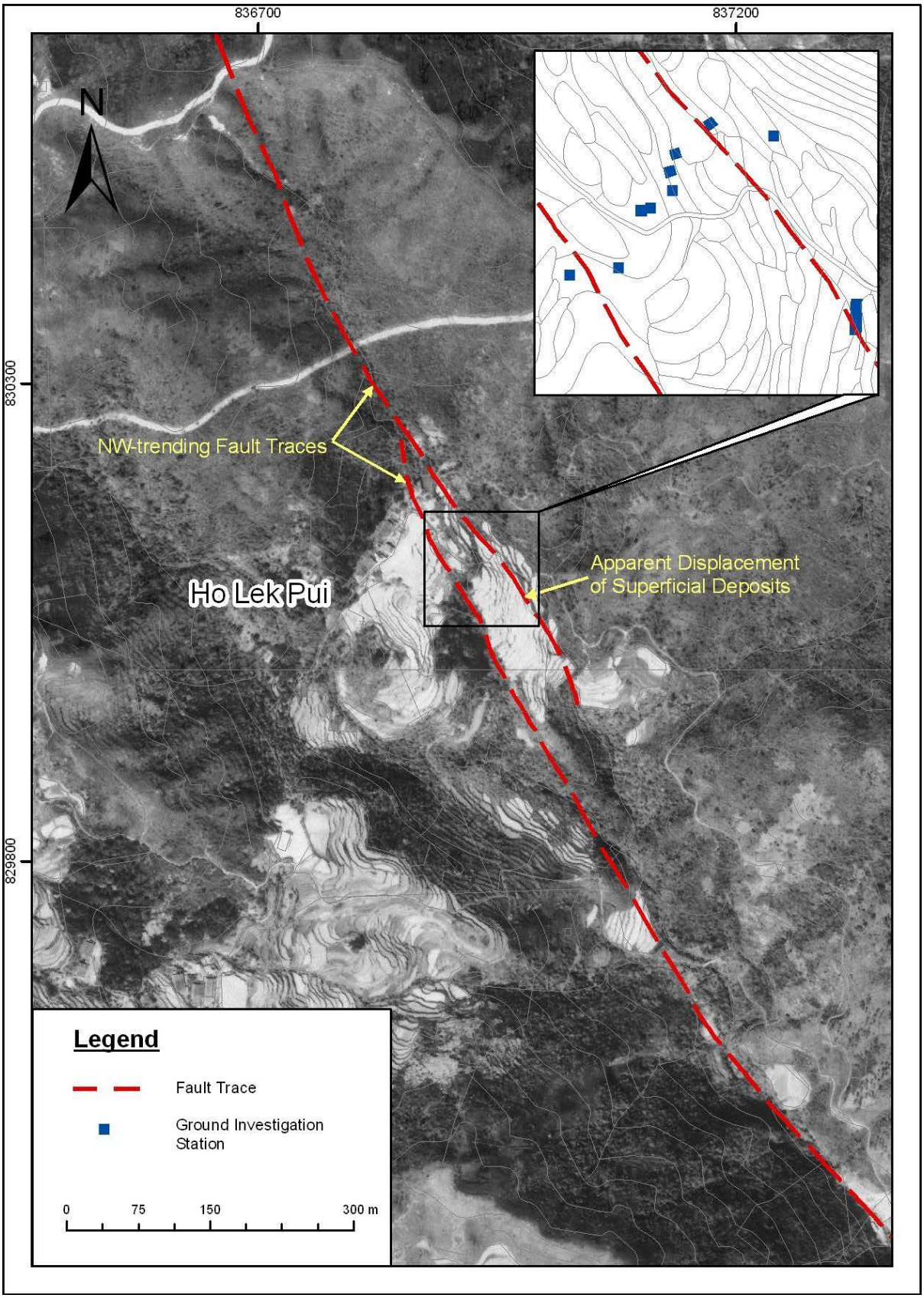

Figure 3.1 NW-Trending Fault and Sampling Locations at the Ho Lek Pui Site

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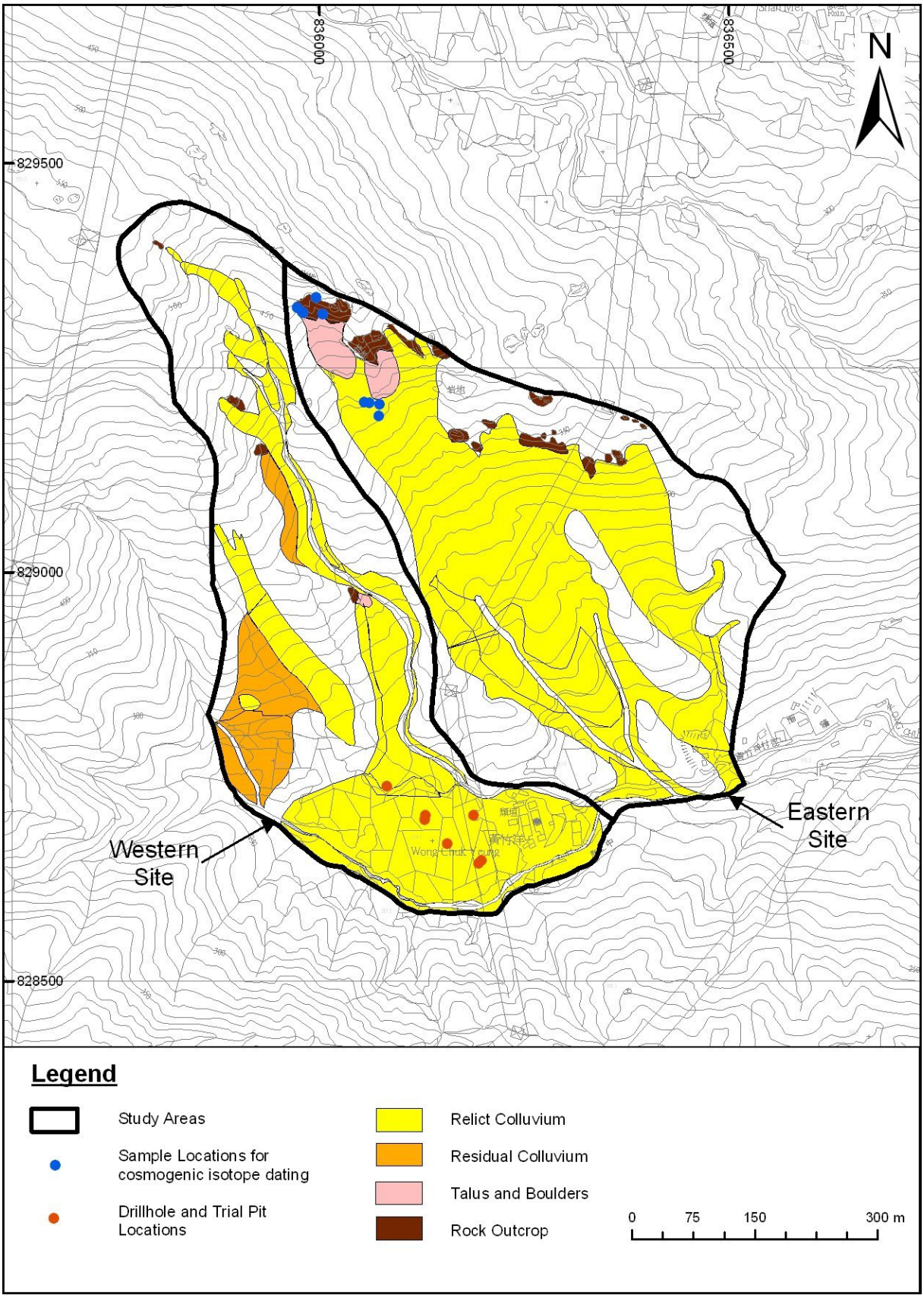

Figure 3.2 Geomorphological Features and Sampling Locations at the Wong Chuk Yeung Site (Modified after Wong & Ding, 2010)

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Wong & Ding (2010) suggested that the large landslides at the Wong Chuk Yeung site could have been triggered by a rainstorm event. However, they did not rule out the possibility that ground shaking due to fault movement at Ho Lek Pui may also have triggered large landslide movement.

3.3 Tung Chung East, Lantau Island

The study at Tung Chung East involved detailed geomorphological assessment, field reconnaissance, sampling and dating of superficial deposits of five large relict landslide debris fans on the hillslope overlooking Yi Tung Road near the Tung Chung East Interchange, Lantau Island (Tang et al, 2010). The site was chosen because of its close proximity to the NE-trending Shek Pik Fault (Figure 3.3). Two thermoluminescence (TL) ages of the fault material are available (Ding & Lai, 1997; GEERRI, 2010, see below), which imply that the latest activity of the fault may have occurred in the early late Pleistocene. OSL dating of the colluvial deposits was used to constrain the timing of the related landslide events.

Five large relict debris fans, ranging from 0.12 Mm^3 to 1.07 Mm^3 were identified at the Tung Chung East site. Detailed geomorphological assessment and field observations revealed that these debris fans were probably formed from multiple landslide events. OSL ages from four large relict debris fans revealed that four major landslide events probably occurred at c. 67.5 ka, c. 25 - 30 ka, c. 10 - 14 ka and c. 3 - 4 ka, respectively. Compared with the published TL ages of fault materials reported by Ding & Lai (1997) and GEERRI (2010) (see below), there is no strong evidence that the landslides are related to movement on the Shek Pik Fault.

3.4 Nam Shan and Pui O, Lantau Island

Two large arcuate scarps, with associated large debris lobes below Yi Tung Shan and Lin Fa Shan were studied at Nam Shan and Pui O, Lantau Island (Figure 3.4). The two sites lie in close proximity to the NE-trending Yam O Fault. Detailed geomorphological assessment, field observation, drillhole sampling and dating of colluvial debris and the overlooking rock outcrops was carried out (Wong et al, 2010).

Combined surface exposure dating and OSL dating of rock scarps and debris at the Nam Shan site suggested that the area had been affected by at least two major landslide events. The oldest event probably occurred between 57.3 ka and 49.7 ka and was characterised by an enormous debris avalanche (0.95 Mm^3) containing boulders up to 500 m^3. Another large-scale debris avalanche landslide event probably occurred between about 37.7 ka and 34.7 ka. A minor landslide event may have occurred between about 51.4 ka and 38.2 ka. Combined surface exposure dating and OSL dating of rock scarps and debris at the Pui O site suggested that a large-scale landslide event (1.22 Mm^3) probably occurred between about 67 ka and 51 ka.

Wong et al (2010) concluded that it was not possible to determine with confidence whether the two oldest landslide features in the Pui O and Nam Shan site could have been generated by rainstorm events or ground shaking due to earthquake activities. However, the enormous volume of the debris avalanches, common occurrence of giant boulders, and overlapping ages, did not rule out the possibility that they both formed as a result of a major seismic shaking event about 55,000 years ago. There was, however, no direct evidence linking a possible ground shaking event to movement on the Yam O Fault.

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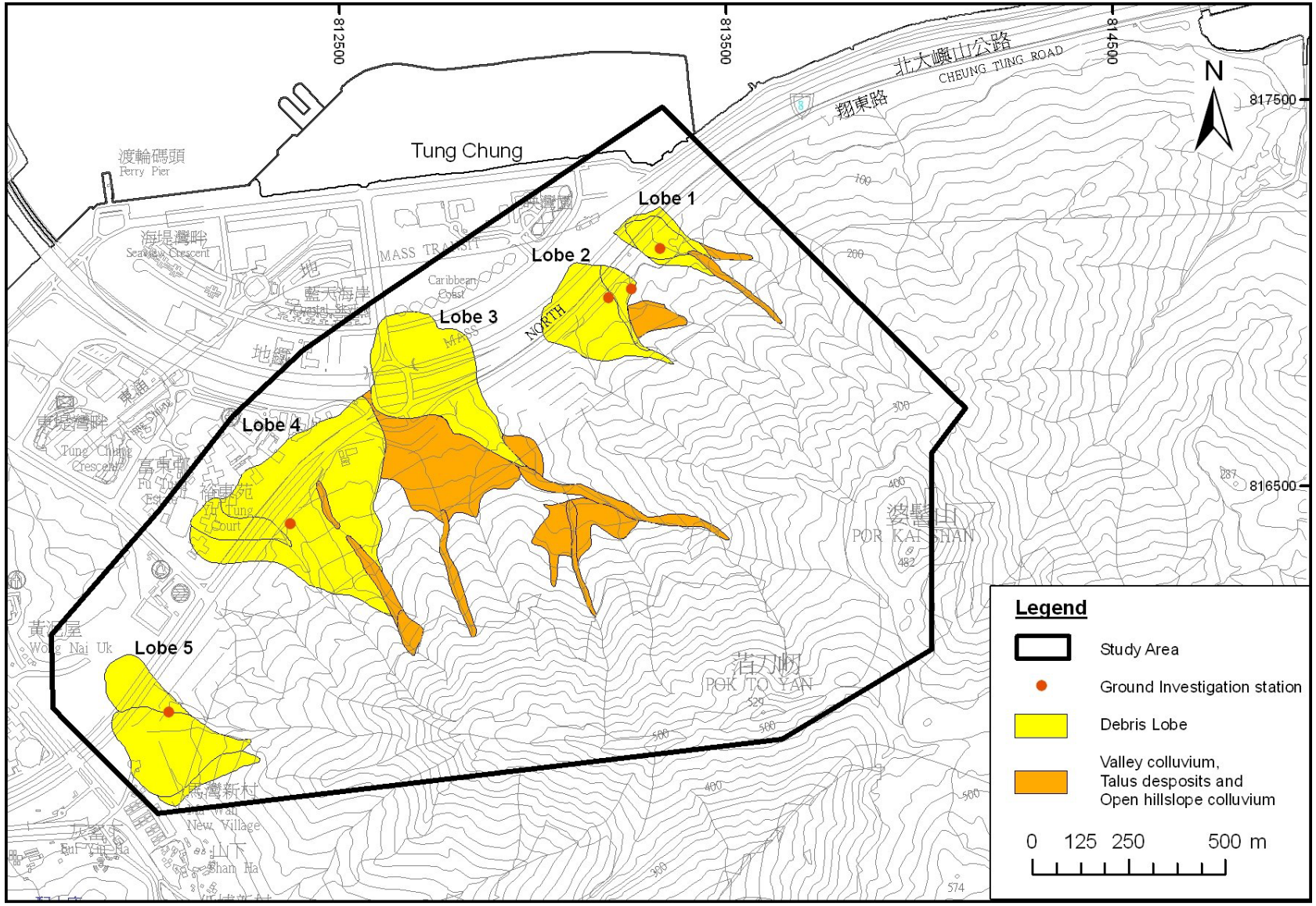

Figure 3.3 Geomorphological Features and Sampling Locations at the Tung Chung East Site (Modified after Tang et al, 2010)

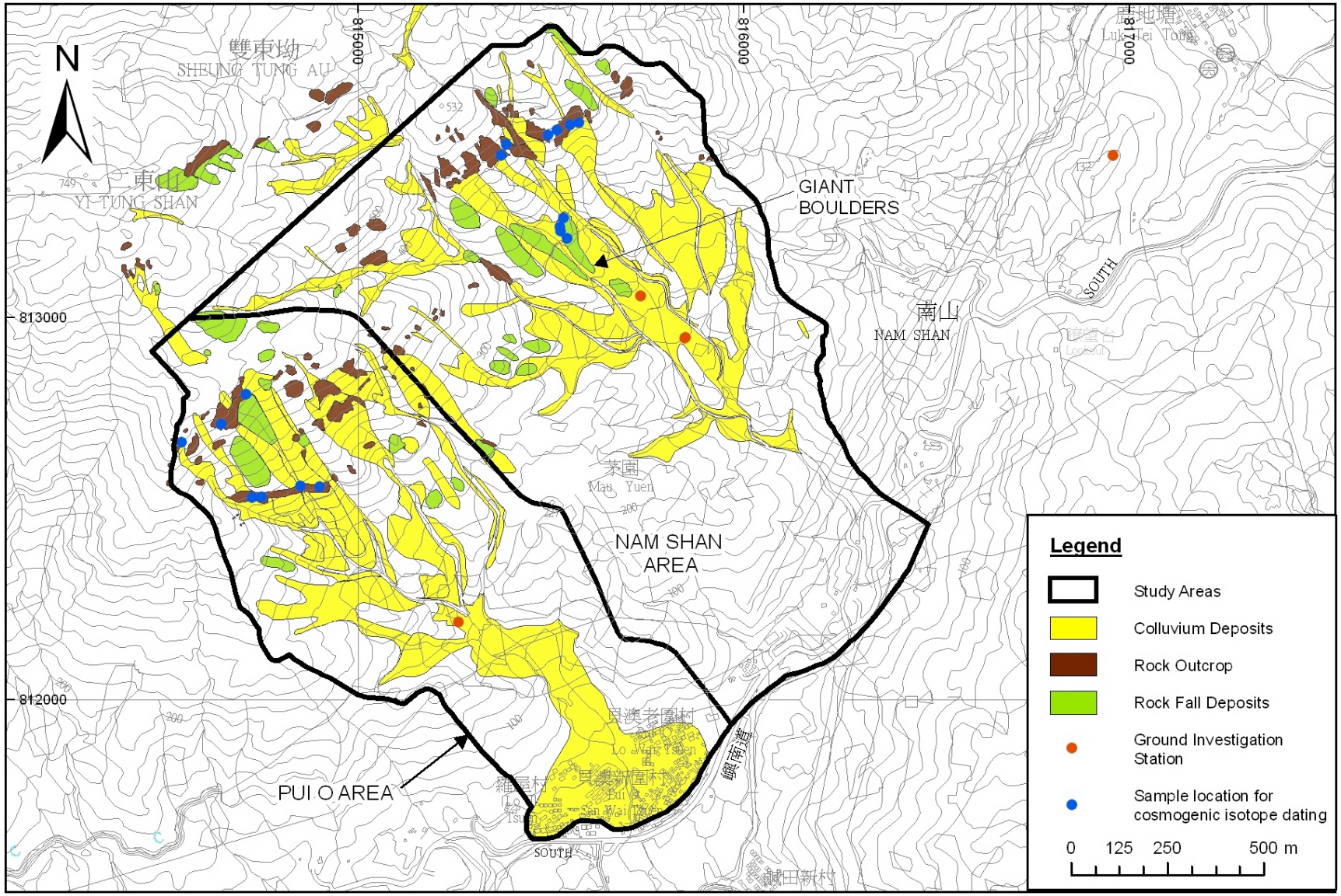

Figure 3.4 Geomorphological Features and Sampling Locations at the Nam Shan and Pui O Site (Modified after Wong et al, 2010)

4 Discussion

4.1 Landslide Age Data and Evidence for Palaeoseismic Landslides in Hong Kong

Between 2001 and 2002, the Geotechnical Engineering Office carried out a detailed dating study of natural terrain landslides in Hong Kong with the aim of accumulating knowledge on various dating methods for natural terrain landslides and to obtain sufficient numerical age data for categorising relict landslides (Sewell & Campbell, 2005). Dating of landslide features was carried out at 19 sites around Hong Kong (Figure 4.1, Table 4.1). Sewell & Campbell (2005) summarised the geomorphological characteristics, types of failure, estimated landslide volume, and age data for these 19 landslide sites. These landslide age data, particularly those of large landslide volume, have been reviewed in combination with the landslide data obtained from the current project.

Deep-seated landslides comprising a clearly defined main scarp and bouldery debris lobe account for seven out of the 19 landslide sites investigated (Sewell & Campbell, 2005). The age data from these sites imply that the landslides were generated from single large events. The 12 remaining sites consist of dominantly shallow open hillslope landslides or rock falls. With the exception of two rock fall sites featuring some very large (up to 150 m^3) single boulders, the age data from the remaining sites suggest that landslide features were generated from multiple smaller events over time. Age data from the rock falls sites suggest that the boulders probably fell in either single events or closely related events.

Table 4.1 Summary of Geomorphological Characteristics and Age Data for Previous Landslide Dating Sites and the Study Sites under the Current Project (Sheet 1 of 2)

Site No.	Study Site	Landslide Type	Features	Estimated Landslide Volume	Age Result
1	Sham Wat Debris Lobe	Deep seated	Main lobe Main lobe Southern lobe Pond	 850,000 m^3 150,000 m^3	19.7 - 37.9 ka 27.9 - 284 ka 32 ka 1,285 yr
2	Lai Cho Road	Deep seated	Lobe A1 Lobe A2 Lobe A4	40,000 m^3 10,000 m^3 100,000 m^3	7.5 ka 5.0 - 6.6 ka 26.4 ka
3	Wong Lung Hang	Deep seated	Lobe no. 2 Lobe no. 3 Lobe no. 3	 10,000 m^3 70,000 m^3	4.58 ka 5.18 ka 194 - 3.39 ka
4	Sunset Peak West	Deep seated	Levee south 2 Rock scar no. 5 Lobe no. 5 Levee south 5 Lobe no. 6 Ancient debris	 4,000 m^3 60,000 m^3	8.95 ka 7.5 - 9.1 ka 5.57 - 283 ka 7.04 ka 7.3, 16.5 ka 24.3 ka
5	Tsing Yi	Deep seated	Lobe no. 1 Colluvium no. 1 Sheeting joint 1 Sheeting joint 2	50,000 m^3	47.6, 47.2 ka 35.2 ka 44.7, 48.4 ka 11.0 ka

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Table 4.1 Summary of Geomorphological Characteristics and Age Data for Previous Landslide Dating Sites and the Study Sites under the Current Project (Sheet 2 of 2)

Site No.	Study Site	Landslide Type	Features	Estimated Landslide Volume	Age Result
6	Tsing Shan C	Deep seated	Levee north Main lobe Rock scar/Old lobe	40,000 m^3 20,000 m^3	14.1 - 18.3 ka 8 - 11 ka 44 ka
7	Tsing Shan A	Deep seated	Main lobe 1	15,000 m^3	6.06 ka
8	Ap Lei Chau	Deep seated	Relict landslide 1 Relict landslide 2 Rock face	12,500 m^3	10.8 - 11.1 ka 72.5, 77.4 ka
9	Tsing Shan B	Deep seated	Main lobe	5,000 m^3	3.05 ka
10	Mid-levels	Deep seated	Rock scar	4,000 m^3	6.9 ka
11	Tai O	Open hillside	Debris fan A Debris fan B Debris fan C	 2,000 m^3 2,000 m^3	825 yr 1.2 ka 4.3 ka
12	Sai Tso Wan	Open hillside	Large depression 1 Large depression 2 Large depression 5 Large depression 6 Relict landslide 1 Relict landslide 2	 700 m^3 700 m^3 800 m^3	7.9 ka 672 - 703 yr 14.8 ka 11.8 ka 1.6 ka 3.5 ka
13	Pat Heung	Open hillside	Large depression 2 Large depression 4 Large depression 5	35 m^3 415 m^3 385 m^3	4.3 ka 2.5 ka 15.7 ka
14	Fei Ngo Shan	Rock fall	Lobe unit no. 1	900 m^3	57.7 ka
15	Lion Rock	Rock fall	Lobe no. 5 Lobe no. 3	850 m^3 150 m^3	2.3 - 5.2 ka 3.7 ka
16	Tung Chung East	Open hillside	Large depression B Large depression C	50 m^3	200 - 378 yr 13.5 ka
17	Lo Lau Uk	Deep seated	Large depression A Large depression B	100 m^3	156 yr
18	Wong Chuk Yeung East	Rock fall	Rock scarp Large boulders	5,000 m^3	10.3 - 79.2 ka 10.7 - 115.9 ka
19	Wong Chuk Yeung West	Deep seated	Debris lobe	1 Mm^3	40.9 - 60.1 ka
20	Tung Chung East		Debris lobe 1b Debris lobe 2 Debris lobe 4 Debris lobe 5b	20,000 m^3 190,000 m^3 70,000 m^3 100,000 m^3	3.49 ka 10.5, 13.5 ka 25.6 ka 18.0, 15.9 ka
21	Nam Shan		Relict colluvium Rock scarp R1 Rock scarp R2 Large boulders	950,000 m^3	34.8 - 57.9 ka 95.7 - 174.7 ka 39.7 - 48.7 ka 49.9 - 104.7 ka
22	Pui O		Relict colluvium Rock scarp R4	1.22 Mm^3	51.3 - 53.3 ka 22.6 - 66.4 ka

Notes: (1) Site Nos. 1 - 17 (adopted from Sewell & Campbell, 2005).
(2) Site Nos. 18 - 22 (under the current project).

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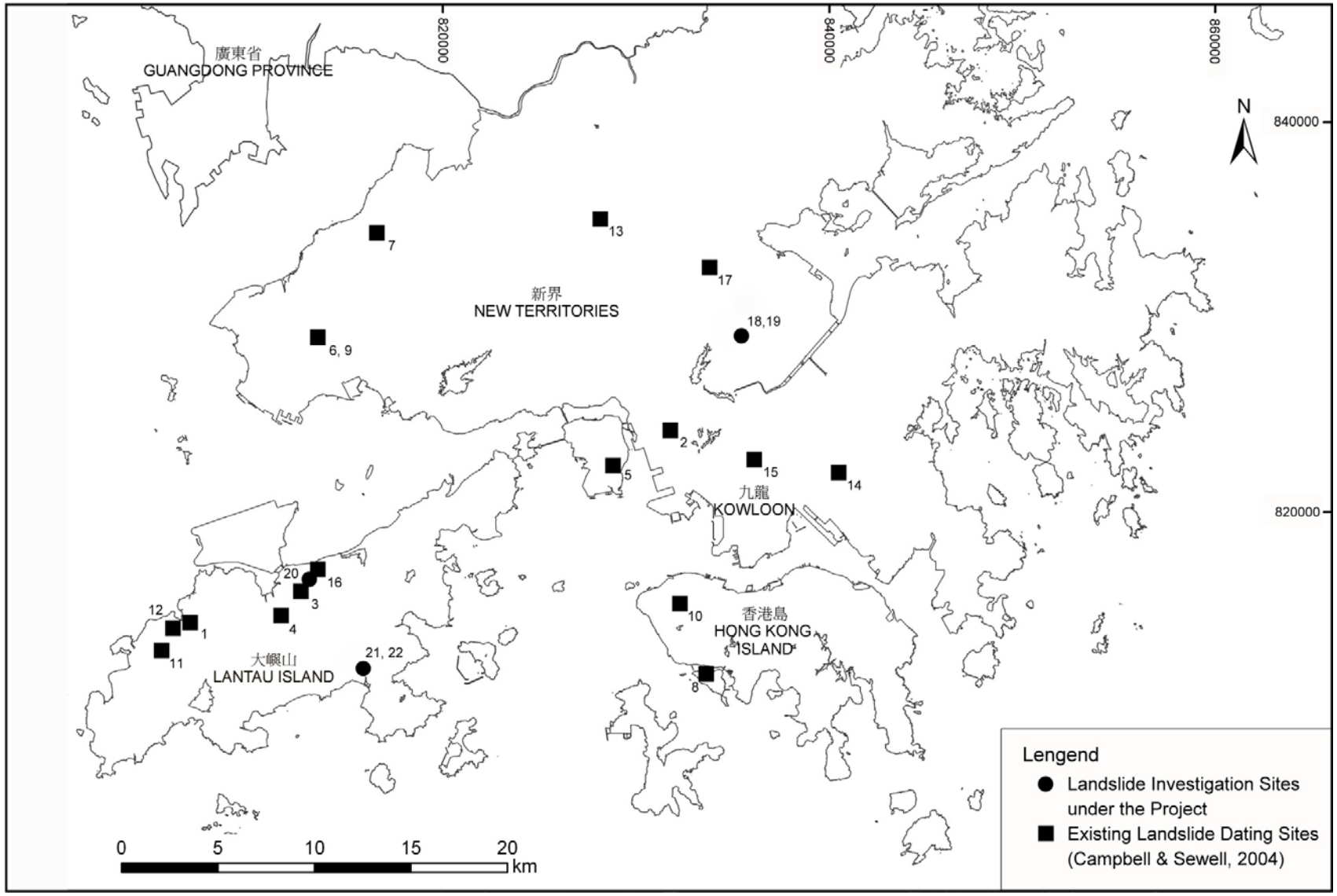

Figure 4.1 Location Plan of Existing Landslide Age Data in Hong Kong (Refer to Table 4.1 for Site Identity Number)

Integration of data from the previous study with that of the current project using the normalised chi-square test (χ^2) of "goodness of fit" reveals an apparent clustering of events within distinct time frames, possibly reflecting pulses of landslide activity. In particular, the data reveal that four of the largest landslides (i.e. ≥ 50,000 m^3), including Wong Chuk Yeung, Tsing Yi, and Nam Shan and Pui O, have similar ages of around 50,000 years old (Figure 4.2). Another cluster of mostly deep-seated landslide events occurs around 30,000 years ago, while generally smaller volume events (< 50,000 m^3) cluster around 16,000, 7,000, and possibly 4,000 years ago. Whereas many of the smaller landslides cannot be easily distinguished from a rainstorm-induced origin (cf. Ko, 2005), the apparent clustering of deep-seated large landslides at around 50,000 and 30,000 years ago possibly reflects evidence of palaeoseismic activity (cf. Nikonov, 1988).

4.2 Review of Evidence for Possible Neotectonic Fault Movement in Hong Kong

In a comprehensive review of the crustal structure and seismotectonics pertinent to Hong Kong, Whitaker et al (1992) found no evidence, in either offshore seismic reflection profiles or onshore exposures, for faults cutting the Quaternary sequences in Hong Kong. Since that time, no new unequivocal evidence has emerged to suggest that there has been fault displacement of Quaternary superficial deposits either onshore or offshore areas of Hong Kong. Nevertheless, other evidence presented as indicating possible neotectonic fault movement in Hong Kong includes:

(a) recorded earthquake epicentres in Hong Kong,

(b) dating of superficial deposits that overlie faults in bedrock (Lai & Langford, 1996),

(c) TL dating of fault materials (Ding & Lai, 1997), and

(d) geomorphological evidence from sites in the New Territories (Ding, 2004; Lai & Langford, 1996). A review of these studies are given below.

4.2.1 Instrumental Records of Earthquakes Centred in Hong Kong

The Hong Kong Observatory (HKO) has recorded nine locally felt earthquakes centred in Hong Kong between 1970 and 2006 (HKO, 2007). These earthquakes have all been relatively small ($2.5 < M_w$[2] < 3.13) and none has occurred on mapped faults. Three earthquakes in 2005 were centred to the east of Lantau Island. However, there is no evidence from adjacent areas that there has been recurrent earthquake activity on a single structure which would be indicative of active faulting. Therefore, these incidents are considered to be unrelated events.

[2] M_w is the Moment Magnitude Scale of an earthquake, which measures the earthquake size in terms of the energy released (Hanks & Kanamori, 1979). The Moment Magnitude of an earthquake is equal to the rigidity of the earth times the average amount of slip on the fault times the amount of fault area that slipped.

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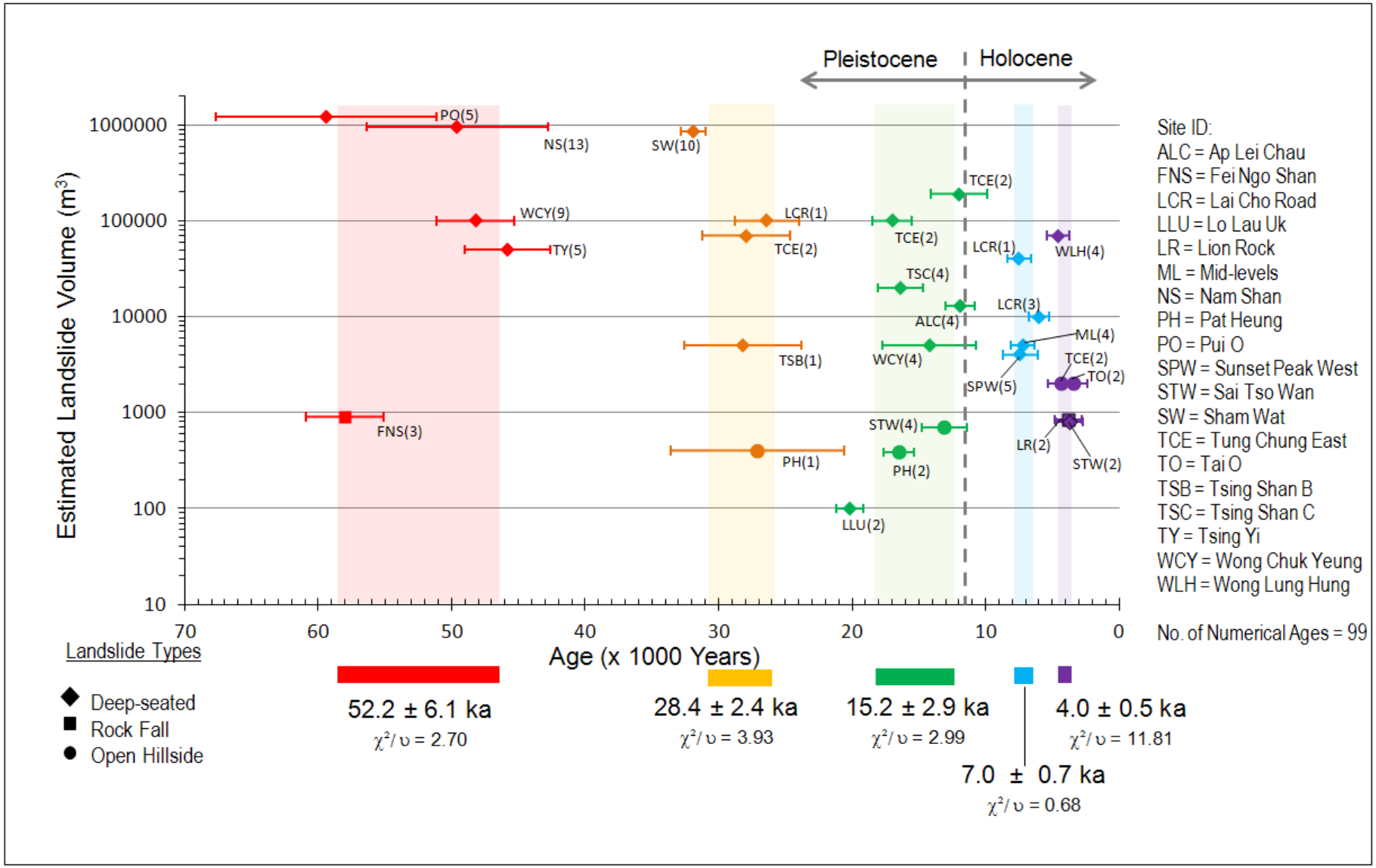

Figure 4.2 Evaluation of Existing Landslide Age Data in Hong Kong

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4.2.2 Dating of Superficial Deposits Overlying Faults in Bedrock

In common with the approach taken at the Ho Lek Pui site (see Section 3.1 above), a minimum age of fault displacement can be estimated by determining the age of superficial deposits immediately overlying faults in bedrock. In the Ho Lek Pui case, the age of superficial deposits immediately overlying bedrock suggested that the timing of last fault movement was most likely late Pleistocene. A similar approach was used by Ding & Lai (1997) to infer the minimum age of movement on a NW-trending fault at Shan Ha Tsuen, south of Yuen Long. There, a sequence of alluvial deposits was dated by OSL, TL and ^{14}C methods (Langford et al, 1989; Duller & Wintle, 1996). The lowermost alluvial unit overlying the faulted bedrock was dated as 81,000 ± 14,000 years before present (BP).

Ding (2004) used the findings of Langford et al (1989) to propose possible recent fault movement at Shan Ha Tsuen. In addition to dating Quaternary deposits overlying faulted bedrock (see above), Ding (2004) obtained new TL and ^{14}C ages from Quaternary deposits on the opposite side of the stream underlain by a NW-trending fault. Comparable ages at different elevations were interpreted as evidence for neotectonic activity since 20,500 years ago. An average slip rate of the fault was calculated to be 0.48 mm/year based on a 10 m offset of the Quaternary deposits. However, a review of the field evidence reveals that the proposed NW-trending fault at Shan Ha Tsuen is not exposed at the surface. The dating alone does not rule out an alternative geomorphological explanation, and there is no obvious field evidence to suggest that the terraced alluvium has been offset by a NW-trending fault. The evidence proposed for recent fault activity at this site is, therefore, questionable.

4.2.3 Dating of Fault Materials

Ding & Lai (1997) presented 22 TL ages of fault gouge from a number of NE-trending and NW-trending faults in western New Territories. The results suggested that the last fault activity could have occurred as recently as approximately 33,300 ± 2,700 years BP, with a peak of activity around 100,000 years BP. Two other major periods of fault movement could have occurred at approximately 180,000 years BP and 270,000 years BP (Ding & Lai, 1997). GEERRI (2010) reported a new TL age on fault material from the ENE-trending Tung Chung – Shek Pik Fault: 98,300 ± 6,300 BP from a 12-m shear zone exposed near Wong Nai Uk, Tung Chung. Based on this and other TL ages, GEERRI (2010) considered the Tung Chung – Shek Pik Fault to be an active fault, and the latest movement along the fault occurred in early late Pleistocene.

Campbell & Sewell (2007) demonstrated that it is possible to apply the argon-argon (^{40}Ar-^{39}Ar) laser microprobe step-heating method to dating of fault material. The technique also appears capable of identifying multiple histories of fault movement from the same fault material. Samples from four major fault zones in Hong Kong were dated using the technique. These included two thrust faults in northern New Territories (San Tin Fault and Tiu Tang Lung Fault), and two strike slip faults in central New Territories (Tolo Channel Fault and Rambler Channel Fault). In all cases, the faults preserved evidence of movement between 70 and 90 Ma and approximately 34 Ma. The latter age is considered to coincide with initiation of regional tectonic activities related to opening of the South China Sea. The two thrust faults also preserved evidence of fault movements at 10 Ma and 3 - 4 Ma. In three out of four of the age spectra, the very first measureable ^{39}Ar gas fractions (< 2%) containing

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low temperature portions returned ^{40}Ar-^{36}Ar ratios within error of the atmospheric value. This was interpreted as possible evidence for more recent late Pleistocene to Holocene fault activity. Although this was a preliminary investigation, the results suggest that major faults in Hong Kong are probably ancient Mesozoic structures that have been periodically reactivated throughout the Cenozoic. The data also imply that other prominent strike slip faults, such as the Shek Pik Fault and Yam O Fault, are likely to have similar histories of movement.

4.2.4 Geomorphological Evidence for Possible Neotectonic Fault Movement

Several sites have been proposed as preserving geomorphological evidence for possible neotectonic fault movement in Hong Kong. These are Lam Tsuen Valley, Tai O, and Ma Wan – Tsing Yi Channel.

4.2.4.1 Lam Tsuen Valley

Lai & Langford (1996) proposed that deflection of the Lam Tsuen River from northeast to southeast may have been caused by Pleistocene movement on a NW-trending fault at Tai Po. The Lam Tsuen Valley in northern New Territories appears to have once drained toward the northeast. The valley is filled with alluvium that has been dated as mid to late Pleistocene (Lai et al, 1996). The Lam Tsuen River appears to have been captured by the Tolo Harbour drainage basin, via the Tai Po River.

4.2.4.2 Tai O, Lantau Island

Extensive alluvial deposits, presumed to be Pleistocene age and to represent the onshore lateral equivalents of the Chek Lap Kok Formation, are exposed along the foreshore east of Tai O, Lantau Island, where they rest unconformably on weathered sedimentary rocks (Langford et al, 1995). Y.Z. Ding (pers. comm.) described evidence for displacement of the alluvial deposits in coastal exposures near Po Chu Tam at Tai O. Ding considered that a sub-vertical discontinuity in the alluvial deposits as representing a NW-trending fault showing recent neotectonic activity. Thickness variation of superficial deposits in drillholes across the fault trace at Tai O was also proposed as evidence for neotectonic activity (Y.Z. Ding, pers. comm.). However, an examination of field exposures and site geomorphology has revealed no evidence of fault movement, nor the presence of a geological lineament across the landscape. A review of existing drillholes across the suspected fault trace has also revealed no significant variations in thickness of superficial deposits. Therefore, the suggestion of an active fault at this site is not supported.

4.2.4.3 Ma Wan – Tsing Yi Channel

Based on the ground investigation data (Drillhole 5SW6) from the 'Ma Wan – Tsing Yi Channel', Ding (2004) proposed that sharp changes in thickness of Holocene marine deposits across the NW-trending Lau Fau Shan – East Lamma Channel Fault was evidence of recent fault activity. Ding (2004) calculated a slip rate of 0.60 mm/year since the Holocene.

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However, a review of the existing drillholes has revealed no significant variation in the thickness of Holocene marine deposits. The available seismic profiles across the Tsing Yi Channel also show no evidence of displacement of superficial deposits. Therefore, the evidence proposed for recent fault activity at this site is unsubstantiated.

4.3 Likely Sources of Seismic Shaking

Although there have been reports of recent earthquakes centred in Hong Kong, the earthquakes have been relatively small (see Section 4.2.1 above), and are not associated with mapped faults. TL ages obtained from some prominent strike slip faults in Hong Kong, which are suggestive of late Pleistocene (< 100,000 years) movement (see Section 4.2.3 above), generally show little correlation with pulses of late Pleistocene landslide activity. The one possible exception is a TL age obtained from a NW-trending fault near Yam O, northern Lantau, which may be indicative of an event at 33,300 ± 2,700 years BP (Ding & Lai, 1997), which almost overlaps with a cluster of large landslide events with an average age of 28,400 ± 1,900 years (Figure 4.2). Overall, however, it is considered that potential sources of seismic shaking that could trigger landslides in Hong Kong most likely are located outside of Hong Kong.

The nearest fault to Hong Kong with a proven history of recurrent movement is probably the Dangan Islands Fault (Figure 1.1). This fault is thought to have been responsible for the M_w 5.7 earthquake in 1874 and the M_w 4.0 earthquake on 14 September 2006. The Dangan Islands Fault lies about 30 km to the southeast of Hong Kong and has been interpreted from seismic tomography to coincide with an onshore-offshore low velocity zone known as the Littoral Fault Zone (Xia et al, 2010, also known as the Binhai Fault). Mainland geologists consider the Dangan Islands Fault to be an active fault capable of generating a magnitude 7.5 earthquake (GEERRI, 2010). Such an earthquake within 30 km of Hong Kong is likely to produce a shaking intensity (Modified Mercalli, MM) in the range VII-IX which is capable of inducing large landslides (Hancox et al, 2002). According to modeling by ARUP (2011), there is a 50% chance in the next 50 years that the short period ground motion for a relatively likely ground motion is exceeded from a M5¾ earthquake at 60 km from Hong Kong. Other sources of seismic shaking that could affect Hong Kong include earthquakes in the southern Taiwan Strait and Shantou areas. Several earthquakes generated in these regions have been felt in Hong Kong (HKO Website).

5 Conclusions

The most direct evidence of neotectonic fault movement in Hong Kong comes from dating of fault materials by TL methods. The data suggest that latest movement on some Hong Kong faults may have peaked in the late Pleistocene around 100,000 years ago, with sporadic movements at approximately 82,000 years ago and 33,000 years ago (Ding & Lai, 1997). Comparison of the available relict large landslide age data with these postulated fault movements reveals no direct correlation, with the possible exception of one event at 33,300 ± 2,700 years ago which may just overlap with a pulse of landslide activity with an average age of 28,400 ± 1,900 years. However, since there is no strong evidence for faults displacing late Pleistocene and Holocene superficial deposits in Hong Kong, it is considered that local neotectonic fault movement (if any) has had no major influence on relict natural terrain large

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landslides in Hong Kong.

Despite the lack of strong evidence for neotectonic fault movement within Hong Kong, there are indications from the ages of relict natural terrain large landslides that Hong Kong may have been affected by periods of intensive seismic shaking in the geologically recent past (i.e. the last 100,000 years). These are represented by at least two clusters of territory-wide deep-seated landslide ages at around 50,000 and 30,000 years ago. Although it is unlikely that seismic sources are located locally, there are several strong candidates from nearby regional sources. These include faults in the southern Taiwan Strait and the Dangan Islands Fault. Whilst possible triggers for large landslides from high intensity rainstorms cannot be ruled out, the apparent existence in the landscape of pulses of widespread deep-seated large landslide ($\geq$ 50,000 m^3) activity at 50,000 and 30,000 years ago is suggestive of a tectonic rather than a climatic influence. On the other hand, pulses of smaller volume (< 50,000 m^3) landslides in Hong Kong dated at around 16,000 years, 7,000 years and possibly 4,000 years ago, may reflect a climatic influence related to post-glacial warming and sea level rise. Further investigation is required before these preliminary findings can be substantiated.

6 References

Aitken, M. & Xie, J. (1992). Optical dating using infra-red diodes: young samples. *Quaternary Science Reviews*, vol. 11, pp 147-152.

ARUP (Ove Arup & Partners Hong Kong Ltd) (2011). *Final Report on Overall Seismic Hazard Assessment*, prepared for the Geotechnical Engineering Office, Civil Engineering and Development Department, HKSAR Government, under Agreement No. CE49/2008(GE) - Pilot Seismic Microzonation Study in Northwest New Territories for the Study of Potential Effect of Earthquake on Natural Terrain - Investigation.

Banjaree, D., Singhvi, A.K., Pande, K., Gogte, V.D. & Chandra, B.P. (1999). Towards a direct dating of fault gouges using luminescence dating techniques - methodological aspects. *Current Science*, vol. 77, pp 256-268.

Campbell, S.D.G. & Sewell, R.J. (2007). *^{40}Ar-^{39}Ar Laser Microprobe Dating of Mafic Dykes and Fault Rocks in Hong Kong*. GEO Report No. 206, Geotechnical Engineering Office, Hong Kong, 78 p.

Crozier, M.J. (1992). Determination of paleoseismicity from landslides. In: D.H. Bell (ed.) Landslides, *Proceedings of the 6th International Symposium*, Christchurch, New Zealand vol. 2, pp 1173-1180.

Ding Y.Z. 丁原章 (2004). *廣東和香港地震風險概論*. 商務印書館(香港)有限公司，香港，共 222 頁。

Ding, Y.Z. & Lai, K.W. (1997). Neotectonic fault activity in Hong Kong: evidence from seismic events and thermoluminescence dating of fault gouge. *Journal of the Geological Society*, vol. 154, pp 1001-1008.

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Duller, G.A.T. & Wintle, A.G. (1996). *Luminescence Dating of Alluvial and Colluvial Deposits in Hong Kong*. Report for the Geotechnical Engineering Office, Hong Kong, 30 p.

Forman, S.L., Pierson, J. & Lepper, K. (2000). Luminescence geochronology. In: J.S. Noller, J.M. Sowers & W.R. Lettis (ed.) *Quaternary Geochronology: Methods and Applications*, American Geophysical Union, pp 157-176.

GEERRI (Guangdong Engineering Earthquake Resistance Research Institute) (2010). *Seismic Hazard Assessment Report*, appendix to the Final Report on Overall Seismic Hazard Assessment, prepared by Ove Arup & Partners Hong Kong Ltd for the Geotechnical Engineering Office, Civil Engineering and Development Department, HKSAR Government, under Agreement No. CE49/2008(GE) - Pilot Seismic Microzonation Study in Northwest New Territories for the Study of Potential Effect of Earthquake on Natural Terrain - Investigation.

Gibbard, P.L., Head, M.J. & Walker, M.J.C. (2009). Formal ratification of the Quaternary System/Period and the Pleistocene Series/Epoch with a base at 2.58 Ma. *Journal of Quaternary Science*, vol. 25, pp 96-102.

Hancox, G.T., Perrin, N.D. & Dellow, G.D. (2002). Recent studies of historical earthquake-induced landsliding, ground damage, and MM intensity in New Zealand. *Bulletin of the New Zealand Society for Earthquake Engineering*, vol. 35, pp 59-95.

Hanks, T.C., & Kanamori, H. (1979). Moment magnitude scale. *Journal of Geophysical Research*, vol. 84 (B5), pp 2348-2350.

HKO (2007). *Earthquake and You*. Hong Kong Observatory online publication (http://www.hko.gov.hk/publica/gen_pub/quake_e.pdf).

HKO Website. http://www.hko.gov.hk/gts/equake/79felt_e.htm.

Ji, F.J. & Gao, P. (1988). Application of thermoluminescence technique to dating of fault. *Seismology and Geology*, vol. 10, pp 207-213 (in Chinese with English abstract).

Ji, F.J., Ma, S.L. & Liu, M.D. (1994). Study on the fault material for the thermoluminescence dating. *Seismology and Geology*, vol. 16, pp 167-174 (in Chinese with English abstract).

Jibson, R.W. (2009). Using landslides for paleoseismic analysis. In: J.P. McCalpin (ed.) *Paleoseismology*. International Geophysics Series, vol. 95, pp 565-601.

Keefer, D.K. (1984). Landslides caused by earthquakes. *Geological Society of America Bulletin*, vol. 95, pp 406-421.

Ko, F.W.Y. (2005). *Correlation Between Rainfall and Natural Terrain Landslide Occurrence in Hong Kong*. GEO Report No. 168, Geotechnical Engineering Office, Hong Kong, 77 p.

Lai, K.W., Campbell, S.D.G. & Shaw, R. (1996). *Geology of the Northeastern New Territories*. Hong Kong Geological Survey Memoir No. 5, Geotechnical Engineering Office, Hong Kong, 143 p.

Lai, K.W. & Langford, R.L. (1996). Spatial and temporal characteristics of major faults of Hong Kong. In: R.B. Owen, R.J. Neller & K.W. Lee (ed.) *Seismicity in Eastern Asia*. Geological Society of Hong Kong Bulletin No. 5, pp 72-84.

Lang, A & Wagner, G.A. (1997). Infrared stimulated luminescence dating of Holocene colluvial sediments using the 410 NM emission. *Quaternary Science Reviews*, vol. 16, pp 393-396.

Langford, R.L., James, J.W.C., Shaw, R., Campbell, S.D.G., Kirk, P.A. & Sewell, R.J. (1995). *Geology of Lantau District*. Hong Kong Geological Survey Memoir No. 6. Geotechnical Engineering Office, Hong Kong, 173 p.

Langford, R.L., Lai, K.W., Arthurton, R.S. & Shaw, R. (1989). *Geology of the Western New Territories*. Hong Kong Geological Survey Memoir No. 3, Geotechnical Control Office, Hong Kong, 140 p.

Noller, J.S., Sower, J.M., Colman, S.M. & Pierce, K.L. (2000). Introduction to Quaternary Geochronology. In: J.S. Noller, J.M. Sowers & W.R. Lettis (ed.) *Quaternary Geochronology: Methods and Applications*, American Geophysical Union, pp 1-10.

Nikonov, A.A. (1988). Reconstruction of the main parameters of old large earthquakes in Soviet Central Asia using the paleoseismogeological method. *Tectonophysics*, vol. 147, pp 297-312.

Olley, J.M., Caitcheon, G.C. & Murray, A.S. (1998). The distribution of apparent does as determined by optically stimulated luminescence in small aliquots of fluvial quartz: implications for dating young sediments. *Quaternary Science Reviews*, vol. 17, pp 1033-1040.

Reimer, P.J., Baillie, M.G.L., Bard, E., Bayliss, A., Beck, J.W., Blackwell, P.G., Bronk Ramsey, C., Buck, C.E., Burr, G.S., Edwards, R.L., Friedrich, M., Grootes, P.M., Guilderson, T.P., Hajdas, T.J., Hogg, A.G., Hughen, K.A., Kaiser, K.F., Kromer, B., McCormac, F.G., Manning, S.W., Reimer, R.W., Richards, D.A., Southon, J.R., Talamo, S., Turney, C.S.M., van der Plicht, J. & Weyhenmeyer, C.E. (2009). IntCal09 and Marine09 radiocarbon age calibration curves, 0-50,000 years Cal BP. *Radiocarbon*, vol. 51, pp 1111-1150.

Renne, P.R. (2000). K-Ar and $^{40}Ar/^{39}Ar$ dating. In: J.S. Noller, J.M. Sowers & W.R. Lettis (ed.) *Quaternary Geochronology: Methods and Applications*, American Geophysical Union, pp 77-100.

Sewell, R.J. & Campbell, S.D.G. (2005). *Report on the Dating of Natural Terrain Landslides in Hong Kong*. GEO Report No. 170, Geotechnical Engineering Office, Hong Kong, 151 p.

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

Sewell, R.J., Wong, J.C.F. & Shaw, R. (2007). *Updating of Hong Kong Geological Survey 1:20,000-scale Maps, Major Findings and Revisions Map Sheet 7 - Sha Tin*. GEO Report No. 179 (2nd Edition). Geotechnical Engineering Office, Hong Kong, 44 p.

Singhvi, A.K., Banerjee, D., Pande, K, Gogte, V. & Valdiya, K.S. (1994). Luminescence studies on neotectonic events in south-central Kumaun Himalaya - a feasibility study. *Quaternary Science Reviews*, vol. 13, pp 595-600.

Tang, D.L.K., Ding, Y.Z., Lee, C.W., Wong, J.C.F. & Sewell, R.J. (2009). *Study of The Potential Evidence For Neotectonic Fault Movement and Correlation with Natural Terrain Landslides in Hong Kong (Part 1: Ho Lek Pui Area)*. GR 1/2009. Geotechnical Engineering Office, Hong Kong, 44 p.

Tang, D.L.K., Sewell, R.J., Wong, J.C.F. & Ding, Y.Z. (2010). *Study of The Potential Evidence For Neotectonic Fault Movement and Correlation with Natural Terrain Landslides in Hong Kong (Part 3: Tung Chung East)*. GR 3/2010. Geotechnical Engineering Office, Hong Kong, 30 p.

Whitaker, A., Musson, R.M.W., Brereton, N.R., Busby, J.P., Evans, C.D.R., & Evans, C.J. (1992). *A Review of the Crustal Structure and Seismotectonics Pertinent to Hong Kong*. British Geological Survey Technical Report WC/92/17, 95 p.

Wong, J.C.F & Ding, Y.Z. (2010). *Study of The Potential Evidence For Neotectonic Fault Movement and Correlation with Natural Terrain Landslides in Hong Kong (Part 2: Wong Chuk Yeung Area)*. GR 1/2010. Geotechnical Engineering Office, Hong Kong, 39 p.

Wong, J.C.F, Tang, D.L.K., Sewell, R.J. & Lee, C.W. (2010). *Study of The Potential Evidence For Neotectonic Fault Movement and Correlation with Natural Terrain Landslides in Hong Kong (Part 4: Nam Shan and Pui O Areas)*. GR 4/2010. Geotechnical Engineering Office, Hong Kong, 36 p.

Xia, S.H., Zhao, M.H., Qiu, X.L., Xu, H.L. & Shi, X.B. (2010). Crustal structure in an onshore-offshore transitional zone near Hong Kong, northern South China Sea. *Journal of Asian Earth Sciences*, vol. 37, pp 460-472.

Zreda, M.G. & Philips, F.M. (2000). Cosmogenic nuclide buildup in surficial materials. In: J.S. Noller, J.M. Sowers & W.R. Lettis (ed.) *Quaternary Geochronology: Methods and Applications*, American Geophysical Union, pp 61-76.

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